DOWNLOADED FROM STUCOR APP

UNIT – I INTRODUCTION

1. Define Drive and Electric Drive.

Drive: A combination of prime mover, transmission equipment and mechanical working load is called a drive

Electric drive: An Electric Drive can be defined as an electromechanical device for converting electrical energy to mechanical energy to impart motion to different machines and mechanisms for various kinds of process control.

2. List out some examples of prime movers.

1. I.C Engines,
2. Steam Engine,
3. Turbines
4. Electric Motors.

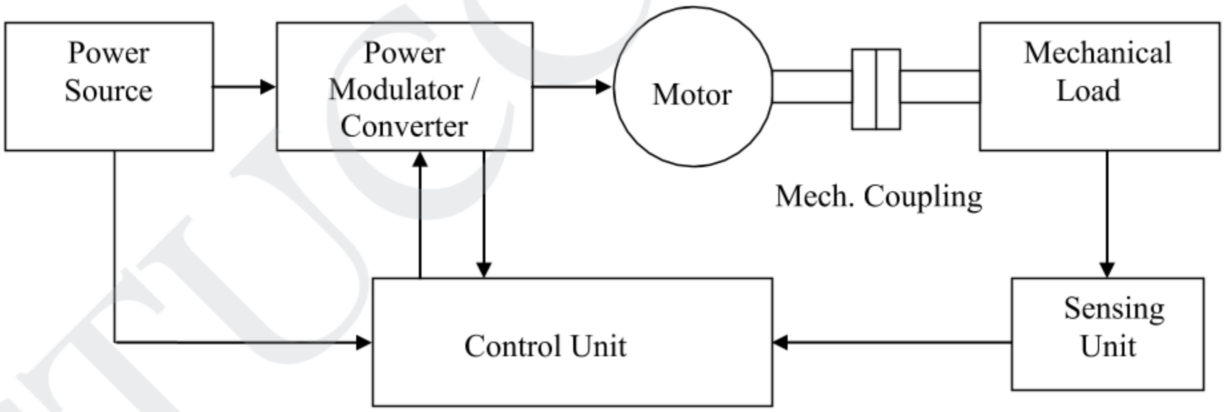
3. Give some examples of Electric Drives.

i. Driving fans, ventilators, compressors and pumps.
ii. Lifting goods by hoists and cranes.
iii. Imparting motion to conveyors in factories, mines and warehouses
iv. Running excavators & escalators, electric locomotives trains, cars trolley buses, lifts & drum winders etc.

4. What are the types of electric drives?

1. Group electric drives (Shaft drive),
2. Individual Drives,
3. Multi motor electric drives.

5. Draw the functional block diagram of electric drive



6. State the some of the advantage of an electric drive system

- Control characteristic can be manipulated as per requirements
- Availability of simple and easy speed control methods
- Electric braking can be employed in easy manner
- The operation is pollution free
- The variety of electric drives with wide range of speed, power and torque ratings are available.
- The efficiency is higher as no load losses are less.
- They have short time overload capacity.

7. List the factors affecting the selection of electric drives.

- Efficiency
- Braking

DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

- Limits of speed range
- Starting requirements
- Power factor
- Load factor
- Availability of supply
- Effects of supply variations
- Economical aspects
- Reliability of operation
- Environmental effects

8. State the selection of motor based on load variation (or) Types of mechanical loads

- Continuous or constant loads
- Continuous variable loads
- Pulsating loads
- Impact loads
- Short time loads

9. State the various classes of duty

- Continuous duty
- Continuous duty, variable loads
- Short time loads
- Intermittent periodic duty
- Intermittent periodic duty with starting
- Intermittent periodic duty with starting and braking

10. What are the elements of an electric drive system?

- Electrical motors and load
- Power modulator
- Source
- Control unit
- Sensing unit

11. List the types of electrical drives?

- DC drives
- AC drives

12. Mention the application of electrical drives?

- Paper mills
- Electric traction
- Cement mills
- Steel mills

13. Define cooling time constant?

It is defined as the ratio between C and A cooling time constant is denoted as 'τ'

$$\tau = C/A$$

Where C = amount of heat required to raise the temperature of the motor body by 1 degree Celsius, A = amount of heat dissipated by the motor per unit time per degree Celsius in J/sec

14. What is the three method of operation for electrics drive?

- Steady state
- Acceleration including starting
- Deceleration including stopping

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

15. Define four – quadrant operation?

A motor operate in two modes and braking. In motoring, it converts electrical energy into mechanical energy, which supports its motion. In braking it works as a generator converting mathematical energy into electrical energy and thus, opposes the motion. Motor can provide motoring and braking operations for both forward and reverse directions.

16. Compare A.C. and D.C. drives.

S.No	DC Drives	AC Drives
1	The commutator makes the motor bulky, costly and heavy	Motors are inexpensive, particular squirrel cage motor
2	The converter technology is well established. The power converter is simple and inexpensive	The inverter technology is still being developed. The power circuit of the converter and its control are simple
3	Line commutation of the converter is used	Forced commutation is used with induction motors. Sometimes machine commutation may be used with synchronous motors
4	Fast response and wide speed range smooth control	With solid state converter the speed range is wide. With conventional methods it is stepped and limited
5	Small power/weight ratio	Large power /weight ratio
6	Cost does not depend on the solid state converter	Solid state converter employed also decides the cost

17. Mention the necessity of power rating?

Power rating of electric drives for particular operation is important since, following reasons.

1. To get economy with reliability
2. To obtain the maximum efficiency on their full load without any damaging.

18. What is duty factor?

The ratio of ON time (T_{on}) of the drive to total time period (T_{on} + T_{off}) is called duty factor.

$$\text{Duty ratio or cycle } \alpha \text{ or } \delta = \frac{T_{ON}}{T} \qquad (\because T = T_{ON} + T_{OFF})$$

19. What is cooling curve?

When a machine is switched off from the mains or when the load on the motor is reduced, the machine cools. The curve obtained temperature drop Vs time when the drive is switched off or load on the drive is removed.

20. What are the advantages and disadvantages of Group drive (Shaft drive)?

Advantages:

- A single large motor can be used instead of a number of small motors.
- The rating of the single motor may be appropriately reduced taking into account the diversity factor of loads.

Disadvantages:

- There is no flexibility, Addition of an extra machine to the main shaft is difficult.
- The efficiency of the drive is low, because of the losses occurring in several transmitting mechanisms.
- The complete drive system requires shutdown if the motor, requires servicing or repair.
- The system is not very safe to operate
- The noise level at the work spot is very high.

21. What is an individual electric drive? Give some examples.

In this drive, each individual machine is driven by a separate motor. This motor also imparts motion to various other parts of the machine. Single spindle drilling machine, Lathe machines etc.

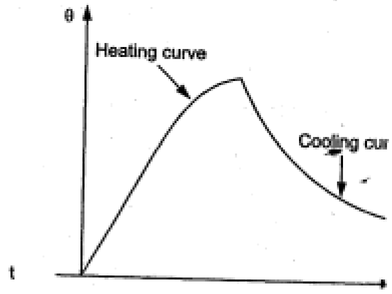
DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

22. What is a multi motor electric drive? Give some examples.

In this drive, there are several drives, each of which serves to activate on of the working parts of the driven mechanisms. Metal cutting machine tools, paper making machines, rolling mills, traction drive, Traveling cranes etc.,

23. Draw the heating and cooling time constant curves



24. Write the expression for computation of power rating of linear movement.

In case of **linear motion** power rating is $P = \dfrac{F \times v}{0.102\,\eta}$, W or $P = \dfrac{F \times v}{102\,\eta}$, kW

Where, F – Force exerted by load, kg
v – Velocity of linear motion, m/s
η - Efficiency of load and transmission system

25. What are the advantages and disadvantages of individual drive?

Advantages:

1. Flexibility of layout
2. If any failure or maintenance carried out in main motor, corresponding load will be affected or idle.
3. Efficiency is high because no load losses are less.
4. Quite operation compared to other drive.
5. It requires less space.

Disadvantages:

1. Cost is high compared to group drive

BIG QUESTIONS

1).What is electric drive? Explain the basic elements of an electric drive system.
2).Explain the classification of electric drives.
3).Explain the various classes of duty. How it affect the selection of rating of a motor for the drive?
4).Draw a typical temperature rise –time curve and derive equation for temperature rise in an electric drive
5).Write a note on cooling curve of an electric derives, stating its expression.

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

UNIT II DRIVE MOTOR CHARACTERISTICS

1).What is back e.m.f in a D.C. Motor? State its expression.

Armature starts rotating, the main flux gets cut by the armature winding and an e.m.f gets induced in the armature. This e.m.f opposes the applied d.c voltage and is called back e.m.f denoted as E_b.

$$E_b = \frac{\phi Z N}{60}\left(\frac{P}{A}\right)$$

ϕ = Flux per pole
P = Number of poles
N = Speed in rpm
Z = Total armature conductors
A = Number of parallel paths

2) Write the voltage equation of D.C. Motor

$V=E_b+I_aR_a$. The back e.m.f is always less than supply voltage ($E_b<V$). But Ra is very small hence under normal running conditions, the difference between back e.m.f and supply voltage is very small.

3) State the various types of D.C. Motors

- Separately excited d.c. Motor
- D.C. Shunt motor
- D.C series motor
- D.C. Compound motor

4) What are the important characteristics of a d.c. motor?

- Torque – Armature current characteristics
- Speed – Armature current characteristics
- Speed- Torque Characteristics

5) Why dc Series motor is never started on No load?

Under light load or no load as flux is very small, the motor tries to run at dangerously high speed which may damage the motor mechanically. This can be seen from the speed – armature current and the speed- torque characteristics that on low armature current and low torque condition motor shows a tendency to rotate with dangerously high speed.

6) List some application of d.c. shunt motor?

- Blowers and fans
- Centrifugal and reciprocating pumps
- Lathe machine
- Machine tools
- Milling machines
- Drilling machines

7) List some application of d.c. series motor?

- Cranes
- Hoists, Elevators
- Trolleys
- Conveyors
- Electric Locomotives

8) List some application of d.c. compound motors?

- Rolling mills
- Punches
- Shears

DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

- Heavy Planers
- Elevators

9) What is synchronous speed?

The speed depends on the supply frequency (f) and the number of poles for which stator winding is wound (P).It is called synchronous speed denoted as N_s and given by

$N_s = 120\ f / P$ in r.p.m

10) What is rotor conductor and end ring?

The rotor core is cylindrical and slotted on its periphery. The rotor consists of un insulated copper or aluminum bars called rotor conductors. The bars are placed in the slots. These bars are permanently shorted at each end with the help of conducting copper ring is called end ring.

11) Compare Slip ring and Squirrel cage motor

S.No	Slip Ring Motor	Squirrel Cage motor
1.	Rotor consists of a three phase winding similar to the stator winding	Rotor consists of bars which are shorted at the ends with the help of end rings
2.	Construction is complex	Construction is very simple
3.	Resistance can be added externally	As Permanently shorted, external resistance cannot be added
4.	High starting torque can be added	Moderate staring torque which cannot be controlled
5.	Speed control by rotor resistance is possible	Speed control by rotor resistance is not possible
6.	Slip rings and brushes are presented to add external resistance	Slip rings and brushes are absent
7.	Rotor copper losses are high hence efficiency is less	Rotor copper losses are less hence have higher efficiency

12).What is slip?

The difference between the synchronous speed (N_s) and actual speed(N) of the rotor is known as slip speed. The percentage of slip is given by

% slip $s = [(N_s - N) / N_s] *100$

13) Induction motor as a transformer?

Transformer is a device in which two windings are magnetically coupled and when one winding is excited by a.c. supply of certain frequency, the e.m.f gets induced in the second winding having same frequency as that of supply given to the first winding. The winding of which supply is given is called primary winding while winding in which e.m.f gets induced is called secondary winding.

14) What is transformation ratio?

$K = E_2 / E_1$ (or) $k = N_2 / N_1$

Were E_1 = Stator e.m.f per phase in volts

E_2 = Rotor induced e.m.f per phase in volts at start when motor is at standstill.

15).What are the types of Single phase induction motors?

- Split phase induction motor
- Capacitor start induction motor
- Capacitor start capacitor run induction motor
- Shaded pole induction motor

16) What are the types of electric braking in D.C. Motors?

- Rheostatic or dynamic braking
- Plugging

DOWNLOADED FROM STUCOR APP STUCOR APP

DOWNLOADED FROM STUCOR APP

- Regenerative braking

17) What is meant by Rheostatic or dynamic braking?

Dynamic braking of electric motors occurs when the energy stored in the rotating mass is dissipated in an electrical resistance. This requires the motor to operate as a generator to convert this stored energy into electrical.

18) What is meant by Plugging?

It is one method of braking of induction motor. When phase sequence of supply of the motor running at a speed is reversed, by interchanging connections of any two phases of stator with respect to supply terminals, operation shifts from motoring to plugging region.

19) What is meant by Regenerative Braking?

Regenerative braking occurs when the motor speed exceeds the synchronous speed. In this case, the induction motor would runs as the induction machine is converting the mechanical power into electrical power, which is delivered back to the electrical system. This method of braking is known as regenerative braking.

20) What are the types of electric braking in induction Motors?

- Rheostatic or dynamic braking
- Plugging
- Regenerative braking
- D.C. Dynamic braking

21) What are the three regions in the speed –torque characteristics of induction motor?

I. Motoring region ($0< s<1$)
II. Generating region($s<0$)
III. Plugging region ($1<s<2$)

22) List the advantage of squirrel cage I.M?

- Cheaper
- Light in weight
- Rugged in construction
- More efficient
- Require less maintenance
- Can be operated in dirty and explosive environments

23. Compare electrical and mechanical braking.

	Mechanical Braking	Electrical Braking
1.	Brakes require frequent maintenance	Very little maintenance
2.	Braking is not smooth	Smooth braking operation
3.	Can be applied to hold the system at any position	Cannot produce holding torque

24. Why a single phase induction motor does not Self start?

When a single phase supply is fed to the single phase induction motor. Its stator winding produces a flux which only alternates along one space axis. It is not a synchronously revolving field, as in the case of a 2 or 3phase stator winding, fed from 2 or 3 phase supply.

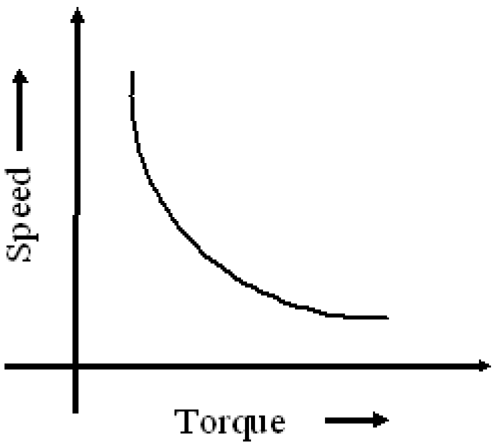
25. What are the types of single phase induction motor?

1. Split phase induction motor
2. Capacitor start induction run motor
3. Capacitor start Capacitor run motor
4. Shaded pole induction motor

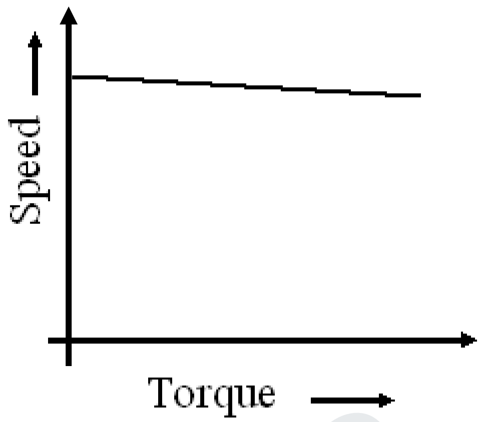
STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

26. Draw the speed torque characteristics of dc shunt and series motors



Speed Torque characteristics of dc Series motor



Speed Torque characteristics of dc Series motor

BIG QUESTION

1).Draw and explain the torque –speed characteristics for the DC motors.
2).What is meant by braking. Explain in details.
3).Draw and explain the speed- torque characteristics curve of 3-phase induction motor.
4) Explain single-phase induction motors speed torque curve in details.
5).What are the braking methods available for induction motors and explain in details.

UNIT III STARTING METHODS

1) What is the Necessity of starter?

At starting, when the motor is stationary, there is no back e.m.f. (E_b = 0) in the armature. Consequently, if the motor is directly switched on to the mains, the armature will draw a heavy current ($I_a = V/R_a$) because of small armature resistance. This current will damage the motor.Hence there is a need of a certain device which can limit such a high stating current. Such a device which limits the high starting current is called a starter.

Current drawn by dc motor is $I_a = \frac{V - E_b}{R_a} \cong \frac{V}{R_a}$ $\because$ $E_b = 0$ (Starting)

2) What is meant by starting resistance?

To restrict this high starting armature current, a variable resistance is connected in series with the armature at start. This resistance is called starter or a starting resistance.

3) What are the two types of starters used for D.C shunt motors?

a). Two Point starter b) Three point starter c) Four Point starter

4) What are the main parts of three point starter?

L = line terminal to be connected to positive of supply
A = to be connected to the armature winding
F = to be connected to the field winding

5) What are the disadvantages of three point starter?

Here NVC and the field winding are in series. so while controlling the speed of the motor above rated, field current is reduced by adding an extra resistance in series with the field winding. To avoid the dependency of NVC and the field winding, four point starter is used in which NVC and the field winding are connected in parallel.

DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

6) What are the main parts of four point starter?

L = line terminal to be connected to positive of supply
A = to be connected to the armature winding
F = to be connected to the field winding
N =Neutral

7) What is automatic starter?

Upon pressing ON-push button (start button), current limiting stating resistors get connected in series with armature circuit in DC motor. Then, some form of automatic control progressively disconnects these resistors until full-line voltage is available to the armature circuit. On pressing an OFF push button the system should get back to its original position.

8).Why starts are used for DC motors?

In DC motors starters are used to limit the starting current within about 2 to 3 times the rated current by adding resistance in series with the armature circuit. Other than this starting resistances starters are variable fitted with protective devices like no –voltage protection and over-load protection.

9).Why stator resistance rarely used?

Due to addition of resistance in the stator side cause the voltage available to the motor X times the normal voltage i.e. The starting current drawn by the motor as well as the current drawn from the supply get reduced by X times where as the starting torque developed gets reduced by X_2 times.

10) What are the effects of increasing rotor resistance in the rotor circuit of a 3-phase induction motor as starting?

Due to addition of resistance in rotor circuit by the stator not only reduces the staring current, in addition to that the starting torque developed than those given by DOL starting.

11) What are the advantages of Electronic starter?

- The moving parts and contacts get completely eliminated.
- The arcing problem gets eliminated.
- Minimum maintenance is required as there are no moving parts.
- The operation is reliable
- Starting time also gets reduced.

12) What are the various types of reducing starting current of induction motor?

- Stator resistance starter
- Autotransformer starter
- Star-delta starter
- Rotor resistance starter
- Direct on line starter

13).What is autotransformer starter?

A three phase star connected autotransformer can be used to reduce the voltage applied to the stator. Such a starter is called as autotransformer starter.

14).What is star-delta starter?

This is the cheapest starter of all and hence used very commonly for the induction motors. It uses triple pole double throw (TPDT) switch. The switch connects the stator winding in star at start. Hence per hase voltage get reduced by the factor 1/.3.Due to this reduced voltage, the staring current is limited.

15) What is the function of starters?

- For large capacity induction motors is to reduce the starting current
- Having necessary control devices to limit the starting current

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

- All starters are provided devices to protect the motor against overload and loss of supply voltage.

16. What is the drawback of three point starter?

In a three-point starter, the no-volt release coil is connected in series with the shunt field circuit so that it carries the shunt field current. During speed control, speed is varied through field regulator; the field current may be weakened to such an extent that the no-volt release coil may not be able to keep the starter arm in the ON position. This may disconnect the motor from the supply when it is not desired. This drawback is overcome in the four point starter.

17. What is the function of No Volt Release (NVR) or No Volt Coil (NVC)?

The No Volt magnet keeps starter handle at run position against the control spring. The No-Volt magnet attracts the soft iron bar placed in the handle. The No-Volt magnet is energized by the .current flowing through the field circuit. If there is no No-Volt magnet the starter handle is pulled back the Off position by the control spring and the motor Point Starter is switched Off.

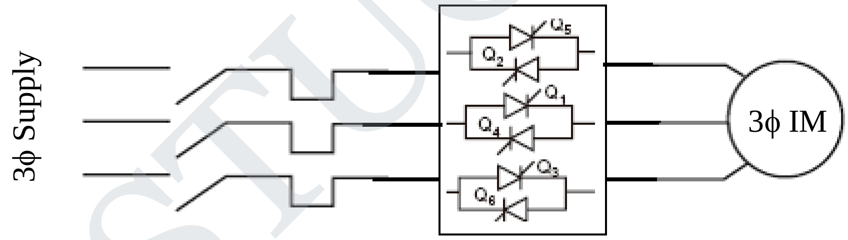
18. What is the function of Over Load Release (OLR) or Over Current magnet (OC)?

When the load on motor increases above the rated limit then the armature takes high current. When the motor is left unprotected from this high current, then it is damaged, the over current magnet is used for this protection. When there is high current due to over load or due to short circuit the over current magnet is energized and attracts soft iron rod H. *As* a result, the soft, iron rod H closes the switch S. When the switch S is closed, it short circuits the No-Volt magnet. As a result No Volt magnet is de-energized and release the starter handle to the Off position. So the motor is switched off' and protected from the over current or high current

19. What is Soft Starter?

Soft starting an ac motor refers to any one of several starting methods that limit the starting current and torque of the motor. The reduced voltage starters, and will be referred to as soft starting. The soft starter eliminates unnecessary jerks during the start. Gradually, the voltage and the torque increase so that the machinery starts to accelerate the motor by means of thyrister (SCRs).

20. Draw the Schematic circuit diagram of Soft Starter



21. What are the advantages of soft starter?

- Reduced wear on mechanical gears, chains and sprockets, and unexpected repair of broken belts and jammed gearboxes.
- Lower inventory of spare mechanical parts and operating costs.
- Increased production rates by reducing machine maintenance downtime.
- Prolonged life of electrical switchgear with lower inrush currents.
- Soft stops on pumping applications reduce piping system stresses and “hammer” effect.

BIG QUESTION

1) Draw and explain a three point starter for a dc motor?
2) What are the different types of AC motor starter?
3) Explain the different types of starters used in cage induction motor with a neat sketch?
4) Why starter is necessary for the induction motor?
5) Draw and explain rotor resistance starter

DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

UNIT IV CONVENTIONAL & SOLID STATE SPEED CONTROL OF D.C. DRIVES

1. What are the factors on which the speed of a dc motor depends?

The speed of a d.c. motor is given by: $N \propto \frac{E_b}{\phi} \propto \frac{V - I_a R}{\phi}$

- Flux in the air gap
- Resistance in the armature circuit
- Voltage applied to the armature circuit

2) What are the advantages of field control?

- The regulating resistance, which has to carry only a small current
- Power wasted in regulating resistance is very small

3) What are the methods on which speed of a dc motor be controlled?

- Flux control
- Armature resistance control
- Armature voltage control

4) What will be the effect of change in supply voltage on the speed of dc shunt motor?

The reduction of supply voltage to the armature of dc shunt motor causes reduction of back-emf of the motor which inturn reduces the speed as the speed is directly proportional to the back emf

6) What is meant by speed control?

The initial change of drive speed to a value required for performing the specific work process is called as a speed control.

7) What are the advantages of field control method?

- Conventional and easy method
- Since, the shunt field current I_{sh} is small the power wasted in the field rheostat also small
- Independent of load on the motor
- Economical and efficient method

8) What are the disadvantages of field control method?

There is a maximum limit of speed that can be obtained with this method. It is due to fact that flux per pole is too much weakened commutation becomes poorer.

9) What is the application of ward- Leonard system speed control?

This method normally adopted in very sensitive speed control like electric excavators, elevators, coillery winders, main drives in steel mills and paper mills.

10) What are the advantages of Ward-Leonard speed control?

- Wide range of speed control is possible
- Full forward and reverse speed can be achieved
- Power is automatically regenerated to the ac line through the motor generator set which speed is reduced.
- Short time over load capacity is large
- The armature current of the motor is smooth

11) In which type of control the field current and armature current control?

i).For armature control method (or) voltage control method the field current is kept constant
ii).For field control (or) flux control the armature current kept constant

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

12) What is meant by solid state speed control?

A process which is used to control the speed by using purely semi conducting material ie power semiconductor devices like thyristors, power Transistors, MOSFET and etc., is called solid state speed control.

13) What are the arrangements are available using power semi conducting materials?

- Controlled converters
- AC voltage regulator
- Switch (or)chopper
- Inverter
- Cycloconverter

14) What are the advantages of solid state drive methods?

- Very fast response
- Less losses
- Higher efficiency
- Pollution free method
- Small size maintenance easy and controlled

15) What are disadvantage of solid state drive methods?

- Very difficult to regeneration of power
- It contains low power overload capacity
- Causes the interference in commutation in communication system due to harmonics in supply

16) What is meant by dc Chopper?

It is a device which is used to converter fixed dc voltage into variable dc voltage. This is designed with the help of power Semiconductor devices like Power Transistors, MOSFETS, Thyristors.

17) What are the different types of choppers?

- Class A or First quadrant chopper –Motoring control
- Class B or Second quadrant chopper – Braking control
- Class C or Two quadrant Type A chopper
- Class D or Two quadrant Type B chopper
- Class E or Four quadrant chopper

18) What is meant by flux control (or) field control method?

By varying the field flux the speed can be controlled is called flux control. This method can be used for increasing the speed of the motor is inversely proportional to the field flux

19) Write the advantage of flux control method

- Convenient and easy method
- In this method is independent of load on the motor
- Economical and efficient method

20) What is meant by armature control?

The armature having controller resistance in series during the speed control. By varying the controller resistance R, the potential drop across the armature is varied. Hence the speed of the motor also varied. This method of speed control is applicable for speed less than no load speed.

21).What is static Ward – Leonard drive?

Controlled rectifiers are used to get variable dc voltage from an ac source of fixed voltage. Controlled rectifiers fed dc drives are known as “static Ward – Leonard drive”.

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

22. What is the function of freewheeling diode?

Free wheeling diodes are introduced to maintain the continuous current flow to the load when ever all thyistors are turned off condition.

23. Write the output voltage equation for single phase full converter and half converter.

Half converter

$$V_0 = \frac{V_m}{2\pi}(1+\cos\alpha)$$

Full converter

$$V_0 = \frac{2V_m}{\pi}\cos\alpha$$

24. State the advantages of dc chopper drives?

DC Chopper device has the advantages of

1. High efficiency,
2. Flexibility in control,
3. Light weight and small size,
4. Quick response and
5. Regeneration down to very low speed.

24. What are the disadvantages of conventional Ward-Leonard schemes?

1. Higher initial cost due to use of two additional machines.
2. Heavy weight and size.
3. Needs more floor space and proper foundation.
4. Required frequent maintenance.
5. Higher noise and higher loss.

25. Mention the drawbacks of rectifier fed dc drives?

1. Distortion of supply.
2. Low power factor.
3. Ripple in motor current

BIG QUESTIONS

1) What is meant by armature control method?
2) List out the methods of speed control in Dc motors?

STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

UNIT - V CONVENTIONAL & SOLID STATE SPEED CONTROL OF A.C. DRIVES

1. List out the various methods of speed control of three phase induction motor

a. Methods applied from stator side:

(i) Changing applied voltage
(ii) Changing the applied frequency
(iii) Changing the number of stator poles.

b. Methods applied from rotor side:

(i) Rotor rheostat control
(ii) By operating two motors in cascade
(iii) By injecting EMF into the rotor circuit.
(iv) Speed control by changing slip

2. List the different methods of speed control to 3 phase squirrel cage induction motor?

- Speed control by changing supply frequency
- Speed control by changing no. of poles
- Speed control by changing slip

3. Define Slip

The difference between the synchronous speed and the actual speed of the motor is called slip.

$$\% \text{ Slip S} = \frac{N_s - N}{N_s} \times 100$$

4. What is meant by voltage control in induction motor? And where it is applicable?

In Induction motor speed can be controlled by varying the stator voltage. This can be done by using transformer. This method is called voltage control. This is suitable only for controlling the speed below rated value.

5. What is stator voltage control?

Three phase induction motor speed can be controlled by varying the stator voltage. This stator voltage can be varied by using ac voltage controller. This method of speed control of induction motor is called as stator voltage control

6. What is Slip-Power recovery system?

The slip power can be recovered to the supply source can be used to supply an additional motor which is mechanically coupled to the main motor. This type of drive is known as slip-power recovery system

7. What is meant by V/F control?

When the frequency is reduced the input voltage must be reduced proportionally so as to maintain constant flux. Otherwise the core will get saturated resulting in excessive iron loss and magnetizing current. This type of induction motor behaviour is similar to the working of dc series motors.

8. Write down the main feature of v/f control?

1. The starting current is constant
2. Maximum torque should be constant

9. What is meant by stator frequency control?

The three phase induction motor speed can be controlled by varying the stator frequency. The variable stator frequency can be obtained by inverters circuit.

10. What are the advantages of slip-power recovery system?

i).The slip power from the slip-rings can be recorded and fed back to the supply.
ii).The overall efficiency also improved

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

11. What are the advantages of stator voltage control?

1. Very simple control circuit
2. More compact and less weight
3. Quick response and economical method.

12. What are the disadvantages of stator voltage control?

1. Input Power factor is low
2. Operating efficiency is low
3. Voltage and current waveform are highly distorted due to harmonics, which affects the efficiency of the machine

13. What is meant by ac voltage controller?

AC voltage controller is nothing but, which is used to converters fixed ac voltage into variable ac voltage without changing supply frequency.

14).What are the possible methods of speed control available by using inverters?

- Variable voltage input (VVI) inverter control
- Variable voltage output (VVO) inverter control
- Pulse width modulated (PWM) inverter control
- Current controlled inverter.

15) Why do we for PWM inverter control?

The output from inverter is square with some harmonic contents so we have to remove or reducing the harmonic contents by using some voltage control technique called PWM

16) Compare static Kramer and Scherbius system

S.No	Kramer Drive	Scherbius Drive
1.	The system consists or SRIM, diode bridge rectifier and line commutated inverter	This system consists of SRIM, two SCR bridge (or) cycloconverter
2.	The slip power can flow in one direction	The slip power can flow in both direction
3.	This is applicable for below synchronous speed operation	Applicable for both below and above synchronous speed operation

17) What are the classifications of PWM technique?

1. Single pulse width modulation
2. Multiple pulse PWM modulation
3. Sinusoidal Pulse PWM

18) What are the limitations of Cycloconverter method of speed control?

1. It requires more semiconductor devices like Thyristors, MOSFETs compared with inverters
2. Harmonic contents more with low power factor.

19. Mention the applications of stator voltage control.

The application of the stator voltage control method is suitable for torque demand reduced with speed, which points towards its suitability for,

- Fan
- Pump drives

20. Mention the applications of ac drives.

AC drives are used in a number of applications are:

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

- Fans
- Blowers
- Steel mills
- Cranes
- Conveyors and
- Traction etc.

21. Mention the advantages of stator voltage control method?

The advantages of stator voltage control method are:

- The control circuitry is simple
- Compact size
- Quick response time

22. What is meant by soft start?

The soft start means, the AC voltage controllers allow a stepless control of supply voltage from zero to rated volt. They are used for soft start of motors.

23. What are the three regions in the speed – torque characteristics of the induction motor?

The three regions in the speed – torque characteristics of the induction motor are:

- Motoring region ($0 \leq S \leq 1$)
- Generating region ($S < 0$)
- Plugging region ($1 \leq S \leq 2$) where S is the slip

24. List the disadvantages of stator voltage control method?

The disadvantages of stator voltage control method are:

- Voltage and current waveforms are highly distorted due to harmonics, which affects the efficiency of the motor.
- Performance is poor under running condition at low speeds.
- Operating efficiency is low as resistance losses are high.
- Maximum torque available from the motor decreases with reduction in stator voltage.

25. List the advantages of squirrel cage induction motor.

The advantages of squirrel cage induction motor are:

- Cheaper
- Light in weight
- Rugged in construction
- More efficient
- Required less maintenance
- It can be operated in dirty and explosive environments.

26. What is meant by frequency control of induction motor?

The frequency control of induction motor means the speed of an induction motor is controlled by changing the supply frequency, because the speed is directly proportional to supply frequency.

27. Frequency control is not normally used. Why?

Frequency control is not normally used because, the supply voltage is maintained fixed value but the supply frequency is reduced, the flux will increase. Due to this, saturation of air gap flux, and the motor parameters would not be valid in determining the speed- torque characteristics. At low frequency, the reactance will decrease and motor current will increase.

28. Define base speed (ω_b).

Base speed (ω_b) defined as the synchronous speed corresponding to the rated frequency.

DOWNLOADED FROM STUCOR APP STUCOR APP

DOWNLOADED FROM STUCOR APP

29. List the disadvantages of Cycloconverter.

The disadvantages of cycloconverter are:

- requires large number of thyristors and
- its control circuitry is complex
- Converter grade thyristors are sufficient but the cost of the converter is high.

.

30. Mention the advantages of V/F control.

The advantages of V/F control are:

- Smooth speed control
- Small input current and improved power factor at low frequency start
- Higher starting torque for low case resistance

31. What is meant by stator current control?

The stator current control means in three phase stator current can be controlled by stator current control. The stator current can be varied by using current source inverter.

32. What is meant by slip power?

The slip power means, the portion of air gap power, which is not converted into mechanical power, it is called slip power. Slip power is nothing but multiplication of slip (S) and air gap power (P_{ag}).

33. List the advantages and disadvantages of rotor resistance control?

The advantages of rotor resistance control are:

- Absence of in-rush starting current
- Availability of full rated torque at starting
- High line power factor
- Absence of line current harmonics
- Smooth and wide range of speed control

The disadvantages of rotor resistance control are:

- Reduced efficiency because of the slip energy is wasted in the rotor circuit resistance.
- Speed changes very widely with load variation.
- Unbalances in voltage and current of the rotor circuit resistances are not equal.

34. Mention the different types of slip power recovery system.

The different types of slip power recovery system are:

1. Kramer system
    a) Conventional Kramer system
    b) Static Kramer system
2. Scherbius system
    a) Conventional Scherbius system
    b) Static Scherbius system
        i) DC link static Scherbius system
        ii) Cycloconverter Scherbius system

35. What is meant by sub-synchronous speed operation?

The sub-synchronous speed operation means, the SRIM speed can be controlled below synchronous speed. That is, the slip power is fed back to the supply.

36. What is meant by super-synchronous speed operation?

The super-synchronous speed operation means, the SRIM speed can be controlled above synchronous speed. That is, the supply is fed back to the rotor side.

37. List the advantages of conventional Kramer method.

The advantages of conventional Kramer method are,

DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

- The speed within the working range can be obtained instead of only two or three, as with other methods of speed control.
- If the rotor converter is over excited, it will take a leading current which compensates for the lagging current drawn by SRIM and hence improves the power factor of the system.

38. Mention the function of static Kramer system.

The function of static Kramer system is, the slip power is converted into dc by diode bridge rectifier and the dc voltage is converted into ac by line commutated inverter and fed back to the supply. As the slip power can flow only in one direction, static Kramer drive offers speed control below synchronous speed only.

39. **List the advantages of static Kramer system.**

The advantages of static Kramer system are:

- The drive system is very efficient and the converter power rating is low, because it has to handle only the slip power.
- The drive system has dc machine – link characteristics and the control is very simple.

40. Where static Kramer drive is used?

The static Kramer drive system are used in larger power pump and fan type drives, where control within narrow range and below synchronous speed.

41. List the advantages of static Kramer system.

The advantages of static Kramer system are:

- It's a very efficient
- Converter power rating is low

42. What is meant by static Scherbius system?

The SRIM speed can be controlled both below and above synchronous speed, static Scherbius drive system is used.

43. Mention the two types of static Scherbius system.

The two types of static Scherbius system are:

- DC link static Scherbius system
- Cycloconverter Scherbius system

44. List the applications of static Scherbius drive system.

The applications of static scherbius drive system are,

- Multi – MW, variable speed pumps / generators.
- Flywheel energy storage system.

45. Mention the advantages and disadvantages of static Scherbius drive.

The advantages of static Scherbius drive are:

- The problem of commutation near synchronous speed disappears.
- The cycloconverter can easily operates as a phase – controlled rectifier
- The near – sinusoidal current waves in the rotor.
- The cycloconverter is to be controlled.

The disadvantages of static Scherbius drive are:

- The cycloconverter cost is increases
- The control of the Scherbius drive is some what complex

DOWNLOADED FROM STUCOR APP

STUCOR APP

DOWNLOADED FROM STUCOR APP

46. Compare conventional method of Kramer and Scherbius system.

The comparison of Conventional method of Kramer and scherbius system

Sl.No	Kramer System	Scherbius System
1	This system consists of SRIM, rotary converter and DC motor	This system consists of SRIM, rotary converter, DC motor and induction generator
2	The return power is mechanical	The return power is mechanical
3	Less cost	More cost

47. Compare the static Kramer and Scherbius system.

The comparison of Kramer and Scherbius system

Sl.No	Static Kramer system	Scherbius system
1	This system consists of SRIM, diode bridge rectifier and line commutated inverter.	This system consists of SRIM, two SCR bridge (or) cycloconverter.
2	The slip power can flow in one direction i.e rotor to supply.	This slip power can flows in both direction i.e rotor to supply.
3	This method is only applicable for below synchronous speed operation.	This method is applicable for both below and above synchronous speed operation.

48. What is meant by Kramer system?

The Kramer system is only applicable for sub – synchronous speed operation beause the slip power is fed back to the supply.

49. Mention the modes of operation of Cycloconverter Scherbius drive.

The modes of operation of cycloconverter scherbius drive.

- Mode 1 : sub – synchronous motoring
- Mode 2 : supper synchronous motoring
- Mode 3 : sub – synchronous regeneration
- Mode 4 : supper synchronous regeneration

50. What happens to the performance of AC motor if the stator voltage control technique is adopted with frequency being constant?

1. Maximum torque decreases
2. Starting torque decreases
3. Performance is poor under running condition at low speeds.

51. Compare Slip Power Recovery Scheme with Rotor Resistance Control.

Compare slip power recovery scheme with rotor resistance control

Sl.No	Rotor Resistance Control	Slip Power Recovery Scheme
1.	Motor speed can be controlled by changing the rotor resistance.	Motor speed can be controlled by changing the firing angle of the SCRs
2	Slip power is wasted in the external resistance.	Slip power is feedback to the supply.
3	Low efficiency	High efficiency

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

4	It provides only sub synchronous speed operation	It provides both sub and supper synchronous speed operation.

52. Mention few general features of an induction motor on a CSI.

The general features of an induction motor on a CSI are,

1. Conduction of two devices in the same leg due to commutation failure does not lead to sharp rise of current through them.
2. It has inherent protection against a short circuit across motor terminals.

53. Mention general features of an induction motor on a CSI.

The general features of an induction motor on a CSI are,

1. Variable speed wind energy systems.
2. Large capacity wind energy systems.
3. Utility system flywheel storage systems.
4. Variable speed hydro pump / generators.

54. List the applications of Cycloconverter.

A cycloconverter drive

- It is attractive for law speed operation
- frequently employed in large
- low speed reversing mils requiring rapid acceleration and deceleration
- Typical applications are large gearless drives,
  e.g. drives for reversing mills, mine heists, etc.

BIG QUESTION

1) What are the different methods of speed control of induction motors?
2) Explain in detail about V/F control?
3) Explain in detail about voltage control method?
4) Explain in details about slip power recovery scheme?
5) Explain in details about single phase half wave converter drive speed control for DC drive
6) Explain in detail the static Kramer methods for controlling speed using solid state devices.
7) Explain the working of following methods with neat circuit diagram
   i).Kramer system ii).Scherbius system
8) Explain in details rotor resistance method of speed control of a slip ring induction motor.

QUESTION BANK

ELECTRICAL DRIVES AND CONTROL

UNIT I

INTRODUCTION

PART-A (2 MARKS)

1. Define Drives
2. Define Electric Drives.
3. What are the basic elements of Electric Drives?
4. Write the classification of Electric Drives.
5. Draw the block diagram of Electric Drive.

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

6. What is meant by Group drive? Give an example.
7. What is meant by Individual drive? Give an example.
8. What is meant by Multi-motor drive? Give an example.
9. What are the advantages and disadvantages of Individual drive system?
10. What are the advantages and disadvantages of Group drive system?
11. What are the advantages of electric drive over mechanical drive?
12. Mention the drawbacks of electric drives.
13. What are the factors influencing the choice of electric drives?
14. Mention the functions of Power modulators.
15. Compare Individual, Group and Multi-motor drives.
16. What are the motors used in Electric drives?
17. Mention the necessity of power rating?
18. Write down the dissipation equation due to convection process.
19. Draw the heating and cooling curve for a particular electric drive.
20. What are the classes of duty for an electric motor?
21. What is meant by continuous duty?
22. What is meant by continuous duty variable load?
23. What happens if the motor is selected at highest load handling capacity at continuous duty variable?
24. What is meant by time intermittent duty?
25. What is meant by periodic intermittent duty?
26. What is duty factor?
27. Give the assumptions for heating and cooling calculation.
28. What is heating curve?
29. Define Heating time constant (ξ1).
30. What is cooling curve?
31. Compare A.C drives and D.C drives.
32. What is meant by short time rating of motor?
33. What are the factors that affect the power rating and size of electric drives?

PART-B

1. Explain the factors governing the selection of motors.
2. Discuss in detail the determination of power rating of motors.
3. (i) Explain the different types of loading of drives.
   (ii) Explain the choice of selection of the motor for different loads.
4. (i) Describe the simplifications based on which the heating and cooling calculations of an electric motor are made.
   (ii) Establish the heating time constant and the heating curves.
5. (i) Compare the D.C and A.C drives.
   (ii) Write a brief note on classes of duty for an electric motor.
6. Draw the typical temperature rise-time curve and derive the equation for temperature rise in an electric drive.
7. Explain the loading of an electric motor and its duty cycle with a simple diagram.
8. Explain in detail about the various types of electric drives.
9. A 100 kW motor, having rated temperature rise of 60°C, has full-load efficiency of 80% and the maximum efficiency occurs at 85% full load. It has thermal time constants of 80 minutes and 65 minutes. It is cyclically loaded, 120% of full load for one hour and 50% of full load for the next hour. Find the temperature rise after 3 hours.
10. The thermal time constant and final steady temperature of a motor on continuous running is 30 minutes and 60°C. Find out the temperature.
    i) After 15 minutes at this load.
    ii) After 1 hour at this load.
    iii) If temperature rise at 1 hour rating is 60°C, find the maximum steady temperature.
    iv) What will be the time required to increase the temperature from 40°C to 60°C at 1 hour rating.

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

UNIT II

DRIVE MOTOR CHARACTERISTICS

PART-A (2 MARKS)

1. Why motor characteristics are important?
2. Why DC series motor should never be started on no-load?
3. Why a fly-wheel setup is used in DC series motor?
4. Why differential compound motors are not used in practical?
5. What is the main reason of fitting fly-wheel along with the motor?
6. Draw the mechanical (or) speed –torque characteristics of all types of DC Motors.
7. State the condition at which the starting toque developed in a slip-ring induction motor is maximum.
8. State the different modes of operation of three phase induction machines.
9. What are mechanical characteristics of a motor?
10. Give the application where DC Shunt, DC Series and DC Compound motors are used.
11. Draw the torque-slip characteristics of a three phase squirrel cage induction motor.
12. What is meant by braking?
13. Mention the Classifications of Braking.
14. What are the advantages and disadvantages of Electrical Braking?
15. Explain the plugging method of braking.
16. Why regenerative braking is not possible ion DC Series motor without modification?
17. Give the types of braking used for DC Motors.
18. What is meant by Regenerative braking in DC Motor?
19. Mention the demerits of mechanical braking.
20. Give the advantage of dynamic braking.
21. What is meant by rheostat (or) dynamic braking?
22. What is meant by Plugging in DC Motor?
23. Draw the speed-torque characteristics of various types of loads.
24. What are the conditions for the stable operations of the motors?
25. List the electrical braking for DC Compound Motor.
26. Differentiate Mechanical and Electrical Braking.
27. Draw the speed-torque characteristics of three phase induction motor.
28. Write short notes about the different types of loads.

PART-B

1. (i) List out the advantages and disadvantages of electrical braking over mechanical braking.
   (ii) Discuss any one method of electrical braking of DC Machines.
2. Explain the Speed-Torque characteristics of three phase induction motor with neat diagrams.
3. Explain about the speed-torque characteristics of a DC Shunt Motor with suitable graph and equations.
4. Explain about the quadrantal diagram of speed-torque characteristics for a motor driving hoist load.
5. Explain how an induction motor is brought to stop by (i) Plugging and (ii) dynamic braking.
6. Explain the various methods of braking of induction motors.
7. Draw and explain various load characteristics of DC Shunt Motor.
8. Explain Rheostat braking in DC Series Motor and Plugging in DC Shunt Motor.
9. Explain various methods of braking of DC Shunt Motors with neat diagrams.
10. Explain various methods of braking of DC Series Motors with neat diagrams.
11. (i) Explain the speed – torque curve of single phase induction motors in detail.
    (ii) Explain the method of regenerative braking employed in DC Motors.
12. Explain about the speed-torque characteristics of a DC Compound Motor with suitable graph and equations.
13. A 220V shunt Motor has an armature resistance of 0.062 Ω and with full field has an emf of 215V at a speed of 960 rpm, the motor is driving an overhauling load with a torque of 172 Nm. Calculate the minimum speed at which the motor can hold the load by means of regenerative braking.

DOWNLOADED FROM STUCOR APP STUCOR APP

DOWNLOADED FROM STUCOR APP

UNIT III

STARTING METHODS

PART-A (2 MARKS)

1. What are the functions of starters?
2. What are the factors influencing the selection of starters?
3. Why starter is necessary for starting a DC Motor?
4. What are the starters used for starting DC Motors?
5. Why is starting current high in a DC Motor?
6. What are the protective devices used in DC Motor Starters?
7. How does the four point starter differ from three point starter?
8. Explain the function of NVR coil in DC Motor Starters?
9. Explain the function of OLR coil in DC Motor Starters?
10. What are the different methods of starting three phase induction motors?
11. How many terminals are provided on the terminal box of a squirrel cage induction motor to be started by a star-delta starter?
12. Mention the reasons for most of the three phase induction motors provided with delta connected stator winding?
13. Write the applications of three phase induction motors?
14. Mention the merits of DOL starter.
15. Mention the demerits of DOL starter.
16. Why stator resistance starter is rarely used?
17. What are the effects of increasing rotor resistance on starting current and starting torque?
18. How reduced voltage starting of induction motor is achieved?
19. How automatic starters are working in DC Motors?
20. How we start the wound-rotor (slip-ring) motors?
21. Why single phase induction motor is not self-starting?

PART-B

1. Draw a neat schematic diagram of a three point starter and explain its working.
2. Draw a neat schematic diagram of a four point starter and explain its working.
3. Explain with neat circuit diagram, the star-delta starter method of starting squirrel cage induction motor.
4. Explain the typical control circuits for DC Series and Shunt motors
5. Explain the different starting methods of three phase squirrel cage induction motors with neat sketches.
6. Explain different methods of starting of DC Motors.
7. Explain with neat diagram the starting of three phase slip ring induction motor.
8. Draw and explain the push-button operated direct-on line starter for three phase induction motor.
9. Draw and explain the manual auto-transformer starter for three phase induction motor.

UNIT IV

CONVENTIONAL AND SOLID STATE SPEED CONTROL OF D.C DRIVES

PART-A (2 MARKS)

1. Enumerate the factors on which the speed of a DC Motor depends.
2. By what methods can the speed of a DC Shunt Motor be controlled?
3. Why the field control is considered superior to armature resistance control for DC Shunt Motors?
4. What is the effect of inserting resistance in the field circuit of a DC Shunt Motor on its speed and torque?
5. What is meant by speed control?
6. Mention the different methods of speed control employed for DC Series Motor.
7. What is meant by armature control?

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

8. What will be the effect of change in supply voltage on the speed of DC Shunt Motor?
9. What are the advantages and disadvantages of armature resistance control of DC Shunt Motor?
10. What are the advantages and disadvantages of Field control (or) Flux control method?
11. What is meant by flux control (or) field control method?
12. In which type of control the field current and armature current kept constant?
13. How we select the shunt and series motor based on the torque and speed in particular application?
14. Write down the applications of Ward-Leonard system of speed control.
15. What are the advantages and disadvantages of Ward-Leonard method of speed control?
16. Write down the disadvantages and applications of armature diverted method of speed control of DC Series Motor.
17. What is meant by solid state speed control?
18. What are the advantages and disadvantage of solid state drive methods?
19. What is meant by DC Chopper?
20. What is meant by duty cycle?
21. What are the different types of Chopper?
22. What is the function of freewheeling diode?
23. Write the output equations for single phase half and full converters.
24. What are the arrangements are available using Power semiconducting materials?
25. What are the two main methods for speed control of DC Shunt Motor?
26. What are the advantages of thyristor control on speed control of DC Motor?
27. Why Chopper based D.C drives give better performance than rectifier controlled drives?
28. Name the solid state controllers used for the speed control of D.C Shunt motor and Series Motor.
29. What is free-wheeling?

PART-B

1. Explain with neat sketch the chopper control method of speed control of DC Motors.
2. Explain with neat sketches about the DC Shunt Motor speed control by using single phase fully controlled bridge converter.
3. Discuss the Ward-Leonard speed control system with a neat circuit diagram. Also mention its advantages and disadvantages.
4. Explain how the speed of a DC Shunt Motor can be varied both above and below the speed at which it runs with full field current.
5. (i) Explain with neat sketch the operation of chopper fed DC Series Motor drive. Also, derive the expression for average motor current.
   (ii) Explain Time ratio control and Current limit control.
6. Explain the speed control schemes of DC Series Motor.
7. Explain the different methods of speed control employed in DC Shunt Motor.
8. Explain the control of DC drives using rectifiers and choppers.
9. Explain the single phase half wave converter drive speed control for DC drive with waveforms.
10. Explain in detail the single phase semi-converter speed control for DC drive for separately excited motor.
11. A 500V series motor having armature resistance and field resistance of 0.2 Ω and 0.3 Ω respectively runs at 500 rpm when taking 70A. Assuming unsaturated field, find out its speed when field diverter of 0.684 Ω is used constant load torque.
12. A 250V DC Series Motor takes 40A of current when developing a full load torque at 1500 rpm. Its resistance is 0.5 Ω. If the load torque varies as the square of the speed determine the resistance to be connected in series with the armature to reduce the speed to 122 rpm. Assume the flux is proportional to the field current.

STUCOR APP
STUCOR APP
STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

UNIT V

CONVENTIONAL AND SOLID STATE SPEED CONTROL OF A.C DRIVES

PART-A (2 MARKS)

1. List the different methods of speed control of three phase induction motor.
2. Write short notes about cascaded method of speed control?
3. Define Slip.
4. What is slip-power recovery system?
5. What are the advantages of Slip-power recovery system?
6. What is meant by Voltage control in induction motor? Where it is applicable?
7. What is meant by Voltage / Frequency control?
8. What are the main features of V/f control?
9. What is meant by Stator frequency control?
10. What is meant by AC Voltage controller?
11. Mention the advantages and disadvantages of Stator voltage control.
12. What are the possible methods of speed control available by using inverter?
13. Why we go for PWM inverter control?
14. Write the classifications of PWM techniques.
15. What is meant by Cycloconverter?
16. Write the types of Cycloconverter.
17. Write the applications of Cycloconverter.
18. Write down the limitation of Cycloconverter method of speed control.
19. Compare the Static Kramer and Scherbius System.
20. What are the advantages and disadvantages of Static Scherbius scheme of speed control?
21. Write the speed equation of an induction motor.
22. What is VVVF control?

PART-B

1. Draw the power circuit arrangement of three phase variable frequency inverter for the speed control of three phase induction motor and explain its working.
2. Explain the V/f control method of AC drive with neat sketches.
3. Discuss the speed control of AC motors by using three phase AC Voltage regulators.
4. Explain the speed control schemes of phase wound induction motors.
5. Explain the concatenation operation of three phase induction motors. Hence derive the speed experienced for the cascaded set.
6. Explain in detail about Slip power recovery scheme.
7. Explain the different methods of speed control used in three phase induction motors.
8. Explain the working of following methods with neat circuit diagram.
   i) Kramer system ii) Scherbius system
9. Explain in detail rotor resistance method of speed control of a slip ring induction motor.
10. (i) Explain the operation of Pole changing method of speed control.
    (ii) Explain the pole amplitude modulation method.
11. Explain the static Kramer method and static Scherbius method of speed control of three phase induction motor.
12. Explain in detail about the various methods of solid state speed control techniques by using inverters.
13. Explain the solid state stator voltage control technique for the speed control of three phase induction motor.
14. Explain the various methods of speed control of a three phase induction motor when fed through semiconductor devices.

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

ANNA UNIVERSITY QUESTION

B.E./B.Tech. DEGREE EXAMINATION, APRIL/MAY 2010

Third Semester

Mechanical Engineering

ME2205 — ELECTRICAL DRIVES AND CONTROL

(Common to Chemical Engineering, Production Engineering)

(Regulation 2008)

Time: Three hours Maximum: 100 Marks

Answer ALL Questions

PART A — (10 × 2 = 20 Marks)

1. State the advantages of Electric Drive.
2. Give the formula for computing power requirement for a liner movement.
3. Write down the torque equation of a DC shunt motor and give the significance of flux.
4. A 6-pole, 3-phase induction motor operating on a 50 Hz supply has rotor emf frequency as 2 Hz. Determine (a) slip and (b) the rotor speed.
5. Why are centrifugal switches provided on many 1-phase induction motors?
6. Draw the block diagram of soft starter for an induction motor.
7. Compare the chopper control and phase control schemes for DC motor drives.
8. State the different methods of speed control of DC series motor.
9. What is advantage of v/f speed control of Induction Motor?
10. Draw the block diagram of speed control scheme for a slip ring Induction motor.

PART B — (5 × 16 = 80 Marks)

11. (a) (i) Briefly explain the various factors that will influence the choice of an electrical drive. (8)

(ii) Explain the method of estimating equivalent continuous power rating of a motor for short time load applications. (8)

Or

(b) (i) Explain the different classes of motor duty with the equations. (8)

(ii) The temperature rise of motor after operating for 30 minutes on full load is 20°C and after another 30 minutes it becomes 30°C on the same load. Find the final temperature rise and time constant. (8)

12. (a) (i) From electrical characteristic, derive the mechanical characteristic of DC series motor. (8)

(ii) Explain the dynamic braking of DC shunt motor with the required diagram and equations. (8)

Or

(b) (i) Derive the Speed-Torque characteristic of 3-phase slip ring induction motor. (8)

(ii) Explain the principle operation of capacitor start and run 1-phase Induction Motor. (8)

13. (a) (i) With a neat diagram explain the operation of four point starter. Also mention the

DOWNLOADED FROM STUCOR APP STUCOR APP

DOWNLOADED FROM STUCOR APP

advantages of this over a three point starter. (12)

(ii) Draw the control circuit for time limit acceleration of DC shunt motor. (4)

Or

(b) State the various starting methods of squirrel cage induction motor. Explain any two of them. (16)

14. (a) (i) Explain the operation of armature control of a DC shunt motor. (8)

(ii) Draw and explain the four quadrant speed control of DC motor using various choppers. (8)

Or

(b) (i) With the block diagram explain the operation of armature and field control of DC motor drive using controlled rectifiers. (12)

(ii) Name the different flux control methods adopted for DC series motor. (4)

15. (a) Explain the operation of speed control techniques employed for 3-phase squirrel cage induction motor. (16)

Or

(b) What is meant by slip power recovery scheme? Explain with the necessary diagram. (16)

STUCOR APP

 STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

B.E./B.Tech. DEGREE EXAMINATION, NOVEMBER/DECEMBER 2010
Third Semester
Mechanical Engineering

ME 2205 — ELECTRICAL DRIVES AND CONTROL
(Common to Chemical Engineering and Production Engineering)
(Regulation 2008)

Time : Three hours   Maximum : 100 Marks

Answer ALL questions

PART A — (10 × 2 = 20 Marks)

1. Define heating time constant.
2. What is meant by continuous rating?
3. Draw the speed-torque characteristics of DC shunt and series motor.
4. State the advantages of electrical braking.
5. What is the necessity of starters in DC motors?
6. Name the different types of starters used in 3-phase induction motors.
7. What are the fields of application of Ward-Leonard drive?
8. Define Duty cycle of DC chopper.
9. What is meant by constant V/F control?
10. State any two merits of slip power recovery scheme.

PART B — (5 × 16 = 80 Marks)

11. (a) Discuss in detail the various factors which affect the selection of electrical drives for a particular application. (16)

Or

(b) (i) Explain the disadvantages of using a motor of wrong rating. (8)

(ii) The temperature rise of a motor when operating for 25 min. on full load is 25°C and becomes 40°C when the motor operates for another 25 min. on the same load. Determine heating time constant and steady state temperature rise. (8)

12. (a) Describe various methods of electrical braking of d.c. shunt motors. Compare their relative merits and demerits. (8 + 4 + 4)

Or

(b) A. d.c. series motor runs at 1000 rpm taking 100 A at 400v. A diverter having doubled the resistance of the field winding is then connected in parallel with it. Estimate the change in speed if the torque varies as the square of the speed. Assume unsaturated field and neglect losses. (16)

13. (a) Discuss different types of D.C. motor starters. (16)

Or

(b) Discuss the various methods of starting of induction motors and compare their relative merits and demerits. (8 + 4 + 4)

14. (a) Describe with the help of a connection diagram the ward Leonard method of speed control. Explain its operation at starting, stopping and reversing. State the merits and demerits of this scheme. (8 + 4 + 4)

DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

Or

(b) A 220v, 24A, 1000 rpm separately excited dc motor has an armature resistance of 2 ohms. Motor is controlled by a chopper operating at 500Hz from a 230 V supply. Calculate the duty ratio for 1.2 times rated torque and 500 rpm. Draw the power circuit for the dc motor drive. (16)

15. (a) Explain how the speed of slip ring induction motor is controlled by feeding back its slip power to the mains. What are its advantages and disadvantages? (8 + 4 + 4)

Or

(b) Discuss a speed control scheme for a 3-phase induction motor using a AC voltage controller. Bring out the merits and demerits of such a scheme. (8 + 4 + 4)

STUCOR APP

DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

Reg. No. :

Question Paper Code : T3053

B.E./B.Tech. DEGREE EXAMINATION, NOVEMBER/DECEMBER 2009

Third Semester

Mechanical Engineering

ME 2205 — ELECTRICAL DRIVES AND CONTROL

(Common to Chemical Engineering, Production Engineering)

(Regulation 2008)

Time : Three hours | Maximum : 100 Marks

Answer ALL Questions

PART A — ($10 \times 2 = 20$ Marks)

1. Give any two factors that influence the choice of Electrical drives.

2. Draw the functional block diagram of an electric drive system.

3. Draw the speed torque characteristics of high speed hoist and Traction load.

4. Draw the Speed torque characteristics of DC Series motor.

5. What is the need of starter in DC motor drives?

6. How the starting current is limited in three phase induction motor using Star-Delta starter?

7. What is meant by time ratio control in DC chopper?

8. List the disadvantages of Ward Leonard method of speed control of DC motor.

9. List the drawbacks of stepped wave inverter fed 3 phase induction motor?

10. Specify the dominant applications of Induction motor.

STUCOR APP
STUCOR APP
STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP STUCOR APP

PART B — (5 × 16 = 80 Marks)

11. (a) Explain the different classes of motor duty with a neat sketch. (16)

Or

(b) Derive the expression for a thermal model of motor for heating and cooling. Also draw the heating and cooling curve. (16)

12. (a) Explain the different methods of braking of a DC motor drives with a neat sketch. (16)

Or

(b) (i) Draw and explain the speed-torque characteristics of 3 phase Induction motor. (6)

(ii) Explain the plugging and Regenerative braking in 3 phase induction motor. (10)

13. (a) Explain the 3 point starter operation with a neat sketch. (16)

Or

(b) Explain the operation of a rotor rheostat starter for a 3 phase induction motor. (16)

14. (a) Explain the operation of a single phase fully controlled rectifier fed DC separately excited motor. Use a neat sketch. (16)

Or

(b) Explain the ward-Leonard method of speed control of DC separately excited motor use a neat sketch. (16)

15. (a) (i) Discuss the operation of a 3 phase AC voltage controller fed 3 phase induction motor. (6)

(ii) With neat speed-torque characteristics explain the voltage/frequency control of 3 phase induction motor. (10)

Or

(b) Explain the operation of two methods of static slip power recovery schemes to control speed of 3 phase slip-ring induction motor. (16)

———————

STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP
STUCOR APP

PANIMALAR ENGINEERING COLLGE

DEPARTMENT OF MECHANICAL ENGINEERING

II YEAR / III SEMESTER

ELECTRICAL DRIVES AND CONTROL

UNIT - I

INTRODUCTION

STUCOR APP
STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

Introduction to Electrical Drives:

Motion control is required in large number of industrial and domestic applications like transportation systems, rolling mills, paper machines, textile mills, machine tools, fans, pumps, robots, washing machines etc.

Systems employed for motion control are called drives, and may employ any of prime movers such as diesel or petrol engines, gas or steam turbines, steam engines, hydraulic motors and electric motors, for supplying mechanical energy for motion control. Drives employing electric motors are known as electrical drives.

An electric drive can be defined as an electromechanical device for converting electrical energy into mechanical energy to impart motion to different machines and mechanisms for various kinds of process control.

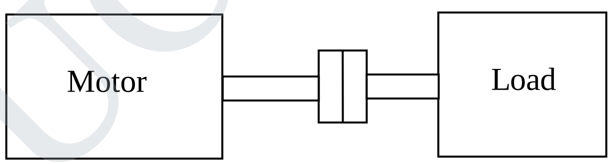
Classification of Electrical Drives

According to Number of machines

- Individual drive
- Group drive
- Multi-motor drive

Individual drive or Single drive:

In this a single motor is dedicated to a single load. This motor also imparts motion to various parts of the machine.



Mech. coupling

Advantages:
1. Flexibility of layout
2. If any failure or maintenance carried out in main motor, corresponding load will be affected or idle.
3. Efficiency is high because no load losses are less.
4. Quite operation compared to other drive.
5. It requires less space.

Disadvantages:
1. Cost is high compared to group drive

Examples: Home appliances such as Mixer, Grinder, Washers, Dryers, Fans, Drilling Machines, Power tools, Pumps, Compressors, etc.,

STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

Group Drive

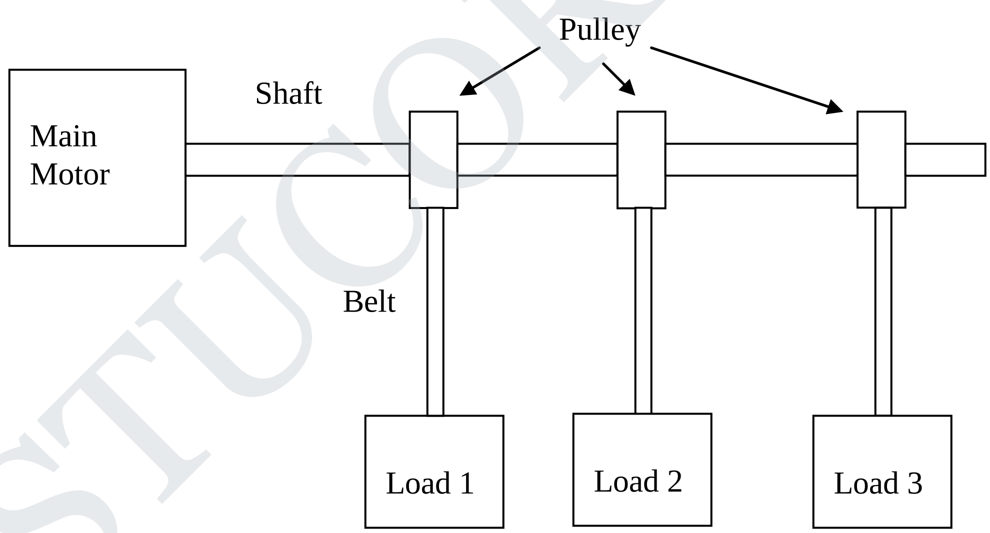
This drive consists of a single motor, which drives one or more line shafts supported on bearings. The line shaft may be fitted with either pulleys and belts or gears, by means of which a group of machines or mechanisms may be operated. It is also sometimes called as shaft drives.

Advantages:

2. The group drive is most economical because, a single large motor can be used instead of number of small motors.
3. The rating of single motor used may be comparatively less than the aggregate of ratings of individual motors required to drive each equipment.
4. Efficiency is increased at full load.

Disadvantages:

1. There is no flexibility layout.
2. If the single motor used develops fault, the whole process will be stopped.
3. Efficiency is less at light load or no load.
4. In this drive noise is high.
5. It requires more space.
6. Addition of an extra machine to the main shaft is difficult.
7. This system is not safe for operator.



Multi Motor Drive

In this drive system, there are several motors used to drives single mechanical load, each of which serves to actuate one of the working parts of the drive mechanisms.

E.g.: Complicated metal cutting machine tools, Robotics, Assembly lines, Paper making machines, Rolling machines, Cloth printing and Traveling cranes etc.

Advantages:

1. Flexibility of installation
2. Reduce the risk of accidents

STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

Disadvantages:

1. Initial cost is high

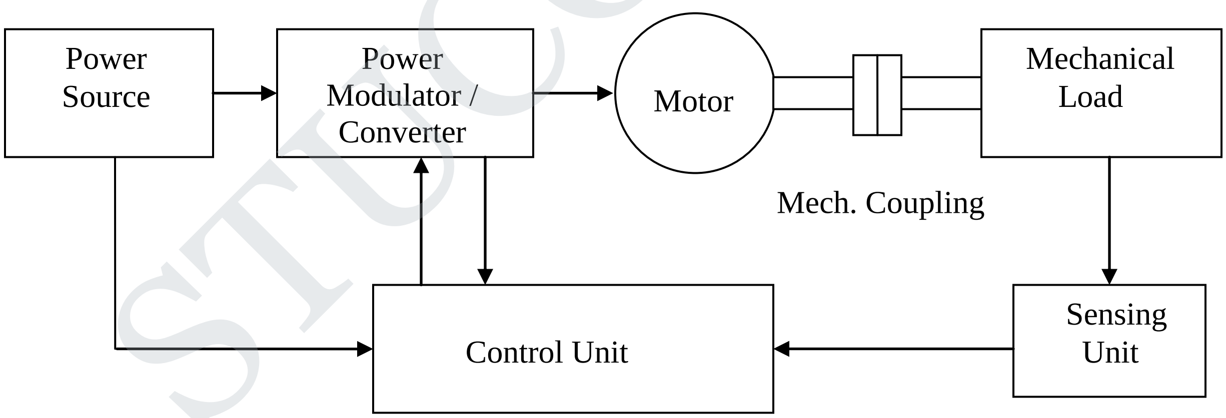
Advantages of Electrical Drive

They have flexible control characteristics. The steady state and dynamic characteristics of electric drives can be shaped to satisfy the load requirements.

1. Drives can be provided with automatic fault detection systems. Programmable logic controller and
2. Computers can be employed to automatically control the drive operations in a desired sequence.
3. They are available in wide range of torque, speed and power.
4. They are adaptable to almost any operating conditions such as explosive and radioactive environments
5. It can operate in all the four quadrants of speed-torque plane
6. They can be started instantly and can immediately be fully loaded
7. Control gear requirement for speed control, starting and braking is usually simple and easy to operate.
8. They have short time over load capacity
9. Noise level is low
10. It require less maintenance

General Electric Drive System

Block diagram of an electric drive system is shown in the figure below.



A modern variable speed electrical drive system has the following components

- Electrical machines (Actuator / Motor)
- Mechanical loads
- Transmission system
- Power Modulator or Converter
- Sources
- Control unit
- Sensing unit

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

Motors

Motors obtain the power from electrical sources. They convert electrical energy to mechanical - therefore can be regarded as energy converters. In braking mode, the flow of power is reversed. Depending upon the type of power converters used, it is also possible for the power to be fed back to the sources (regenerative braking) rather than dissipated as heat (dynamic braking).

Most commonly used electrical machines for speed control applications are the following

DC Machines

Shunt, series, compound, separately excited DC motors and switched reluctance machines.

AC Machines

Induction, wound rotor, synchronous, PM synchronous and synchronous reluctance machines.

Special Machines

Brush less DC motors, stepper motors, switched reluctance motors are used.

Power Modulators or Converters

Functions:

Modulates flow of power from the source to the motor in such a manner that motor is imparted speed-torque characteristics required by the load

During transient operation, such as starting, braking and speed reversal, it restricts source and motor currents with in permissible limits.

It converts electrical energy of the source in the form of suitable to the motor. Select the mode of operation of the motor (i.e.) Motoring and Braking.

- More efficient – since ideally no losses occur in power electronic converters
- Flexible – voltage and current can be shaped by simply controlling the switching functions of the power converter
- Compact – smaller, compact and higher ratings solid–state power electronic devices are continuously being developed – the prices are getting cheaper.

Types of power modulators

In the electric drive system, the power modulators can be any one of the following

- Controlled rectifiers (ac to dc converters)
- Inverters (dc to ac converters)
- AC voltage controllers (AC to AC converters)
- DC choppers (DC to DC converters)
- Cycloconverters (Frequency conversion)

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

Electrical Sources

Very low power drives are generally fed from single phase sources. Rest of the drives is powered from a 3 phase source. Low and medium power motors are fed from a 400V supply. For higher ratings, motors may be rated at 3.3KV, 6.6KV and 11 KV. Some drives are powered from battery or DC supply.

Sensing Unit

The most common sensing devices are transducers, which converts non-electrical quantities (Physical quantities) into electrical signal. Sensors are used to measure the speed, torque, velocity (linear and angular), displacement etc.

- Speed Sensing (Tachogenerator)
- Torque Sensing
- Position Sensing (Hall sensor, Optical encoders)
- Current sensing and Voltage Sensing from Lines or from motor terminals
- Temperature Sensing

Control Unit

Control unit for a power modulator are provided in the control unit. It matches the motor and power converter to meet the load requirements.

Controller is an important device which governs the entire operation of the drive system. There are different controller employed in drive system such as electromechanical relays, electronic controller (P, PI, PD, and PID controller), microprocessor, microcontroller, embedded controller and DSP controller etc

Transmission System

The electric motor to drive the load through transmitting system. The mechanical power can be transferred to load via Pulley, V-belt, Flat belt, Chain, Rope, Gear, Coupling etc.

Classification of electric drive

1. DC drive
2. AC drive

Comparison between DC and AC drives

DC DRIVES	AC DRIVES
The power circuit and control circuit is simple and inexpensive	The power circuit and control circuit are complex
It requires frequent maintenance	Less Maintenance
The commutator makes the motor bulky, costly and heavy	These problems are not there in these motors and are inexpensive, particularly squirrel cage induction motors
Fast response and wide speed range	In solid state control the speed range is wide

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP STUCOR APP

Method of control, can be achieved smoothly by conventional and solid	Solid state and conventional method of speed Control is stepped and limited
Speed and design ratings are limited due to commutations	Speed and design ratings have upper limits
Small power/weigh ratio	Large power/weight ratio
Self starting and fast acceleration	All AC motors are self starting except Synchronous motor
Cost does not depend on power converter	Cost of the drive depend on the solid state Converter
Line commutation is used in this converter	Forced commutation is used with induction motor. Some time load commutation used in Synchronous motor.
The converter technology is well developed	The inverter technology is still being developed

Applications of electric drive

- Domestic / Home appliances: Fan, Mixer, Grinder, Refrigerator, Air Conditioner, Vacuum Cleaner, Washing Machines etc.
- Industrial applications: Steel mills, Rolling mills, Printing, Textile, Cement, Sugar and process industries etc.
- Agriculture: Water irrigation, Centrifugal pumps and Reciprocating pumps
- Transportation: Conveyors, Trolley Busses, Train, Car, Electric locomotive
- Commercial applications: Compressors, Escalator, Lift, Hoist, Excavator, Cranes

Choice (or) Selection of Electrical Drives

Choice of an electric drive depends on a number of factors. Some of the important factors are.

1. Steady State Operating conditions requirements
    - Nature of speed torque characteristics
    - Speed regulation
    - Speed range
    - Efficiency
    - Duty cycle
    - Quadrants of operation
    - Speed fluctuations

2. Transient operation requirements
    - Values of acceleration
    - Deceleration
    - Starting
    - Braking
    - Reversing

STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP
STUCOR APP

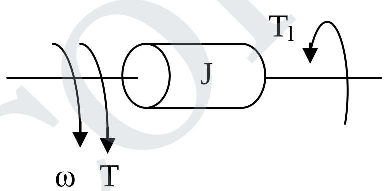
3. Requirements related to the source
   Types of source and its capacity, magnitude of voltage, voltage fluctuations, power factor, harmonics and their effect on other loads, ability to accept regenerative power
4. Capital and running cost, maintenance needs life.
5. Space and weight restriction if any.
6. Environment and location.
7. Reliability.
8. Mechanical characteristics
   - Type of enclosures (Open type, Screen protected, Splash proof, Flame proof, Drip proof, Totally enclosed, Pipe ventilated)
   - Type of bearings (Ball, Sleeve and Bush bearings)
   - Transmission systems (Belt, Chain, Rope, Gear and Coupling drive)
   - Noise level

Dynamics of Motor Load

Fundamentals of Torque Equations

A motor generally drives a load (Machines) through some transmission system. While motor always rotates, the load may rotate or undergo a translational motion.

Equivalent rotational system of motor and load is shown in the figure.



J = Moment of inertia of motor load system referred to the motor shaft, kg-m^2
ω = Instantaneous angular velocity of motor shaft, rad/sec.
T = Instantaneous value of developed motor torque, N-m
T_l = Instantaneous value of load torque, referred to the motor shaft, N-m
Load torque includes friction and wind age torque of motor.

Motor-load system shown in figure can be described by the following fundamental torque equation.

Under equilibrium condition, $T - T_l = 0$ or $T = T_l$

$$T_l = J\frac{d\omega}{dt}, \qquad T - T_l = J\frac{d\omega}{dt}, \qquad T = T_l + J\frac{d\omega}{dt}$$

Classification of Load Torques:

Various load torques can be classified into broad categories.

1. Active load torques
2. Passive load torques

STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

Active load torque

Load torques which has the potential to drive the motor under equilibrium conditions are called active load torques. Such load torques usually retain their sign when the drive rotation is changed (reversed)

Eg: Torque due to force of gravity
Torque due tension
Torque due to compression and torsion etc

Passive load torque

Load torques which always oppose the motion and change their sign on the reversal of motion are called passive load torques

Eg: Torque due to friction, cutting etc.

Components of Load Torques:

The load torque T_l can be further divided in to following components

(i) Friction Torque (T_F)

Friction will be present at the motor shaft and also in various parts of the load. T_F is the equivalent value of various friction torques referred to the motor shaft.

(ii) Windage Torque (T_W)

When motor runs, wind generates a torque opposing the motion. This is known as windage torque.

(iii) Torque required to do useful mechanical work.

Nature of this torque depends upon particular application. It may be constant and independent of speed. It may be some function of speed, it may be time invariant or time variant, its nature may also change with the load's mode of operation.

Value of friction torque with speed is shown in figure below

Its value at stand still is much higher than its value slightly above zero speed. Friction at zero speed is called stiction or static friction. In order to start the drive the motor should at least exceed stiction.

Types of Mechanical loads

One of the essential requirements in the section of a particular type of motor for driving a machine is the matching of speed-torque characteristics of the given drive unit and that of the motor. Therefore the knowledge of how the load torque varies with speed of the driven machine is necessary. Different types of loads exhibit different speed torque characteristics. However, most of the industrial loads can be classified into the following four categories.

- Continuous load
- Continuous variable load
- Pulsating load
- Impact load
- Short time load
- Short time intermittent load

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

Continuous load:

These loads occur for long time under the same conditions.

e.g.: Fans, Centrifugal pumps, paper making machines

Continuous variable load:

The load is variable over a period of time, but occurs repetitively for a long duration.

e.g.: Metal cutting lathes, Conveyors, Hoist, Winches

Pulsating load:

Certain types of load exhibits a torque behavior is constant torque superimposed by pulsations.

e.g.: reciprocation pumps, all load having crank shafts.

Impact load:

Peak load or pulses occur at regular intervals of time. This type of load requires flywheels for load equalization.

e.g.: Rolling mills, shearing machines, Presses, Forging hammer.

Short time load:

A constant load appears on the drive a short time and the system rest for long time or remainder.

e.g.: Battery charging, Home appliances

Short time intermittent load:

The load appears periodically in identical duty cycle, each consist of a period of application of load and one of rest.

e.g.: Cranes, Hoist, and Excavator

Typical load torque characteristics of mechanical loads

- Constant torque type load
- Torque proportional to speed (Generator Type load)
- Torque proportional to square of the speed (Fan type load)
- Torque inversely proportional to speed (Constant power type load)

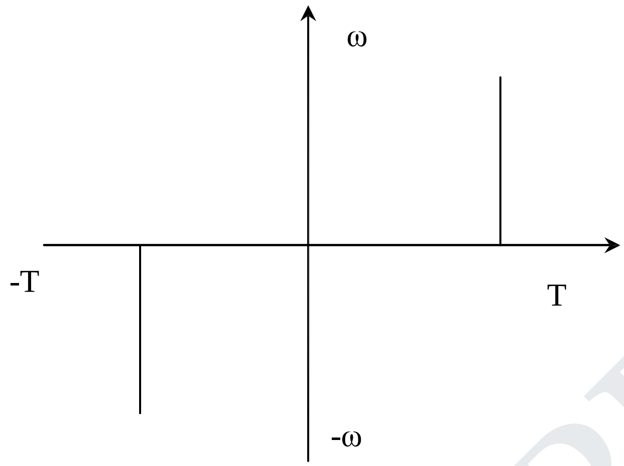
Constant Torque characteristics:

Most of the working machines that have mechanical nature of work like shaping, cutting, grinding or shearing, require constant torque irrespective of speed. Similarly cranes during the hoisting and conveyors handling constant weight of material per unit time also exhibit this type of characteristics.

STUCOR APP
DOWNLOADED FROM STUCOR APP

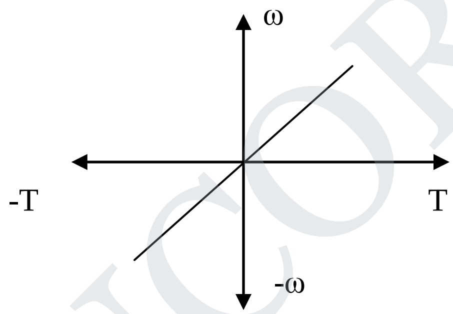
DOWNLOADED FROM STUCOR APP

Constant torque load:



Torque Proportional to speed:

Separately excited dc generators connected to a constant resistance load, eddy current brakes have speed torque characteristics given by $T = k\omega$



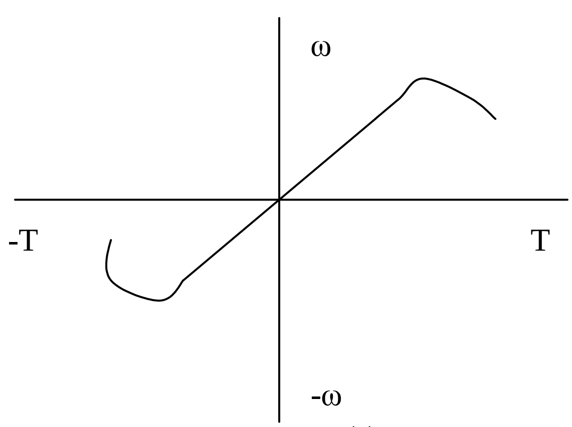
e.g.: Calendaring machine, Eddy current brake

Torque proportional to square of the speed:

Another type of load met in practice is the one in which load torque is proportional to the square of the speed.

e.g.: Fans, Rotary pumps, Compressors and Ship propellers.

$T \propto \omega^2$

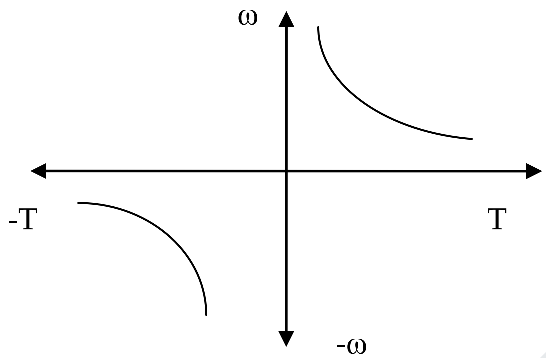


DOWNLOADED FROM STUCOR APP
STUCOR APP

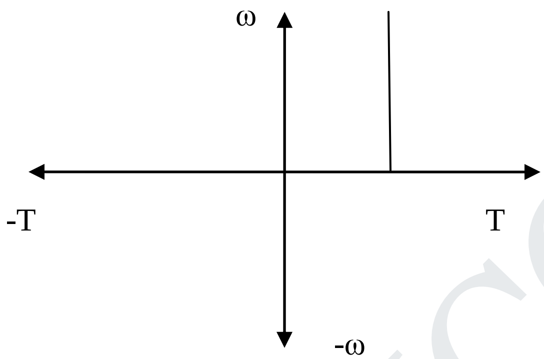
DOWNLOADED FROM STUCOR APP STUCOR APP

Torque Inversely proportional to speed:

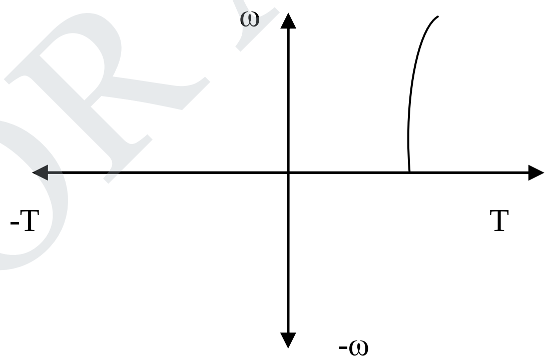
Certain types of lathes, boring machines, milling machines, steel mill coiler and electric traction load exhibit hyperbolic speed-torque characteristics.



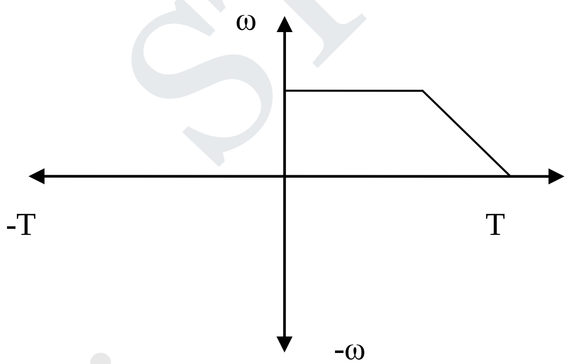
Low speed hoist load



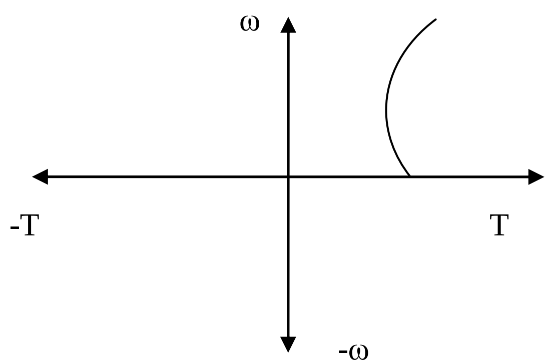
High speed hoist load



Torque in excavator



Traction load

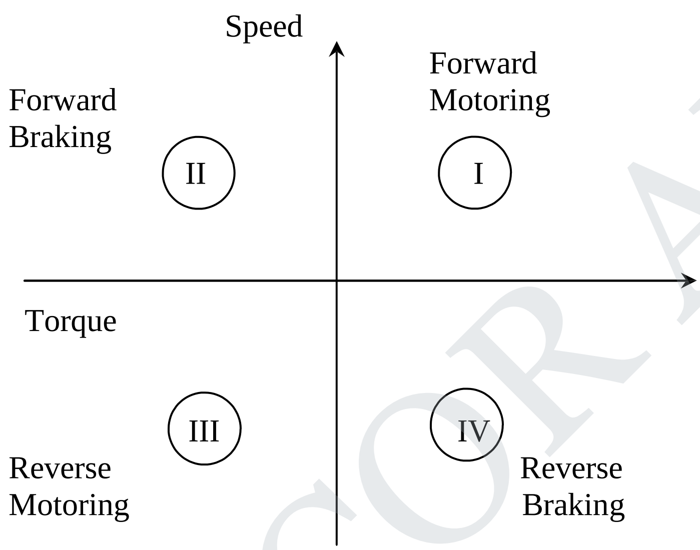


STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

Four quadrant Operation

For consideration of multi quadrant operation of drives, it is useful to establish suitable conventions about the signs of torque and speed. A motor operates in two modes – Motoring and braking. In motoring, it converts electrical energy into mechanical energy, which supports its motion. In braking it works as a generator converting mechanical energy into electrical energy and thus opposes the motion. Motor can provide motoring and braking operations for both forward and reverse directions. Figure shows the torque and speed co-ordinates for both forward and reverse motions. Power developed by a motor is given by the product of speed and torque. For motoring operations power developed is positive and for braking operations power developed is negative.



A hoist consists of a rope wound on a drum coupled to the motor shaft one end of the rope is tied to a cage which is used to transport man or material from one level to another level . Other end of the rope has a counter weight. Weight of the counter weight is chosen to be higher than the weight of empty cage but lower than of a fully loaded cage. Forward direction of motor speed will be one which gives upward motion of the cage. Load torque line in quadrants I and IV represents speed-torque characteristics of the loaded hoist. This torque is the difference of torques due to loaded hoist and counter weight

In quadrant I, developed power is positive, hence machine works as a motor supplying mechanical energy. Operation in quadrant-I is therefore called Forward Motoring. In quadrant II, power developed is negative. Hence, machine works under braking opposing the motion. Therefore operation in quadrant II is known as forward braking. Similarly operation in quadrant III and IV can be identified as reverse motoring and reverse braking since speed in these quadrants is negative. For better understanding of the above notations, let us consider operation of hoist in four quadrants as shown in the figure. Direction of motor and load torques and direction of speed are marked by arrows.

The load torque in quadrants II and III is the speed torque characteristics for an empty hoist. This torque is the difference of torques due to counter weight and the empty hoist. Its sigh is negative because the counter weight is always higher than that of an empty cage.

STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP STUCOR APP

The quadrant I operation of a hoist requires movement of cage upward, which corresponds to the positive motor speed which is in counter clockwise direction here. This motion will be obtained if the motor products positive torque in CCW direction equal to the magnitude of load torque T_{L1}. Since developed power is positive, this is forward motoring operation. Quadrant IV is obtained when a loaded cage is lowered. Since the weight of the loaded cage is higher than that of the counter weight .It is able to overcome due to gravity itself.

In order to limit the cage within a safe value, motor must produce a positive torque T equal to T_{L2} in anticlockwise direction. As both power and speed are negative, drive is operating in reverse braking operation. Operation in quadrant II is obtained when an empty cage is moved up. Since a counter weigh is heavier than an empty cage, it's able to pull it up. In order to limit the speed within a safe value, motor must produce a braking torque equal to T_{L2} in clockwise direction. Since speed is positive and developed power is negative, it's forward braking operation.

Operation in quadrant III is obtained when an empty cage is lowered. Since an empty cage has a lesser weight than a counter weight, the motor should produce a torque in CW direction. Since speed is negative and developed power is positive, this is reverse motoring operation.

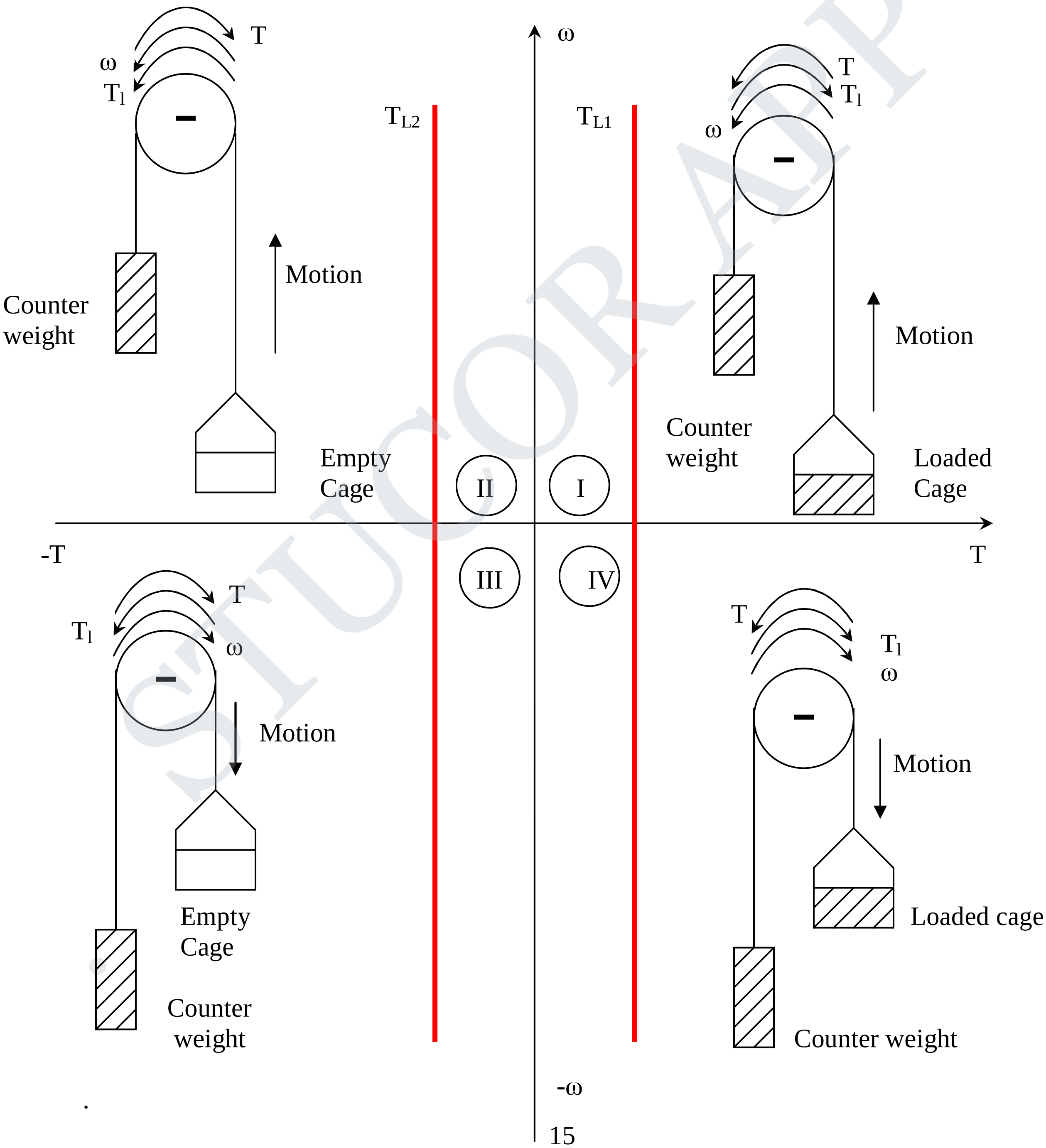
Steady State Stability:

Equilibrium speed of motor-load system can be obtained when motor torque equals the load torque. Electric drive system will operate in steady state at this speed, provided it is the speed of stable state equilibrium. Concept of steady state stability has been developed to readily evaluate the stability of an equilibrium point from the steady state speed torque curves of the motor and load system.

In most of the electrical drives, the electrical time constant of the motor is negligible compared with the mechanical time constant. During transient condition, electrical motor can be assumed to be in electrical equilibrium implying that steady state speed torque curves are also applicable to the transient state operation.

STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

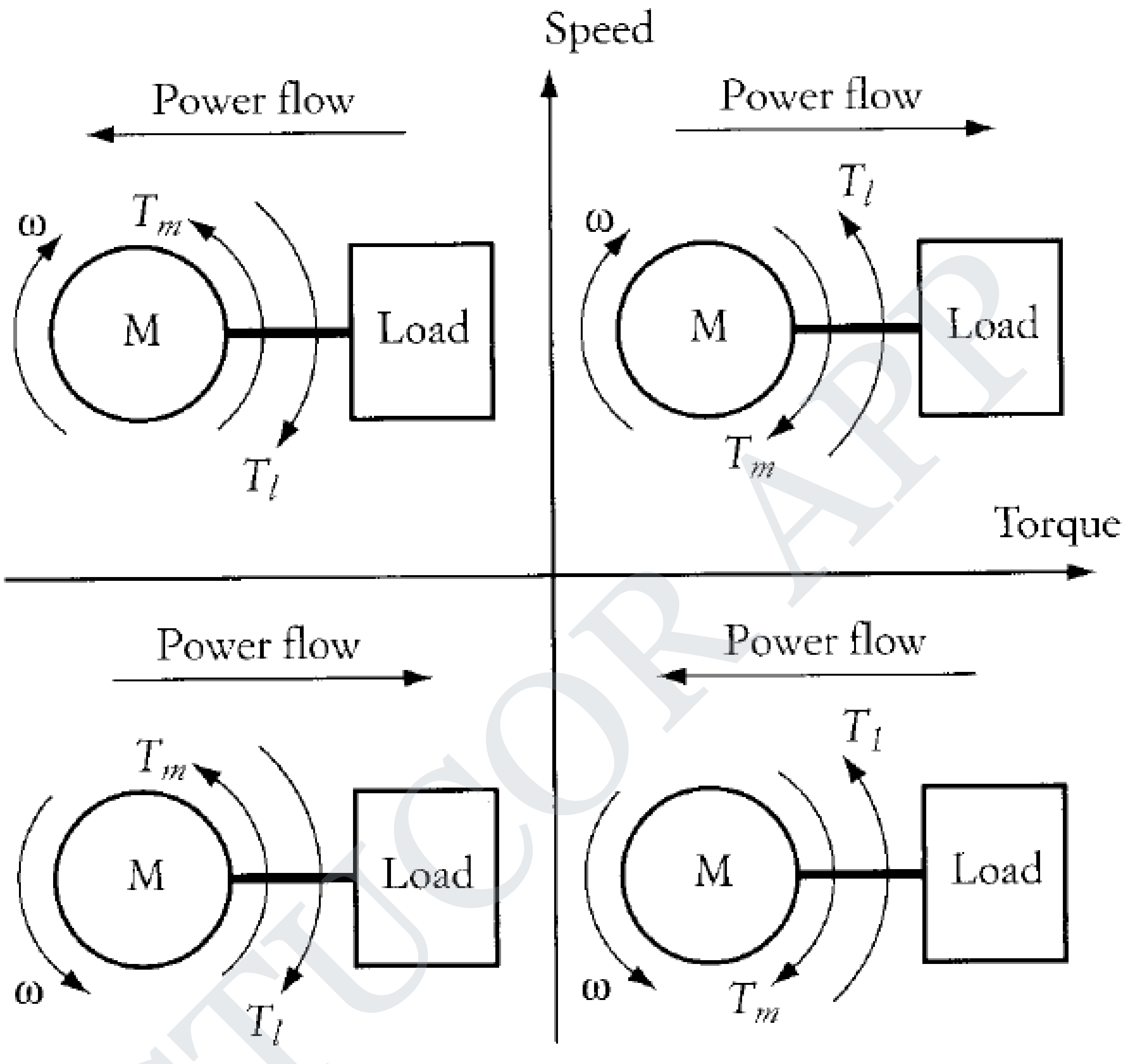
DOWNLOADED FROM STUCOR APP



STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP
STUCOR APP

Four-quadrant drives



CLASSES OF DUTY OR TYPES OF DUTY

1. Continuous duty
2. Short time duty operation of motor
3. Intermittent periodic duty

} Main classes of duties

4. Intermittent periodic duty with starting
5. Intermittent periodic duty with starting & braking
6. Continuous duty with intermittent periodic loading
7. Continuous duty with starting & braking
8. Continuous duty with periodic load changes

STUCOR APP
STUCOR APP
STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

1. Continuous duty

The motor is loaded continuously. The motor operates with constant load of sufficient duration for thermal equilibrium to be reached. Obviously the rating of the motor must at least equal the continuous loading of the machine. Normally, motor with next higher power rating from commercial available rating is selected.

e.g.: Fans, Conveyors, pumps and compressors etc.

2. Short time duty

In this duty, operation at constant load during short time interval or given time and rest for sufficiently longer time. The time of operation is considerably less than the thermal time constant. The motor is allowed to cool to ambient temperature before the new load cycle is applied. The recommended values for the short time duty are 10, 30, 60 and 90 minutes.

e.g.: Home appliances like Mixer, Grinder, Vacuum cleaner etc.

3. Intermittent periodic duty

A sequence of identical duty cycles consists of a periodic operation at constant load and a rest period. The load cycle is repeated periodically. The machine is not allowed to cool to ambient when the next load cycle is applied. The temperature will fluctuate and the mean value will eventually settle to a steady state value. The machine can be overloaded and amount of overloading depends on the duty cycle of the load.

e.g.: Tram, Trolley Busses and Hoist etc.

Cyclic duration factor $CDF = \frac{N}{N+R}$ where, N – Duration of rated load

R – Duration of rest or idle

4. Intermittent periodic duty with starting

This type of duty consists of a sequence of identical duty cycles each consisting of a periodic of starting, a period of operation at constant load and a rest period, the operating and rest periods are too short to obtain thermal equilibrium during one duty cycle.

The duty factor is $CDF = \frac{D+N}{D+N+R}$ where, D – starting period

5. Intermittent periodic duty with starting and braking

This type of duty consists of a sequence of identical duty cycles each consisting of a period of starting, a period of operation at constant load, a period of braking and a rest period. The operating and rest periods are too short to obtain thermal equilibrium during one duty cycle.
The type of braking is by electrical means. The duty factor is

$CDF = \frac{D+N+F}{D+N+F+R}$ where, F – braking period

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

6. Continuous duty with intermittent periodic duty

This type of duty consists of a sequence of identical duty cycles each consisting of a period of operation at constant load and period of operation at no load. The operation and no load periods are too short to attain thermal equilibrium during one cycle
The duty cycle is usually 10 minutes and the recommended duty factors are 15, 25, 40 and 60 percent.

The duty factor is given by $CDF = \frac{N}{N+V}$ where, V – period of operation of no load in seconds

7. Continuous duty with starting and braking

This type of duty consists of a sequence of identical duty cycles each having a period of starting, a period of operation at constant load and a-period of electric braking. There is no rest period.
The duty factor for this duty cycle is 1.

8. Continuous duty with periodic speed changes

This type of duty consists of a sequence of identical duty cycles each consisting of a period of operation at constant load corresponding to a particular speed of rotation, followed immediately by a period of operation at another load corresponding to a different speed of operation. The operating period is too short to attain thermal equilibrium during one duty cycle and there is no rest and de-energized period.

The various duty factors are $= \frac{D_1 + N_1}{D_1 + N_1 + F_1 + N_2 + F_2 + N_3}$

$$= \frac{F_1 + N_2}{D_1 + N_1 + F_1 + N_2 + F_2 + N_3}$$

$$= \frac{F_2 + N_3}{D_1 + N_1 + F_1 + N_2 + F_2 + N_3}$$

Where, F_1, F_2 - braking period in seconds
D - acceleration period
N_1, N_2, N_3 - operation under rated condition are different speeds, in seconds

Load Vs Time diagram

The load-time diagrams for various duty cycles are given below

STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP STUCOR APP

1. Continuous duty

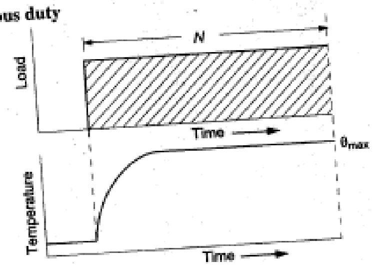


Fig. 1.8

2. Short time duty

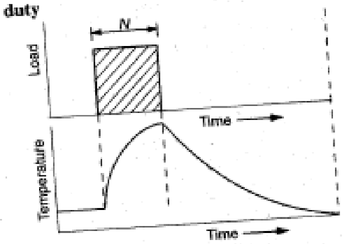


Fig. 1.9

3. Intermittent period duty

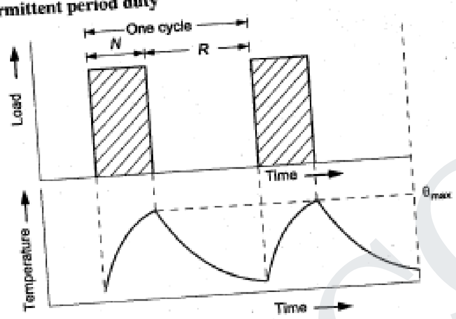


Fig. 1.10

4. Intermittent periodic duty with starting

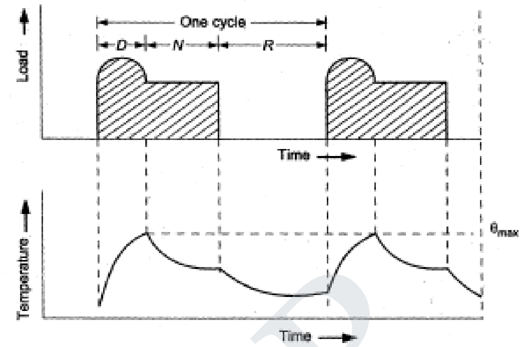


Fig. 1.11

5. Intermittent periodic duty with starting and braking

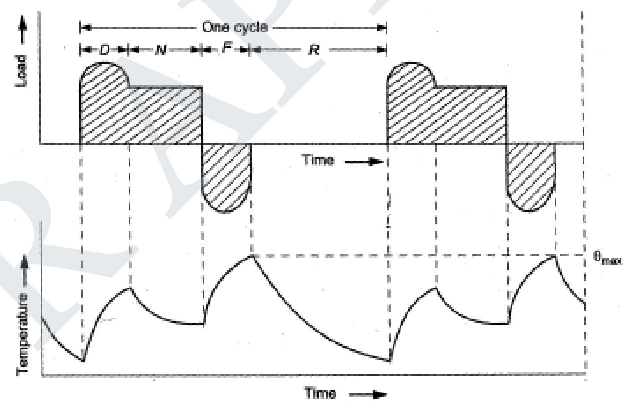


Fig. 1.12

3

STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP STUCOR APP

6. Continuous duty with intermittent periodic loading

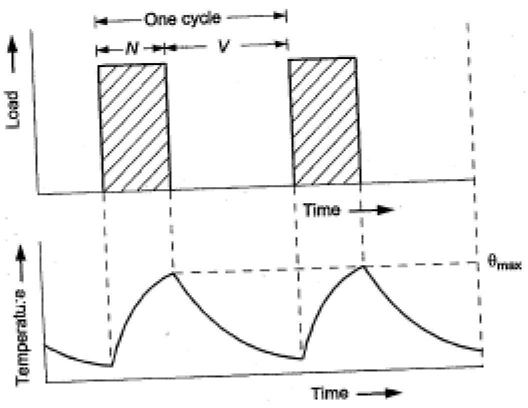


Fig. 1.13

8. Continuous duty with periodic speed changes

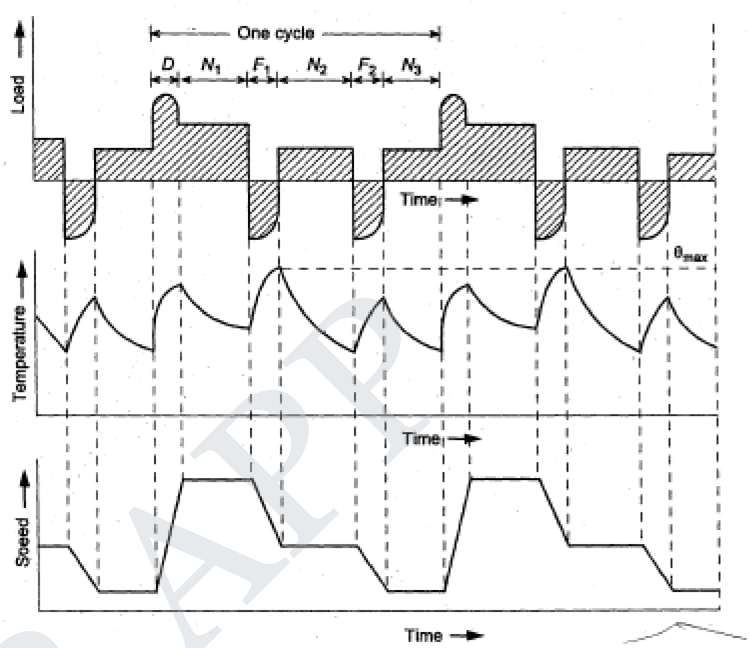


Fig. 1.15

7. Continuous duty with starting and braking

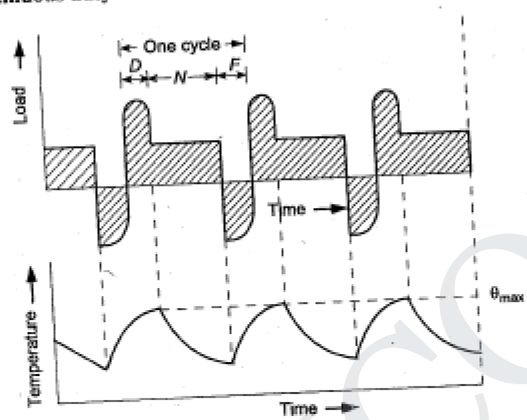


Fig. 1.14

Heating and Cooling time constant

Heating time constant

A machine can be considered as a homogeneous body developing heat internally at uniform rate and dissipating heat proportionately to its temperature rise, the relationship between temperature rise and time can be shown to be an exponential function.

Assumption made for heating and cooling time constant derivation:

1. The machine is considered to be homogeneous body having a uniform temperature gradient.
2. All the points at which the heat is generated at the steady state temperature.
3. All the points at which the heat is dissipated to the cooling medium at same temperature.
4. Heat dissipation taking place is proportional to the difference of temperature of the body and surrounding medium. No heat radiated.
5. The rate of heat dissipation is constant at all temperature.
6. Heat developed is proportional to losses.

Let, p – Power loss or heat developed, joules/sec or watts
G – Weight of motor, kg

STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

h – Specific heat of the material of the body, J / kg / °C
λ – Specific heat dissipation or emissivity, J/s / m^2 / °C
S – Area of cooling surface, m
θ - Temperature rise, °C
θ_m – Final temperature rise, °C
t – Time, seconds
τ - Heating time constant, seconds
τ' - Cooling time constant, seconds

Assume that a machine attains a temperature rise θ after the lapse of time t seconds.
In an element of time 'dt' a small temperature rise 'dθ' takes place.

heat developed = p. dt
heat dissipated = S λ θ dt
heat stored = Gh dθ

Therefore, Total heat developed = Heat dissipated + Heat stored

$$Gh\,d\theta + S\theta\lambda.dt = pdt$$

$$\frac{d\theta}{dt} = \frac{p}{Gh} - \theta\frac{S\lambda}{Gh} = \frac{p-\theta S\lambda}{Gh} \quad \Rightarrow \quad dt = \frac{d\theta.Gh}{p - S\lambda\theta}$$

Integrating both sides we get,

$$\int dt = \int \frac{d\theta.Gh}{p-S\lambda} \quad \Rightarrow \quad t = \int\left(\frac{Gh}{p-S\lambda\theta}\right)d\theta \quad \Rightarrow \quad t = \int\left(\frac{Gh/S\lambda}{p/S\lambda - \theta}\right)d\theta$$

$$t = \frac{Gh}{S\lambda}\int\left(\frac{1}{\theta_m - \theta}\right)d\theta \quad \text{where } \theta_m = \frac{p}{S\lambda}$$

$$\frac{S\lambda}{Gh}t = -(\log(\theta_m - \theta) - \log c) \quad \text{where log c = constant}$$

$$-\frac{S\lambda}{Gh}t = (\log(\theta_m - \theta) - \log c) \Rightarrow -\frac{S\lambda}{Gh}t = \log\left(\frac{\theta_m - \theta}{c}\right),$$

Taking antilog on both sides, we get

$$e^{-S\lambda/Ght} = \frac{\theta_m - \theta}{c} \qquad At\ t=0, \quad \theta = 0 \qquad 1 = \frac{\theta_m}{c} \Rightarrow c = \theta_m$$

$$e^{-S\lambda/Ght} = \frac{\theta_m - \theta}{\theta_m} = 1 - \frac{\theta}{\theta_m} \quad \Rightarrow \quad \frac{\theta}{\theta_m} = 1 - e^{-S\lambda/Ght}$$

$$\theta = \theta_m\left(1 - e^{-S\lambda/Ght}\right) = \theta_m\left(1 - e^{-t/\tau}\right) \quad \text{where } \tau = \frac{Gh}{S\lambda} = \text{heating time constant}$$

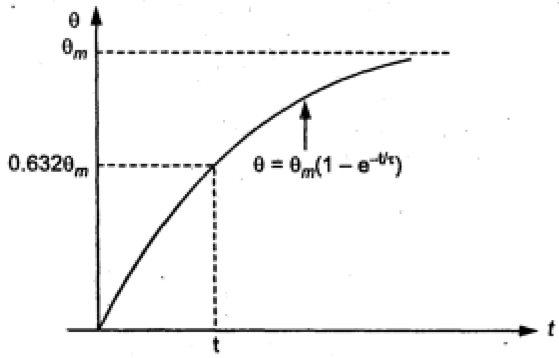
$$\boxed{\theta = \theta_m\left(1 - e^{-t/\tau}\right)}$$

if t = τ   θ = 0.632 θ_m
if t = 2τ   θ = 0.865 θ_m
if t = 3τ   θ = 0.950 θ_m

DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

The above expression is valid for with zero initial condition (i.e $\theta_o = 0$)



Heating time constant curve

Temperature rise expression with initial temperature

$$\theta = \theta_m\left(1 - e^{-t/\tau}\right) + \theta_0\, e^{-t/\tau}$$

The final or maximum or steady state temperature θ_m or θ_f

Cooling time constant

When a machine is switched off from the mains or when the load on the motor is reduced, now gradually motor temperature is reduced to ambient temperature.

If rate of heat generation is less than the rate of heat dissipation cooling will takes place.

$$p'\,dt + Gh.d\theta = S\lambda'\theta\,dt$$

$Gh.d\theta = (S\lambda'\theta - p')dt$ divide by Sλ' both sides and integrating both sides we get,

$$\frac{Gh}{S\lambda'}d\theta = \left(\theta - \frac{p'}{S\lambda'}\right)dt \Rightarrow -\int\left(\frac{1}{\theta - \frac{p'}{S\lambda'}}\right)d\theta = \frac{S\lambda'}{Gh}\int dt \longrightarrow (1)$$

'-' ve sign indicates 'dθ' decreases

Let θ_m' be the final temperature drop, $\theta_m' = \frac{p'}{S\lambda'} \longrightarrow (2)$

Sub equation (2) in equation (1)

$$-\int\left(\frac{1}{\theta - \theta_m'}\right)d\theta = \frac{S\lambda'}{Gh}\int dt$$

$$-\frac{S\lambda'}{Gh}t + c = \log(\theta - \theta_m') \quad \text{where, c = constant}$$

at $t = 0$ $\theta = \theta_m$ $c = \log(\theta_m - \theta_m')$

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

$$-\frac{S\lambda'}{Gh}t = \log(\theta-\theta_m') - \log(\theta_m - \theta_m') \quad \Rightarrow \quad -\frac{S\lambda'}{Gh}t = \log\left(\frac{\theta-\theta_m'}{\theta_m-\theta_m'}\right)$$

Taking antilog on both sides, we get

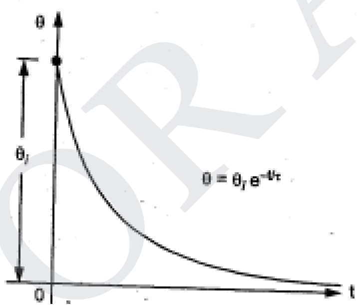
$$\frac{\theta-\theta_m'}{\theta_m-\theta_m'} = e^{-\frac{S\lambda'}{Gh}t} \Rightarrow \theta-\theta_m' = (\theta_m-\theta_m')e^{-\frac{S\lambda'}{Gh}t}$$

$$\theta = \theta_m' + \theta_m\, e^{-\frac{S\lambda'}{Gh}t} - \theta_m'\, e^{-\frac{S\lambda'}{Gh}t} \Rightarrow \theta = \underbrace{\theta_m'\left(1-e^{-\frac{S\lambda'}{Gh}t}\right)}_{=0} + \theta_m\, e^{-\frac{S\lambda'}{Gh}t}$$

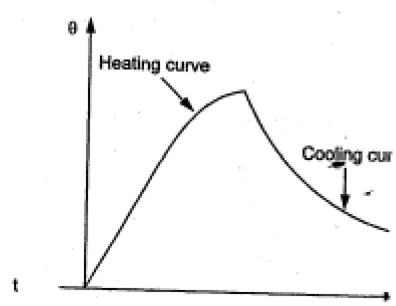
$$\theta = \theta_m\, e^{-\frac{S\lambda'}{Gh}t} \quad \Rightarrow \quad \theta = \theta_m\, e^{-t/\tau'} \qquad \text{where } \tau' = \frac{Gh}{S\lambda'} = \text{cooling time constant}$$

$$\boxed{\theta = \theta_m e^{-t/\tau'}}$$

if $t = \tau'$ $\theta = 0.367\ \theta_m$
if $t = 2\tau'$ $\theta = 0.135\ \theta_m$
if $t = 3\tau'$ $\theta = 0.050\ \theta_m$



Cooling time constant curve



Heating and Cooling time constant curve

Heating time constant (τ)

The heating time constant of the motor is defined as the time taken to temperature rise to reach the 63.2% of its final or steady state temperature rise θ_m or θ_f.

Cooling time constant (τ')

The cooling time constant of the motor is defined as the time taken to machine cool down from final temperature to 36.7% of its initial temperature rise above the ambient temperature.

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

Selection of rating of motor based on thermal overloading and load variation factor:

Continuous with Constant Load:

The suitable size and rating of a motor for continuous with constant load for the following cases.

We know that, Power $P = \dfrac{2\pi NT}{60\,\eta}$, watts

Where, P – Power in watts
N – Speed in rpm
T – Torque in N-m
η - Efficiency of load and transmission system

a. In case of **linear motion** power rating is $P = \dfrac{F \times v}{0.102\,\eta}$, W or $P = \dfrac{F \times v}{102\,\eta}$, kW

Where, F – Force exerted by load, kg
v – Velocity of linear motion, m/s
η - Efficiency of load and transmission system

b. In case of **rotary motion** power rating is $P = \dfrac{T\,N}{975\,\eta}$, kW

Where, N – Speed in rpm
T – Torque in kg-m
η - Efficiency of load and transmission system

or $P = \dfrac{T\,N}{99.38\,\eta}$, kW

Where, T – Torque in N-m

c. Rating of motor for an **elevator or lift** $P = \dfrac{F \times v}{2 \times 102\,\eta}$, kW

Where, 2 – Virtue of counter weight
F – Force exerted by load, kg
v – Velocity of linear motion, m/s
η - Efficiency of load and transmission system

Velocity of normal passenger lift range is 0.5 to 1.5

d. Rating of a **fan motor** $P = \dfrac{Q \times H}{102\,\eta}$, kW

Where Q – Volume of air, m^3 / s
H – Pressure of air in mm of water or kg / m^2
η = 0.6 for small power fan
η = 0.8 for large power fan

e. Rating of the motor for a **pump** $P = \rho \dfrac{Q \times H}{102\,\eta}$, kW

Where ρ – Density of the liquid being pumped, kg / m^3
Q – Delivery of the pump (Liquid), m^3 / s
H – Gross head comprising of suction, delivery, friction and velocity, m

STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

η = 0.4 to 0.8 for centrifugal pump
η = 0.8 to 0.9 for reciprocating pump

f. The rating of a motor used in metal shearing **lathe** $P = \dfrac{F \times v}{102 \times 60\,\eta}$, kW

Where, F – Shearing force, kg
v – Velocity of shearing, m / min
η – Mechanical efficiency of the lathe

Continuous with Variable Load:

Determination of rating of a motor for continuous with variable load based on average power losses.

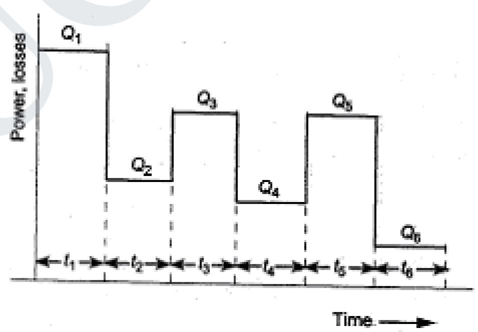
1. Average power losses method
2. Root mean square method or equivalent method
   a. Equivalent Torque method
   b. Equivalent Current method
   c. Equivalent Power(HP or kW) method

Average losses method

Determine the rating of a motor subjected to a cyclic variable load is known as average losses method.

Total losses in a motor $W = W_c + W_{cu}$ Also, $W_{cu} = I_{eq}^2 R$

Where, W_c - Constant loss
W_{cu} – Variable loss or Copper loss
I_{eq} – Equivalent current
R – Armature resistance



Average losses $W_{cu} = \dfrac{Q_1 t_1 + Q_2 t_2 + ... + Q_n t_n}{t_1 + t_2 + ... + t_n}$

For the given load power Vs time $P_{av} = \dfrac{\sum_{i=1}^{n} P_i t_i}{\sum_{i=1}^{n} t_i}$, then appropriate motor rating is chosen from the formula $P_r = k\,P_{av}$

DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

where, k varies from 1.1 to 1.3
P_r – Rated power
P_{av} – Average power

Equivalent method

$$\text{Equivalent Torque } T_{eq} = \sqrt{\frac{\sum_{i=1}^{n} T_i^2 t_i}{\sum_{i=1}^{n} t_i}} = \left[\frac{T_1^2 t_1 + T_2^2 t_2 + ... + T_n^2 t_n}{t_1 + t_2 + ... + t_n}\right]^{1/2}$$

$$\text{Equivalent Current } I_{eq} = \sqrt{\frac{\sum_{i=1}^{n} I_i^2 t_i}{\sum_{i=1}^{n} t_i}} = \left[\frac{I_1^2 t_1 + I_2^2 t_2 + ... + I_n^2 t_n}{t_1 + t_2 + ... + t_n}\right]^{1/2}$$

$$\text{Equivalent Power } P_{eq} = \sqrt{\frac{\sum_{i=1}^{n} P_i^2 t_i}{\sum_{i=1}^{n} t_i}} = \left[\frac{P_1^2 t_1 + P_2^2 t_2 + ... + P_n^2 t_n}{t_1 + t_2 + ... + t_n}\right]^{1/2}$$

$$\text{Equivalent Horse power } H_{eq} = \sqrt{\frac{\sum_{i=1}^{n} H_i^2 t_i}{\sum_{i=1}^{n} t_i}} = \left[\frac{H_1^2 t_1 + H_2^2 t_2 + ... + H_n^2 t_n}{t_1 + t_2 + ... + t_n}\right]^{1/2}$$

Rating of motor with short time duty:

Let us assume that heating of the motor is proportional to the losses W_L,

W_L – Total losses
t – Duration of short time
P_x – Short time rating
P_r – Rated power
τ – Heating time constant
θ_m – Maximum temperature
θ_m' – Permissible temperature rise of the motor during short time
W_{Lx} – Losses at short time load (P_x)
W_{Lr} – Losses at rated load (P_r)
x – Fraction of a rated load
W_{cu} = full load copper loss
α - coefficient

$$\alpha = \frac{\text{constant loss}}{\text{variable loss}} = \frac{W_c}{W_{cu}}, \quad W_c = \alpha\, W_{cu} \quad \text{Also,} \quad W = W_c + x^2\, W_{cu}$$

DOWNLOADED FROM STUCOR APP STUCOR APP

DOWNLOADED FROM STUCOR APP

If drive motor is loaded continuously with P_x , $\theta = \theta_m'(1-e^{-t/\tau})$, let $x = \frac{P_x}{P_r}$

$$\frac{W_{Lx}}{W_{Lr}} = \frac{\theta_m'}{\theta_m} = \frac{1}{1-e^{-t/\tau}},$$

$W_{Lr} = W_c + W_{cu} = \alpha\, W_{cu} + W_{cu} = W_{cu}\,(1+\alpha)$

$$W_{Lr} = W_{cu}(1+\alpha) \longrightarrow (1)$$

$$W_{Lx} = W_c + x^2 W_{cu} = W_c + W_{cu}\left(\frac{P_x}{P_r}\right)^2$$

$$W_{Lx} = \alpha W_{cu} + W_{cu}\left(\frac{P_x}{P_r}\right)^2 = W_{cu}\left(\alpha + \left(\frac{P_x}{P_r}\right)^2\right) \longrightarrow (2)$$

Equation (2) divided by equation (1)

$$\frac{W_{Lx}}{W_{Lr}} = \frac{W_{cu}\left[\alpha + \left(\frac{P_x}{P_r}\right)^2\right]}{W_{cu}[\alpha+1]} = \frac{1}{1-e^{-t/\tau}}$$

$$\frac{\left[\alpha + \left(\frac{P_x}{P_r}\right)^2\right]}{[\alpha+1]} = \frac{1}{1-e^{-t/\tau}} \Rightarrow \alpha + \left(\frac{P_x}{P_r}\right)^2 = \frac{1+\alpha}{1-e^{-t/\tau}}$$

$$\left(\frac{P_x}{P_r}\right)^2 = \frac{1+\alpha}{1-e^{-t/\tau}} - \alpha \Rightarrow \frac{P_x}{P_r} = \sqrt{\frac{1+\alpha}{1-e^{-t/\tau}} - \alpha}$$

$$\frac{P_x}{P_r} = \sqrt{\frac{1+\alpha}{1-e^{-t/\tau}} - \alpha}$$

Rating of a motor for intermittent load or duty

- $$\frac{P_x}{P_r} = \sqrt{\frac{(1+\alpha)\left(1-e^{-(t_1/\tau + t_2/\tau')}\right)}{1-e^{-t_1/\tau}} - \alpha}$$

Where, t_1 – Duration of rated load
t_2 – Duration of rest

DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

P_x – Intermittent rating
P_r – Rated power
τ – Heating time constant
τ' – cooling time constant

If efficiency of the motor is given, then take $\alpha = \left(\%\eta / 100\right)^2$

Problem:

Determine a suitable capacity of a continuously rated motor for which the duty cycle it has to perform is given below:

50 kW for 15 minutes
No load for 5 minutes
25 kW for 10 minutes
10 kW for 5 minutes

This cycle is repeated indefinitely.

Solution:

By using equivalent power method $P = \left[\frac{P_1^2 t_1 + P_2^2 t_2 + ... + P_n^2 t_n}{t_1 + t_2 + ... + t_n}\right]^{1/2}$

$$= \left[\frac{(50)^2 \times 15 + (0)^2 \times 5 + (25)^2 \times 10 + (10)^2 \times 5}{15 + 5 + 10 + 5}\right]^{1/2}$$

= 35.56 kW

A motor with standard rating of 36 kW is selected.

Problem:

A motor driving a colliery winder has to deliver a load rising uniformly from zero to a maximum of 1500 kW in 20 seconds during the accelerating. period, 750 kW for 40 seconds during the full speed period and during the declaration period of10 seconds, when the regenerative braking takes place, the kW which is returned to the supply falls from an initial value of 250 kW to zero. The interval for decking (period of rest) before the next load cycle starts is 20 seconds. Estimate a suitable rating for the motor.

Solution:

The load diagram is divided into two triangles and rectangle by equivalent power method,

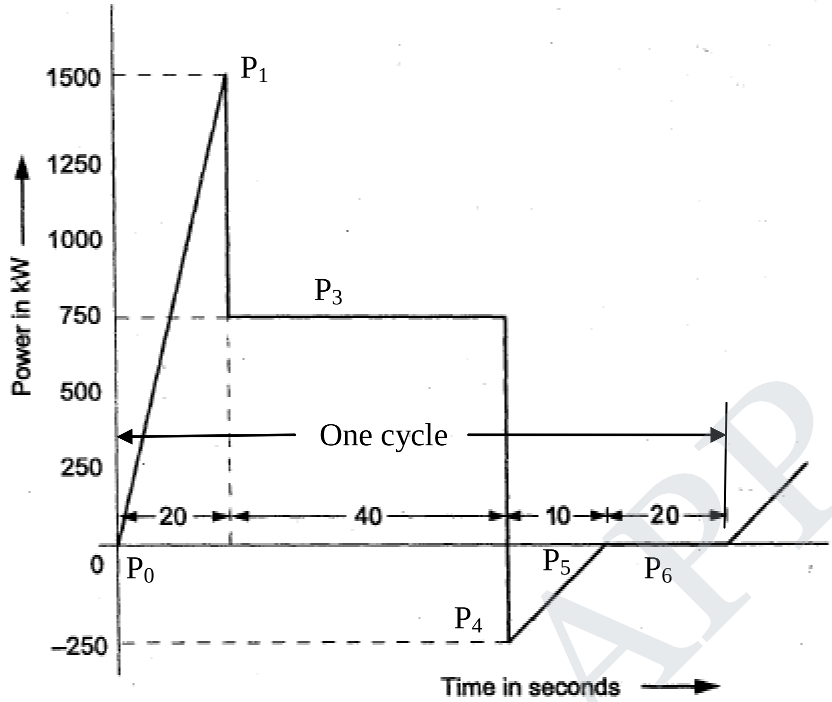
Equivalent power $P_{eq} = \sqrt{\frac{1/3\left(P_1^2 + P_1P_2 + P_2^2\right)\times t_1 + P_3^2 t_2 + 1/3\left(P_4^2 + P_4P_5 + P_5^2\right)\times t_3 + P_6^2 t_4}{t_1 + t_2 + t_3 + t_4}}$

$$= \sqrt{\frac{1/3\left(0^2 + 0\times 1500 + 1500^2\right)\times 20 + (750^2 \times 40) + 1/3\left((-250)^2 + (-250\times 0) + 0^2\right)\times 10 + (0^2 \times 20)}{20 + 40 + 10 + 20}}$$

P = 648 kW

STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP STUCOR APP



Problem:

A motor has continuous rating of 60 kW and heating time constant of 90 minutes. Find the short time rating for 30 minutes assuming that the motor cools down completely between, the load period. Assume constant losses of the motor as 80% of the copper losses on full load corresponding to the continuous rating.

Given data: P_r = 60 kW, τ = 90 min, short time t = 30 min, find: P_x

Solution:

We know that $\dfrac{P_x}{P_r} = \sqrt{\dfrac{1+\alpha}{1-e^{-t/\tau}} - \alpha}$

α = 80% = 0.8

Short time rating $P_x = P_r\sqrt{\dfrac{1+\alpha}{1-e^{-t/\tau}} - \alpha} \qquad = 60\sqrt{\dfrac{1+0.8}{1-e^{-30/90}} - 0.8}$

= 141 kW

Short time rating or 30 minutes rating of the motor is 141 kW

STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

Problem:

A 25 HP motor has a heating time constant of 90 minutes. When run continuously on full load, it attains a final steady temperature of 45°C. Calculate the temperature of the motor after 30 minutes, the initial temperature being 10°C. (AU-Nov/Dec 2004)

Given data: P = 25 HP, $\tau = 90$ min, final temp $\theta_m = 45^oC$, initial temp $\theta_0 = 10^oC$,
t = 30 min, find: temp θ

Solution:

Temperature rise expression with initial temperature, θ_0

$$\theta = \theta_m\left(1-e^{-t/\tau}\right)+\theta_0\, e^{-t/\tau}$$

$$\theta = 45\left(1-e^{-30/90}\right)+10\, e^{-30/90}$$

$\theta = 19.93^oC \approx 20^oC$

Review Questions:

PART-A (2 MARKS)

1. Define Drives
2. Define Electric Drives.
3. What are the basic elements of Electric Drives?
4. Write the classification of Electric Drives.
5. Draw the block diagram of Electric Drive.
6. What is meant by Group drive? Give an example.
7. What is meant by Individual drive? Give an example.
8. What is meant by Multimotor drive? Give an example.
9. What are the advantages and disadvantages of Individual drive system?
10. What are the advantages and disadvantages of Group drive system?
11. What are the advantages of electric drive over mechanical drive?
12. Mention the drawbacks of electric drives.
13. What are the factors influencing the choice of electric drives?
14. Mention the functions of Power modulators.
15. Compare Individual, Group and Multimotor drives.
16. What are the motors used in Electric drives?
17. Mention the necessity of power rating?
18. Write down the dissipation equation due to convection process.
19. Draw the heating and cooling curve for a particular electric drive.
20. What are the classes of duty for an electric motor?
21. What is meant by continuous duty?
22. What is meant by continuous duty with variable load?
23. What happens if the motor is selected at highest load handling capacity at continuous duty variable?
24. What is meant by time intermittent duty?
25. What is meant by periodic intermittent duty?
26. What is duty factor?

DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

27. Give the assumptions for heating and cooling calculation.
28. What is heating curve?
29. Define Heating time constant.
30. What is cooling curve?
31. Compare A.C drives and D.C drives.
32. What is meant by short time rating of motor?
33. What are the factors that affect the power rating and size of electric drives?

PART-B

1. Explain the factors governing the selection of motors. (16)
2. Discuss in detail the determination of power rating of motors. (16)
3. (i) Explain the different types of loading of drives. (8)
   (ii) Explain the choice of selection of the motor for different loads. (8)
4. (i) Describe the simplifications based on which the heating and cooling calculations of an electric motor are made. (3)
   (ii) Establish the heating time constant and the heating curves. (13)
5. (i) Compare the D.C and A.C drives. (6)
   (ii) Write a brief note on classes of duty for an electric motor. (10)
6. Draw the typical temperature rise-time curve and derive the equation for temperature rise in an electric drive. (16)
7. Explain the loading of an electric motor and its duty cycle with a simple diagram. (16)
8. Explain in detail about the various types of electric drives. (16)

9. A 100 kW motor, having rated temperature rise of 60°C, has full-load efficiency of 80% and the maximum efficiency occurs at 85% full load. It has thermal time constants of 80 minutes and 65 minutes. It is cyclically loaded, 120% of full load for one hour and 50% of full load for the next hour. Find the temperature rise after 3 hours. (16)

10. The thermal time constant and final steady temperature of a motor on continuous running is 30 min and 60°C. Find out the temperature.
    i) After 15 minutes at this load.
    ii) After 1 hour at this load.
    iii) If temperature rise at 1 hour rating is 60°C, find the maximum steady temperature.
    iv) What will be the time required to increase the temperature from 40°C to 60°C at 1 hour rating.

Exercise Problems:

1. The heating time constant of a motor is 50 minutes and cooling time constant when stationary is 100 minutes. The final temperature attained by the· motor is 50°C. Determine the temperature of the motor if it is run on full load for 20 minutes and then remain in idle for 10 minutes. Assume that, this cycle is repeated indefinitely. [Ans: 14.85°C]

2. The load cycle of a motor for 15 minutes in driving some equipment is as follows:
   (i) 0 - 5 minutes for 30 HP
   (ii) 5 - 9 minutes for No load

STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

(iii) 9 - 12 minutes for 45 HP

(iv) 12-15 minutes for No load.

The load cycle is repeated indefinitely. Suggest a suitable size of continuously rated motor for these conditions. [Ans: 26.55 HP]

3. A constant speed drive has the following duty cycle:
   (i) Load rising from 0 to 400 kW : 5 minutes
   (ii) Uniform load of 500 kW : 5 minutes
   (iii) Regenerative power of 400 kW returned to the supply : 4 minutes
   (iv) Remains idle for : 2 minutes

   Estimate the power rating of the motor. Assume losses to be proportional to $(\text{power})^2$
   [Ans: 367 kW]

4. The temperature rise of a motor when operating for 25 minutes on full load is 25°C and becomes 40°C when the motor operates for another 25 minutes on the same load. Determine the heating time constant and the steady temperature rise. [Ans: 40.92 minutes, 54.4^{o}C]

5. A motor has a thermal heating time constant of 50 minutes. When the motor runs continuously on full rating, its final temperature rise is 80°C.
   (i) What is the temperature rise after 1 hour if the motor runs continuously on full load?
   (ii) If the temperature on one hour rating is 80°C, find the maximum steady temperature at this rating?
   (iii) How much time does the motor take for its temperature to rise from 50°C to 80°C if it is working at it's one hour rating? [Ans: 55.92°C, 114.45°C, 28.7 min]

STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP
STUCOR APP

PANIMALAR ENGINEERING COLLGE

DEPARTMENT OF MECHANICAL ENGINEERING

II YEAR / III SEMESTER

ELECTRICAL DRIVES AND CONTROL

<u>UNIT - II</u>

DRIVE MOTOR CHARACTERISTICS

STUCOR APP
STUCOR APP
DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

Unit-II

Drive motor characteristics

DC Motor Characteristics:

The performance of a d.c. motor can be judged from its characteristic curves known as motor characteristics, following are the three important characteristics of a d.c. motor:

i. **Torque and Armature current characteristic (T_a - I_a)**
It is the curve between armature torque T_a and armature current I_a of a d.c. motor. It is also known as electrical characteristic of the motor.

ii. **Speed and armature current characteristic (N - I_a)**
It is the curve between speed N and armature current I_a of a d.c. motor. It is very important characteristic as it is often the deciding factor in the selection of the motor for a particular application.

iii. **Speed and torque characteristic (N - T_a)**
It is the curve between speed N and armature torque T_a of a d.c. motor. It is also known as mechanical characteristic.

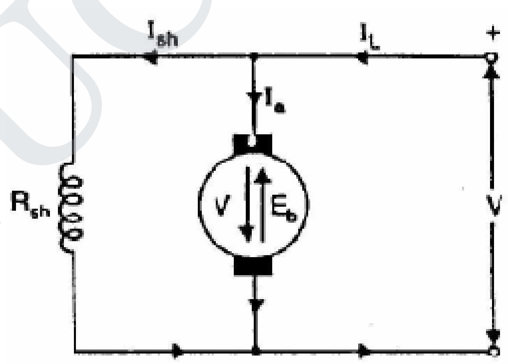
Types of D.C. Motors:

DC motors are broadly classified into three types based on field winding connected with armature.

1. Shunt motor
2. Series motor
3. Compound motor
   i. Long shunt compound motor
   ii. Short Shunt compound motor

Basics of DC Motors:

The electrical equivalent circuit of dc motor as shown in fig.



Let in a d.c. motor,

V = applied voltage, V
E_b = back e.m.f., V
R_a = armature resistance, Ω
I_a = armature current, A
R_{sh} or R_f = shunt field resistance, Ω
I_L = Line or supply current, A
T_a = developed motor torque or armature torque, N-m
T_{sh} = shaft torque, N-m

DOWNLOADED FROM STUCOR APP STUCOR APP

DOWNLOADED FROM STUCOR APP

The back e.m.f. E_b (= P ϕ ZN/60 A) is always less than the applied voltage V, since back e.m.f. E_b acts in opposition to the supply voltage or applied voltage V, The net voltage across the armature circuit is V- E_b.

The armature current I_a is given by

$$I_a = \frac{V - E_b}{R_a}$$

or

$$V = E_b + I_a R_a \quad \text{Voltage equation}$$

$$VI_a = E_b I_a + I_a^2 R_a \quad \text{Power equation}$$

Power P = V x I_a in watts

VI_a = electric power supplied to armature (armature input)

E_bI_a = power developed by armature (armature output)

I_a^2 R_a = electric power wasted in armature (armature Cu loss)

Alternate back emf expression in dc machines,

$$E_b = \frac{P\phi ZN}{60\,A}$$

$$\therefore \frac{P\phi Z}{A} = \frac{60 \times E_b}{N}$$

Motor or armature torque expression T_a

$$T_a = 0.159 \times \left(\frac{60 \times E_b}{N}\right) \times I_a$$

$$T_a = 9.55 \times \frac{E_b I_a}{N} \text{ N - m}$$

Also,

$$T_a = 0.159\, Z \phi I_a \left(\frac{P}{A}\right) \text{ N - m}$$

Shaft torque T_{sh}

$$T_{sh} = 9.55 \times \frac{\text{Output in watts}}{N} \text{ N - m}$$

Since Z, P and A are fixed for a given machine,

$\therefore T_a \propto \phi I_a$

Hence torque in a d.c. motor is directly proportional to flux per pole and armature current.

i. For a shunt motor, flux ϕ is practically constant

$\therefore T_a \propto I_a$

ii. For a series motor, flux ϕ is directly proportional to armature current I_a provided magnetic saturation does not take place.

$\therefore T_a \propto I_a^2$ $\qquad$ $\therefore \phi \propto I_a$

Where,
P – No. of stator poles
ϕ - Flux per pole, web
A – No. of armature parallel path
Z – Total number of armature conductors

DOWNLOADED FROM STUCOR APP

STUCOR APP

DOWNLOADED FROM STUCOR APP

N – Speed in rpm

Speed of a D.C. Motor

$$E_b \quad V - I_a R_a$$

But $$E_b = \frac{P\phi Z N}{60\ A}$$

$$\therefore \quad \frac{P\phi Z N}{60\ A} = V \quad I_a R_a$$

or $$N = \frac{(V - I_a R_a)}{\phi} \frac{60\ A}{PZ}$$

or $$N = K \frac{(V - I_a R_a)}{\phi} \qquad \text{where} \qquad K = \frac{60\ A}{PZ}$$

But $$V \quad I_a R_a = E_a$$

$$\therefore \quad N = K \frac{E_b}{\phi}$$

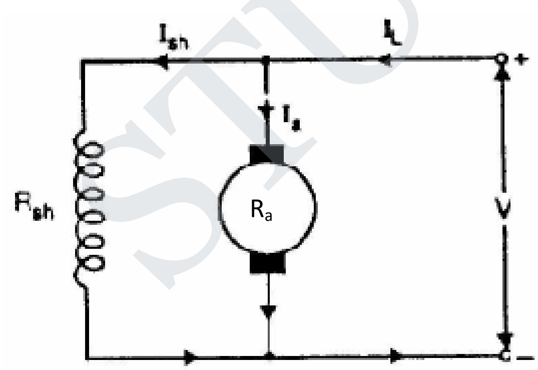
or $$N \propto \frac{E_b}{\phi}$$

Therefore, in a d.c. motor, speed is directly proportional to back e.m.f. E_b and inversely proportional to flux per pole ϕ.

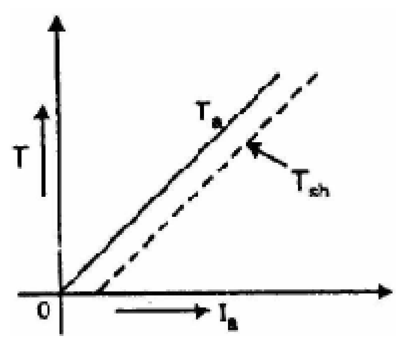
DC Shunt Motor Characteristics:

Shunt motor in which the field winding is connected in parallel with the armature. Shown in fig. The field current I_{sh} is constant since the field winding is directly connected to the supply voltage V which is assumed to be constant. Hence, the flux in a shunt motor is approximately constant.

i. T_a / I_a Characteristic



DC Shunt motor



T_a Vs I_a Characteristics

We know that in a d.c. motor,

$$T_a \propto \phi I_a$$

Since the motor is operating from a constant supply voltage, flux ϕ is constant (neglecting armature reaction).

$$T_a \propto I_a$$

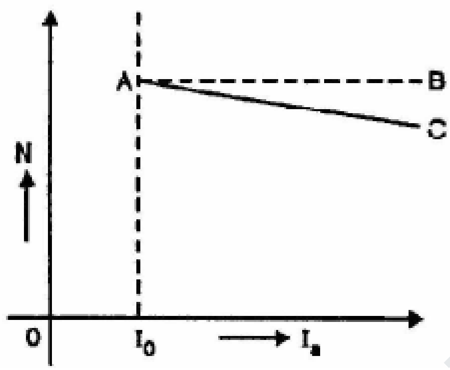
STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

Hence T_a / I_a characteristic is a straight line passing through the origin as shown in fig. The shaft torque (T_{sh}) is less than Ta and is shown by a dotted line. It is clear from the curve that a very large current is required to start a heavy load. Therefore, a shunt motor should not be started on heavy load.

ii. N / I_a Characteristic

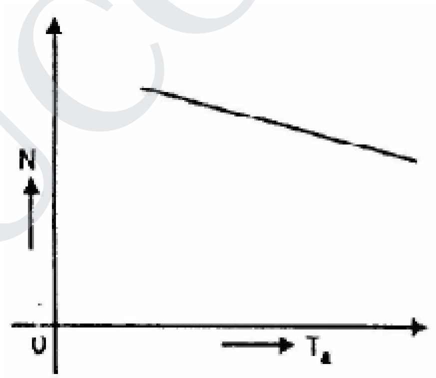
The speed N of a. d.c. motor is given by;



The flux ϕ and back e.m.f. E_b in a shunt motor are almost constant under normal conditions. Therefore, speed of a shunt motor will remain constant as the armature current varies (dotted line AB in Fig.). Strictly speaking, when load is increased, E_b (= V- I_aR_a) and ϕ decrease due to the armature resistance drop and armature reaction respectively. However, E_b decreases slightly more than f so that the speed of the motor decreases slightly with load (line AC).

iii. N / T_a Characteristic.

The curve is obtained by plotting the values of N and T_a for various armature currents (See Fig.). It may be seen that speed falls somewhat as the load torque increases



Conclusions

Following two important conclusions are drawn from the above characteristics:

(i) There is slight change in the speed of a shunt motor from no-load to full load. Hence, it is essentially a constant-speed motor.

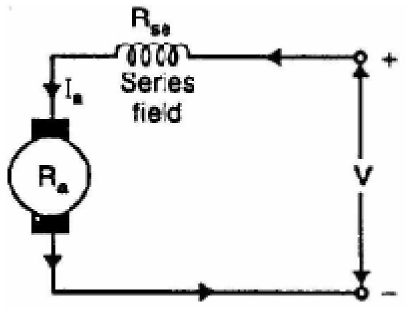
(ii) The starting torque is not high because $T_a \alpha I_a$.

Characteristics of DC Series Motor:

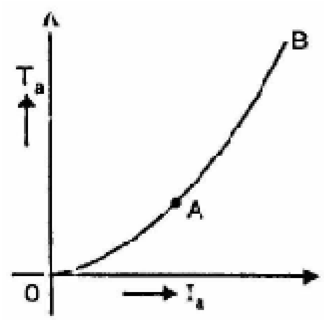
Fig. shows the connections of a dc series motor. Note that current passing through the field winding is the same as that in the armature. If the mechanical load on the motor increases, the armature current also increases. Hence, the flux in a series motor increases with the increase in armature current and vice-versa.

 STUCOR APP
DOWNLOADED FROM STUCOR APP STUCOR APP

DOWNLOADED FROM STUCOR APP



DC Series Motor



$T_a - I_a$ Characteristics

(i) Ta/Ia Characteristic.

We know that: $T_a \propto \phi I_a$

Up to magnetic saturation, $\phi \propto I_a$ so that $T_a \propto I_a^2$

After magnetic saturation, ϕ is constant so that $T_a \propto I_a$

Thus upto magnetic saturation, the armature torque is directly proportional to the square of armature current. If I_a is doubled, T_a is almost quadrupled.

Therefore, T_a/I_a curve upto magnetic saturation is a parabola (portion OA of the curve in Fig.). However, after magnetic saturation, torque is directly proportional to the armature current. Therefore, T_a/I_a curve after magnetic saturation is a straight line (portion AB of the curve). It may be seen that in the initial portion of the curve (i.e. upto magnetic saturation), $T_a \propto I_a^2$. This means that starting torque of a d.c. series motor will be very high as compared to a shunt motor (where that $T_a \propto I_a$).

(ii) N / I_a Characteristic.

The speed N of a series motor is given by;

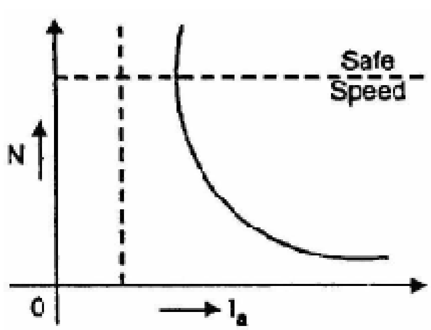
$$N \propto \frac{E_b}{\phi} \quad \text{where} \quad E_b = V - I_a(R_a + R_{se})$$

When the armature current increases, the back e.m.f. E_b decreases due to I_a $(R_a + R_{se})$ drop while the flux f increases. However, I_a $(R_a + R_{se})$ drop is quite small under normal conditions and may be neglected.

$$\therefore \quad N \propto \frac{1}{\phi}$$

$$\propto \frac{1}{I_a} \quad \text{upto magnetic saturation}$$

Thus, upto magnetic saturation, the N/I_a curve follows the hyperbolic path as shown in Fig. After saturation, the flux becomes constant and so does the speed.



$N - I_a$ Characteristics

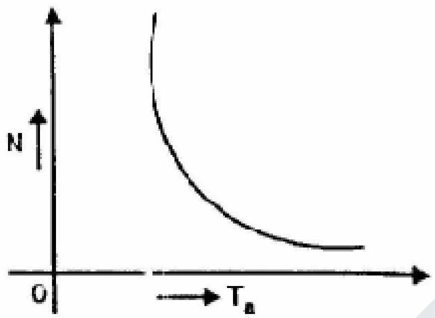
DOWNLOADED FROM STUCOR APP

STUCOR APP

DOWNLOADED FROM STUCOR APP

iii. N / T_a Characteristic:

The N/Ta characteristic of a series motor is shown in Fig. It is clear that series motor develops high torque at low speed and vice-versa. It is because an increase in torque requires an increase in armature current, which is also the field current. The result is that flux is strengthened and hence the speed drops ($\because$ $N \propto 1/\phi$). Reverse happens should the torque be low.



N – T Characteristics

Following three important conclusions are drawn from the above characteristics of series motors:

(i) It has a high starting torque because initially $T_a \alpha I_a^2$

(ii) It is a variable speed motor (See N/I_a curve in Fig) i.e., it automatically adjusts the speed as the load changes. Thus if the load decreases, its speed is automatically raised and vice-versa.

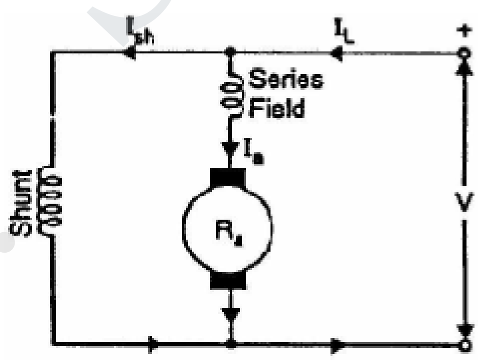
(iii) At no-load, the armature current is very small and so is the flux. Hence, the speed rises to an excessive high value ($N \propto 1/\phi$). This is dangerous for the machine which may be destroyed due to centrifugal forces set up in the rotating parts. Therefore, a series motor should never be started on no-load. However, to start a series motor, mechanical load is first put and then the motor is started.

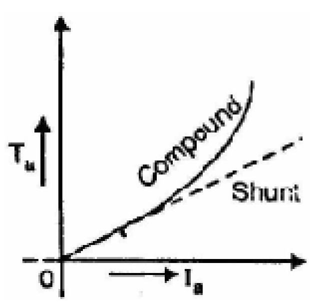
Characteristics of Cumulative Compound Motors

Fig. shows the connections of a cumulative-compound motor. Each pole carries a series as well as shunt field winding; the series field aiding the shunt field.

(i) T_a/I_a Characteristic.

As the load increases, the series field increases but shunt field strength remains constant. Consequently, total flux is increased and hence the armature torque (T_a α I_a) It may be noted that torque of a cumulative-compound motor is greater than that of shunt motor for a given armature current due to series field [See Fig.].



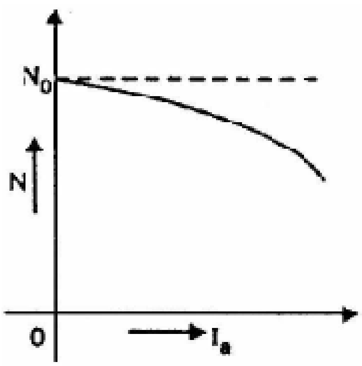


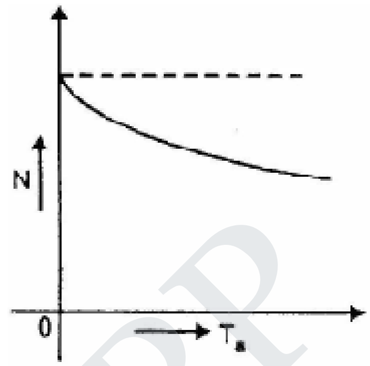
DOWNLOADED FROM STUCOR APP STUCOR APP

DOWNLOADED FROM STUCOR APP

(ii) N / I_a Characteristic.

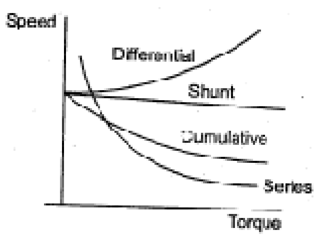
As explained above, as the lead increases, the flux per pole also increases. Consequently, the speed ($N \propto 1/\phi$) of the motor tails as the load increases (See Fig.). It may be noted that as the load is added, the increased amount of flux causes the speed to decrease more than does the speed of a shunt motor. Thus the speed regulation of a cumulative compound motor is poorer than that of a shunt motor.

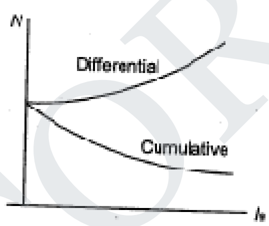




(iii)N / T_a Characteristic.

Fig. shows N / T_a characteristic of a cumulative compound motor. For a given armature current, the torque of a cumulative compound motor is more than that of a shunt motor but less than that of a series motor.





Applications of D.C. Motors

1. **Shunt motors**
   Lathes, drills, boring mills, shapers, spinning and weaving machines, wood working machines, reciprocating pumps, blowers, centrifugal pumps, milling machines, grinders etc.
2. **Series motors**
   Electric locomotives, tram cars, trolley cars, cranes, hoists, elevators, conveyors, winches etc.
3. **DC differential compound motor**
   Battery boosters, experimental and research work only.
4. **Cumulative compound motor**
   Punching, shearing and planning machines, lifts, air compressors, rolling mills, printing presses, etc.

Braking Characteristics of DC Motors

Sometimes it is desirable to stop a d.c. motor quickly. This may be necessary in case of emergency stop or to save time. The motor and its load may be brought to rest by using either (i) mechanical (friction) braking or (ii) electric braking.

In mechanical braking, the motor is stopped due to the friction between the moving parts of the motor and the brake shoe i.e. kinetic energy of the motor is dissipated as heat. Mechanical braking has several disadvantages including non-smooth stop and greater stopping time.

DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

In electric braking, the kinetic energy of the moving parts (i.e., motor) is converted into electrical energy which is dissipated in a resistance as heat or alternatively, it is returned to the supply source (Regenerative braking).

For d.c. shunt as well as series motors, the following three methods of electric braking are used:

i) Rheostatic or Dynamic braking
ii) Plugging or Reverse current or Counter current braking
iii) Regenerative braking

It may be noted that electric braking cannot hold the motor stationary and mechanical braking is necessary. However, the main advantage of using electric braking is that it reduces the wear and tear of mechanical brakes and cuts down the stopping time considerably due to high braking retardation.

Comparison between mechanical and electrical braking

Sl.No	Mechanical Braking	Electrical Braking
1.	**Disadvantages:** Less efficient method	**Advantages:** High efficient method
2.	It requires frequent maintenance due to excessive wear on the brake linings, shoes, adjustment of brakes. They are prone to wear and tear.	It requires very little maintenance due to absence of mechanical parts/equipments.
3.	Maintenance cost is high	Maintenance cost is low
4.	Depending upon the condition the braking may not be very smooth.	Braking is very smooth, without mechanical jerking and snatching.
5.	Due to frequent operation heat is produced at brake linings, shoes/drum, which may lead to failure of brakes.	Heat is produced due to braking operation but no way the produced heat is harmful to braking system.
6.	The stored energy of rotating parts is wasted in the form of heat or friction.	The kinetic energy of rotating parts can be converted into electrical energy, which can be either utilized or returned to supply mains.
7.	Nose level is high	Noise level is low
8.	Brake shoes, linings and drum are required.	Equipment of higher rating than the motor rating may be required in certain types of braking.
9.	**Advantages:** This type of braking is applied to hold system at any position.	**Disadvantages:** It can't produce holding torque. It requires electrical energy to achieve braking operation.

Braking Characteristics of DC Shunt Motors

i) Rheostatic or Dynamic braking of dc shunt motor:

Dynamic braking is used to stop the motor by dissipating its stored kinetic enrgy into a resistive load or external resistance or braking reistance R_b. once the kinetic energy is totally dissipated, the motor stops rotating if no external torque is exerted.

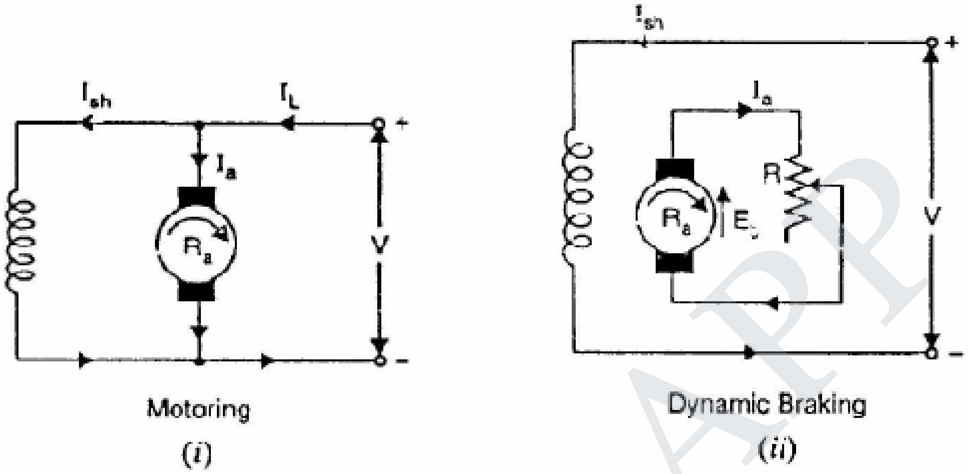
In this method, the armature of the running motor is disconnected from the supply and is connected across a variable resistance R. However, the field winding is remains connected to the supply. The armature, while slowing down, rotates in a strong magnetic field and, therefore, operates as

STUCOR APP
DOWNLOADED FROM STUCOR APP

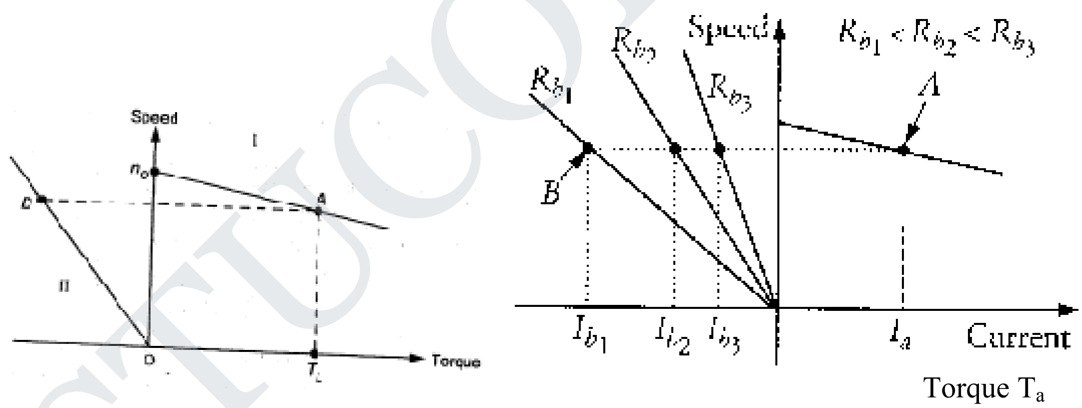
DOWNLOADED FROM STUCOR APP

a generator, sending a large current through resistance R. This causes the energy possessed by the rotating armature to be dissipated quickly as heat in the resistance. As a result, the motor is brought to standstill quickly.

Fig.(i) shows dynamic braking of a shunt motor. The braking torque can be controlled by varying the resistance R. If the value of R is decreased as the motor speed decreases, the braking torque may be maintained at a high value. At a low value of speed, the braking torque becomes small and the final stopping of the motor is due to friction.



This type of braking is used extensively in connection with the control of elevators and hoists and in other applications in which motors must be started, stopped and reversed frequently.



$$I_a = \frac{V - E_b}{R_a + R_b} = \frac{-E_b}{R_a + R_b} = \frac{-k_b \phi N}{R_a + R_b}, \quad V = 0, \quad \text{Also, } E_b \propto \phi N$$

Developed torque T_d = Braking torque T_b

$$T_b = k_t \phi I_a = \frac{-k_t k_b \phi^2 N}{R_a + R_b}$$ where, k_t – torque constant, R_b – braking resistance

k_b – back emf constant

For a shunt motor, ϕ is constant. Braking torque, $T_b \propto N$

Advantages:

1. This method is effective and the motor stops very quickly
2. This method is adopted for non reversing drives where regeneration is not possible.

Disadvantages:

1. Generated energy is wasted in the form of heat loss at resistance.
2. This method is inefficient in case of failure of electric supply.

  STUCOR APP
DOWNLOADED FROM STUCOR APP

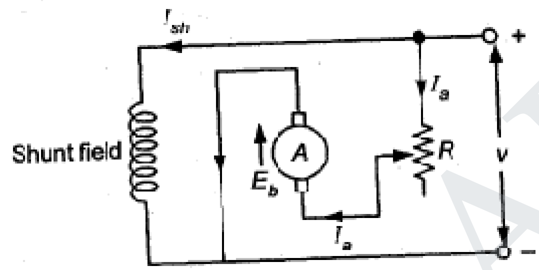
DOWNLOADED FROM STUCOR APP

ii) Plugging (or) Counter current braking (or) Reverse current braking

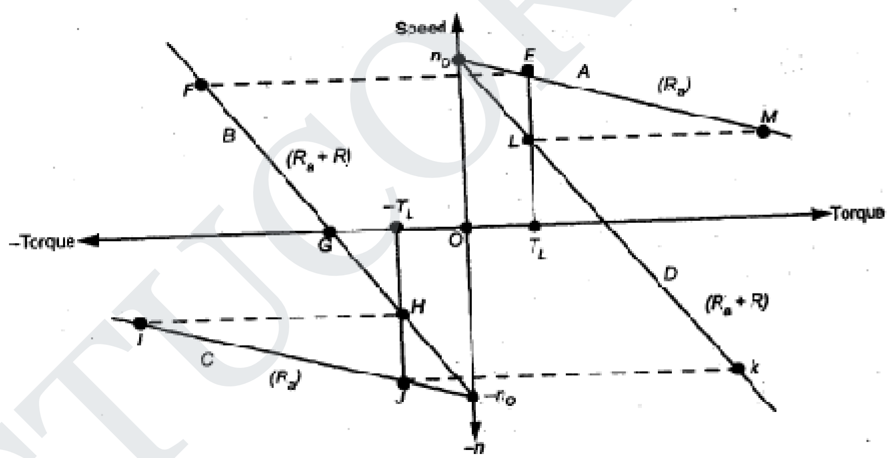
In this method, connections to the armature are reversed so that motor tends to rotate in the opposite direction, thus providing the necessary braking effect. When the motor comes to rest, the supply must be cut off otherwise the motor will start rotating in the opposite direction.

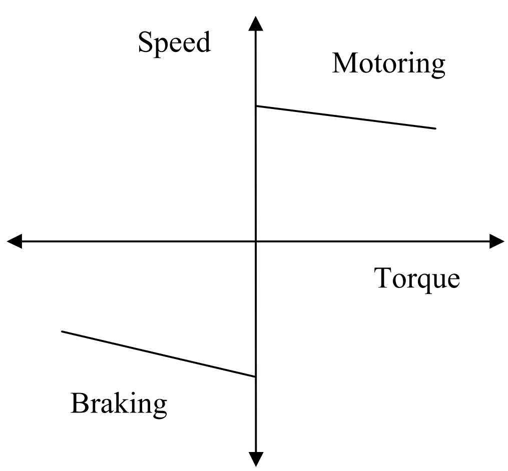
Due to the reversal of armature connections, both V and E_b start acting in the same direction around the circuit. In order to limit the armature current to a safe value, it is essential to insert a resistor in the circuit while reversing the armature connections.

When compared with rheostatic braking, plugging gives better braking torque. This method is commonly used for printing presses, elevators, rolling mills and machine tools



The speed torque characteristic under plugging condition is given below in figure.





DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

$$N = \frac{V}{k_b \phi} \frac{1}{R_a + R_{ex}} + \frac{T_b (R_a + R_{ex})}{k_t k_b \phi^2}$$

V and I_a are negative

R_{ex} – external resistance

$$T_d = T_b = k_t \phi I_a$$

Advantages:

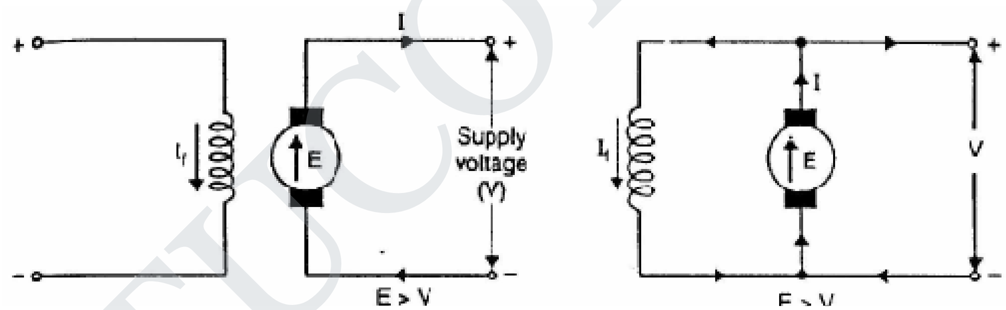
1. In this method quick stoping is achived
2. For reversing the drives requires a short time for reversal

iii) Regenerative braking

In the regenerative braking, the motor is run as a generator. As a result, the kinetic energy of the motor is converted into electrical energy and returned to the supply. Fig. shows two methods of regenerative braking for a shunt motor.

Regeneration takes place when E_b becomes greater than V. This happens when the overhauling load acts as a prime mover and so drives the machine as a generator. Hence, the direction of I_a and armature torque is reversed and speed falls until E_b becomes less than V.

During slowing down of the motor, power is returned to the line which may be used for supplying another train on an upgrade motion thereby relieving the power supply house, a part of its load. As a safety measure, it is essential to have some type of mechanical braking also in order to hold the load in the event of power failure.



In one method, field winding is disconnected from the supply and field current is increased by exciting it from another source. As a result, induced e.m.f. E exceeds the supply voltage V and the machine feeds energy into the supply. Thus braking torque is provided upto the speed at which induced e.m.f. and supply voltage are equal. As the machine slows down, it is not possible to maintain induced e.m.f. at a higher value than the supply voltage. Therefore, this method is possible only for a limited range of speed.

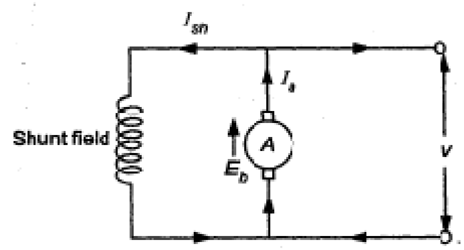
In a second method, the field excitation does not change but the load causes the motor to run above the normal speed (e.g., descending load on a crane). As a result, the induced e.m.f. E becomes greater than the supply voltage V. The direction of armature current I, therefore, reverses but the direction of shunt field current I_f remains unaltered. Hence the torque is reversed and the speed falls until E becomes less than V.

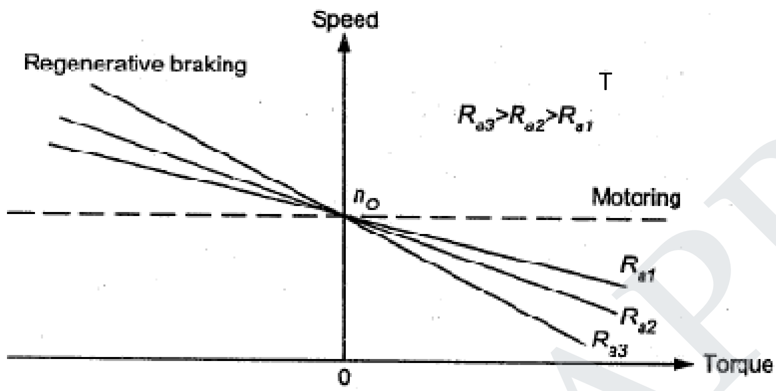
This method is used when the load on the motor has overhauling characteristics as m the lowering of the case of a hoist or downgrade motion of electric train.

From the characteristic curves, it is clear that, higher the armature circuit resistance, the higher is the speed at which the motor has to run for a given braking torque.

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP





Speed – Torque characteristics of dc shunt motor during Regenerative braking.

$T_b = k_t \phi I_a$ $I_a = \frac{T}{k_t \phi}$ Also, $I_a = \frac{V - E_b}{R_a}$ $E_b > V$ I_a is –ve

$N = \frac{V}{k_b \phi} - \frac{I_a R_a}{k_b \phi}$ $N = \frac{V}{k_b \phi} + \frac{T_b R_a}{k_t k_b \phi^2}$

Advantages:

1. The kinetic energy converted to electrical energy, which can be usefully utilized or returned to supply mains.
2. Energy efficiency increases.

Disadvantages:

1. Need a set of battery bank to store the regenerated energy.
2. Load forces capable to accelerate the motor which is greater than the no load rated speed.

Braking Characteristics of DC Series Motors

i. Rheostatic braking

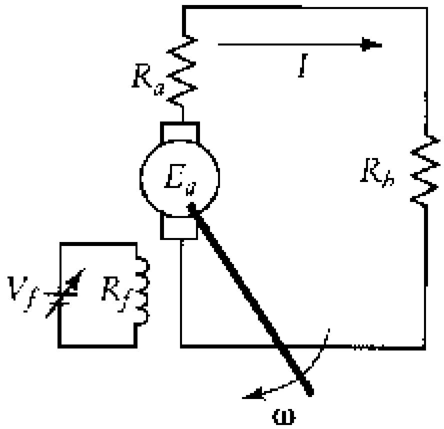
In series motor field is proportional to the armature current. At the beginning of dynamic braking, the field is strong, but gradually weakens because of the reduction of armature current, which may prolong the braking time. To brake the motor faster the series field can be separated from the armature circuit and excited by a different voltage source.

The speed-torque characteristics of dc series motor during rheostatic braking is shown in the following figure (Fig.). Explanations are similar to rheostatic braking method applied to DC shunt motor.

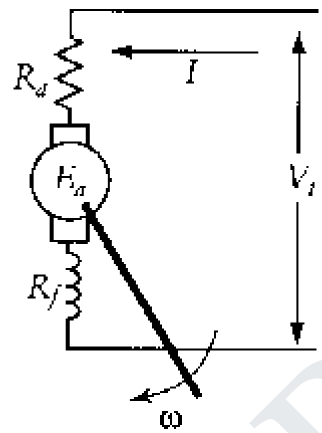
$$T_b = T_d = -\frac{k_t k_b \phi^2 N}{R_a + R_b}$$

DOWNLOADED FROM STUCOR APP
STUCOR APP

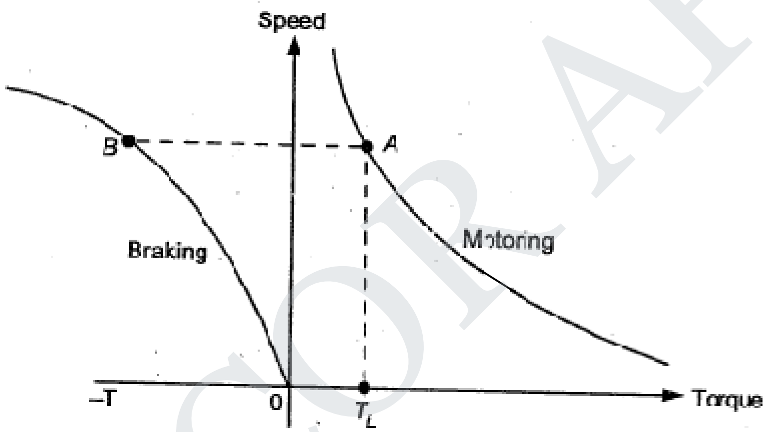
DOWNLOADED FROM STUCOR APP

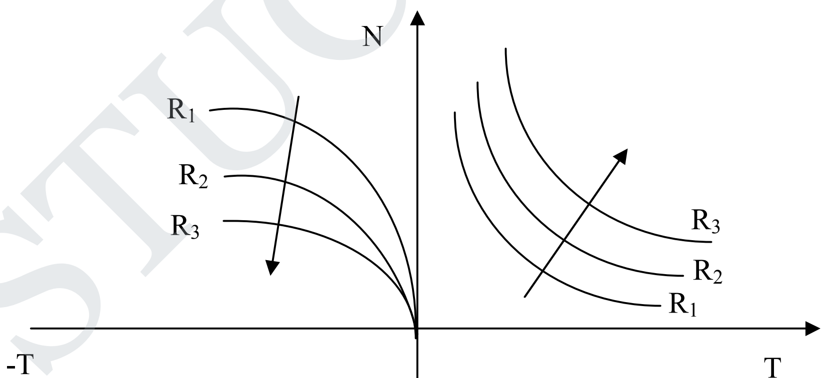


Dynamic braking operation



Motoring operation





Speed - torque characteristics

ii. Plugging or Counter current braking

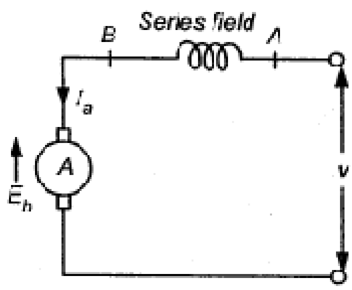
In this method of braking, the connections of the armature are reversed and a variable resistance *R* is put in series with the armature as shown in Fig. To limit the armature current an external resistance may be required in the armature circuit compared to dc shunt motor. Braking torque of dc series motor falls very rapidly with speed.

The speed torque characteristics of a de series motor for plugging condition is shown below (Fig.). The above characteristics have been constructed in the same manner as that of plugging conditions applied to DC shunt motor.

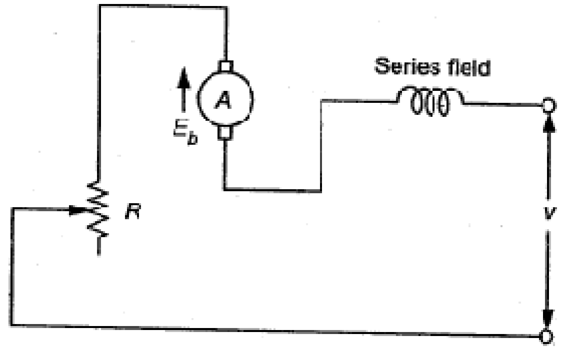
DOWNLOADED FROM STUCOR APP

STUCOR APP

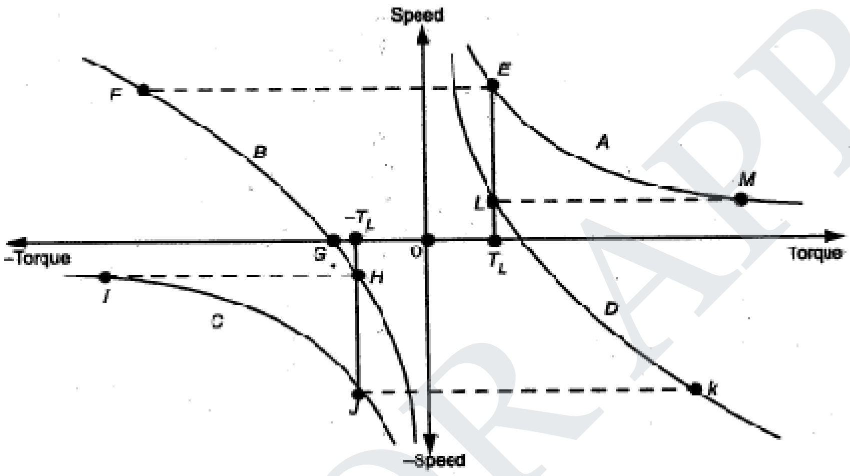
DOWNLOADED FROM STUCOR APP STUCOR APP



Motoring



Plugging



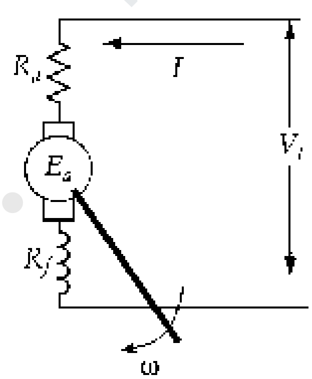
Speed - torque characteristics

iii. Regenerative braking

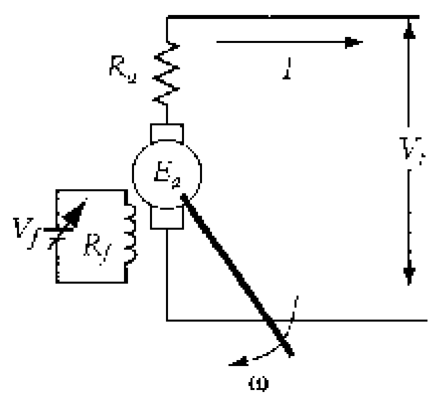
In DC series motor, regenerative braking is not possible without necessary modifications, because reversal of I_a would result in reversal of field and hence of E_b. This method is however used in traction motors and hoist load with special arrangements.

At no load the speed increases asymptotically, which results decreases in armature current and field flux. The induced emf cannot be greater than the supply or terminal voltage. Hence regeneration is not possible in a plain dc series motor, since the field current cannot be made greater than the armature current.

The regeneration in such a case is achieved by separately exciting the field, now dc series motor work as dc shunt motor and motor characteristics similar to those of a separately excited shunt motor.



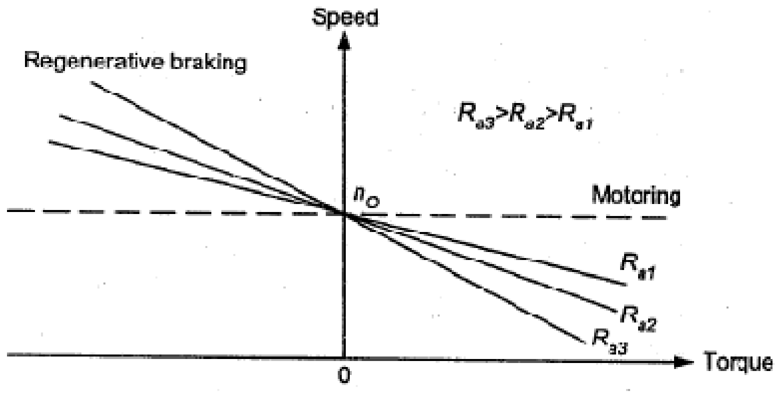
Series motor (Motoring)



Modified series motor (Regenerative braking)

STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP STUCOR APP



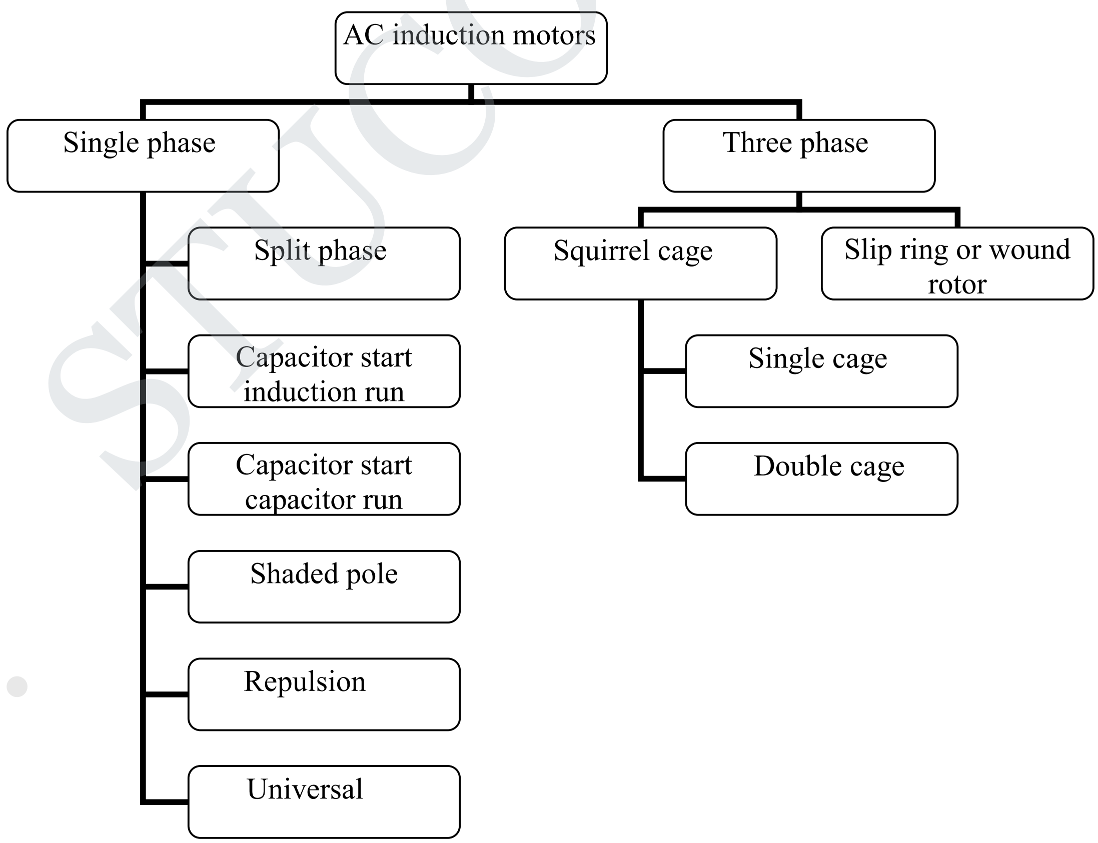
Speed - torque characteristics

Characteristics of AC Motors

The most common type of ac motor being used throughout the world is the induction motor. Induction motors are most rugged, requires less maintenance and are less expensive than de machines of equal kW ratings and speed ratings.

Induction motors are constructed both for single phase and three phase operation. Three phase induction motors are widely used for all types of industrial applications such as lifts, cranes, pumps, lathes, machine tools, etc. whereas single phase induction motors are used mainly for domestic electrical appliances such as fans, refrigerators, washing machines, etc.

Classification ac motors as follows



STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

Three phase induction motor characteristics:

A 3-phase induction motor has a stator and a rotor. The stator carries a 3-phase winding (called stator winding) while the rotor carries a short-circuited winding (called rotor winding). Only the stator winding is fed from 3-phase supply. The rotor winding derives its voltage and power from the externally energized stator winding through electromagnetic induction and hence the name, in which electrical energy is converted into mechanical energy.

Advantages

1. It has simple and rugged construction.
2. It is relatively cheap.
3. It requires little maintenance.
4. It has high efficiency and reasonably good power factor.
5. It has self starting torque.

Disadvantages

1. It is essentially a constant speed motor and its speed cannot be changed easily.
2. Its starting torque is inferior to d.c. shunt motor.

Three phase induction motors are of two types namely, squirrel cage type and slip ring type. Almost 90% of the induction motors are squirrel cage type only. The squirrel cage rotor consists of a cylindrical laminated core with parallel slots for carrying the rotor conductors are heavy bars of copper, aluminium or alloys. The rotor bars are permanently short circuited on themselves using end rings; hence it is not possible to add any external resistance in series with the rotor circuit for starting purposes.

The slip ring rotor is provided with 3 phase, double layer, distributed winding consisting of coils as used in alternators. The rotor is wound for as many poles as the number of stator poles and is always wound 3 phase even when the stator is wound 2 phase. The three phases are connected internally. The other three winding terminals are brought out and connected to three insulated slip rings mounted on the shaft with brushes resting on them.

These three brushes are further externally connected to a 3 phase star connected rheostat. It's makes possible the introduction additional resistance in the rotor circuit during the starting period for increasing the starting torque of the motor.

When under normal running conditions after starting the slip rings are automatically short circuited and brushes will be lifted from the slip ring to reduce the frictional losses and the wear and tear. Hence, under normal running conditions, the slip ring rotor is short circuited on itself and now it looks like squirrel cage rotor.

Slip (s)

The difference between the synchronous speed N_s and the actual speed N of the rotor is known as slip.

Slip $s = \frac{N_s - N}{N_s}$ or $\% s = \frac{N_s - N}{N_s} \times 100$

Synchronuous speed $N_s = \frac{120 f}{P}$ in rpm where, f – Supply frequency, Hz

Synchronuous speed $n_s = \frac{N_s}{60}$ in rps P – No.of stator poles

Slip speed = $N_s - N$ in rpm T – Torque developed, N-m

The rotor (or motor) speed $N = N_s (1 - s) = (1 - s)\frac{120 f}{P}$ in rpm

Rotor current frequency $f' = sf$

DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

Power (P)

Out put power $P = T \times \omega = \dfrac{2\pi N T}{60}$ in watts where, $\omega = \dfrac{2\pi N}{60}$ rad/sec

Starting torque (T_{st})

The torque developed by the motor at the instant of starting is called starting torque.

$$T_{st} \;\alpha\; \frac{E_2^2 R_2}{R_2^2 + X_2^2} = k \frac{E_2^2 R_2}{R_2^2 + X_2^2} = \frac{3}{2\pi n_s} \frac{E_2^2 R_2}{R_2^2 + X_2^2}$$

Where, E_2 - rotor emf per phase at standstill
R_2 - rotor resistance per phase
X_2 - rotor reactance per phase
k – constant
n_s – synchronous speed in rps

Running torque (T)

The torque developed by the motor during running can be expressed by

$$T = k \frac{sE_2^2 R_2}{R_2^2 + (sX_2)^2} \qquad where \;\; k = \frac{3}{2\pi n_s}$$

Maximum torque (T_m)

The expression for maximum torque is obtained by substituting s = R_2 / X_2 in the equation for torque under running condition.

$$T_m = k \frac{E_2^2}{2X_2}$$

It can be proved that starting torque is maximum when rotor resistance equals rotor reactance i.e., $R_2 = X_2$. The torque under running condition is maximum at the value of the slip *s* which makes rotor reactance per phase equal to rotor resistance per phase.

The slip corresponding to maximum torque is $s_m = \dfrac{R_2}{X_2}$

From the above expression, it is clear that,

1. Maximum torque is independent of rotor resistance.
2. However, the speed or slip at which maximum torque occurs is determined by the rotor resistance. Hence, by varying rotor resistance (possible only with slip ring motors), maximum torque can be made to occur at any desired slip (or motor speed).
3. Maximum torque varies inversely as standstill reactance. Hence, it should be kept as small as possible.
4. Maximum torque varies directly as the square of the applied voltage

Effect of Change of Supply Voltage (V)

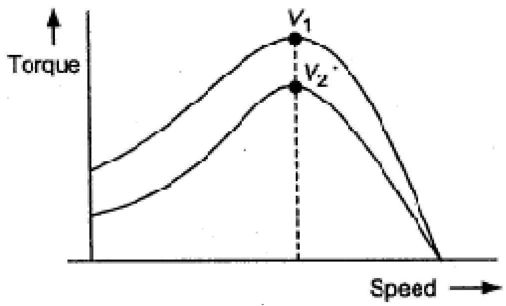
Torque at any speed is proportional to the square of the applied voltage. The slip at maximum torque is independent of supply voltage, variation of supply voltage does not alter the synchronous speed also. Changes in supply voltage not only affect the starting torque, but also the torque under running conditions. From the curve, it is clear that, if *V* decreases then amplitude of curve also decreases.

$$T_{st} \;\alpha\; \frac{E_2^2 R_2}{R_2^2 + X_2^2} = k \frac{E_2^2 R_2}{R_2^2 + X_2^2}$$, Since supply voltage V ≈ E_2, $$T_{st} = k \frac{V^2 R_2}{R_2^2 + X_2^2} = k_1 V^2$$

$$T_m = k \frac{E_2^2}{2X_2} \qquad \text{i.e.} \quad T_m \;\alpha\; V^2$$

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

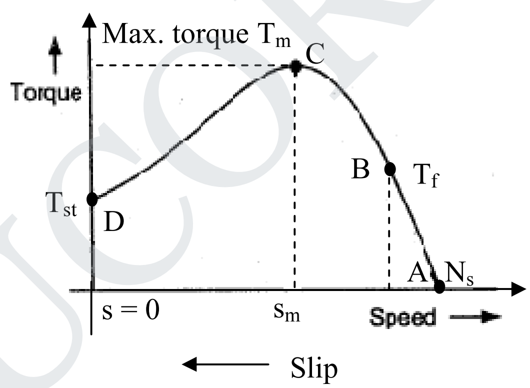


Ratio of various torque

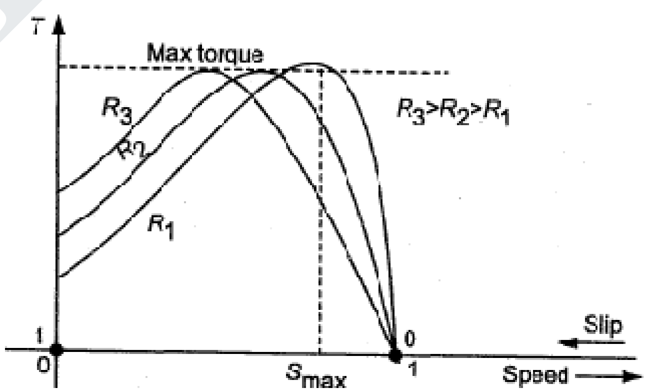
$$\frac{T_{st}}{T_m} = \frac{2 s_m}{1+s_m^2}, \qquad \frac{T_f}{T_m} = \frac{2 s_m s_f}{s_m^2 + s_f^2}, \qquad \frac{T_{st}}{T_f} = \frac{s_m^2 + s_f^2}{s_f(1+s_m^2)}, \qquad \frac{T_{st}}{T} = x^2\left(\frac{I_{sc}}{I_{st}}\right)^2$$

Where, T_{st} – starting torque
T_m – maximum torque
T_f – full load torque
T – running torque
s_m – slip at maximum torque
I_{st} – starting current
I_{sc} – DOL starting or short circuit current
x – fraction of normal voltage
s_f – slip at full load

Speed torque characteristics of three phase induction motor



Speed - Torque Characteristics



Slip - Torque Characteristics

The following points may be noted carefully:

(i) At s = 0, T = 0 so that torque-slip curve starts from the origin.

(ii) At normal speed, slip is small so that s X_2 is negligible as compared to R_2.

DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

$T \propto s / R_2$ $X_2 << R_2$

$T \propto s$ as R_2 is constant

Hence torque slip curve is a straight line from zero slip to a slip that corresponds to full-load.

(iii) As slip increases beyond full-load slip, the torque increases and becomes maximum at $s = R_2 / X_2$. This maximum torque in an induction motor is called pull-out torque or break-down torque. Its value is at least twice the full-load value when the motor is operated at rated voltage and frequency.

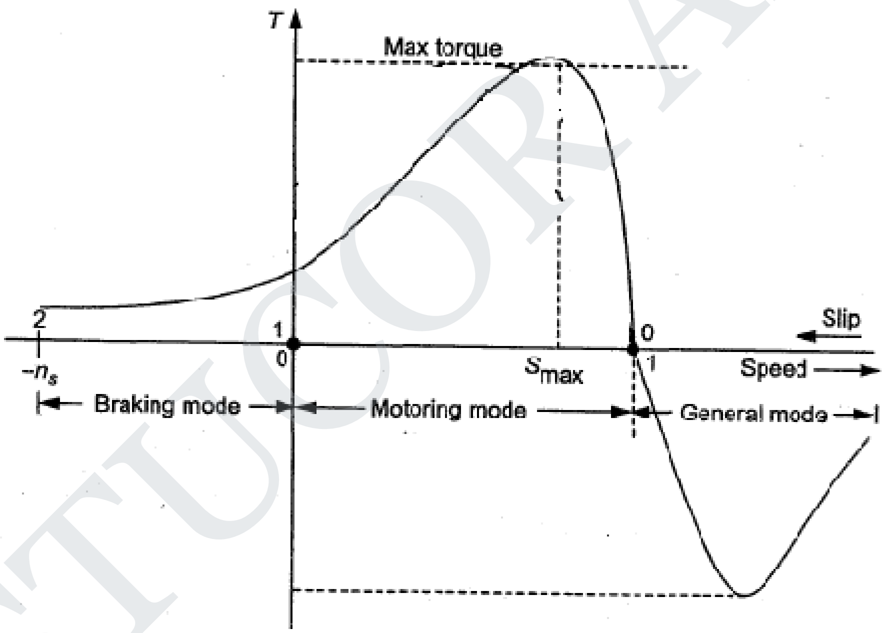
(iv) To maximum torque, the term $s^2 X_2^2$ increases very rapidly so that R_2^2 may be neglected as compared $s^2 X_2^2$

$T \propto s / s^2 X_2^2$

$T \propto 1 / s$ as X_2 is constant

Thus the torque is now inversely proportional to slip. Hence torque-slip curve is a rectangular hyperbola.

(v) The maximum torque remains the same and is independent of the value of rotor resistance. Therefore, the addition of resistance to the rotor circuit does not change the value of maximum torque but it only changes the value of slip at which maximum torque occurs.



Complete Speed Torque Chracteristics of 3ϕ Induction motor

The speed-torque characteristics can be drawn by considering three modes of operation of 3ϕ induction motor.

1. Motoring mode: $0 < s < 1$
2. Generating mode: $s < 0$
3. Braking mode: $s > 1$

1. Motoring mode: $0 < s < 1$

For this range of slip, mechanical power is given as output (or) torque developed is in the direction in which the rotor rotates.

2. Generating mode: $s < 0$

Negative slip refers to the motor running at super synchronous speed i.e. $N > N_s$. For this mode, mechanical power is input and electrical power is given as output at the machine terminals.

DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

3. Braking mode: $s > 1$

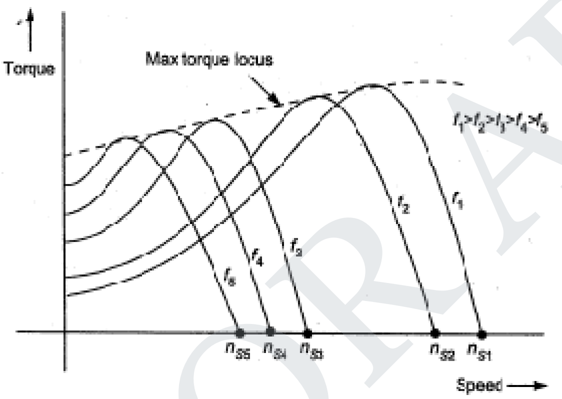
The motor runs in opposite direction to the rotating field i.e., N is negative. Braking effect takes place and the motor stops at the instant

Effect of change in supply frequency on torque and speed

Smooth stepless speed control is obtained by smooth variation of supply frequency. If supply frequency is varied by keeping the supply voltage constant, then the magnetic flux will change. But, it is desirable that an induction motor is operated with its magnetic flux maintained constant.

To maintain the magnetic flux constant, it is therefore necessary to control the supply frequency and voltage in such a way that V/f remains constant.

A family of torque-speed curves for an induction motor obtained by supply frequency variation with V/f = constant.



Speed-Torque Characteristics

Slip-Ring Motors Versus Squirrel Cage Motors

The slip-ring induction motors have the following advantages over the squirrel cage motors:

(i) High starting torque with low starting current.
(ii) Smooth acceleration under heavy loads.
(iii) No abnormal heating during starting.
(iv) Good running characteristics after external rotor resistances are cut out.
(v) Adjustable speed.

The disadvantages of slip-ring motors are:

(i) The initial and maintenance costs are greater than those of squirrel cage motors.
(ii) The speed regulation is poor when run with resistance in the rotor circuit

Speed – Torque characteristics of Single phase induction motors:

Single phase motors are manufactured in fractional kilowatt range to be operated on single phase supply and for use in numerous applications like ceiling fans, refrigerators, food mixers, hair driers, portable drills, vacuum cleaners, washing machines, sewing machines, electric shavers, office machinery, etc.

Single phase motors are manufactured in different types to meet the requirements of various applications. Single phase motors are classified on the basis of their construction and starting methods employed. The main types of single phase motors are listed below.

1. Single-phase induction motors
   i) Split-phase ii) Capacitor start induction run iii) Capacitor start capacitor run
   iv) Shaded-pole type

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

2. A.C. series motor or universal motor

3. Repulsion motors
   (i) Repulsion-start induction-run motor
   (ii) Repulsion-induction motor

4. Synchronous motors
   (i) Reluctance motor (ii) Hysteresis motor

Making single phase motor self starting

In order to make a single phase induction motor self starting, it is temporarily converted into a two phase motor during starting period. To achieve this, the stator is provided with an extra winding, known as starting winding in addition to the main winding.

The starting winding is otherwise called as auxiliary winding and main winding is otherwise called as running winding. These two windings are arranged such that, the phase difference between the currents in the two stator windings is very large i.e. the maximum angle is 90°. These two currents produce revolving flux and hence make the motor self starting. There are many methods by which the necessary phase difference between the two currents can be created.

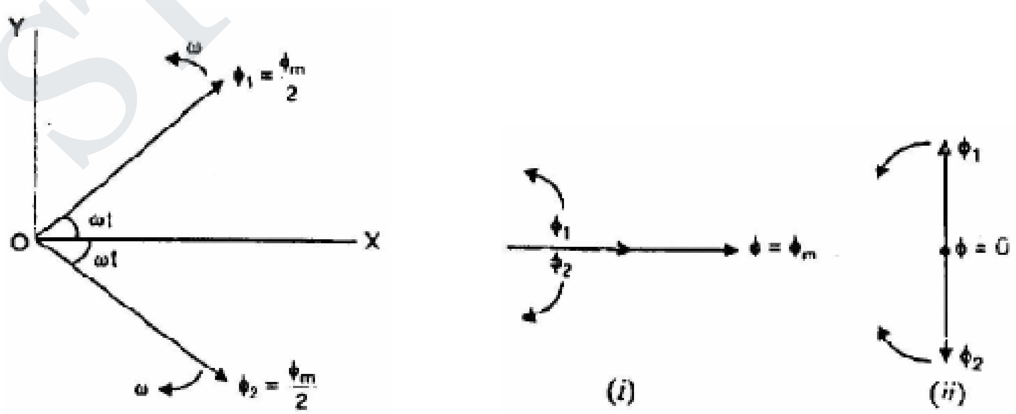
The double-field revolving theory is proposed to explain this dilemma of no torque at start and yet torque once rotated. This theory is based on the fact that an alternating sinusoidal flux ($\phi = \phi_m \cos \omega t$) can be represented by two revolving fluxes, each equal to one-half of the maximum value of alternating flux (i.e., $\phi_m/2$) and each rotating at synchronous speed ($N_s = 120f / P$, $\omega = 2\pi f$) in opposite directions.

The above statement will now be proved. The instantaneous value of flux due to the stator current of a single-phase induction motor is given by;

$$\phi = \phi_m \cos \omega t$$

Consider two rotating magnetic fluxes ϕ_1 and ϕ_2 each of magnitude $\phi_m/2$ and rotating in opposite directions with angular velocity ω.

Let the two fluxes start rotating from OX axis at t = 0. After time t seconds, the angle through which the flux vectors have rotated is at. Resolving the flux vectors along-X-axis and Y-axis, we have,



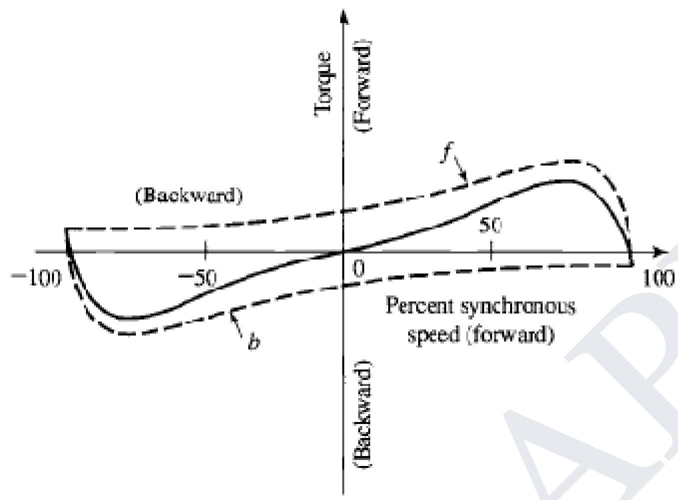
STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

$$\text{Total X-component} = \frac{\phi_m}{2}\cos\omega t + \frac{\phi_m}{2}\cos\omega t = \phi_m \cos\omega t$$

$$\text{Total Y-component} = \frac{\phi_m}{2}\sin\omega t - \frac{\phi_m}{2}\sin\omega t = 0$$

$$\text{Resultant flux, } \phi = \sqrt{(\phi_m \cos\omega t)^2 + 0^2} = \phi_m \cos\omega t$$



Speed - Torque Characteristics

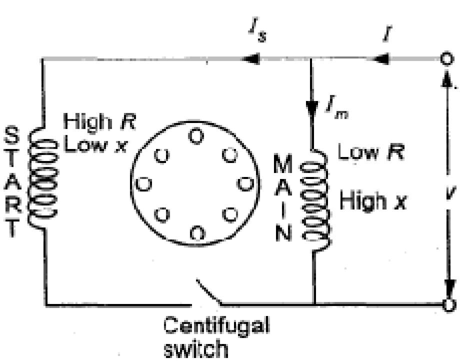
Thus the resultant flux vector is $\phi = \phi_m \cos \omega t$ along X-axis. Therefore, an alternating field can be replaced by two relating fields of half its amplitude rotating in opposite directions at synchronous speed. Note that the resultant vector of two revolving flux vectors is a stationary vector that oscillates in length with time along X-axis. When the rotating flux vectors are in phase (fig(i)), the resultant vector is $\phi = \phi_m$; when out of phase by 180° (Fig.(ii)), the resultant vector $\phi = 0$.

Split phase resistance start induction motor:

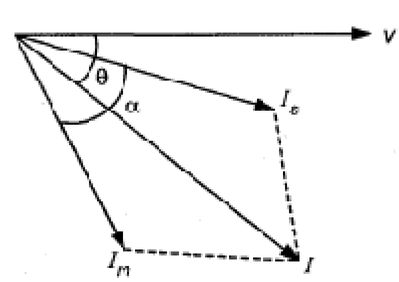
The stator of a split-phase induction motor is provided with an auxiliary or starting winding S in addition to the main or running winding M. The starting winding is located 90° electrical from the main winding.

The starting winding has fewer turns and is wound of smaller diameter copper wire than the running winding. Therefore, the starting winding has low reactance and high resistance. The running or main winding has a low resistance and high reactance.

The current I_s drawn by the starting winding lags behind applied voltage by a small angle whereas current I_m taken by the main winding large behind V by a very large angle. The phase angle between I_s and I_m is made as large as possible, because, the starting torque of a split phase motor is proportional to sinα.



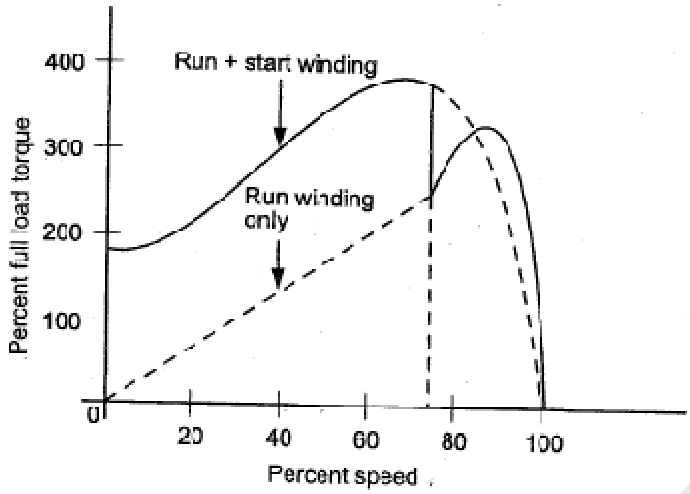
Electrical equivalent circuit



Phasor diagram

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP



Speed – Torque Characteristics

Operation

(i) When the two stator windings are energized from a single-phase supply, the main winding carries current I_m while the starting winding carries current I_s.

(ii) Since main winding is made highly inductive while the starting winding highly resistive, the currents I_m and I_s have a reasonable phase angle a (25° to 30°) between them as shown in Fig. Consequently, a weak revolving field approximating to that of a 2-phase machine is produced which starts the motor. The starting torque is given by;

$T_s = kI_m I_s \sin\alpha$

where k is a constant whose magnitude depends upon the design of the motor.

(iii) When the motor reaches about 75% of synchronous speed, the centrifugal switch opens the circuit of the starting winding. The motor then operates as a single-phase induction motor and continues to accelerate till it reaches the normal speed. The normal speed of the motor is below the synchronous speed and depends upon the load on the motor.

Characteristics

(i) The sinning torque is 15 to 2 times the full-loud torque mid (lie starting current is 6 to 8 times the full-load current.

(ii) Due to their low cost, split-phase induction motors are most popular single phase motors in the market.

(iii) Since the starting winding is made of fine wire, the current density is high and the winding heats up quickly. If the starting period exceeds 5 seconds, the winding may burn out unless the motor is protected by built-in-thermal relay. This motor is, therefore, suitable where starting periods are not frequent.

(iv) An important characteristic of these motors is that they are essentially constant-speed motors. The speed variation is 2-5% from no-load to full load.

(v) These motors are suitable where a moderate starting torque is required and where starting periods are infrequent e.g., to drive:

(a) fans (b) washing machines (c) oil burners (d) small machine tools (e) blowers etc.

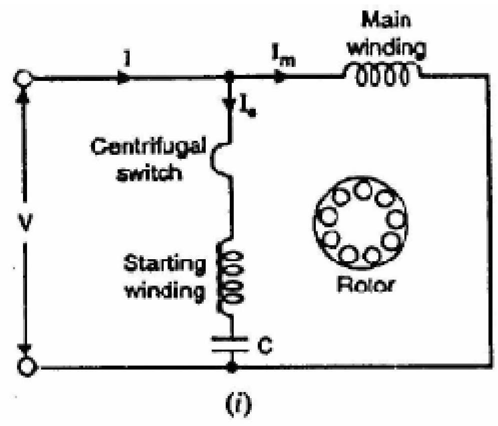
The power rating of such motors generally lies between 60 W and 250 W.

Capacitor-Start Motor

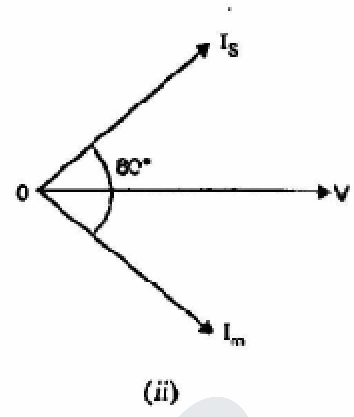
The capacitor-start motor is identical to a split-phase motor except that the starting winding has as many turns as the main winding. Moreover, a capacitor C is connected in series with the starting winding as shown in Fig. (i). The value of capacitor is so chosen that Is leads I_m by about 80° (i.e., $\alpha \approx$ 80°) which is considerably greater than 25° found in split-phase motor [See Fig. (ii). Consequently, starting torque (T_s = k I_m I_s sinα) is much more than that of a split-phase motor Again, the starting winding is opened by the centrifugal switch when the motor attains about 75% of synchronous speed. The motor then operates as a single-phase induction motor and continues to accelerate till it reaches the normal speed.

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP



Electrical equivalent circuit



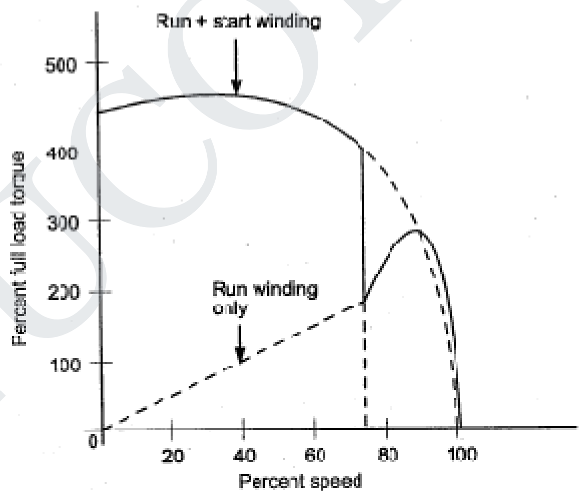
Phasor diagram

Characteristics

(i) Although starting characteristics of a capacitor-start motor are better than those of a split-phase motor, both machines possess the same running characteristics because the main windings are identical.

(ii) The phase angle between the two currents is about 80° compared to about 25° in a split-phase motor.

Consequently, for the same starting torque, the current in the starting winding is only about half that in a split-phase motor. Therefore, the starting winding of a capacitor start motor heats up less quickly and is well suited to applications involving either frequent or prolonged starting periods.



Speed – Torque Characteristics

Applications: Due to its higher starting torque, the capacitor start split phase motors are used in pumps, compressors, air .conditioners, large washing I!1achines and refrigeration units.

Capacitor-Start Capacitor-Run Motor or Permanent split capacitor start induction motor

This motor is identical to a capacitor-start motor except that starting winding is not opened after starting so that both the windings remain connected to the supply when running as well as at starting two designs are generally used.

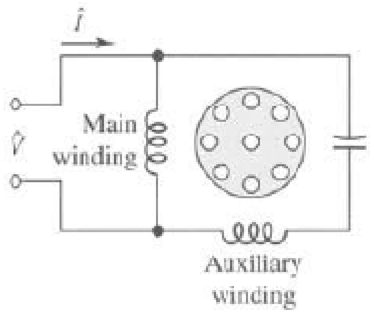
(i) **Single value capacitor motor**, a single capacitor C is used for both starting and running as shown in

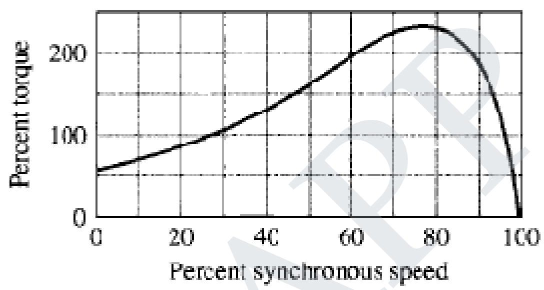
DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP STUCOR APP

Fig.(i). This design eliminates the need of a centrifugal switch and at the same time improves the power factor and efficiency of the motor.

Normally, capacitors of 2 to 20 µF capacitors are employed. Since capacitors are permanently connected, they are designed for continuous duty and they are made of oil filled type. Since a single value capacitor is used for both starting and running, a compromise has to be struck between best running performance and best starting performance. As a result, neither optimum starting nor optimum running performance is obtained. Since, both starting and running windings are identical, It is very easy to reverse the direction of rotation or rotor by having one reversing switch outside the motor (Fig.). The only one drawback of this type of motor is, it has low starting torque: The speed torque curve is shown below (Fig.).





Permanent split phase capacitor start motor or Single value capacitor motor

Speed – Torque Characteristics

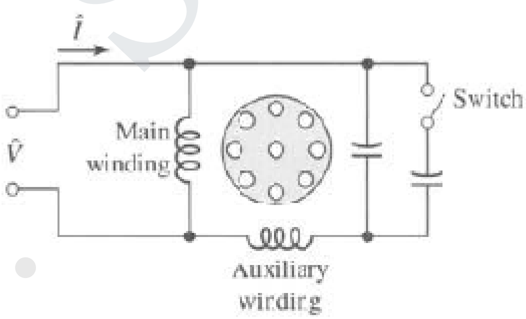
Applications: Due to noiseless operation, this type of motors are desirable for use in offices and laboratories.

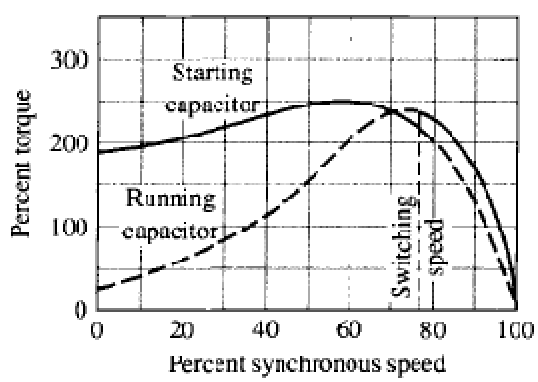
These motors are used where the starting torque is low such as fans, blowers, voltage regulators, furnace controls; valve controls, arc welding controls, etc etc.

(ii)Two value capacitor motor

This is otherwise called as capacitor start and run motor. This motor is similar to the split phase capacitor start induction motor except that the starting winding and capacitor are permanently connected in the circuit at all times. There is no need of centrifugal switch. Since the capacitor is permanently connected, this motor possesses the following merits,

1. Higher power factor at full load,
2. Improvement of overload capacity,
3. Higher efficiency,
4. Noiseless operation





Permanent split phase capacitor start motor or Two value capacitor motor

Speed – Torque Characteristics

In the other design, two capacitors C_1 and C_2 are used in the starting winding as shown in Fig.(ii)). The smaller capacitor C_1 required for optimum running conditions is permanently connected in

STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

series with the starting winding. The much larger capacitor C_2 is connected in parallel with C_1 for optimum starting and remains in the circuit during starting. The starting capacitor C_1 is disconnected when the motor approaches about 75% of synchronous speed. The motor then runs as a single-phase induction motor.

Characteristics

(i) The starting winding and the capacitor can be designed for perfect 2-phase operation at any load. The motor then produces a constant torque and not a pulsating torque as in other single-phase motors.

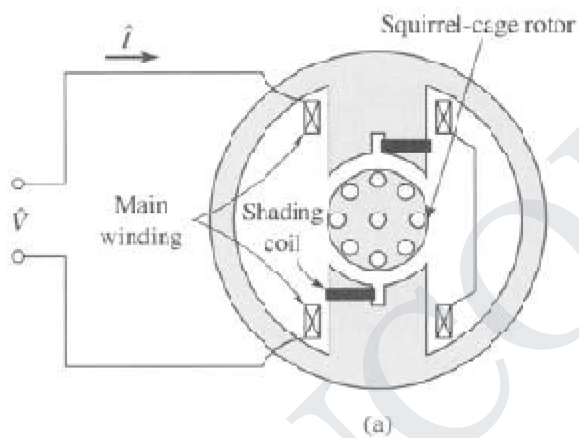
(ii) Because of constant torque, the motor is vibration free

Applications:

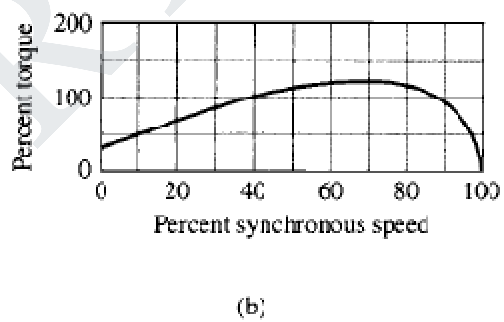
(a) hospitals (b) studios and (c) other places where silence is important. (c) smaller home air conditioning

Shaded-Pole Motor

The shaded-pole motor is very popular for ratings below 0.05 H.P (~ 40W) because of its extremely simple construction. It has salient poles on the stator excited by single-phase supply and a squirrel cage rotor as shown in Fig. A portion of each pole is surrounded by a short-circuited turn of copper strip called shading coil.



Shaded pole induction motor



Speed – Torque Characteristics

These motors have salient poles on the stator and a squirrel cage rotor. The necessary phase splitting is produced by induction principle. The 1/3rd part of the pole is shaded portion and the other as unshaded portion. When the exciting winding is connected to an AC supply, the magnetic axis will shift from the unshaded portion of the pole to the shaded portion of the pole. This shift in magnetic axis is equivalent to physical motion of the pole. As a result, the squirrel cage rotor will rotate in a direction from the unshaded portion to the shaded portion. Its direction of motion is fixed.

Shaded de motors are simple in construction, almost reliable rugged and cheaper.

These motors has low starting torque, low efficiency and very little overload capacity

Applications: Due to its low starting torque, the shaded pole motors are generally used for small hand fans, toys, hair driers, electric clocks, advertising displays, motion picture projectors, etc.

Braking characteristics of 3ϕ induction motor:

1. Rheostatic or Dynamic braking

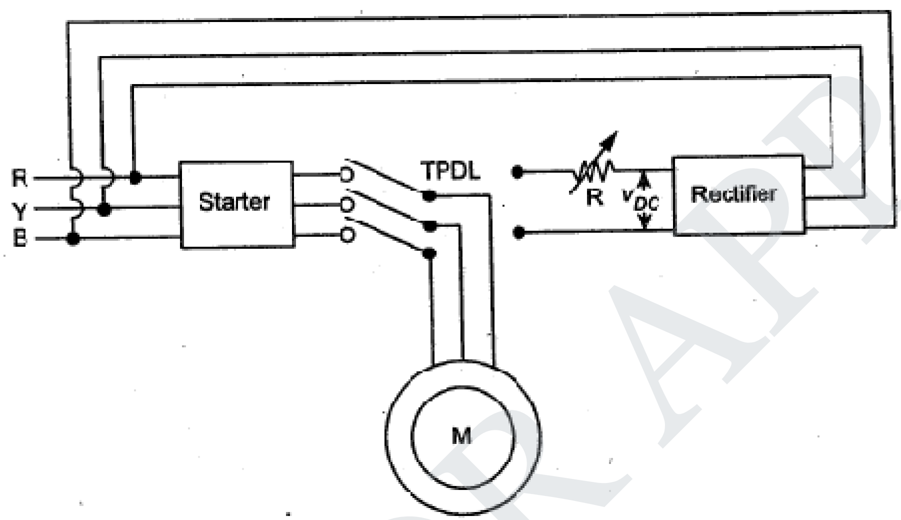
The dynamic or rheostatic braking is employed to brake a non-reversing drive, stator is disconnected from the three phase ac mains and a d.c. current is fed into the stator via two of its

DOWNLOADED FROM STUCOR APP
STUCOR APP

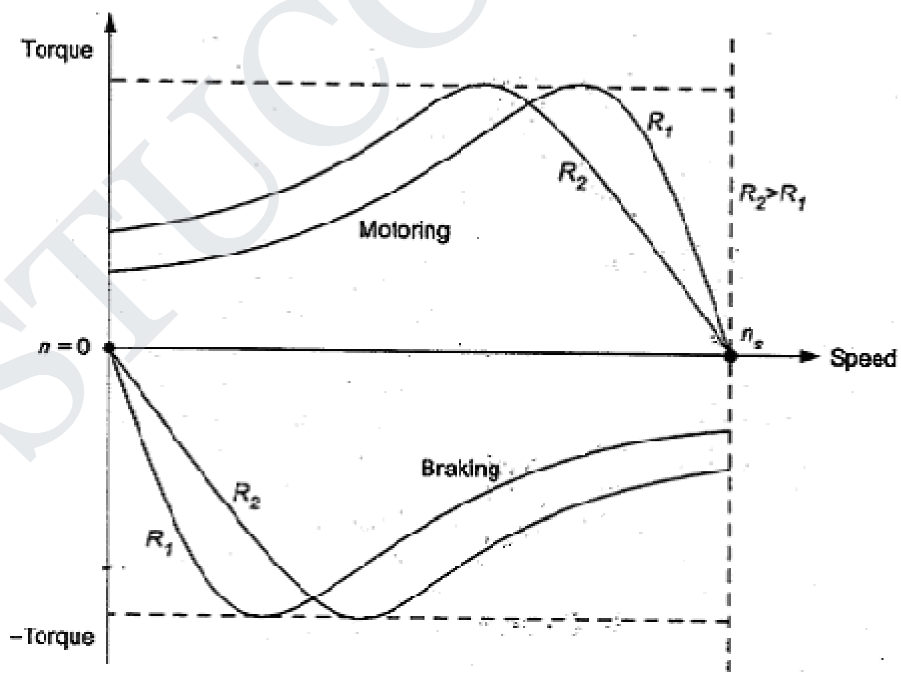
DOWNLOADED FROM STUCOR APP

terminals. The d.c. supply is usually obtained from a rectifier fed via a low-voltage high-current transformer.

The speed of rotation of the air-gap field is directly proportional to the supply frequency, so it should be clear that since d.c. is effectively zero frequency, the air-gap field will be stationary. The rotor always tries to run at the same speed as the field. So, if the field is stationary, and the rotor is not, a braking torque will be exerted, so that the braking (negative) torque falls to zero as the rotor comes to rest. Since there will be induced currents in the rotor (and hence torque) only when the rotor is 'cutting' the flux. As with plugging, injection (or dynamic) braking is a dissipative process, all the kinetic energy being turned into heat inside the motor.



Schematic diagram of dynamic braking



Speed – Torque Characteristics

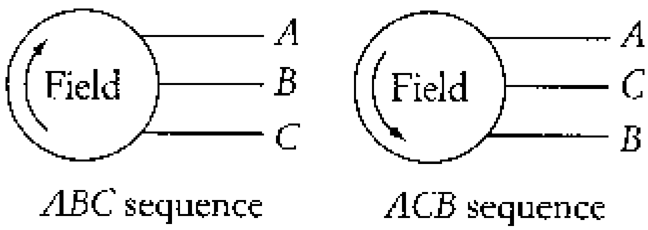
2. Plugging or Counter current or reverse current braking

Plugging method gives more amount of braking than, dynamic braking method. In 3ϕ induction motor, the direction of rotating magnetic field depends on the phase sequence of the 3ϕ supply fed to the stator winding. The direction of torque developed in the rotor is in the same direction as that of the

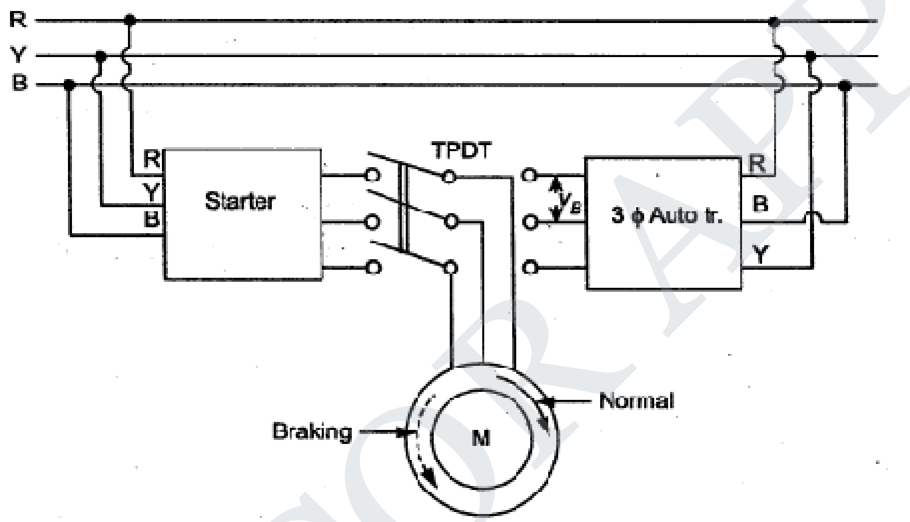
STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

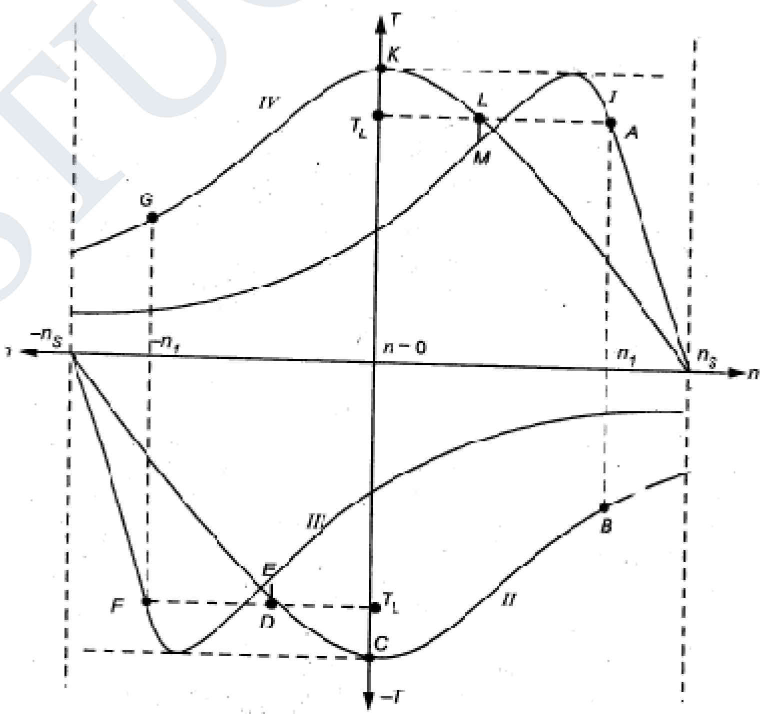
rotating magnetic field. Therefore, in order to develop braking torque in a direction opposite to the movement of the shaft. It is just enough if we change the order of phase sequence of the 3ϕ supply fed to stator. The circuit connection for this method of braking is shown below



Motoring Plugging



Schematic diagram of dynamic braking



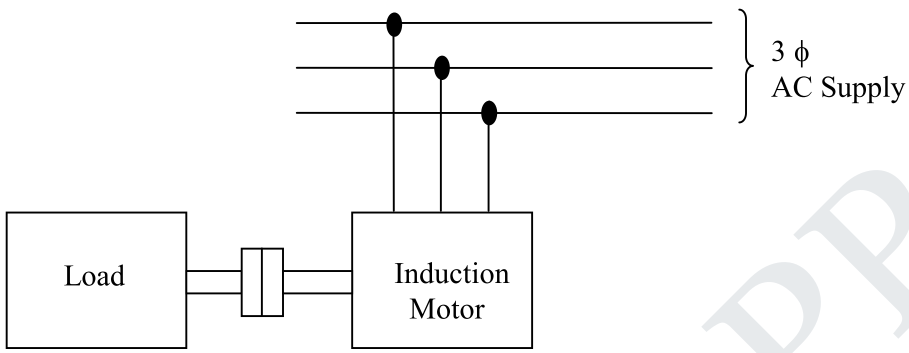
Speed – Torque Characteristics

DOWNLOADED FROM STUCOR APP
STUCOR APP

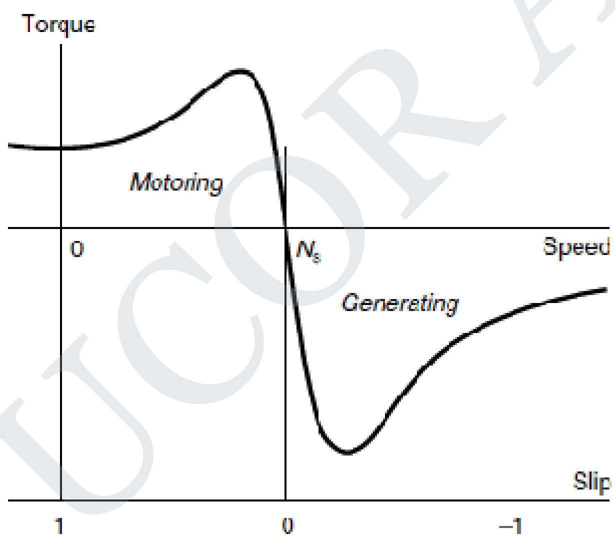
DOWNLOADED FROM STUCOR APP

3. Regenerative braking

This is the most economical method of braking. During regenerative braking, the induction motor is made to operate as an induction generator, converting the acquired mechanical energy into electrical energy and feeding it back to the supply mains. It is worthwhile to mention that, when rotor of induction motor is made to rotate at a speed greater than synchronous speed i.e., super synchronous speed, induction motor will now behave as induction generator.



Schematic diagram of regenerative braking



Speed – Torque Characteristics

Three phase power equation $P = \sqrt{3}\, V_L\, I_L \cos\phi$ where ϕ - angle between V_L and I_L

$\phi < 90^o$ induction machine act as Motor

$\phi > 90^o$ induction machine act as Generator

When rotor of an induction motor runs faster than the stator field (synchronous speed) speed, then slip becomes negative, now machine act as generator. Overhauling load, hoist load and crane or downhill motion has tendency to run the rotor above the synchronous speed. Regenerative braking is also possible with a pole changing method and by varying the supply frequency $\left(N_s = \dfrac{120 f}{P} \right)$.

DOWNLOADED FROM STUCOR APP

STUCOR APP

DOWNLOADED FROM STUCOR APP **PART-A**

(2 MARKS)

1. Why motor characteristics are important?
2. Why DC series motor should never be started on no-load?
3. Why a fly-wheel setup is used in DC series motor?
4. Why differential compound motors are not used in practical?
5. What is the main reason of fitting fly-wheel along with the motor?
6. Draw the mechanical (or) speed –torque characteristics of all types of DC Motors.
7. State the condition at which the starting toque developed in a slip-ring induction motor is maximum.
8. State the different modes of operation of three phase induction machines.
9. What is a mechanical characteristic of a motor?
10. Give the application where DC Shunt, DC Series and DC Compound motors are used.
11. Draw the torque-slip characteristics of a three phase squirrel cage induction motor.
12. What is meant by braking?
13. Mention the Classifications of Braking.
14. What are the advantages and disadvantages of Electrical Braking?
15. Explain the plugging method of braking.
16. Why regenerative braking is not possible ion DC Series motor without modification?
17. Give the types of braking used for DC Motors.
18. What is meant by Regenerative braking in DC Motor?
19. Mention the demerits of mechanical braking.
20. Give the advantage of dynamic braking.
21. What is meant by rheostat (or) dynamic braking?
22. What is meant by Plugging in DC Motor?
23. Draw the speed-torque characteristics of various types of loads.
24. What are the conditions for the stable operations of the motors?
25. List the electrical braking for DC Compound Motor.
26. Differentiate Mechanical and Electrical Braking.
27. Draw the speed-torque characteristics of three phase induction motor.
28. Write short notes about the different types of loads.

PART-B

1. (i) List out the advantages and disadvantages of electrical braking over mechanical braking. (8)
   (ii) Discuss any one method of electrical braking of DC Machines. (8)

2. Explain the Speed-Torque characteristics of three phase induction motor with neat diagrams. (16)

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

3. Explain about the speed-torque characteristics of a DC Shunt Motor with suitable graph and equations. (16)
4. Explain how an induction motor is brought to stop by (i) Plugging and (ii) dynamic braking.(16)
5. Explain the various methods of braking of induction motors. (16)
6. Draw and explain various load characteristics of DC Shunt Motor. (16)
9. Explain Rheostat braking in DC Series Motor and Plugging in DC Shunt Motor. (16)
10. Explain various methods of braking of DC Shunt Motors with neat diagrams. (16)
11. Explain Various methods of braking of DC Series Motors with neat diagrams. (16)
12. (i) Explain the speed – torque curve of single phase induction motors in detail. (8)
    (ii) Explain the method of regenerative braking employed in DC Motors. (8)
13. Explain about the speed-torque characteristics of a DC Compound Motor with suitable graph and equations. (16)
14. A 220V shunt Motor has an armature resistance of 0.062Ω and with full field has an emf of 215V at a speed of 960 rpm, the motor is driving an overhauling load with a torque of 172 Nm. Calculate the minimum speed at which the motor can hold the load by means of regenerative braking. (16)

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

PANIMALAR ENGINEERING COLLGE

DEPARTMENT OF MECHANICAL ENGINEERING

II YEAR / III SEMESTER

ELECTRICAL DRIVES AND CONTROL

UNIT - III

STARTING METHODS

STUCOR APP
STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

Starting methods for ac and dc motors

Starting methods of dc motors

Need for Starter in case of DC motor

At starting, when the motor is stationary, there is no back e.m.f. ($E_b = 0$) in the armature. Consequently, if the motor is directly switched on to the mains, the armature will draw a heavy current ($I_a = V/R_a$) because of small armature resistance. This current will damage the motor.

The voltage and current equation of dc motor is given by $V = E_b + I_a R_a$, $I_a = \frac{V - E_b}{R_a}$

Where, E_b - Back emf, R_a - Armature resistance, V - Supply voltage

From the voltage equation, current drawn by dc motor is $I_a = \frac{V - E_b}{R_a} \cong \frac{V}{R_a}$ $\because E_b = 0$ (Starting)

This high starting current may result in:

(i) Burning of armature due to excessive heating effect,
(ii) Damaging the commutator and brushes due to heavy sparking,
(iii) Excessive voltage drops in the line to which the motor is connected.

In order to avoid excessive current at starting, a variable resistance (known as starting resistance) is inserted in series with the armature circuit. This resistance is gradually reduced as the motor gains speed (and hence E_b increases) and eventually it is cut out completely when the motor has attained full speed.

As an example, 5H.P, 220V shunt motor has a full-load current of 20A and an armature resistance of about 0.5 Ω. If this motor is directly switched on to supply, it would take an armature current of 220/0.5 = 440 A which is 22 times the full-load current.

The starting operation of a d.c. motor consists in the insertion of external resistance into the armature circuit to limit the starting current taken by the motor and the removal of this resistance in steps as the motor accelerates. When the motor attains the normal speed, this resistance is totally cut out of the armature circuit. It is very important and desirable to provide the starter with protective devices to enable the starter arm to return to OFF position

(i) When the supply fails, thus preventing the armature being directly across the mains when this voltage is restored. For this purpose, we use no-volt release coil.
(ii) When the motor becomes overloaded or develops a fault causing the motor to take an excessive current. For this purpose, we use overload release coil.

Types of dc motor starters

There are three types of starters namely:

1. Two point starter
2. Three point starter
3. Four point starter

Two point starter

The two point starter is used to start the dc Series motor

The two types of TWO point starter

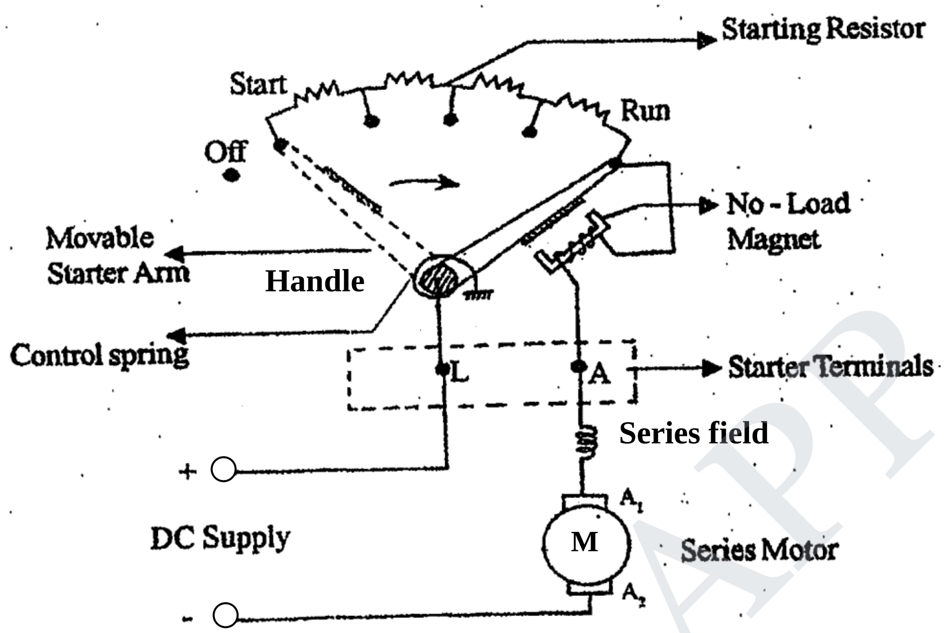
1). 2- Point starter with No Load Protection   2). 2-Point starter with No Volt Protection

DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

TWO Point Starter with No Load Protection

A two point starter is used for starting a DC series motor which has the problem of over-speeding due to the loss of load from its shaft. At this point, we have to keep in mind that, a DC series motor never be started without load. A two point starter is shown below.



Typical Control Circuit for Starting DC Series Motor using TWO point starter with No Load Protection

Here for starting the motor, the control arm is moved clockwise from its OFF position to the ON position against the spring tension. The control arm is held in the ON position by an electromagnet. The Hold ON electromagnet is connected in series with the armature circuit. If the motor loses its load, current decreases and hence the strength of the electromagnet also decreases. The control arm returns to the OFF position due to spring tension, thus preventing the motor from over-speeding. The starter arm also returns to the OFF position when the supply voltage decreases appreciably. The L and A or F are the starter terminals which are connected with the supply and motor terminals.

L – Line (Supply) F – Field A – Armature

No load protection:

When the DC series motor is started without any load, the starting current is very low due to the absence of load, the No-Load armature current is very low because of starting resistance. Since the magnet is not sufficiently energized to attract the starting handle. So, if the starter handle is placed at run position it returns back to the off position due to spring action. The DC series motor is now switched off and No Load protection is thus accomplished.

TWO Point Starter with No Volt Protection

This is a special starter with three terminals such as L_1, L_2 and A

L_1 - Terminal that is connected with supply main

L_2 - Terminal that is connected to a resistance R and No Volt magnet.

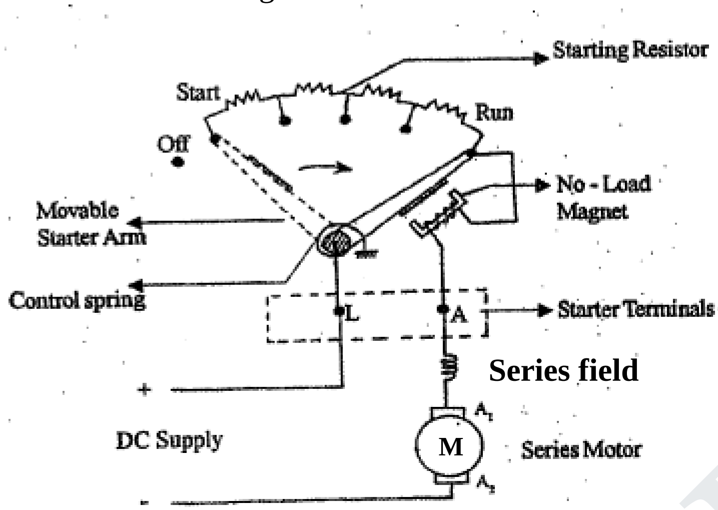
A - The terminal that is connected to armature and series field

The operation this starter is similar to the two point starter with no load protection. Now handle is gradually moved from off position, full starting resistance is connected to armature of the dc series motor and the high starting current is limited. Finally handle reach the RUN position. Where the entire starting resistance is removed from the series circuit. The handle is kept at run position due to the presence of No-Volt magnet, which is connected across the DC supply through the resistance R. If there is no resistance

STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

then No-Volt magnet circuit acts as a short circuit. The starting resistance is connected to terminal A. The terminal A is connected to series field winding and armature of DC series motor.



Typical Control Circuit for Starting DC Series Motor using TWO point starter with No Volt Protection

No Volt Protection

When supply fails the No-Volt magnet that is connected in parallel across the supply gets de-energized. As a result it releases the starter handle: So the starter handle reaches the off position, protecting the DC series motor from No-Volt. If No-Volt protection is not there, the starter handle remains at Run position. When supply returns the DC series motor is directly connected across the supply producing high starting current.

Three Point Starter

This type of starter is widely used for starting shunt and compound motors.

Schematic diagram

Fig. shows the schematic diagram of a three-point starter for a shunt motor with protective devices. It is so called because it has three terminals L, F and A. The starter consists of starting resistance divided into several sections and connected in series with the armature. The tapping points of the starting resistance are brought out to a number of studs. The three terminals L, F and A of the starter are connected respectively to the positive line terminal, shunt field terminal and armature terminal. The other terminals of the armature and shunt field windings are connected to the negative terminal of the supply.

The no-volt release coil is connected in the shunt field circuit. One end of the handle is connected to the terminal L through the over-load release coil. The other end of the handle moves against a spiral spring and makes contact with each stud during starting operation, cutting out more and more starting resistance as it passes over each stud in clockwise direction.

Operation

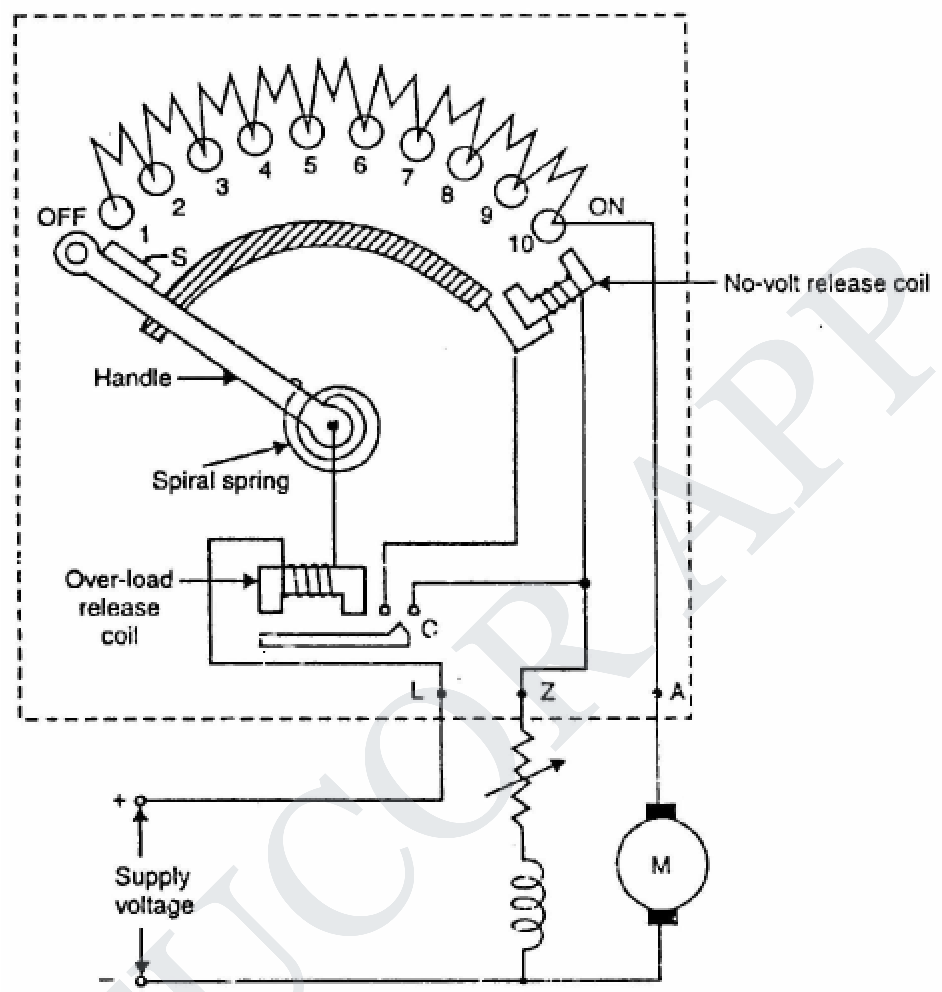
(i) To start with, the d.c. supply is switched on with handle in the OFF position.
(ii) The handle is now moved clockwise to the first stud. As soon as it comes in contact with the first stud, the shunt field winding is directly connected across the supply, while the whole starting resistance is inserted in series with the armature circuit.
(iii) As the handle is gradually moved over to the final stud, the starting resistance is cut out of the armature circuit in steps. The handle is now held magnetically by the no-volt release coil which is energized by shunt field current.
(iv) If the supply voltage is suddenly interrupted or if the field excitation is accidentally cut, the no-volt release coil is demagnetized and the handle goes back to the OFF position under the pull of the spring. If no-volt release coil were not used, then in case of failure of supply, the handle would

DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

remain on the final stud. If then supply is restored, the motor will be directly connected across the supply, resulting in an excessive armature current.

(v) If the motor is over-loaded (or a fault occurs), it will draw excessive current from the supply. This current will increase the ampere-turns of the over-load release coil and pull the armature C, thus short-circuiting the no volt release coil. The no-volt coil is demagnetized and the handle is pulled to the OFF position by the spring. Thus, the motor is automatically disconnected from the supply.



Three point starter

Drawback

In a three-point starter, the no-volt release coil is connected in series with the shunt field circuit so that it carries the shunt field current. During speed control, speed is varied through field regulator; the field current may be weakened to such an extent that the no-volt release coil may not be able to keep the starter arm in the ON position. This may disconnect the motor from the supply when it is not desired. This drawback is overcome in the four point starter.

Four Point Starter

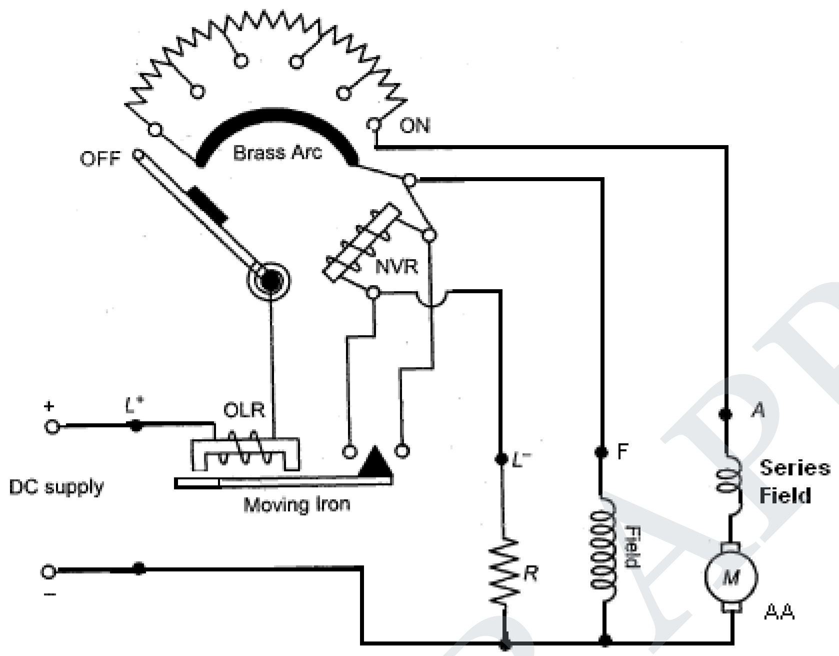
The disadvantage of a three point starter is overcome in a four point starter by connecting the hold-on coil across the line instead of in series with the shunt field circuit. This makes a wide range of field adjustments possible.

The connection diagram for a four point starter is shown in Fig. Therefore, when the starting arm touches the starting resistance, current from the supply is divided into three paths. One through the starting resistance and armature, one through the field circuit and one through the NVR coil.

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

A protective resistance is connected in series with the NVR coil (or) Hold-on magnet coil. With this arrangement, any change of current in the shunt filed circuit not at all affect the current passing through the HOLD-ON coil because the two circuits are independent of each other. It means that the electromagnetic pull exerted by the Hold-on coil will always be sufficient and will prevent the spring from restoring the starting arm to OFF position no matter how the field rheostat or regulator is adjusted.



Four point starter

The starter terminals are

L+ or L_1 – Terminal that is connected to supply (Line)
L- or L_2 – Terminal that is connected to the No volt coil (NVR or NVC)
F – Terminal that is connected to shunt field winding
A – Terminal that is connected to the armature of the motor

Function of over load release (OLR) or Over Current magnet (OC)

When the load on motor increases above the rated limit then the armature takes high current. When the motor is left unprotected from this high current, then it is damaged, the over current magnet is used for this protection. When there is high current due to over load or due to short circuit the over current magnet is energized and attracts soft iron rod H. *As* a result, the soft, iron rod H closes the switch S. When the switch S is closed, it short circuits the No-Volt magnet. As a result No Volt magnet is de-energized and release the starter handle to the Off position. So the motor is switched off' and protected from the over current or high current.

Function of No volt release (NVR) or No volt coil (NVC)

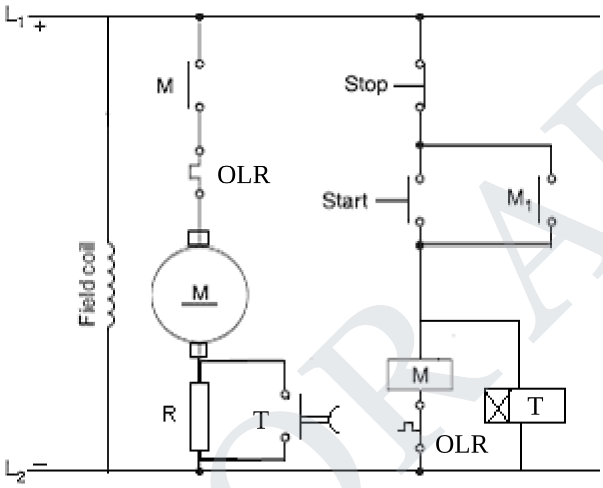
The No Volt magnet keeps starter handle at run position against the control spring. The No-Volt magnet attracts the soft iron bar placed in the handle. The No-Volt magnet is energized by the .current flowing through the field circuit. If there is no No-Volt magnet the starter handle is pulled back the Off position by the control spring and the motor Point Starter is switched Off.

DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP STUCOR APP

Typical control circuit for dc shunt motor

The armature has been shown connected directly across the lines through resistance R. When the START-push button is pressed, the main contactor *M* gets energized by getting supply through the START-push button and the OLR. As soon as the contactor closes, normally open contact M_1 will close and act as seal-in contact while the releasing of Start push button. The M will remain energized by getting supply through holding contact M_1 which has been connected in parallel with the START-push button. It may be understood that ON delay timer T also energized, after certain time delay T will closed. Now starting resistance R connected in series with armature were removed (shorted). The dc motor operates rated condition. In case of any emergency stop or operation is completed, press the STOP push button to stop the motor. Normal operating condition over load release not energized, there is any sudden increase in load (above the rated load or current), now OLR get energized and corresponding OLR contact opened which results the armature supply disconnected and motor is stopped.



Typical control circuit for dc shunt motor

Counter EMF Starter

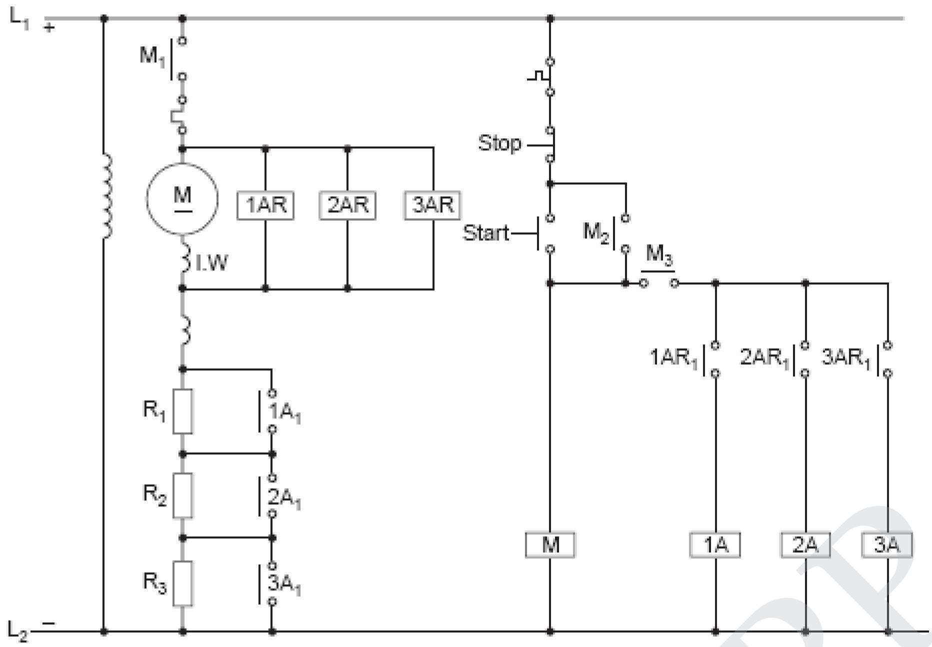
These starters are economical and perform well for small motors up to 5 hp rating. These starters use voltage relays to cut off resistance from the armature circuit in steps. Voltage relays are voltage sensitive and they can be set to pick up at any desired voltage level. In this type of starter counter emf generated in armature is utilised to energise voltage accelerating relays. These relays are connected in parallel with the armature of the motor as shown in Fig.

When motor just starts, counter emf in the armature is zero. As the motor accelerates, counter emf also starts building up. The accelerating voltage relays 1*AR*, 2*AR* and 3*AR* are set to pick up at different increasing values of emf and their contacts energise contactors 1*A*, 2*A* and 3*A* to cut off resistance *R*1, *R*2, *R*3 from armature circuit. In the four step starter shown in Fig., the voltage accelerating relays may be set to pick up at 50, 75 and 90 percent rated speed. The working of the control is explained as under:

When the START-push button is pressed, contacotor *M* is energised and it gets hold through its own contact M_2. Its main contact *M*1 energises the armature with resistance R_1, R_2 and R_3 in the circuit. The motor accelerates and when say 50% of the normal speed is reached, emf generated causes the relay 1*AR* to pick up. Contact of 1*AR* closes to energise contactor 1*A* which shorts resistance R_1 through its main contact 1*A*1. Due to cutting of resistance *R*1, the motor accelerates further and at 75% of normal speed counter emf generated makes the relay 2*AR* to pick up. When 2*AR* picks up contact 2*A*1 of contactor 2*A* closes and shorts resistance R_2. Thus the motor accelerates still further and at 90% of the normal speed, relay 3*AR* picks up and thus the third resistance R_3 is short circuited by contactor 3*A*. Now the motor gets connected directly to the lines and reaches its final speed.

STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP STUCOR APP

DOWNLOADED FROM STUCOR APP



Circuit diagram for counter EMF starter for a dc motor

Starter Resistance Step Calculations for D.C. Shunt Motor

Fig. shows a d.c. shunt motor starter with n resistance sections and (n + 1) studs.

Let R_1 = Total resistance in the armature circuit when the starter arm is on stud no.1 (See Fig.)
R_2 = Total resistance in the armature circuit when the starter arm is on stud no.2 and so on
I_m = Maximum or Upper current limit
I = Lower current limit
n = Number of sections in the starter resistance
V = Applied voltage
R_a = Armature resistance

On stud 1. When the starter arm-moves to stud 1, the total resistance in the armature circuit is R_1 and the circuit current jumps to maximum values I_m given by;

$$I_m = \frac{V}{R_1}$$

Since, torque $\propto$ I_a, it follows that the maximum torque acts on the armature to accelerate it. As the armature accelerates, the induced e.m.f. (back e.m.f.) increases and the armature current decreases when the current has fallen to the predetermined value I, the starter arm is moved over to stud 2. Let the value of back e.m.f. be E_{b1} at the instant the starter arm leaves the stud 1. Then current I is given by;

$$I = \frac{V - E_{b1}}{R_1}$$

On stud 2. As the starter arm moves over to stud 2, sufficient resistance is cut out (now total circuit resistance is R_2) and current rises to maximum value I_m once again given by;

$$I_m = \frac{V - E_{b1}}{R_2}$$

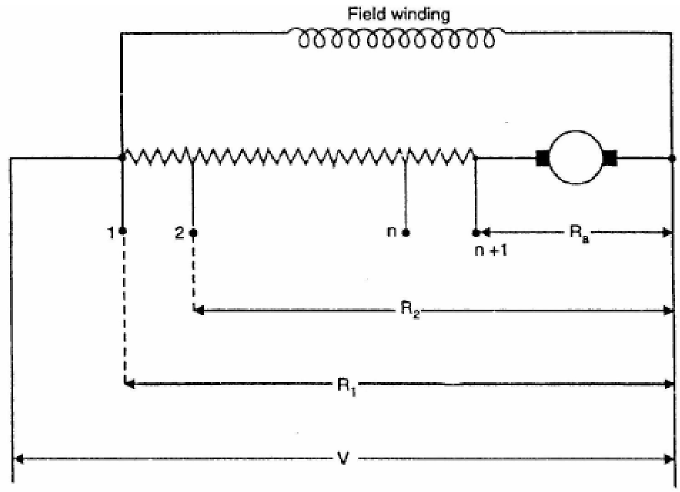
The acceleration continues and the back e.m.f. increases and the armature current decreases. When the current has fallen to the predetermined value I, the starter arm is moved over to stud 3. Let E_{b2} be the value of back e.m.f. at the instant the starter arm leaves the stud 2. Then,

$$I = \frac{V - E_{b2}}{R_2}$$

DOWNLOADED FROM STUCOR APP

STUCOR APP

DOWNLOADED FROM STUCOR APP



On stud 3.

As the starter arm moves to stud 3, $I_m = \dfrac{V - E_{b2}}{R_3}$

As the starter arm leaves stud 3, $I = \dfrac{V - E_{b3}}{R_3}$

On nth stud.

As the starter arm leaves nth stud, $I = \dfrac{V - E_{bn}}{R_n}$

On (n + 1)th stud. When the starter arm moves over to (n + 1)th stud, all the external starting resistance is cut out, leaving only the armature resistance R_a.

$$\therefore \quad I_m = \frac{V - E_{bn}}{R_a} \quad \text{and} \quad I = \frac{V - E_b}{R_a}$$

Dividing Eq.(ii) by Eq.(iii), we get,

$$\frac{I}{I_m} = \frac{R_2}{R_1}$$

Dividing Eq.(iv) by Eq. (v), we get,

$$\frac{I}{I_m} = \frac{R_3}{R_2}$$

Continuing these divisions, we Lave finally,

$$\frac{I}{I_m} = \frac{R_a}{R_n}$$

Let $\dfrac{I}{I_m} = k.$ Then $\dfrac{R_2}{R_1} = \dfrac{R_3}{R_2} = \ldots = \dfrac{R_a}{R_n} = k$

If we multiply these n equal ratios together, then,

$$\frac{R_2}{R_1} \times \frac{R_3}{R_2} \times \frac{R_4}{R_3} \times \ldots \times \frac{R_a}{R_n} = k^n$$

$$\therefore \quad \frac{R_a}{R_1} = k^n$$

Thus we can calculate the values of R_2, R_3, R_4 etc. if the values of R_1, R_a and n are known.

STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

Starting of Three Phase Induction Motors

In the case of an induction motor, at start when the rotor is at standstill, the squirrel cage rotor is just like a short circuited secondary. Therefore, the current in the rotor circuit will be very high and at the same time, the stator also will draw a high current from the supply lines if full line voltage were applied at start.

The magnitude of this current depends on the electrical design of the motor and is independent of the mechanical load. The duration of starting current, however, depends upon the time required for acceleration, which in turn depends on the nature of the driven load.

Modern well designed induction motors will usually take about 5 to 7 times the rated full load current at the starting if rated voltage is applied to it. Best way to reduce the starting current is to apply reduced voltage across the stator winding at start. With the reduction in voltage applied to the stator of an induction motor, the short circuit current will be reduced in the same proportion.

The major factor to be considered if we employ reduced voltage for starting of squirrel cage induction motor is the large reduction in starting torque, since starting torque is proportional to the square of applied voltage. Whether or not such a large reduction in starting torque is permissible will depend upon the applications.

There are several methods of starting of three phase induction motors.

The most commonly used methods are given below:

Squirrel cage induction motors

(1) Primary resistor starters
(2) Direct on line starters (DOL)
(3) Auto transformer starters or Auto starter
(4) Start-delta starter (Y-Δ)

Slip ring induction motors

(1) Rotor rheostat starter or Rotor resistance starter

Primary resistor starters

The use of primary resistors is to drop some voltage arid hence reduce the voltage applied across the motor terminals. In this way, the initial current drawn by the motor is reduced (Fig.). By using primary resistors, the applied voltage per phase can be reduced by a fraction ‘x’, then

$$I_{st} = xI_{sc}$$

$$\frac{T_{st}}{T_f} = \left(\frac{I_{st}}{I_f}\right)^2 s_f = \left(\frac{xI_{sc}}{I_f}\right)^2 s_f$$

$$\frac{T_{st}}{T_f} = x^2\left(\frac{I_{sc}}{I_f}\right)^2 s_f$$

where, I_{st} – Starting current

I_f – Full load current

I_{sc} - Short circuit current or DOL current

s_f – Slip at full load

x – fraction of load or % tapping or reduced voltage

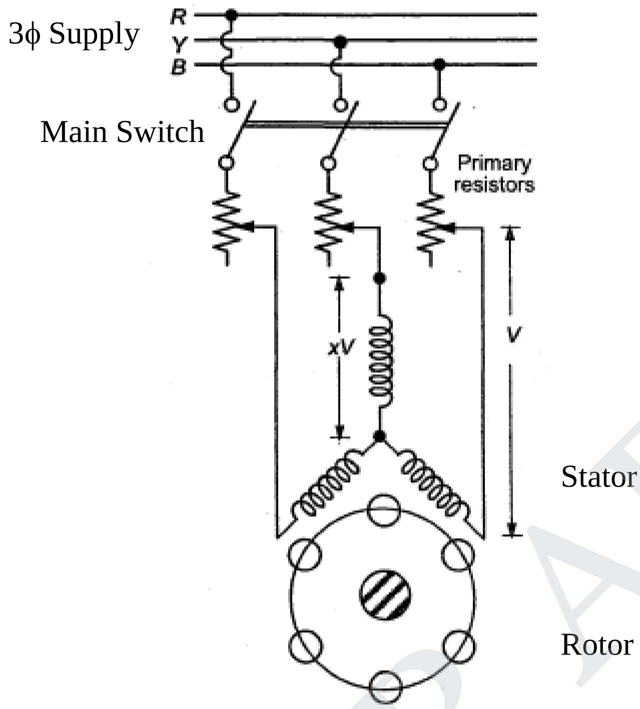
The ratio of the starting torque to full load torque is x^2 times of that obtained with direct switching or across the line starting. This method is useful for the smooth starting of small machines only.

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

With protective device

The Fig. shows the connection for starting squirrel cage induction motor using primary resistors with protective devices incorporated. It consists of three line starters, two sets of three line contactors, two contactors, a timing relay, overload protection, a push-button station and several auxiliary contacts.



Primary resistor starter

Direct on line Starters (DOL)

This is the most economical method of starting of induction motors. Squirrel cage motors of capacity upto 2 kW, double cage motors and squirrel cage motors of larger capacity having very high rotor resistance are started by this method. As the name implies, this method refers to switching the motor directly on to the supply without using any device for reducing the starting current. Now, the starting torque is given by

Rotor input $= 2\pi N_s T = kT$ But Rotor Cu loss = s × Rotor input

$$3(I'_2)^2 R_2 = s \times kT \quad \text{or} \quad T \propto \frac{(I'_2)^2}{s}$$

Starting torque $T_{st} \propto \dfrac{I_{st}^2}{s}$ $\qquad (\because I'_2 \propto I_1)$

If I_{st} is the starting current, then starting torque (T_{st}) is $T_{st} \propto I_{st}^2$ (at starting s = 1)

If I_f is the full-load current and s_f is the full-load slip, then,

$$T_{st} \propto \frac{I_{st}^2}{s} \quad , \qquad \frac{T_{st}}{T_f} = \left(\frac{I_{st}}{I_f}\right)^2 s_f$$

When the motor is started direct-on-line, the starting current is equal to the short-circuit (blocked-rotor) current I_{sc}.

$$\frac{T_{st}}{T_f} = \left(\frac{I_{sc}}{I_f}\right)^2 s_f$$

Note that starting current is as large as five times the full-load current but starting torque is just equal to the full-load torque. Therefore, starting current is very high and the starting torque is

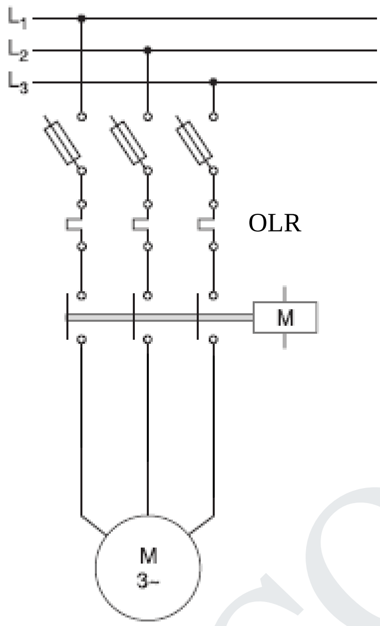
DOWNLOADED FROM STUCOR APP
STUCOR APP

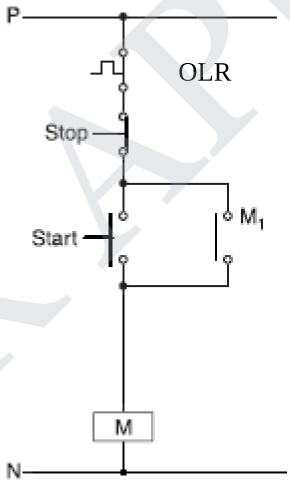
DOWNLOADED FROM STUCOR APP

comparatively low. If this large starting current flows for a long time, it may overheat the motor and damage the insulation

Typical Control circuit of DOL Starter

A DOL starter with protective devices included. To start the motor, it is merely necessary to press the START button. This energies the *M* contactor through the overload relay contacts *OL* (normally closed) which, in turn, close the main contacts *M*. Contacts M_1 many also close to seal the main contactor, so that the START button may be released. Overload protection is provided by two thermal elements *OL* place in the motor leads. If there is any overload, motor may get overheated and now at this instant, thermal elements open the *OL* contacts in the control circuit to de-energize the main coil. This opens the *M* contacts and disconnects the motor from the supply.





Direct on-Line Starter: (a) Power circuit (b) Control circuit

Auto transformer starter

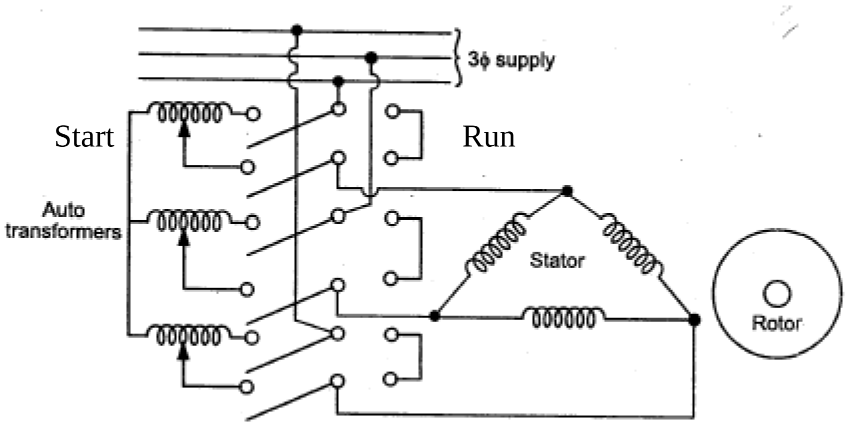
These starters are also called as auto-starters (or) compensators. It consists of an auto-transformer with necessary switches. This method can be used for both star and delta connected motors. Reduced voltage for starting can be obtained form three auto transformers connected in star as shown in Fig. If the voltage is reduced to a fraction *x* of the rated voltage *V*, the motor starting current is $I_{st} = xI_{sc}$

The tapping on the autotransformer is so set that when it is in the circuit, 65% to 80% of line voltage is applied to the motor. At the instant of starting, the change-over switch is thrown to “start” position. This puts the autotransformer in the circuit and thus reduced voltage is applied to the circuit. Consequently, starting current is limited to safe value. When the motor attains about 80% of normal speed, the changeover switch is thrown to “run” position. This takes out the autotransformer from the circuit and puts the motor to full line voltage. Autotransformer starting has several advantages viz low power loss, low starting current and less radiated heat. For large machines (over 25 H.P.), this method of starting is often used. Auto-transformers may be either manually or magnetically operated.

Relation between starting and F.L. Torques. Consider a star-connected squirrel cage induction motor. If V is the line voltage, then voltage across motor phase on direct switching is $V/\sqrt{3}$ and starting current is $I_{st} = I_{sc}$. In case of autotransformer, if a tapping of transformation ratio K (a fraction) is used, then phase voltage across motor is $xV / \sqrt{3}$ and $I_{st} = x\ I_{sc}$,

DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP



Autotransformer Starter

$$I_{st} = xI_{sc}$$

$$\frac{T_{st}}{T_f} = \left(\frac{I_{st}}{I_f}\right)^2 s_f = \left(\frac{xI_{sc}}{I_f}\right)^2 s_f \quad \text{or} \quad \frac{T_{st}}{T_f} = x^2\left(\frac{I_{sc}}{I_f}\right)^2 s_f$$

It is found that while the starting torque is reduced to a fraction x^2 of that obtainable by direct starting, the starting line current is also reduced by the same fraction. Compared to the primary resistors starting, the line current reduces further a fraction *x* while torque remains the same. The auto-transformer starting is much superior to primary resistors starting. Also smooth starting and high acceleration are possible by gradually raising the voltage to the full line value.

Star-delta starting

The stator winding of the motor is designed for delta operation and is connected in star during the starting period. When the machine is up to speed, the connections are changed to delta. The circuit arrangement for star-delta starting is shown in Fig.

The six leads of the stator windings are connected to the changeover switch as shown. At the instant of starting, the changeover switch is thrown to "Start" position which connects the stator windings in star. Therefore, each stator phase gets V/√3 volts where V is the line voltage. This reduces the starting current. When the motor picks up speed, the changeover switch is thrown to "Run" position which connects the stator windings in delta. Now each stator phase gets full line voltage V.

The disadvantages of this method are:

(a) With star-connection during starting, stator phase voltage is 1/√3 times the line voltage. Consequently, starting torque is $(1/\sqrt{3})^2$ or 1/3 times the value it would have with Δ-connection. This is rather a large reduction in starting torque.

(b) The reduction in voltage is fixed.

This method of starting is used for medium-size machines (upto 25 H.P.).

Relation between starting and F.L. Torques. In direct delta starting,

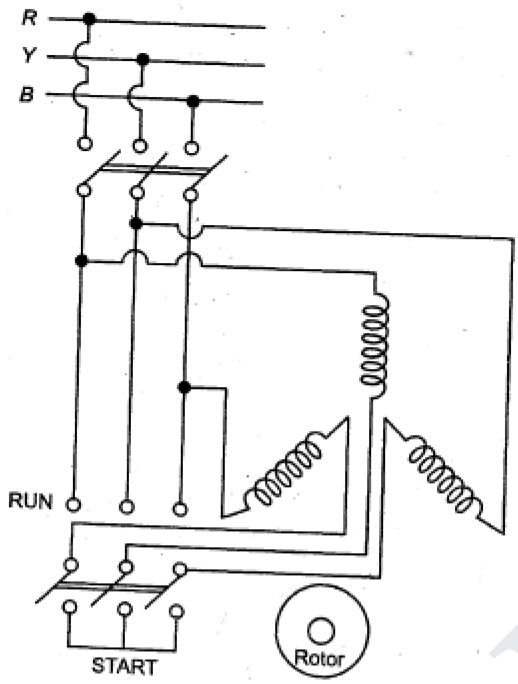
Starting current/phase, $I_{sc} = V/Z_{sc}$ Starting line current = $\sqrt{3}\, I_{sc}$ where V = line voltage

In star starting, we have,

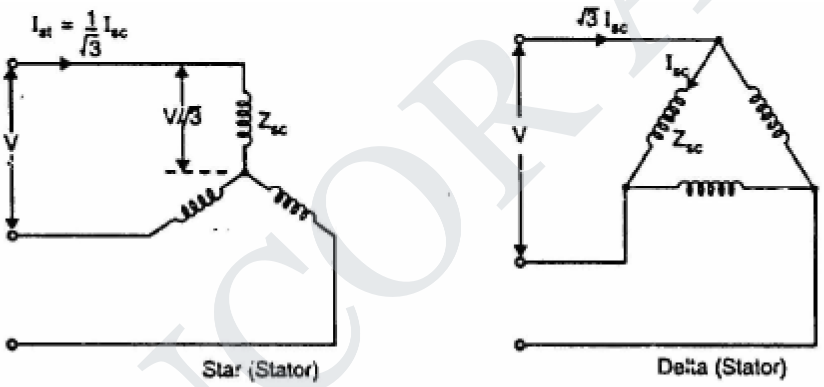
Starting current/phase, $I_{st} = \dfrac{V/\sqrt{3}}{Z_{sc}} = \dfrac{1}{\sqrt{3}} I_{sc}$

DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP



Star – Delta Starter



$$\frac{T_{st}}{T_f} = \left(\frac{I_{st}}{I_f}\right)^2 s_f = \left(\frac{I_{sc}}{\sqrt{3} I_f}\right)^2 s_f \quad \text{or} \quad \frac{T_{st}}{T_f} = \frac{1}{3}\left(\frac{I_{sc}}{I_f}\right)^2 s_f$$

Where I_{sc} = starting phase current (delta), I_f = F.L. phase current (delta)

Note that in star-delta starting, the starting line current is reduced to one-third as compared to starting with the winding delta connected. Further, starting torque is reduced to one-third of that obtainable by direct delta starting. This method is cheap but limited to applications where high starting torque is not necessary e.g., machine tools, pumps etc.

It is clear that the star-delta starting reduces the starting torque to one to one third that obtainable by direct delta starting and also the starting line current the star-delta starter is equivalent to an auto-transformer of ratio of 1/√3 or 58% tapping approximately.

DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

Starting of slip ring induction motors

Rotor rheostat starter or Rotor resistance starter

The slip ring motors are practically always started with full line voltage applied across the stator terminals. The value of starting current is adjusted by introducing a variable resistance in the rotor circuit. The controlling resistance is in the form of rheostat connected in star (Fig.), the resistance being gradually cut out of the rotor circuit as the motor gathers speed.

By increasing the rotor resistance, riot only the motor current is reduced at starting but at the same time torque is also increased due to improvement in power factor. The rheostat is either of stud or contactor type and may be hand operated or automatic.

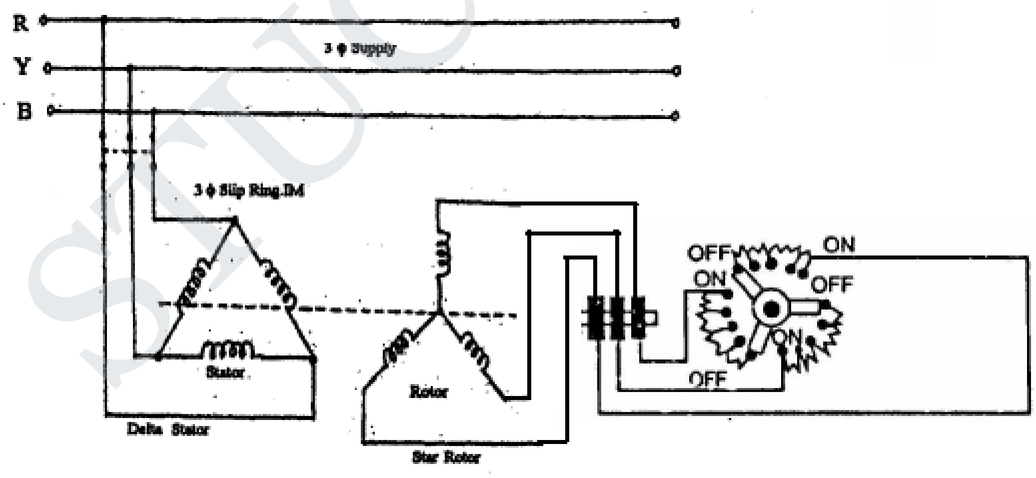
The introduction of additional external resistance in the rotor circuit enables slip ring motor to develop a high starting torque with reasonable starting current. Hence, such motors can be started under load.

When the motor runs under normal conditions the rings are short circuited and brushes will be automatically lifted from them.

Slip-ring motors are invariably started by rotor resistance starting. In this method, a variable star-connected rheostat is connected in the rotor circuit through slip rings and full voltage is applied to the stator winding as shown in Fig.

(i) At starting, the handle of rheostat is set in the OFF position so that maximum resistance is placed in each phase of the rotor circuit. This reduces the starting current and at the same time starting torque is increased.

(ii) As the motor picks up speed, the handle of rheostat is gradually moved in clockwise direction and cuts out the external resistance in each phase of the rotor circuit. When the motor attains normal speed, the change-over switch is in the ON position and the whole external resistance is cut out from the rotor circuit.



Rotor resistance starter

Slip-Ring Motors Vs Squirrel Cage Motors

The slip-ring induction motors have the following advantages over the squirrel cage motors:

(i) High starting torque with low starting current.
(ii) Smooth acceleration under heavy loads.
(iii) No abnormal heating during starting.
(iv) Good running characteristics after external rotor resistances are cut out.
(v) Adjustable speed.

DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

The disadvantages of slip-ring motors are:

(i) The initial and maintenance costs are greater than those of squirrel cage motors.

(ii) The speed regulation is poor when run with resistance in the rotor circuit

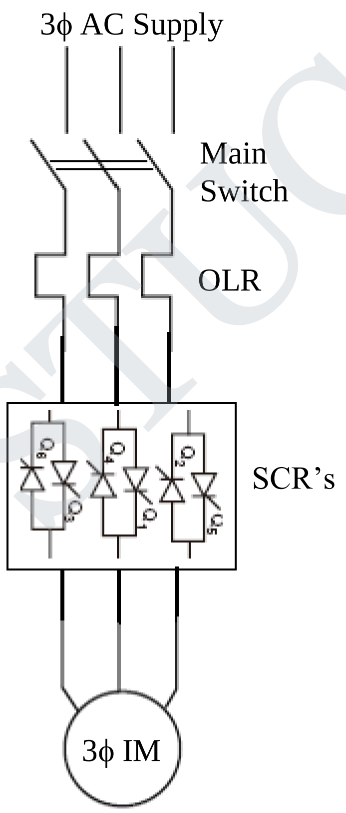
SOFT STARTER

A softstarter has different characteristics to the other starting methods. It has thyristors in the main circuit, and the motor voltage is regulated with a printed circuit board. The softstarter makes use of the fact that when the motor voltage is low during start, the starting current and starting torque is also low.

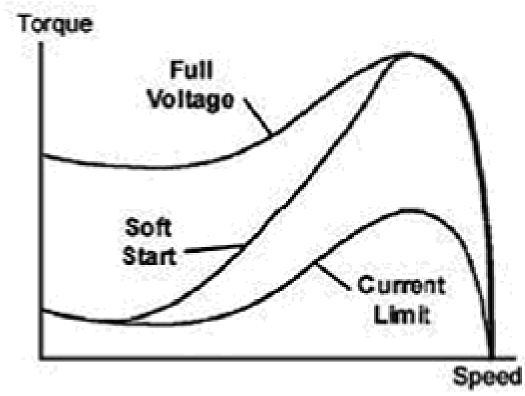
The soft starter eliminates unnecessary jerks during the start. Gradually, the voltage and the torque increase so that the machinery starts to accelerate One of the benefits with this starting method is the possibility to adjust the torque to the exact need, whether the application is loaded or not. In principle the full starting torque is available, but with the big difference that the starting procedure is much more forgiving to the driven machinery, with lower maintenance costs as a result.

Another feature of the soft starter is the soft stop function, which is very useful when stopping pumps where the problem is water hammering in the pipe system at direct stop as for star-delta starter and direct-on-line starter. The soft stop function can also be used when stopping conveyor belts to prevent material from damage when the belts stop too quickly.

Soft starting an ac motor refers to any one of several starting methods that limit the starting current and torque of the motor. The reduced voltage starters, and will be referred to as soft starting. Most soft starters use voltage control to limit the motor starting current and torque by continuously ramping the applied motor voltage when starting and stopping. Other reduced voltage starting techniques cause a step change in the applied motor voltage, using electro mechanical contactor switching.



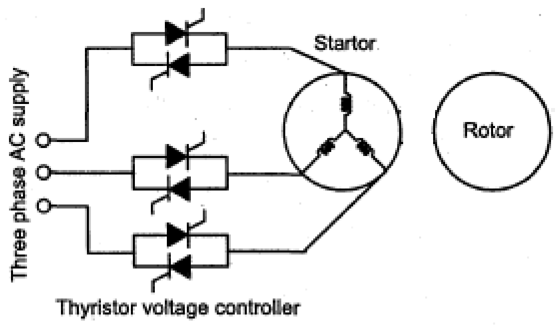
Soft starter circuit



Speed torque characteristics of soft started motor

DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP



Simple Soft starter circuit

Soft starting an ac motor refers to any one of several starting methods that limit the starting current and torque of the motor. The reduced voltage starters, and will be referred to as soft starting. Most soft starters use voltage control to limit the motor starting current and torque by continuously ramping the applied motor voltage when starting and stopping. Other reduced voltage starting techniques cause a step change in the applied motor voltage, using electro mechanical contactor switching.

Operation of Soft Starters

By using six SCR's in a back-to-back configuration as shown in figure, the soft starter is able to regulate the voltage applied to the motor during starting from 0 volts up to line voltage. Timing of when to turn on the SCR's is the key to controlling the voltage output of a soft starter. During the starting sequence the logic of the soft starter determines when to turn on the SCR's. It does not turn on the SCR's at the point that the voltage goes from negative to positive, but waits for some time after that. This is known as "phasing back" the SCR's. The point that the SCR's are turned on is set or programmed by what is called initial torque, initial current or current limit setting.

Advantages of soft starter

- Reduced wear on mechanical gears, chains and sprockets, and unexpected repair of broken belts and jammed gearboxes.
- Lower inventory of spare mechanical parts and operating costs.
- Increased production rates by reducing machine maintenance downtime.
- Prolonged life of electrical switchgear with lower inrush currents.
- Soft stops on pumping applications reduce piping system stresses and "hammer" effect.
- Energy optimizing reduces motor energy losses when operating motor below maximum capacity.

PART-A (2 MARKS)

1. What are the functions of starters?
2. What are the factors influencing the selection of starters?
3. Why starter is necessary for starting a DC Motor?
4. What are the starters used for starting DC Motors?
5. Why is starting current high in a DC Motor?
6. What are the protective devices used in DC Motor Starters?
7. How does the four point starter differ from three point starter?
8. Explain the function of NVR coil in DC Motor Starters?
9. Explain the function of OLR coil in DC Motor Starters?
10. What are the different methods of starting three phase induction motors?
11. How many terminals are provided on the terminal box of a squirrel cage induction motor to be started by a star-delta starter?
12. Mention the reasons for most of the three phase induction motors provided with delta connected stator winding?

STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

13. Write the applications of three phase induction motors
14. Mention the merits of DOL starter.
15. Mention the demerits of DOL starter.
16. Why stator resistance starter is rarely used?
17. What are the effects of increasing rotor resistance on starting current and starting torque?
18. How reduced voltage starting of induction motor is achieved?
19. How automatic starters are working in DC Motors?
20. How we start the wound-rotor (slip-ring) motors?
21. Why single phase induction motor is not self-starting?

PART-B

1. Draw a neat schematic diagram of a three point starter and explain its working. (16)
2. Draw a neat schematic diagram of a four point starter and explain its working. (16)
3. Explain with neat circuit diagram, the star-delta starter method of starting squirrel cage induction motor. (16)
4. Explain the typical control circuits for DC Series and Shunt motors (16)
5. Explain the different starting methods of three phase squirrel cage induction motor with neat sketches. (16)
6. Explain the different starting methods of DC motors. (16)
7. Explain with neat diagram the starting of three phase slip ring induction motor. (16)
8. Draw and explain the push-button operated direct-on line starter for three phase induction motor.
9. Draw and explain the manual auto-transformer starter for three phase induction motor. (16)

Problem:

A squirrel cage induction motor has a short circuit current of 4 times the full load value and has a full load slip of 5%. Determine the suitable auto transformation ratio if the supply line current is not to exceed twice the full load current. Also, express the starting torque in terms of the full load torque. Neglect magnetizing current.

► **Solution**

$$\frac{T_{st}}{T_{fl}} = x^2\left(\frac{I_{sc}}{I_{fl}}\right)^2 \cdot s_{fl}$$

$$\text{supply line current} = x^2 I_{sc}$$

$$I_{sc} = 4\,I_{fl}$$

$$s_{fl} = 0.05$$

$$\text{supply line current} = 2\,I_{fl}$$

$$\therefore \quad 2I_{fl} = x^2\,4I_{fl}$$

$$x = 70.7\%$$

$$\text{and} \quad \frac{T_{st}}{T_{fl}} = (0.707)^2\left(\frac{4I_{fl}}{I_{fl}}\right)^2 (0.05) = 0.4$$

Problem:

Calculate the percentage tapping required in an auto-transformer used for squirrel cage induction motor to start the motor against of full load torque. The short circuit current on normal voltage is 5 times the full load current and full load slip is 5%.

DOWNLOADED FROM STUCOR APP STUCOR APP

DOWNLOADED FROM STUCOR APP

Solution

$$s_{fl} = 0.05$$

$$\frac{I_{sc}}{I_{fl}} = 5$$

$$\frac{T_{st}}{T_{fl}} = \frac{1}{2}$$

$$\frac{T_{st}}{T_{fl}} = x^2 \left(\frac{I_{sc}}{I_{fl}}\right)^2 s_{fl}$$

$$\frac{1}{2} = x^2 \times 5^2 \times 0.05$$

$$\therefore \quad x = \text{\%tapping required} = 0.632 \text{ or } 63.2\%$$

Problem:

A 3ϕ induction motor is designed to run at 5% slip on full load. If motor draws 6 times the full load current at starting at the rated voltage, estimate the ratio of starting torque to the full load torque.

Solution

$$s_{fl} = 0.05$$

$$I_{st} = 6\, I_{fl}$$

$$\therefore \quad \frac{T_{st}}{T_{fl}} = \left(\frac{I_{st}}{I_{fl}}\right)^2 \cdot s_{fl}$$

$$\frac{T_{st}}{T_{fl}} = (6)^2 \times 0.05 = 1.8$$

Problem:

A 3 phase, 4 Pole, 50Hz induction motor takes 50Amps at full load speed of 1450 rpm and develops a torque of 175 N-m. The starting current at rated voltage is 325 Amps. Calculate the starting torque? If a star-delta starter is used, calculate the starting current?

Solution

For direct starting

$$\frac{T_{st}}{T_{fl}} = \left(\frac{I_{sc}}{I_{fl}}\right)^2 \cdot s_{fl}$$

$$I_{sc} = I_{st} = 325 \text{ A}$$

$$I_{fl} = 50 \text{ A}$$

$$s_{fl} = \frac{1500 - 1450}{1500} = 0.033$$

$$T_{fl} = 175 \text{ N} - \text{m}$$

$$\therefore \quad T_{st} = \left(\frac{325}{50}\right)^2 \cdot (0.033)(175)$$

$$= 243.99 \text{ N} - \text{m.}$$

When start-delta starter is used,

$$\text{Starting current} = \frac{1}{3} \times \text{starting current with DOL starting}$$

$$= \frac{1}{3} \times 325$$

$$= 108.33 \text{ Amps.}$$

STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

Problem:

Calculate the starting torque of a 3 phase induction motor in terms of full load torque when started by means of (a) start-delta starter (b) and autotransformer with 60% tapping. The short circuit current of the motor is 6 times the full load current and full load slip is 6%.

► **Solution**

a. Using star-delta starter

$$\frac{T_{st}}{T_{fl}} = \frac{1}{3}\left(\frac{I_{sc}}{I_{fl}}\right)^2 s_{fl}$$
$$= \frac{1}{3}(6)^2(0.06)$$
$$= 0.72$$
$$T_{st} = 72\%\ T_{fl}$$

b. Using auto-transformer with 60% tapping

$$k = 0.6$$
$$k^2 = 0.36$$
$$\frac{T_{st}}{T_{fl}} = k^2\left(\frac{I_{sc}}{I_{fl}}\right)^2 s_{fl}$$
$$= (0.36)(6)^2(0.06)$$
$$= 0.78$$
$$T_{st} = 78\%\ T_{fl}$$

Problem:

Calculate the ratio of starting to full load current, if the motor is provided with a star-delta starter. Ignore magnetizing current. The other data are: 10 kW rating, 400V, 3ϕ motor has full load efficiency is 90% and power factor is 0.8 lagging. The blocked rotor line current is 40A at 200V.

► **Solution**

Blocked rotor current with full voltage is

$$I_{sc} = 40 \times \frac{400}{200} = 80\text{ A}$$

From
$$\sqrt{3}\times 400\times I_{fl}\times 0.8 = \frac{10000}{0.9}$$
$$I_{fl} = 20.05\text{ A}$$

For the use of star-delta starter,

$$I_{st} = \frac{I_{sc}}{\sqrt{3}} = \frac{80}{\sqrt{3}} = 46.18\text{ A}$$

Therefore,
$$\frac{I_{st}}{I_{fl}} = \frac{46.18}{20.05} = 2.3$$

STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

PANIMALAR ENGINEERING COLLGE

DEPARTMENT OF MECHANICAL ENGINEERING

II YEAR / III SEMESTER

ELECTRICAL DRIVES AND CONTROL

UNIT - IV

CONVENTIONAL AND SOLID STATE SPEED CONTROL OF DC DRIVES

STUCOR APP

DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

Conventional Speed Control of DC Motors:

The nature of the speed control requirement for an industrial drive depends upon its type. Some drives may require continuous variation of speed for the whole of the range i.e from zero to full speed, or over a portion of this range, while others may require two or more fixed speeds. Some machines may require a creeping speed for adjusting or setting up the work. For most of the drives, however, a control of speed is within the range of ±20% may be suitable.

Factors Controlling Motor Speed

The speed of a d.c. motor is given by: $N \propto \frac{E_b}{\phi} \propto \frac{V - I_a R}{\phi}$ .... (1)

where $R = R_a$ for shunt motor

$= R_a + R_{se}$ for series motor

From exp. (i), it is clear that there are three main methods of controlling the speed of a dc motor,

(i) By varying the flux per pole (ϕ). This is known as flux control method.

(ii) By varying the resistance (R) in the armature circuit. This is known as armature control method.

(iii) By varying the applied voltage V. This is known as voltage control method.

These methods as applied to shunt, series and compound motors.

Field Control Method

Field control is the most common method. In this method speed can be varied above the rated or base speed of the motor. The speed is inversely proportional to the field current. In this method of speed control back emf kept constant and varying field current so, flux can be varied and hence the speed can be varied.

$$N \propto \frac{1}{\phi} \quad \text{or} \quad N \propto \frac{1}{I_f} \qquad (\because \ \phi \propto I_f)$$

The advantages of this method are:

1. Good working efficiency
2. Accurate speed control
3. Speed control can be performed effectively even at light loads
4. Inexpensive
5. Provides smooth and stepless control of speed
6. Very less losses
7. Speeds above rated speed an be obtained by this method
8. Since voltage across the motor remains constant, it continues to deliver constant output. This characteristics, makes this method more suitable for fixed output loads.

The drawbacks of this method are listed below:

1. Inability to obtain speeds below the basic speed.
2. Instability at high speeds because of-armature reaction.
3. The highest speed is limited electrically by the effects of armature reaction under weak field conditions in causing motor instability and poor commutation. There is possible commutator damage at high speeds.

Armature Rheostatic Control

This method consists of obtaining reduced speeds by including external series resistance in the armature circuit. It can be used with series, shunt and compound motor. This method is used when speeds below the no load speed is required. It is common method of speed control for series motors and is analogous in action to wound rotor induction motor control by series rotor resistance. In this method of speed control flux or field kept constant and the armature resistance is varied.

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

Advantages

1. Ability to achieve speeds below basic speed.
2. Simplicity and ease of connection.
3. The possibility of combining the functions of motor starting with speed control.

Disadvantages

1. Speed changes with every change in load, because speed variations depend not only on controlling resistance but on load current also. This double dependence makes it impossible to keep the speed sensibly constant on fastly changing loads.
2. Large amount of power is wasted in the controller resistance. Loss of power is directly proportional to the reduction in speed. So, efficiency is decreased.
3. Maximum power developed is diminished in the same ratio as speed.
4. It needs expensive arrangement for dissipation of heat produced in the controller resistance.
5. It gives speeds below the normal, not above it, because armature voltage can be decreased (not increased) by the controller resistance.
6. Poor speed regulation for any given no load speed setting.
7. Difficulty in obtaining stepless control of speed in high power ratings.

Speed control of DC Series Motor

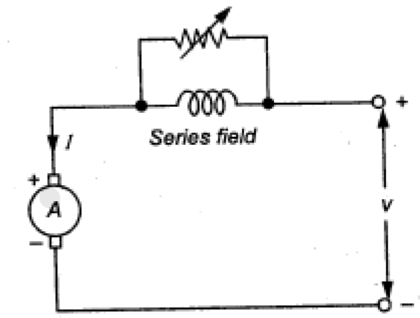
1. Field control method
   a. Armature diverter
   b. Field diverter
   c. Grouping of field coils (Series and Parallel Connection)
   d. Tapped field control
   e. Series – Parallel control
2. Armature Resistance or Rheostatic control
3. Armature voltage control

Field or Flux control methods

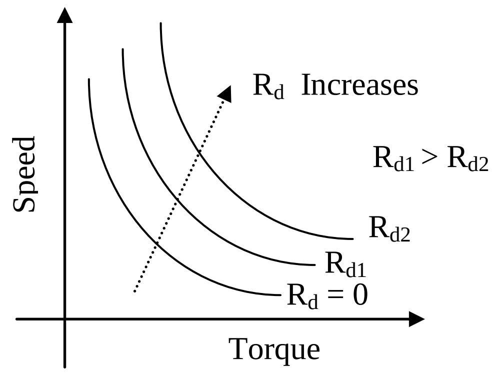
a. Field diverter control

In this method, a variable resistance (called field diverter) is connected in parallel with series field winding as shown in Fig. Its effect is to shunt some portion of the line current from the series field winding, thus weakening the field and increasing the speed ($N \propto 1/\phi$). The lowest speed obtainable is that corresponding to zero current in the diverter (i.e., diverter is open). Obviously, the lowest speed obtainable is the normal speed of the motor. Consequently, this method can only provide speeds above the normal speed. The series field diverter method is often employed in traction work. (R_d – diverter resistance)

$$N \propto \frac{1}{\phi} \quad \text{or} \quad N \propto \frac{1}{I_f} \qquad (\because\ \phi \propto I_f) \qquad (R_d \uparrow,\ I_f \downarrow),\ \ (\phi \downarrow,\ N \uparrow)$$



Circuit diagram



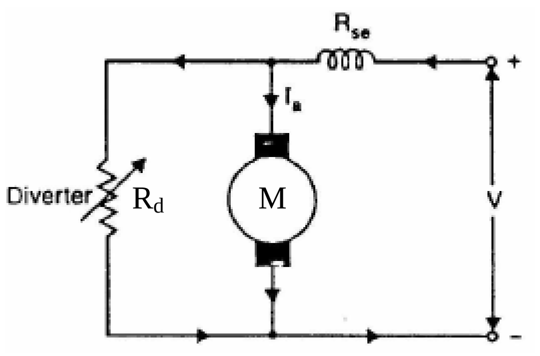
Speed - Torque characteristics

DOWNLOADED FROM STUCOR APP
STUCOR APP

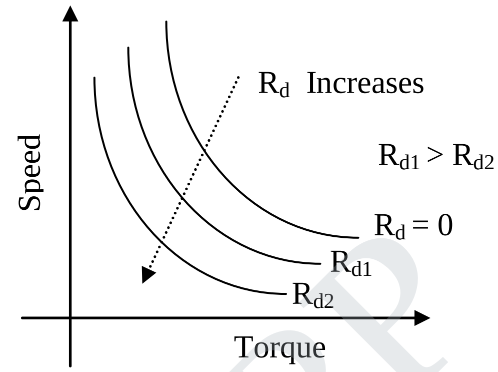
DOWNLOADED FROM STUCOR APP

b. Armature diverter control

In order to obtain speeds below the normal speed, a variable resistance (called armature diverter) is connected in parallel with the armature as shown in Fig. The diverter shunts some of the line current, thus reducing the armature current. Now for a given load, if I_a is decreased, the flux ϕ must increase ($\because\ T \propto \phi I_a$). Since, $N \propto 1/\phi$ the motor speed is decreased. By adjusting the armature diverter, any speed lower than the normal speed can be obtained.



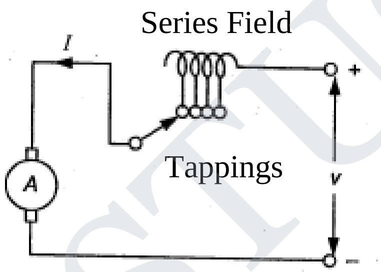
Circuit diagram



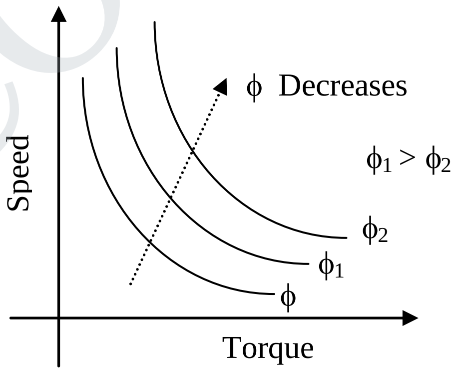
Speed - Torque characteristics

c. Tapped field control.

In this method, the flux is reduced (and hence speed is increased) by decreasing the number of turns of the series field winding as shown in Fig. The switch S can short circuit any part of the field winding, thus decreasing the flux and raising the speed. With full turns of the field winding, the motor runs at normal speed and as the field turns are cut out, speeds higher than normal speed are achieved. This method is often employed in electric traction.



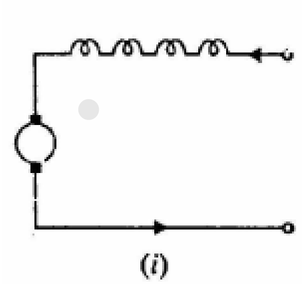
Circuit diagram



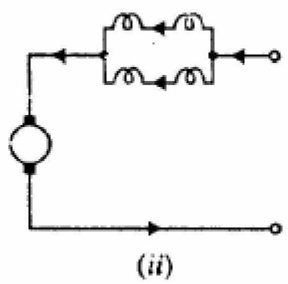
Speed - Torque characteristics

d. Series – Parallel grouping of field coils.

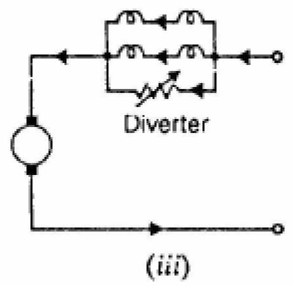
This method is usually employed in the case of fan motors. By regrouping the field coils as shown in Fig. several fixed speeds can be obtained.



Series field coils



Series – Parallel field coils



Series – Parallel field coils with diverter

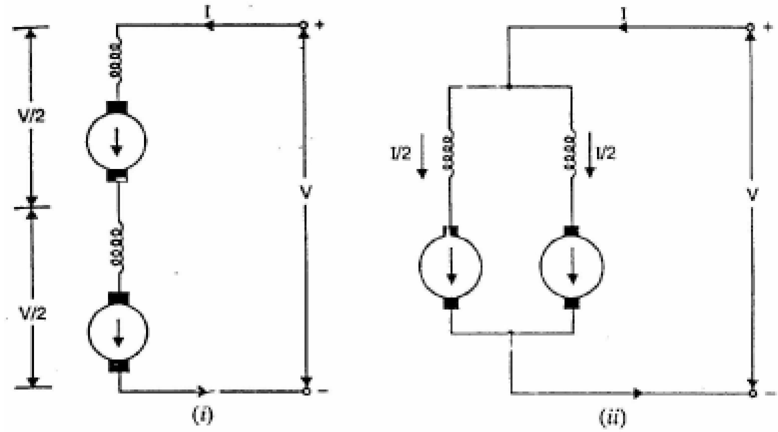
DOWNLOADED FROM STUCOR APP STUCOR APP

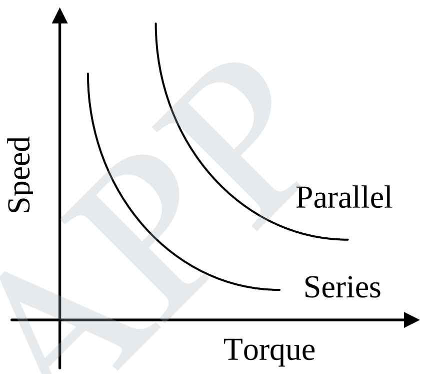
DOWNLOADED FROM STUCOR APP

Series-Parallel Control

Another method used for the speed control of d.c. series motors is the series parallel method. In this system which is widely used in traction system, two (or more) similar d.c. series motors are mechanically coupled to the same load.

When the motors are connected in series [See Fig. (i)], each motor armature will receive one-half the normal voltage. Therefore, the speed will be low. When the motors are connected in parallel, each motor armature receives the normal voltage and the speed is high [See Fig. (ii)]. Thus we can obtain two speeds. Note that for the same load on the pair of motors, the system would run approximately four times the speed when the machines are in parallel as when they are in series.

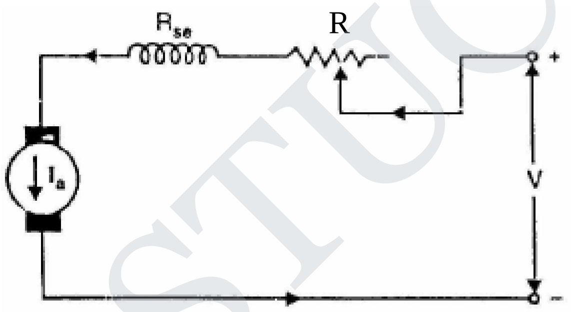


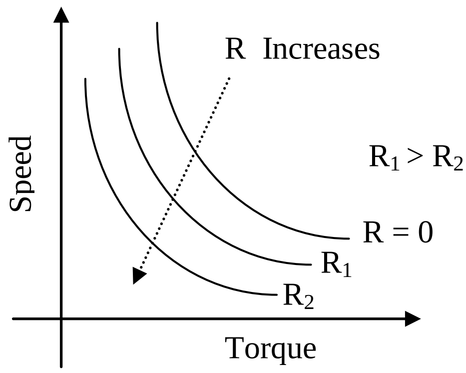


Circuit diagrams (i) Series Connection (ii) Parallel Connection Speed - Torque characteristics

2. Armature Resistance Control

In this method, a variable resistance is directly connected in series with the supply to the complete motor as shown in Fig. This reduces the voltage available across the armature and hence the speed falls.





Circuit diagram Speed - Torque characteristics

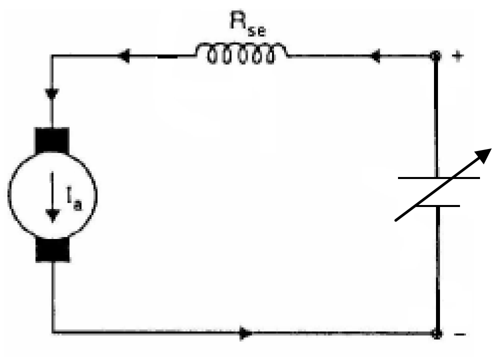
By changing the value of variable resistance, any speed below the normal speed can be obtained. This is the most common method employed to control the speed of d.c. series motors. Although this method has poor speed regulation, this has no significance for series motors because they are used in varying speed applications. The loss of power in the series resistance for many applications of series motors is not too serious since in these applications, the control is utilized for a large portion of the time for reducing the speed under light-load conditions and is only used intermittently when the motor is carrying full-load

3. Armature Voltage Control

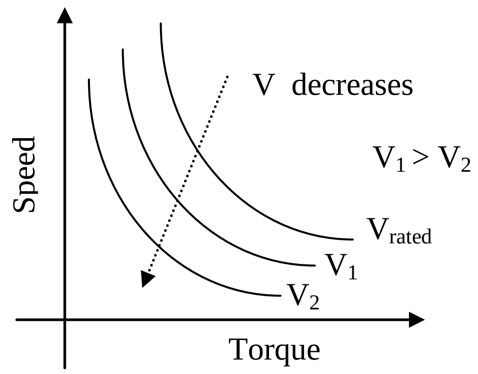
In this method voltage applied to the motor is varied by suitable arrangement and motor speed is decreases as shown in fig.

DOWNLOADED FROM STUCOR APP STUCOR APP

DOWNLOADED FROM STUCOR APP



Circuit diagram



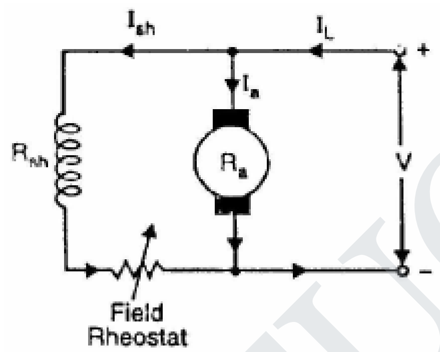
Speed - Torque characteristics

Speed control of DC Shunt Motor

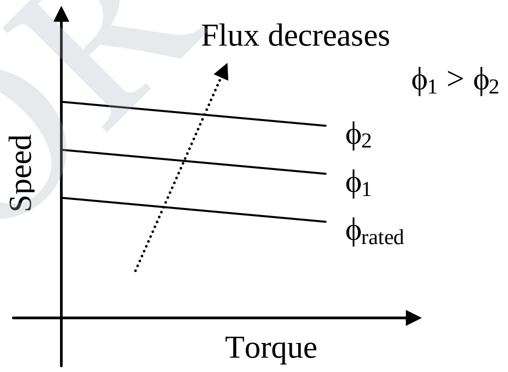
The speed of a shunt motor can be changed by (i) flux control method (ii) armature control method (iii) voltage control method. The first method (i.e. flux control method) is frequently used because it is simple and inexpensive.

1. Flux control method

It is based on the fact that by varying the flux f, the motor speed ($N \propto 1/\phi$) can be changed and hence the name flux control method. In this method, a variable resistance (known as shunt field rheostat) is placed in series with shunt field winding as shown in Fig.



Circuit diagram



Speed - Torque characteristics

The shunt field rheostat reduces the shunt field current I_{sh} and hence the flux ϕ. Therefore, we can only raise the speed of the motor above the normal speed (See Fig.). Generally, this method permits to increase the speed in the ratio 3:1. Wider speed ranges tend to produce instability and poor commutation.

Advantages

(i) This is an easy and convenient method.

(ii) It is an inexpensive method since very little power is wasted in the shunt field rheostat due to relatively small value of I_{sh}.

(iii) The speed control exercised by this method is independent of load on the machine.

Disadvantages

(i) Only speeds higher than the normal speed can be obtained since the total field circuit resistance cannot be reduced below R_{sh} - the shunt field winding resistance.

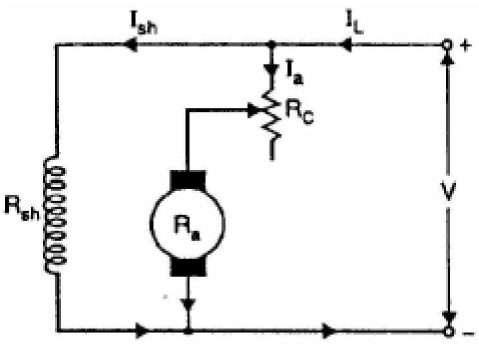
(ii) There is a limit to the maximum speed obtainable by this method. It is because if the flux is too much weakened, commutation becomes poorer.

DOWNLOADED FROM STUCOR APP
STUCOR APP

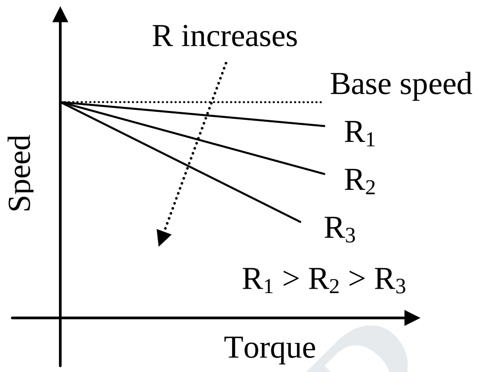
DOWNLOADED FROM STUCOR APP

2. Armature control method

This method is based on the fact that by varying the voltage available across the armature, the back e.m.f and hence the speed of the motor can be changed. This is done by inserting a variable resistance R_{ex} in series with the armature as shown in Fig.



Circuit diagram



Speed - Torque characteristics

$N \propto V - I_a(R_a + R_{ex})$ where R_{ex} = external resistance or R_c = controller resistance

Due to voltage drop in the controller resistance, the back e.m.f. (E_b) is decreased. Since, $N \propto E_b$ the speed of the motor is reduced. The highest speed obtainable is that corresponding to R_c = 0 i.e., normal speed. Hence, this method can only provide speeds below the normal speed (See Fig.).

Advantages

i. Easy and smooth speed control below the base speed is possible
ii. The rheostat in the armature act as a. starter during the starting. So the high current during starting can be avoided.

Disadvantages

(i) A large amount of power is wasted in the controller resistance since it carries full armature current I_a.
(ii) The speed varies widely with load since the speed depends upon the voltage drop in the controller resistance and hence on the armature current demanded by the load.
(iii) The output and efficiency of the motor are reduced.
(iv) This method results in poor speed regulation.

Due to above disadvantages, this method is seldom used to control tie speed of shunt motors.

Note. The armature control method is a very common method for the speed control of d.c. series motors. The disadvantage of poor speed regulation is not important in a series motor which is used only where varying speed service is required.

3. Voltage control method

In this method, the voltage source supplying the field current is different from that which supplies the armature. This method avoids the disadvantages of poor speed regulation and low efficiency as in armature control method. However, it is quite expensive. Therefore, this method of speed control is employed for large size motors where efficiency is of great importance.

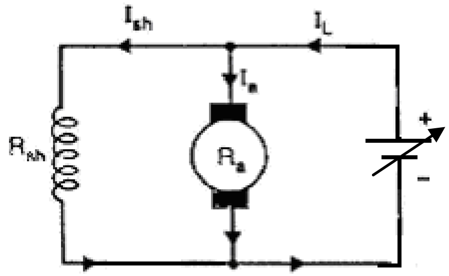
1. Multiple voltage control.

In this method, the shunt field of the motor is connected permanently across a-fixed voltage source. The armature can be connected across several different voltages through suitable switchgear. In this way, voltage applied across the armature can be changed. The speed will be approximately

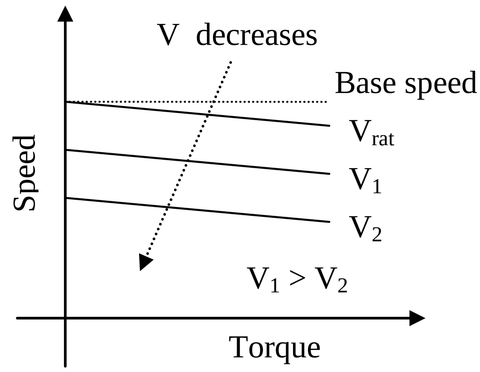
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

proportional to the voltage applied across the armature. Intermediate speeds can be obtained by means of a shunt field regulator.



Circuit diagram

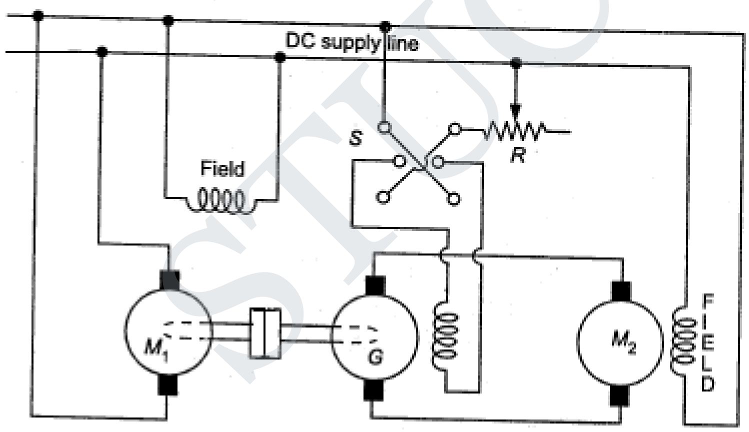


Speed - Torque characteristics

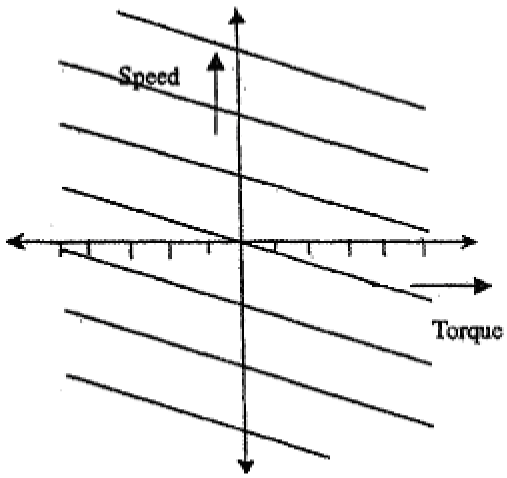
2. Ward-Leonard Speed Control system.

In this method, it possible to control the speed of a dc motor by simply connecting its armature to a variable voltage source. This method of speed control is known as the **Ward-Leonard method.**

The adjustable voltage for the armature is obtained from an adjustable voltage generator while the field circuit is supplied from a separate source. This is illustrated in Fig. The armature of the shunt motor M_2 (whose speed is to be controlled, i.e., main motor) is connected directly to a d.c. generator G driven by a constant-speed d.c. motor M_1. The field of the shunt motor is supplied from a constant-voltage exciter E. The field of the generator G is also supplied from the dc bus. The voltage of the generator G can be varied by means of its field regulator R. By reversing the field current of generator G by switch S, the voltage applied to the motor may be reversed. Sometimes, a field regulator is included in the field circuit of shunt motor M_1 for additional speed adjustment. With this method, the motor may be operated at any speed upto its maximum speed.



Ward Leonard Schematic diagram



Speed - Torque characteristics

The motor M_1 runs at an approximately constant speed, the output voltage of G is directly fed to the main motor M_2. The output voltage of the generator can be varied from zero to its maximum value by varying field regulator of the generator. If the field current of generator G is reversed by means of reversing the switch S, generated voltage can be reversed and hence the direction of rotation of main motor M_2 is reversed. Modern installations SCR modules used for variable dc output voltage from AC mains through a transformer. This arrangement is costlier, neat and relatively free from maintenance problems. It is also easily adapted to feedback schemes for automatic control of speed.

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

Advantages:

1. Range of speed control from standstill to high speeds in either direction.
2. Rapid and instant reversal without excessive high armature currents.
3. Starting without the necessity of series armature resistance.
4. Stepless and smooth control in either direction.
5. Extremely good speed regulation at any speed.
6. Regenerative braking is possible.

Disadvantages:

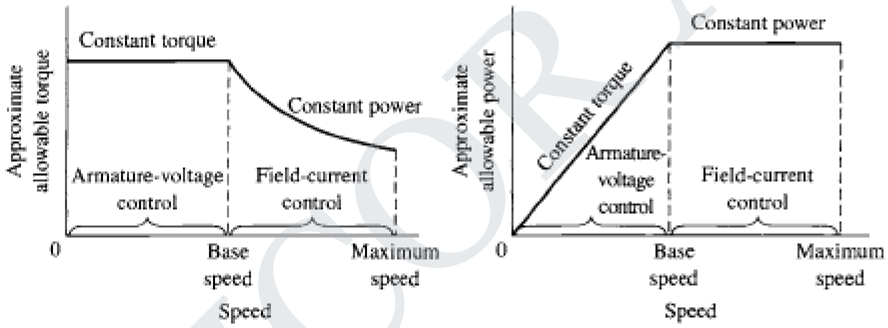
1. This arrangement is costlier, because it requires two extra machines.
2. The overall efficiency of the system is low, especially at light loads.
3. It requires more maintenance.

Applications:

Inspite of high capital cost, this method finds wide applications in industries

l. Steel mills for reversing the rolling mills
2. Seamless tube mills and shears
3. High and medium speed elevators in tall buildings,
4. Hoists and paper machine drives
5. Coillery winders and electric excavator.

Constant speed and Torque operation characteristics of a dc motors



Introduction to Solid State Speed Control of DC Drives

Power Converters:

Static converter is power electronic converters that can conversion of electric power from one to another.

Advantages of Solid State Speed Control or Power Converters

- Higher efficiency
- Higher accuracy and availability
- Highest reliability
- Lowest cost
- Smallest size and Less weight
- Non-rotating or moving mechanical components
- Quick response
- Smooth starting, acceleration, braking and speed control
- Longer life and require less or minimal maintenance (No moving parts)
- Easy and flexibility in operation due to digital control and interface
- Automatic control which improves the production and quality of production
- Regenerative braking is possible

DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

Disadvantages of Solid State Speed Control or Power Converters

- Over load capability is limited
- It produces harmonics which is undesirable
- Harmonics increases motor losses and derating of the motor
- It affects the communication networks or systems

Power electronics Applications:

i. DC Power supply, Un-interruptible power supply,
ii. Power generation and transmission (HVDC),
iii. Electroplating, Welding, Heating, Cooling,
iv. Electronic ballast

Drive applications

i. AC and DC Drives
ii. Electric trains, Electric vehicles,
iii. Air conditioning System,
iv. Pumps, Compressor, Conveyer Belt, etc.,

The speed control of DC drive using solid - state devices such as SCR and solid state circuits such as rectifier and chopper is known as Solid State speed control of DC drives. The SCR is known as thyristor.

Some of the thyristor family power electronic devices are

SCR	-	Silicon Controlled Rectifier
TRIAC	-	Triode AC Switch
BJT	-	Bipolar Junction Transistor
IGBT	-	Insulated Gate Bipolar Junction Transistor
MOSFET	-	Metal Oxide Semiconductor Field Effect Transistor
GTO	-	Gate Turn-Off Thyristor

A thyristor (SCR) is basically a three-junction *PNPN* device that can be represented by *PNP* and *NPN* component transistors connected in back to back mode, as shown in Fig(a). The device blocks voltage in both the forward and reverse directions. When the anode is positive, the device can be triggered into conduction by a short positive gate current pulse, but once the device is conducting, the gate control is lost. A thyristor (SCR) can also be turned on by means of excessive anode voltage, high *dv/dt*, a rise in junction temperature, or light shining on the junctions.

The *V-I* characteristics of the device are shown in Fig(b). With gate current $I_G = 0$, the device blocks voltage in the forward direction, and only small leakage current flows. With $I_G = I_{G3}$, the entire forward blocking voltage is removed, and the device acts as a diode as shown in the figure. The latching current is the minimum anode current required to turn on the device successfully, and holding current is the minimum on-current required to keep the device on without which the device will go to the forward blocking mode.

 STUCOR APP
DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP STUCOR APP

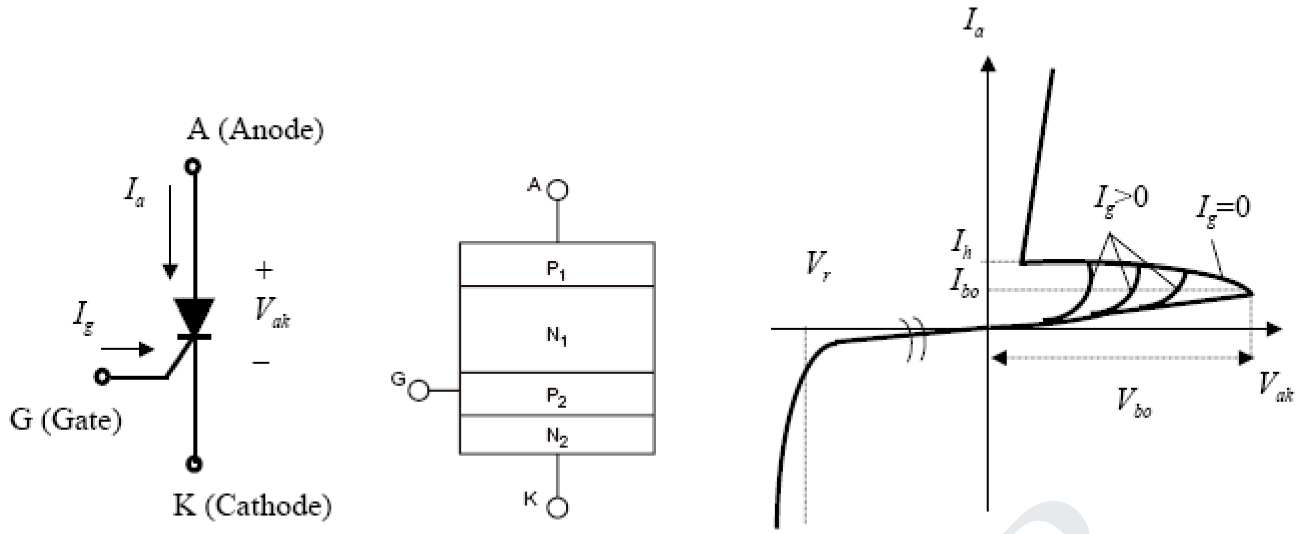
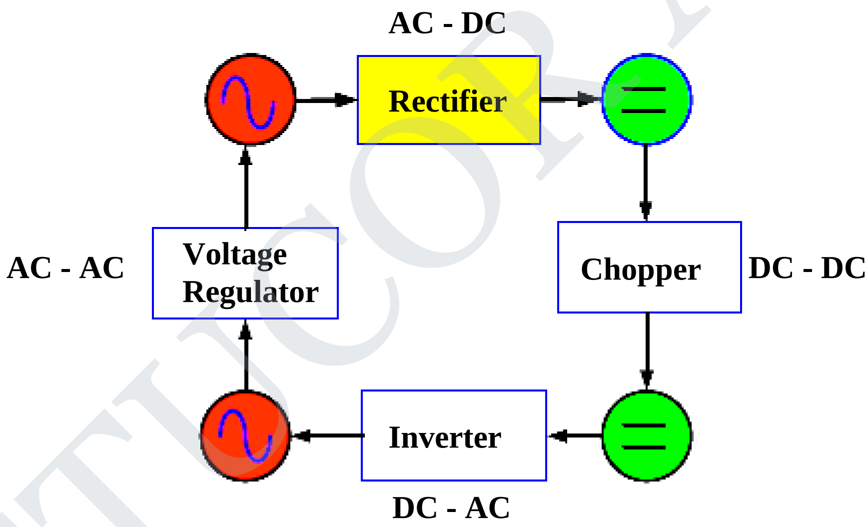


Fig. (a) Symbol (b). Structure (c). V-I Characteristics

Power Electronic Converters

The main function of converters is to transform the waveform of a power sources to that the required by an electric motor in order to achieve the desired performance.



Block Diagram of Power Electronic Converters

Types of converters:

The power semiconductor devices or power electronic converter fall generally into six categories:

- AC to DC Converter (Controlled Rectifier)
- DC to DC Converter (DC Chopper)
- AC to AC Converter (AC voltage regulator)
- DC to AC Converter (Inverter)
- Static Switches

2. AC to DC Converter or Rectifier:

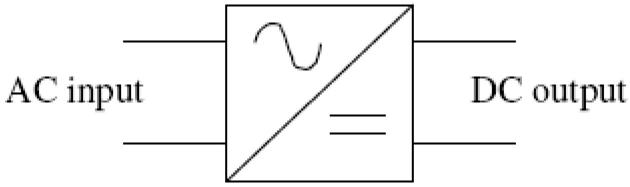
AC to DC converter circuit can convert AC voltage into a DC voltage. The DC output voltage can be controlled by varying the firing angle of the thyristors. The output of this converter is variable magnitude of dc voltage from the single or three-phase ac voltage. The types of rectifiers are,

STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

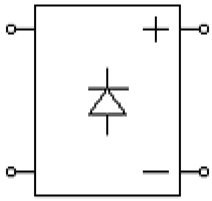
DOWNLOADED FROM STUCOR APP

i. **Uncontrolled Rectifier or Diode Rectifier**
It is fed from single-phase or three-phase ac mains supply and provide fixed dc output for motor drive.

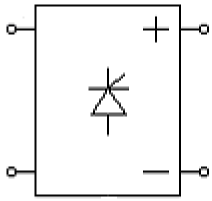
ii. **Controlled Rectifier**
It is fed from single-phase or three-phase ac mains supply and provide variable dc output for motor drive.



Block diagram of Rectifier



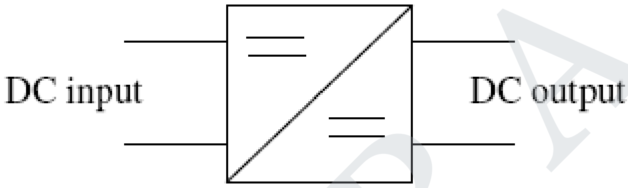
Uncontrolled (Diode) Rectifier



Controlled (SCR) Rectifier

3. DC to DC Converter or DC Chopper:

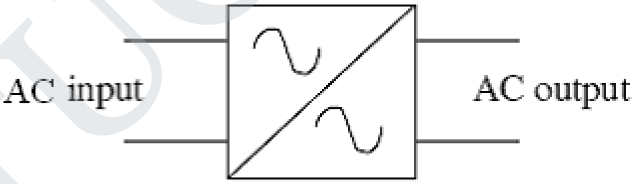
These converters can converter a fixed DC input voltage into variable DC voltage or vice versa. The DC output voltage is controlled by varying of duty cycle. The output of this converter is variable magnitude of dc voltage from the fixed dc voltage.



Block diagram of DC Chopper

4. AC to AC Converter or AC Voltage controller or AC Chopper:

This converter can convert from a fixed ac input voltage into variable AC output voltage. The output voltage is controlled by varying firing angle of TRIAC. These type converters are known as AC voltage regulator. The output of this converter is frequency and ac variable voltage, the input is constant frequency and ac voltage



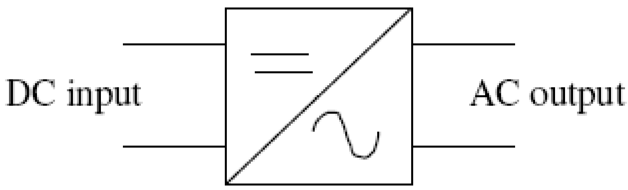
Block diagram of AC Chopper or Voltage controller

5. DC to AC Converter or Inverter:

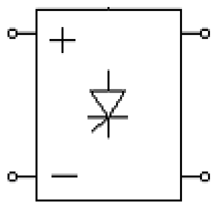
This module converts dc output of battery or rectified ac source to provide variable ac voltages and currents at desired frequency and phase.

Cycloconverter or Frequency Changer or Converter:

Directly convert fixed frequency ac voltage/current to variable voltage/current of variable frequency for driving ac machines.



Block diagram of Inverter



Inverter

DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

- For low cost, low power applications (up to about 10kW) a single phase rectifiers can be used. Low power, economical drives can also be constructed using single phase half-wave rectifier with free-wheeling diodes.
- For higher power drives (up to MW range), three-phase supply with three-phase rectifier is normally employed.
- For low to medium power DC supplied drives (such as battery), a chopper (DC-DC converter) is used.
- It is also common to find in some applications (especially locomotives), choppers are used in conjunction with uncontrolled bridge rectifiers. They are normally rated at medium power (100s of kW)

Speed Control of DC Series Motor using Controlled Rectifier (Phase Control)

SCR "phase-angle controlled" drive

- By changing the firing angle, variable DC output voltage can be obtained.
- Single phase (low power) and three phase (high and very high power) supply can be used
- The line current is unidirectional, but the output voltage can reverse polarity. Hence 2- quadrant operation is inherently possible.
- 4-quadrant is also possible using "two sets" of controlled rectifiers (i.e. Dual converters).

The phase controlled rectifiers are broadly classified into

a. Single phase controlled rectifiers

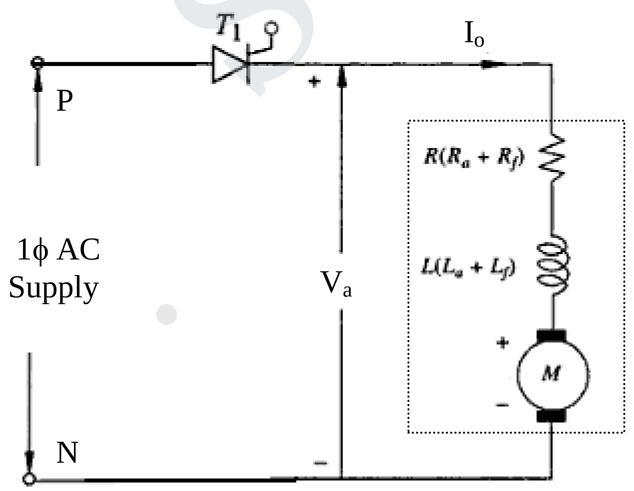
b. Three phase controlled rectifiers

These controllers further divided into

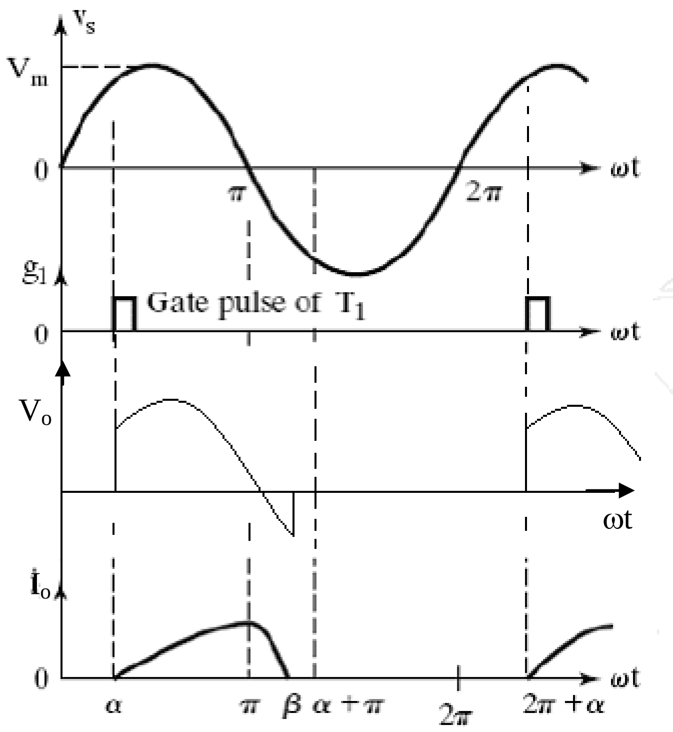
1. Half wave controlled rectifiers
2. Semi controlled rectifiers
3. Fully wave controlled rectifiers

1. Half Wave Controlled Rectifier fed DC Series Motor

The schematic circuit diagram of a dc series motor fed from a single phase half wave controlled rectifier shown in fig.



Single phase half controlled rectifier fed Series Motor



Output Voltage, Current and Gate signal wave

DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

As simplicity the firing or gate control circuit of thyristor (SCR) are not shown in fig. The series motors are capable of high starting torque and constant power operation at all speeds. They are used in electric traction, cranes, hoists, lift, etc. The voltage and current wave forms of a series motor fed half controlled rectifier as shown in fig.

The thyrister circuit uses phase commutation and is the single phase half wave rectifier. The gating pulse is applied during the positive half cycle of the anode voltage the thyrister immediately conducts and the supply voltage appears across the load for the remainder of the positive half cycle. At the end of positive half cycle, the thyrister current falls and the supply voltage reverses. This applies reverse bias across the thyrister and turns it off rapidly. The angle by which the thyrister retards the starting of conduction is known as delay angle or firing angle α. If the α is varied from zero to π, it reduces the average d.c output voltage from maximum to zero. The process is known as phase commutation.

The average dc output voltage across armature V_o or V_a is given by

$$V_0 = \frac{1}{T}\int_{\alpha}^{\beta} v_i \, d\omega t = \frac{1}{2\pi}\int_{\alpha}^{\beta} V_m \sin \omega t \, d\omega t = \frac{V_m}{2\pi}\left[-\cos\omega t\right]_{\alpha}^{\beta} \qquad (\because\ v_i = V_m \sin \omega t\ )$$

$$\boxed{V_0 = \frac{V_m}{2\pi}\left(\cos\alpha - \cos\beta\right)}$$

where, V_m – Peak or Maximum voltage

α - Firing angle or Delay angle

β - Conduction angle or Extinction angle

The value of AC voltage becomes zero, when it reaches 180° or it radians. After this point the value of AC I voltage becomes negative and SCR never conducts. The SCR .therefore conducts from α toβ. This angle is known as Conduction angle β. During negative half cycle of input AC supply, the SCR never conducts (i.e. from π to 2π). So the current flowing through the load never changes its direction. Rectified DC voltage is applied across the load.

Advantages:

1. Cost is low because only one thyrister is employed
2. Construction is simple

Disadvantages:

1. Only one quadrant operation and regeneration is not possible
2. The motor current always discontinuous
3. Low average current
4. Torque developed is very small
5. Speed regulation is poor

The discontinuous conduction is the limitation of above circuit. This can be eliminated using free wheeling diode in the circuit.

2. Half Wave Controlled Rectifier fed DC Series Motor with Free Wheeling Diode (FWD)

In the above circuit free wheeling diode is required always due motor loads. It is a one quadrant operation drive. The application above drive is 0.5 kW power level. The free wheeling diode is connected across the motor load to achieve the continuous conduction as shown in fig.

If the load is inductive (i.e motor load) the build of the current is slow at start and decaying inductive current continuous conduction of current after ωt = π, For inductive loads a free wheeling diode is placed across it in the circuit. At the end of the positive half cycle current in inductive load decays by circulating through the free wheeling diode. The decay is affected at its natural time constant.

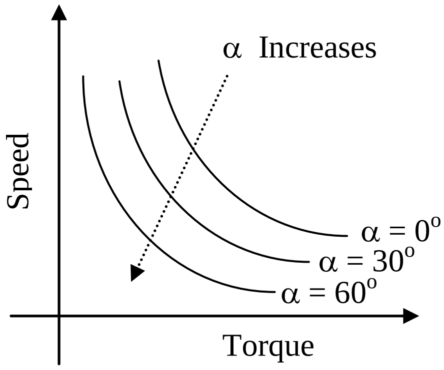
The average dc output voltage across armature V_o or V_a is given by

DOWNLOADED FROM STUCOR APP
STUCOR APP

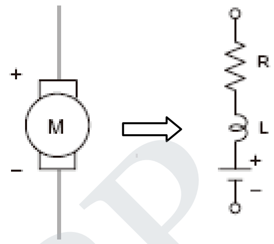
DOWNLOADED FROM STUCOR APP

$$V_0 = \frac{1}{T}\int_{\alpha}^{\pi} v_i \, d\omega t = \frac{1}{2\pi}\int_{\alpha}^{\pi} V_m \sin\omega t \, d\omega t = \frac{V_m}{2\pi}\left[-\cos\omega t\right]_{\alpha}^{\pi} \qquad (\because \; v_i = V_m \sin\omega t)$$

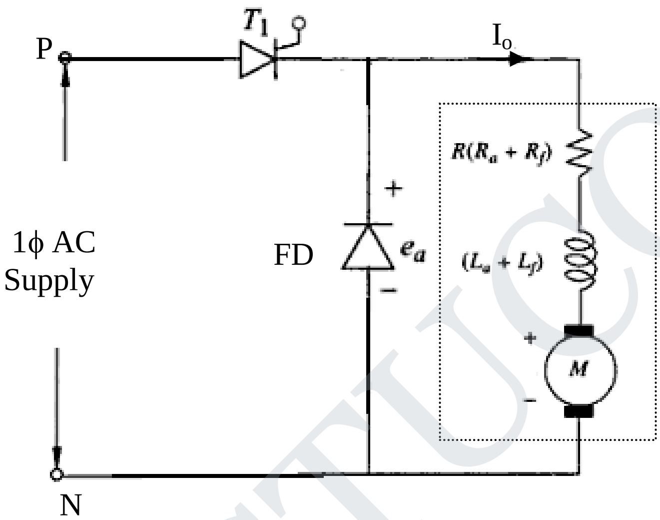
$$\boxed{V_0 = \frac{V_m}{2\pi}(1+\cos\alpha)} \quad \text{for } 0 < \alpha < \pi \qquad \text{where, } V_m - \text{peak or maximum voltage}$$



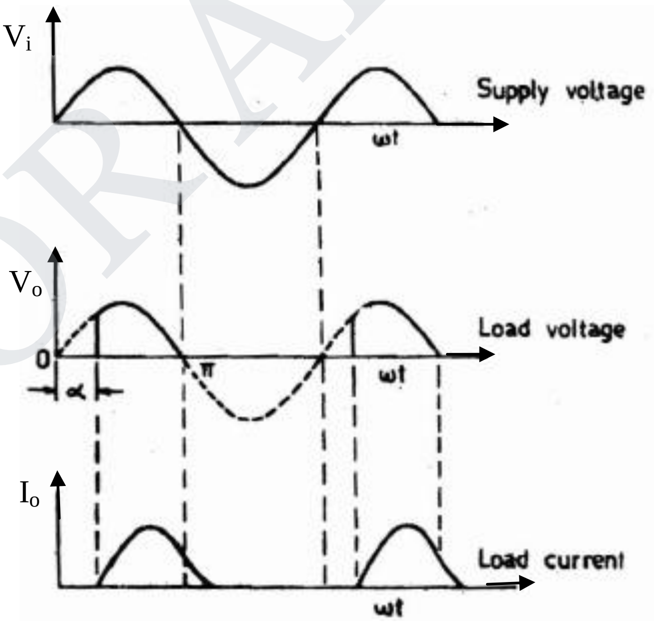
Speed Torque Characteristics for dc Series Motor



Motor Equivalent Circuit



Single phase half controlled rectifier
fed Series Motor with free wheeling diode



Output Voltage, Current and Gate signal wave form

Advantages:

1. It is improving the drive performance.
2. It is improve the power factor.
3. It is provide continuous load current.

3. Single Phase Semi Controlled Rectifier fed DC Series Motor

The single phase semi converter (bridge) fed dc series motor circuit shown in fig. It consists of two thyristors in upper arm and two diodes in the lower arm of the bridge converter which make symmetrical connection. Also the free wheeling diode is connected across motor load which provide better power factor and continuous load current. The output voltage and current wave form are shown in fig. Operation of the circuit explained below

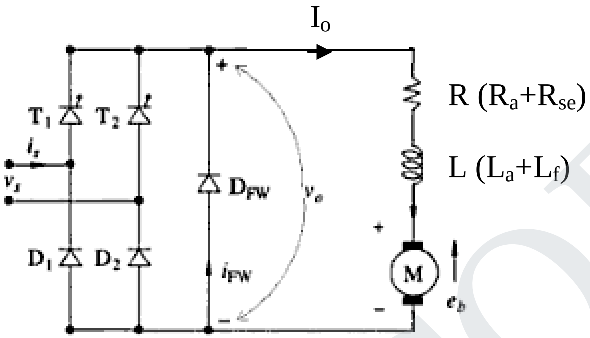
DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

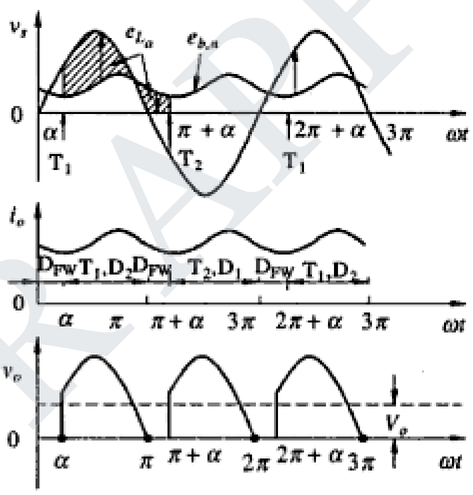
- During positive half cycle of the source, the thyrister T_1 and diode D_2 get forward biased. Thyrister T_1 is triggered (fired) and its starts conduction and diode D_2 is also conducts from α to π. Now inductor stores the energy for this duration.
- Thyristor T_1 and diode D_2 are turned off at the moment of supply voltage crosses zero. For this period free wheeling diode FD or FWD get forward biased which starts conduct to from π to π + α and ensure the continuous load current through the load and voltage across the load is zero.

- During negative half cycle of the source, the thyrister T_2 and diode D_1 get forward biased. Thyrister T_2 is triggered (fired) and its starts conduction and diode D_1 is also conducts from π + α to 2π. Now inductor stores the energy for this duration. Operation is repeats similar to positive half cycle.

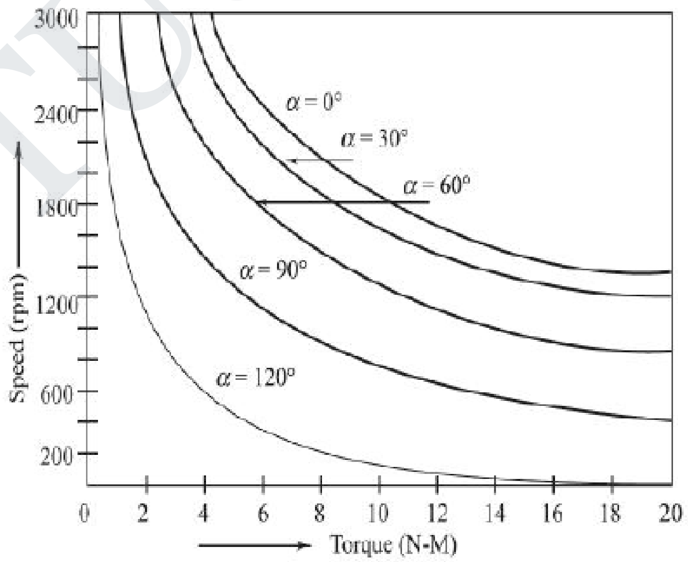
- The free wheeling diode provides power factor improvement and continuous load current.



Single phase Semi controlled rectifier
fed Series Motor with free wheeling diode



Output Voltage, Current and Gate
Signal wave form



Speed Torque Characteristics of dc Series Motor with different firing angles

Average dc output voltage V_o or V_{dc} is given by

$$V_0 = \frac{2}{T}\int_{\alpha}^{\pi} v_i \, d\omega t = \frac{2}{2\pi}\int_{\alpha}^{\pi} V_m \sin\omega t \, d\omega t = \frac{V_m}{\pi}\left[-\cos\omega t\right]_{\alpha}^{\pi} \qquad (\because\ v_i = V_m \sin\omega t\ )$$

DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

$$\boxed{V_0 = \frac{V_m}{\pi}(1+\cos\alpha)}$$ for $0 \le \alpha < \pi$ where, V_m – peak or maximum voltage

3. Single Phase Fully Controlled Rectifier fed DC Series Motor

In this circuit four thyristor are used and connected in bridge form to act as converter and supply d.c. voltage to the load. Compared to the half wave circuit, this circuit has a much improved form factor of the output voltage (rms voltage/average voltage). In this circuit, inversion and regenerative braking is possible.

For continuous conduction, the armature voltage or average dc output voltage is given by

$$V_0 = \frac{1}{T/2}\int_{\alpha}^{\pi+\alpha} v_i \, d\omega t = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin\omega t \, d\omega t = \frac{2V_m}{\pi}\left[-\cos\omega t\right]_{\alpha}^{\pi+\alpha} \qquad (\because\ v_i = V_m \sin\omega t)$$

$$\boxed{V_0 = \frac{2V_m}{\pi}\cos\alpha}$$ for $0 \le \alpha \le \pi$ where, V_m – peak or maximum voltage

Modes of operation

There are two modes of operation

1. Continuous mode conduction
2. Discontinuous mode conduction

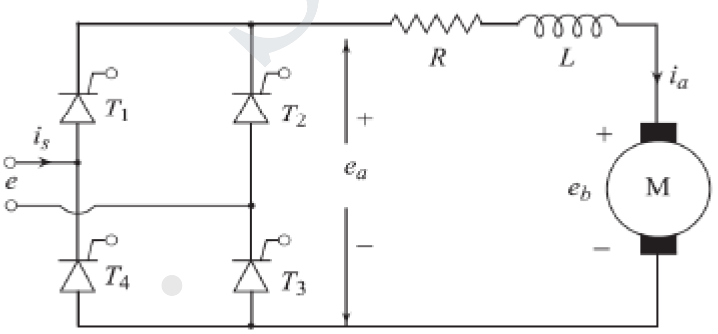
Continuous conduction

During positive half cycle of the supply the thyristor T_1 and T_3 are forward biased and fired simultaneously at $\omega t = \alpha$. Thyristor T_1 and T_3 are conduct from α to $\pi + \alpha$ and motor is connected to supply. At $\omega t = \pi$, output voltage V_a is negative (reverses), but load current in the same direction.

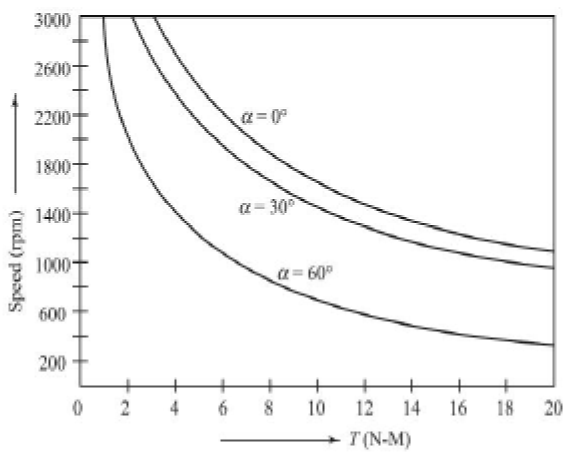
Motor current flow: supply – T_1 – motor – T_2 – supply

During next (-ve) half cycle the thyristor T_2 and T_4 are forward biased and fired simultaneously at $\omega t = \pi + \alpha$, Thyristor T_1 and T_3 are turns OFF due to reverse voltage across them i.e natural or line commutation.

Motor current flow: supply – T_2 – motor – T_4 – supply



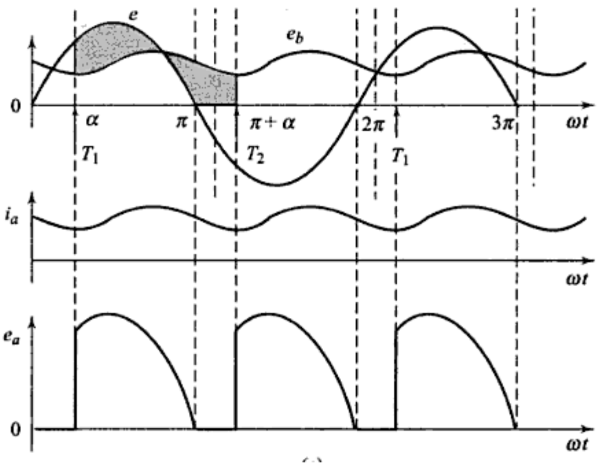
Single Phase Fully Controlled Rectifier fed DC Series Motor



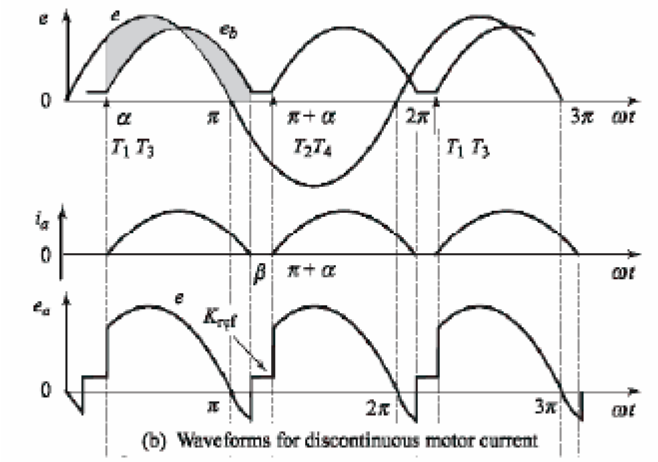
Speed Torque Characteristics

DOWNLOADED FROM STUCOR APP STUCOR APP

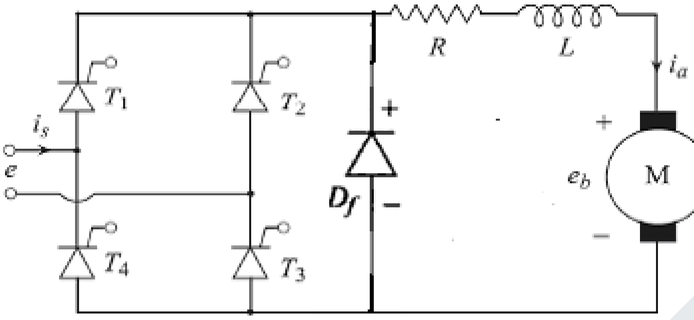
DOWNLOADED FROM STUCOR APP



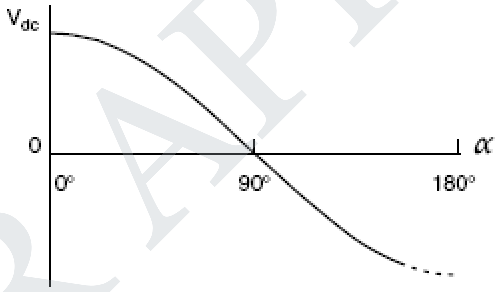
a) Waveform for continuous current



b) Waveform for discontinuous current

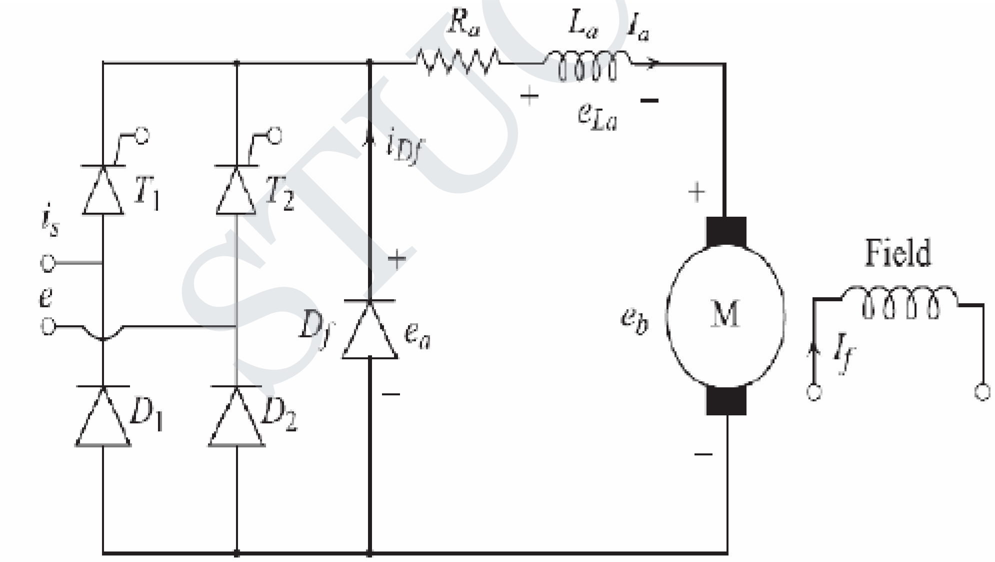


Single Phase Fully Controlled Rectifier fed DC Series Motor with free wheeling diode

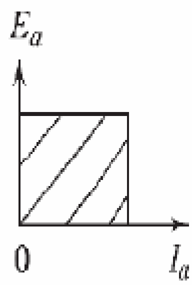


Average d.c. output voltage of fully controlled converter as a function of the firing angle α

Speed Control of DC Shunt Motor using Semi Controlled Rectifier



Single Phase Semi Controlled Rectifier fed DC Separately excited Shun Motor with free wheeling diode

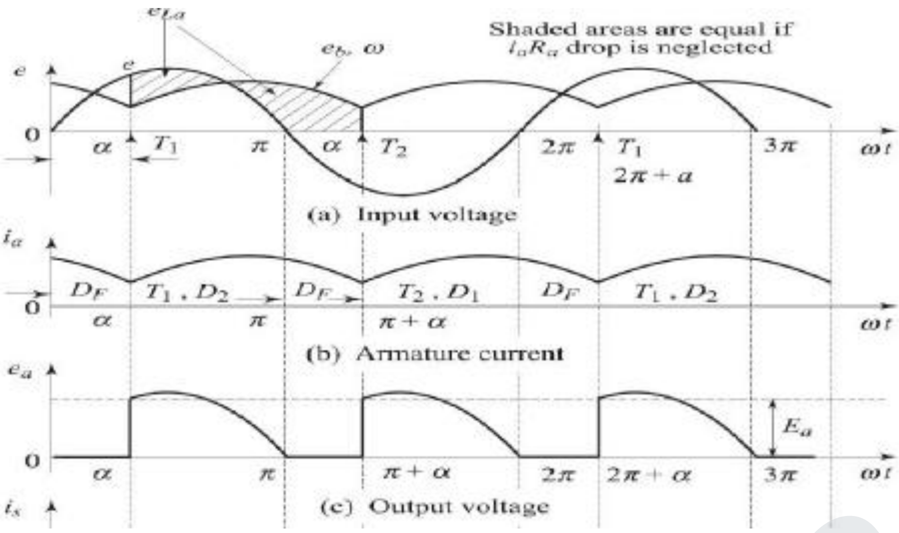


One Quadrant Operation

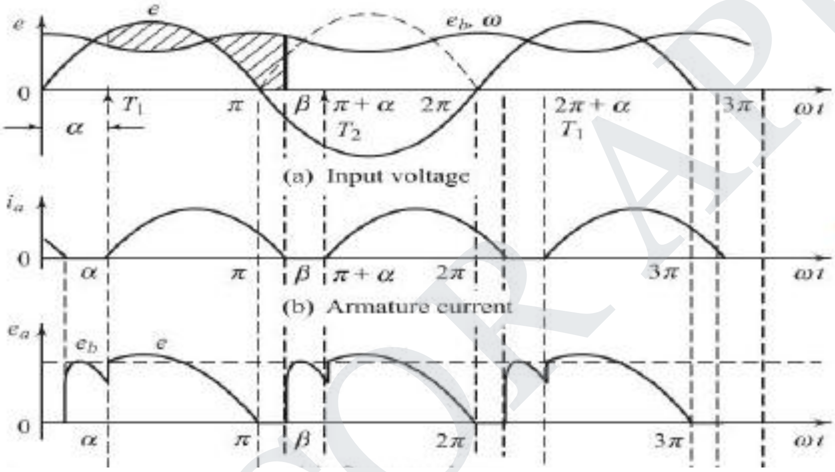
DOWNLOADED FROM STUCOR APP

STUCOR APP

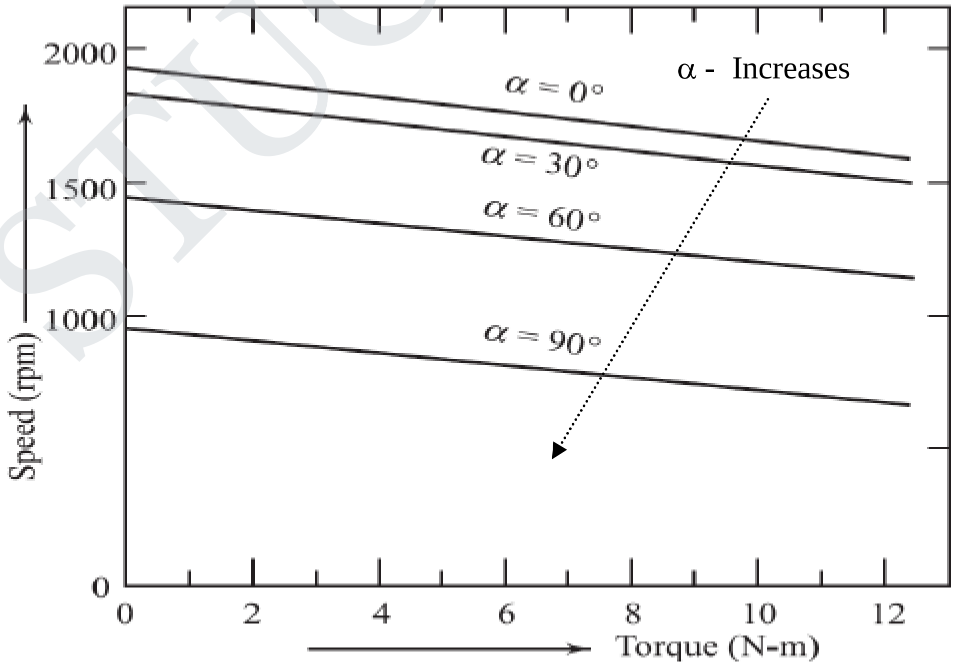
DOWNLOADED FROM STUCOR APP



Continuous Current waveform



Discontinuous wave form



Speed Torque Characteristics of Separately DC Shunt Motor

DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

Speed Control of Separately DC Shunt Motor Using Fully Controlled Rectifier

A fully controlled rectifier fed separately excited dc shunt motor as shown in fig. It is two quadrant converters in which the voltage polarity of output can reverse, but the load current remains same direction.In controlled rectifier, the output DC voltage is controlled by controlling the delay angles (or firing angles) of the SCRs used in the converter.

Average dc output voltage V_o or V_{dc} is given by

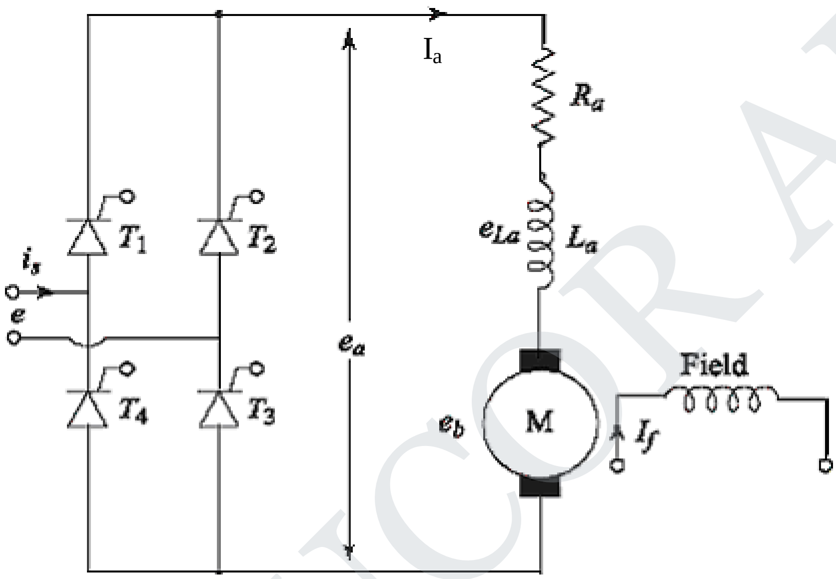
$$V_0 = \frac{1}{T/2}\int_{\alpha}^{\pi+\alpha} v_i \, d\omega t = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin\omega t \, d\omega t = \frac{2V_m}{\pi}\left[-\cos\omega t\right]_{\alpha}^{\pi+\alpha} \qquad (\because \; v_i = V_m \sin\omega t)$$

$$\boxed{V_0 = \frac{2V_m}{\pi}\cos\alpha} \qquad \text{for } 0 \le \alpha \le \pi$$

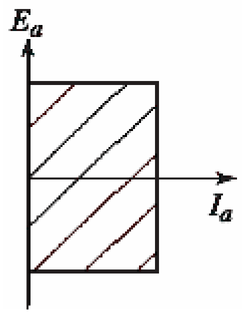
where, V_m – peak or maximum voltage

α - Firing or delay angle

Note that this relation is only valid for continuous current mode. It describes the ‘average’ behavior of the rectifier over a period of the output voltage.



Single Phase Fully Controlled Rectifier fed DC Separately excited Shun Motor with free wheeling diode



Two Quadrant Operation

Continuous Current waveform

DISADVANTAGES OF SINGLE PHASE HALF WAVE CONTROLLED RECTIFIERS

Single phase half wave controlled rectifier gives

- Low dc output voltage.
- Low dc output power and lower efficiency.
- Higher ripple voltage & ripple current.
- Higher ripple factor.
- Low transformer utilization factor.
- The input supply current waveform has a dc component which can result in dc saturation of the transformer core

DOWNLOADED FROM STUCOR APP

STUCOR APP

DOWNLOADED FROM STUCOR APP

CHOPPER-CONTROLLED DC MOTOR DRIVES:

- Chopper DC drives are still widely used in traction applications. A DC-DC converter is connected between a fixed voltage DC source and a DC motor to vary the armature voltage.
- In addition to armature voltage control, a DC chopper can provide regenerative braking of the motor and hence return energy back to the supply.
- This energy saving feature is particularly attractive in transportation systems with frequent stops. Chopper drives are also used in battery fed vehicles.
- When energy storage systems are included, very significant savings in energy are achieved.
- If the supply is non-receptive during regenerative braking, the line voltage would increase and regenerative braking may not be possible. With non-receptive supplies, rheostatic braking is normally used.
- The possible control modes of a DC chopper drive are:
    - Power (acceleration) control
    - Regenerative brake control
    - Rheostatic brake control
    - Combined regenerative and rheostatic brake control

Choppers are of two types

- Step-down choppers
- Step-up choppers.

In step-down choppers, the output voltage will be less than the input voltage whereas in step-up choppers output voltage will be more than the input voltage.

Control Strategies

The average value of output voltage V_o can be controlled by opening and closing the semiconductor switch periodically. The various control strategies for varying duty cycle ex are as follows

Constant Frequency Control or Time Ratio control (TRC)

In this scheme, the on-time T_{on} is varied but chopping frequency f (or chopping period T) is kept constant. Variation of T_{on} means adjustment of pulse width, as such this scheme is also called *pulse width modulation scheme*. This scheme has also been referred to as *time-ratio control* (TRC). Ideally α can be varied from zero to infinity. Therefore output voltage V_o can be varied between zero and source voltage V_s.

Variable Frequency Control

In this scheme, the chopping frequency *f (or* chopping period *T)* is varied and either (i) on-time T_{on} is kept constant or *(ii)* off-time T_{off} is kept constant. This method of controlling is also called frequency-modulation scheme.

STUCOR APP

STUCOR APP STUCOR APP

DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

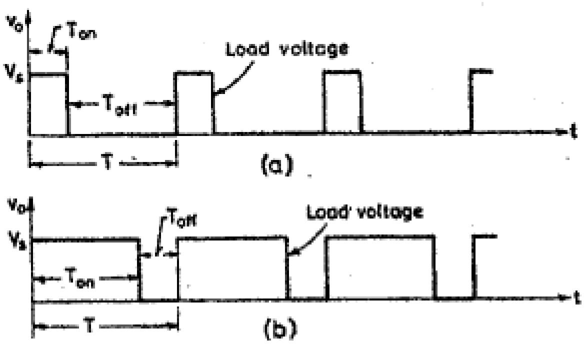


Fig. Pulse width modulation (constant T').

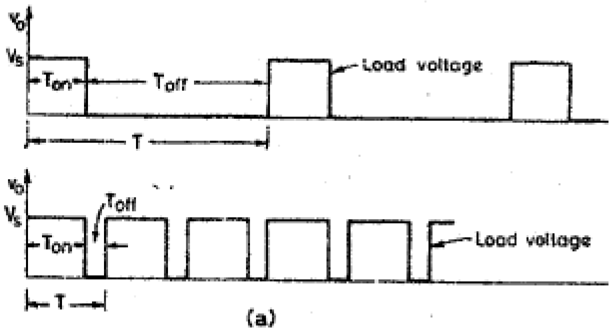
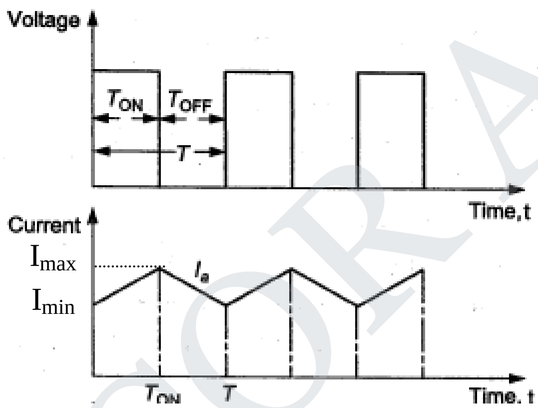


Fig. Frequency modulation (constant T_{on})

Current Limit Control (CLC)

In this method of firing based on the variation of load current limits (i.e. I_{max} and I_{min}). When the motor current reaches the upper limit (I_{max}) the thyristor is turned OFF and when the motor current free wheels and decays to lower limit (I_{min}) the thyristor is again turned ON. This scheme is known as current limit control.



Voltage and current waveforms

PRINCIPLE OF STEP-DOWN CHOPPER

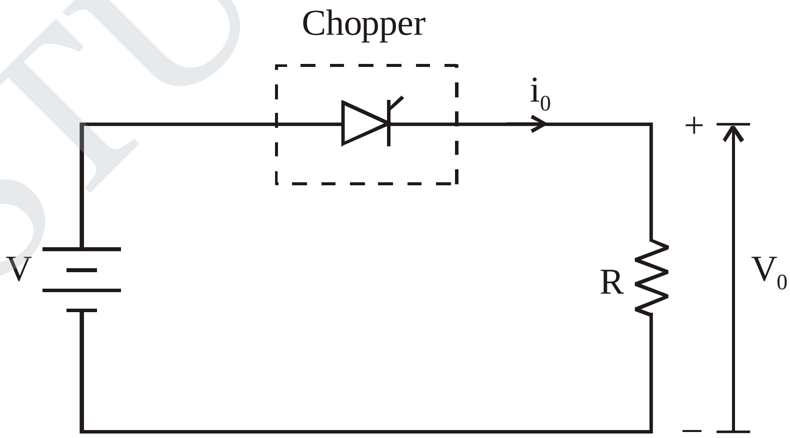


Fig. Step-down Chopper with Resistive Load

Fig. Shows a step-down chopper with resistive load. The thyristor in the circuit acts as a switch. When thyristor is ON, supply voltage appears across the load and when thyristor is OFF, the voltage across the load will be zero. The output voltage and current waveforms are as shown in figure.

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

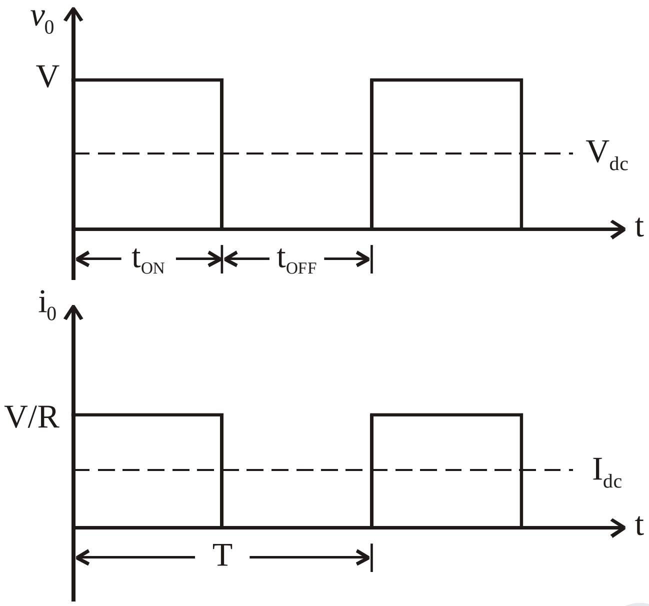


Fig. 2.2: Step-down choppers — output voltage and current waveforms

V_{dc} = average value of output or load voltage

I_{dc} = average value of output or load current

t_{ON} = time interval for which SCR conducts

t_{OFF} = time interval for which SCR is OFF.

$T = t_{ON} + t_{OFF}$ = period of switching or chopping period

$f = \frac{1}{T} =$ frequency of chopper switching or chopping frequency

V_s = Supply voltage

α or δ = Duty cycle or ratio

Average output voltage for step down chopper

$$V_{dc} = \left(\frac{t_{on}}{t_{on} + t_{off}}\right) V_s = \alpha V_s$$

$$V_{dc} = \left(\frac{t_{on}}{T}\right) V_s = \alpha V_s \qquad \text{where } \alpha \text{ or } \delta = \left(\frac{t_{on}}{T}\right)$$

Average output voltage for step up chopper

$$V_{dc} = \frac{V_s}{1 - \delta} \qquad \text{where } \alpha \text{ or } \delta = \left(\frac{t_{on}}{T}\right)$$

CLASSIFICATION OF CHOPPERS

Choppers are classified as follows

- Class A Chopper
- Class B Chopper
- Class C Chopper
- Class D Chopper
- Class E Chopper

DOWNLOADED FROM STUCOR APP

STUCOR APP

DOWNLOADED FROM STUCOR APP

CLASS A CHOPPER

Figure 2.14 shows a *Class A Chopper* circuit with inductive load and free-wheeling diode. When chopper is *ON*, supply voltage *V* is connected across the load i.e., $v_O = V$ and current i_0 flows as shown in figure. When chopper is OFF, v_o = 0 and the load current i_O continues to flow in the same direction through the free wheeling diode. Therefore the average values of output voltage and current i.e., v_O and i_O are always positive. Hence, *Class A Chopper* is a first quadrant chopper (or single quadrant chopper). Figure 2.15 shows output voltage and current waveforms for a continuous load current.

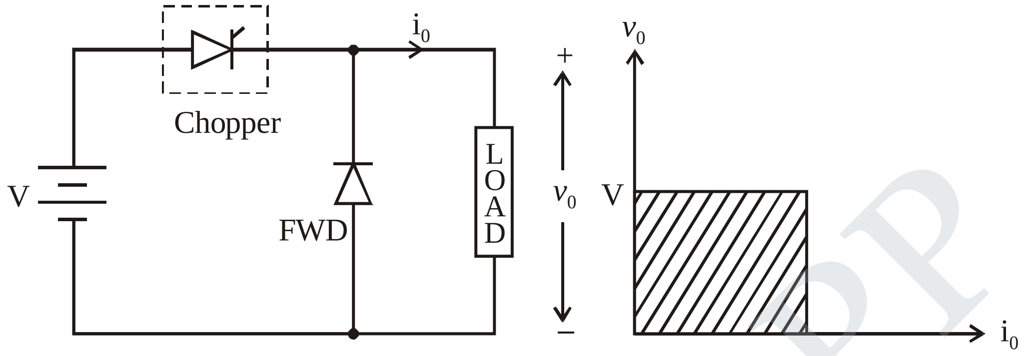


Fig. 2.14: Class A Chopper and $v_O - i_O$ Characteristic

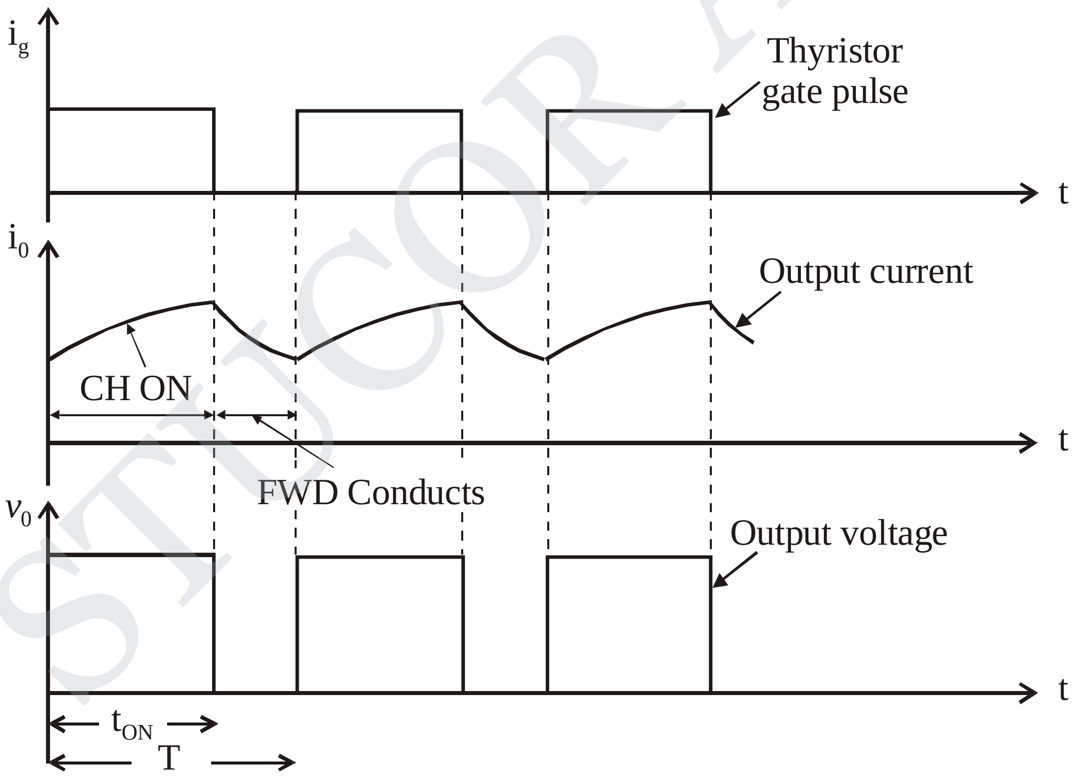


Fig. 2.15: First quadrant Chopper - Output Voltage and Current Waveforms

Class A Chopper is a step-down chopper in which power always flows from source to load. It is used to control the speed of dc motor. The output current equations obtained in step down chopper with *R-L* load can be used to study the performance of *Class A Chopper*.

CLASS B CHOPPER

Fig. 2.16 shows a *Class B Chopper* circuit. When chopper is ON, $v_O = 0$ and *E* drives a current i_O through *L* and R in a direction opposite to that shown in figure 2.16. During the ON period of the

DOWNLOADED FROM STUCOR APP STUCOR APP

DOWNLOADED FROM STUCOR APP

chopper, the inductance L stores energy. When Chopper is OFF, diode D conducts, $v_O = V$ and part of the energy stored in inductor L is returned to the supply. Also the current i_O continues to flow from the load to source. Hence the average output voltage is positive and average output current is negative. Therefore *Class B Chopper* operates in second quadrant. In this chopper, power flows from load to source. *Class B Chopper* is used for regenerative braking of dc motor. Figure 2.17 shows the output voltage and current waveforms of a *Class B Chopper*.

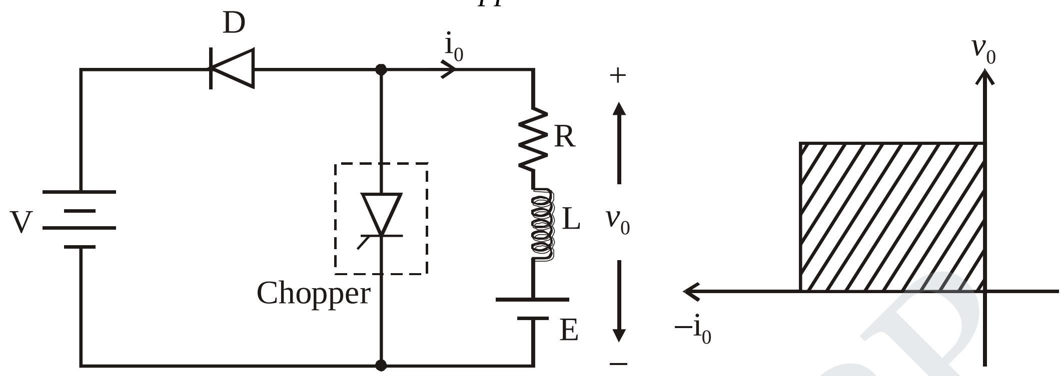


Fig. 2.16: Class B Chopper

The output current equations can be obtained as follows. During the interval diode 'D' conducts (chopper is off) voltage equation is given by

$$V = \frac{Ldi_O}{dt} + Ri_O + E$$

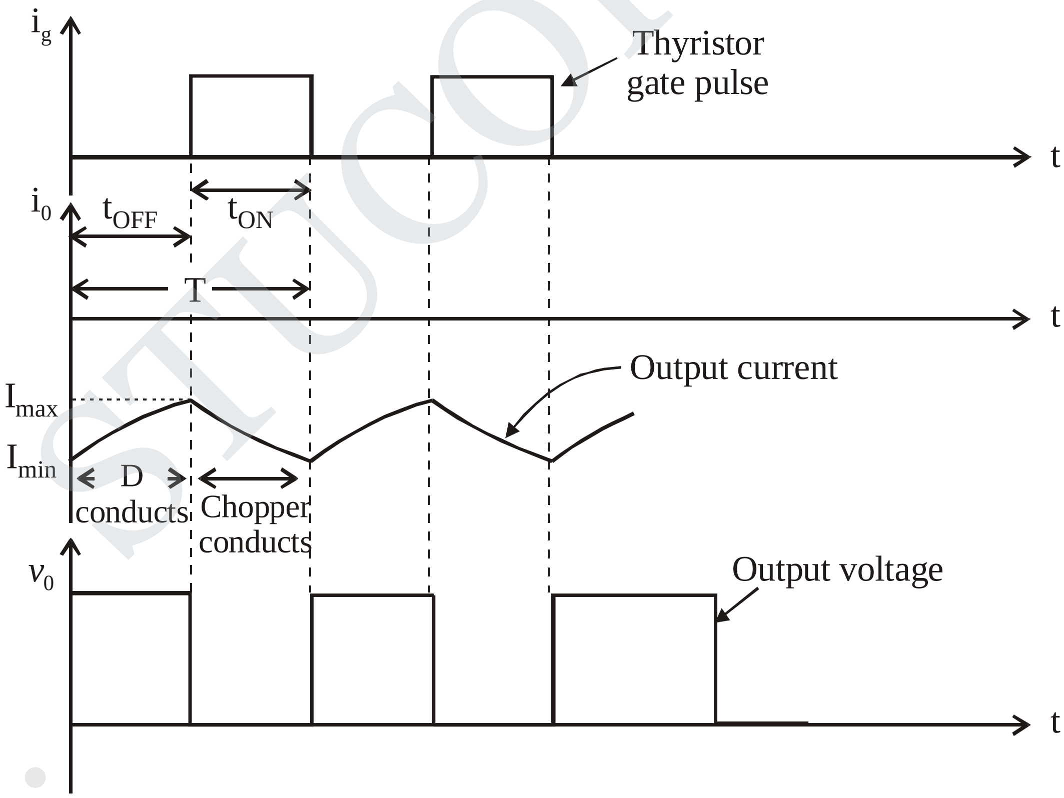


Fig. 2.17: Class B Chopper - Output Voltage and Current Waveforms

 STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

CLASS C CHOPPER

Class C Chopper is a combination of *Class A* and *Class B Choppers*. Figure 2.18 shows a *Class C* two quadrant Chopper circuit. For first quadrant operation, CH_1 is ON or D_2 conducts and for second quadrant operation, CH_2 is ON or D_1 conducts. When CH_1 is ON, the load current i_O is positive. i.e., i_O flows in the direction as shown in figure 2.18.

The output voltage is equal to $V\left(v_O = V\right)$ and the load receives power from the source.

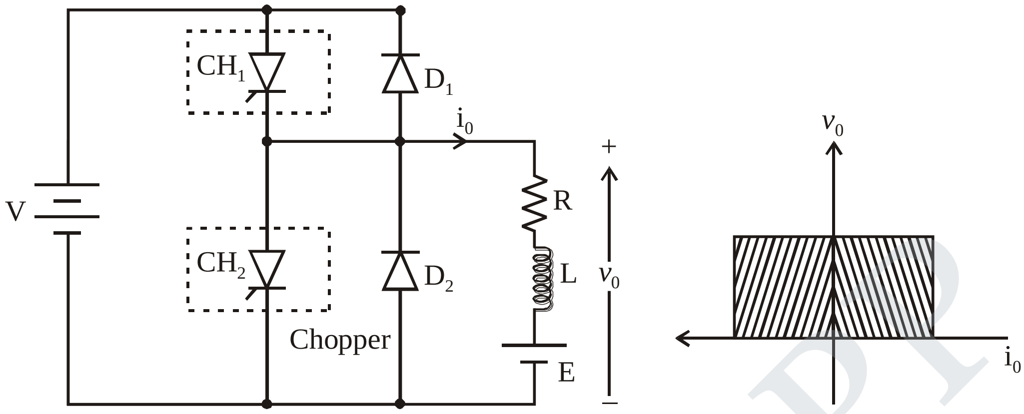


Fig. 2.18: Class C Chopper

When CH_1 is turned OFF, energy stored in inductance L forces current to flow through the diode D_2 and the output voltage $v_O = 0$, but i_O continues to flow in positive direction. When CH_2 is triggered, the voltage E forces i_O to flow in opposite direction through L and CH_2. The output voltage $v_O = 0$. On turning OFF CH_2, the energy stored in the inductance drives current through diode D_1 and the supply; output voltage $v_O = V$ the input current becomes negative and power flows from load to source.

Thus the average output voltage v_O is positive but the average output current i_O can take both positive and negative values. Choppers CH_1 and CH_2 should not be turned ON simultaneously as it would result in short circuiting the supply. *Class C Chopper* can be used both for dc motor control and regenerative braking of dc motor. Figure 2.19 shows the output voltage and current waveforms.

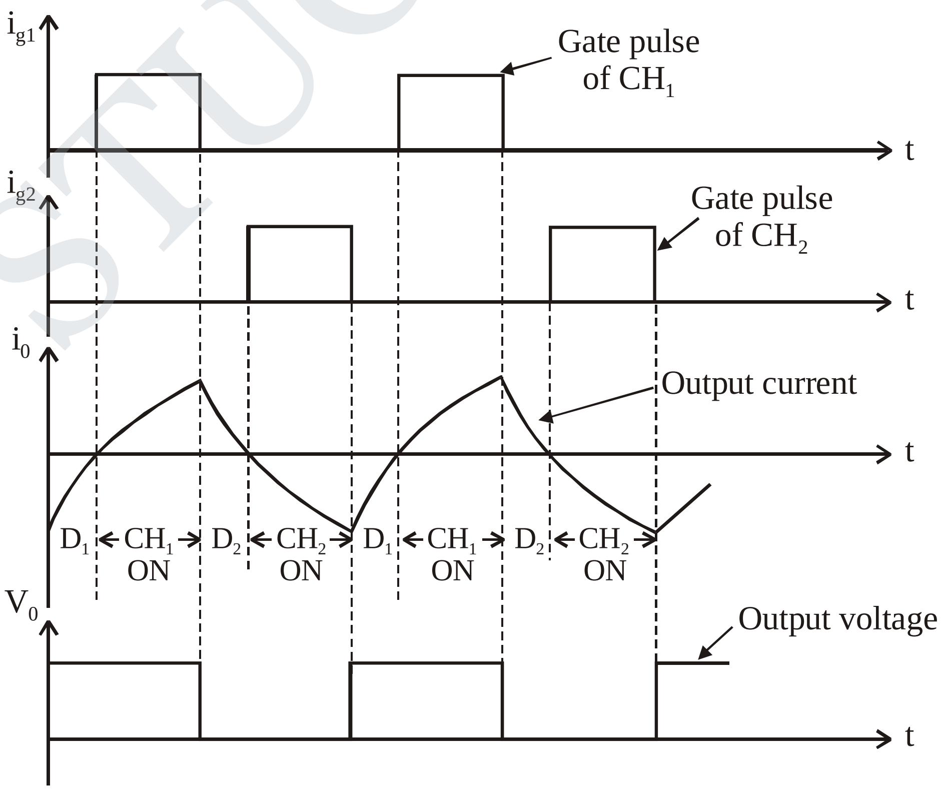


Fig. 2.19: Class C Chopper - Output Voltage and Current Waveforms

DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

CLASS D CHOPPER

Figure 2.20 shows a class D two quadrant chopper circuit. When both CH_1 and CH_2 are triggered simultaneously, the output voltage $v_O = V$ and output current i_O flows through the load in the direction shown in figure 2.20.

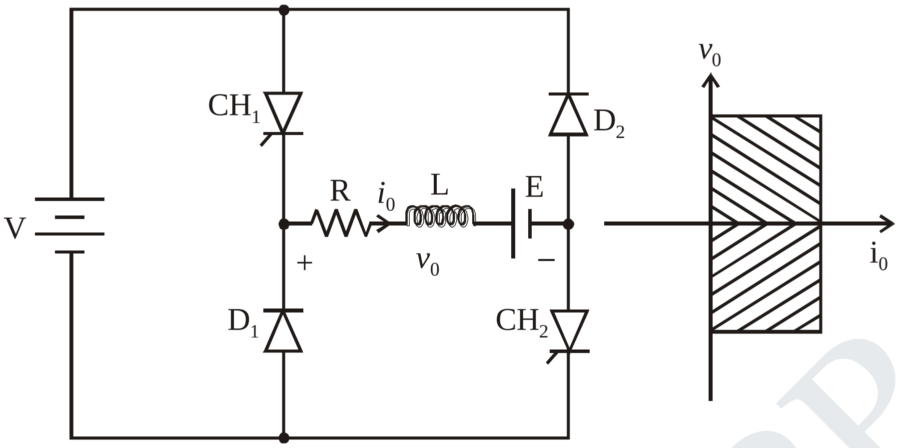


Fig. 2.20: Class D Chopper

When CH_1 and CH_2 are turned OFF, the load current i_O continues to flow in the same direction through load, D_1 and D_2, due to the energy stored in the inductor L, but output voltage $v_O = -V$. The average load voltage v_O is positive if chopper ON-time (t_{ON}) is more than their OFF-time (t_{OFF}) and average output voltage becomes negative if $t_{ON} < t_{OFF}$. Hence the direction of load current is always positive but load voltage can be positive or negative. Waveforms are shown in figures 2.21 and 2.22.

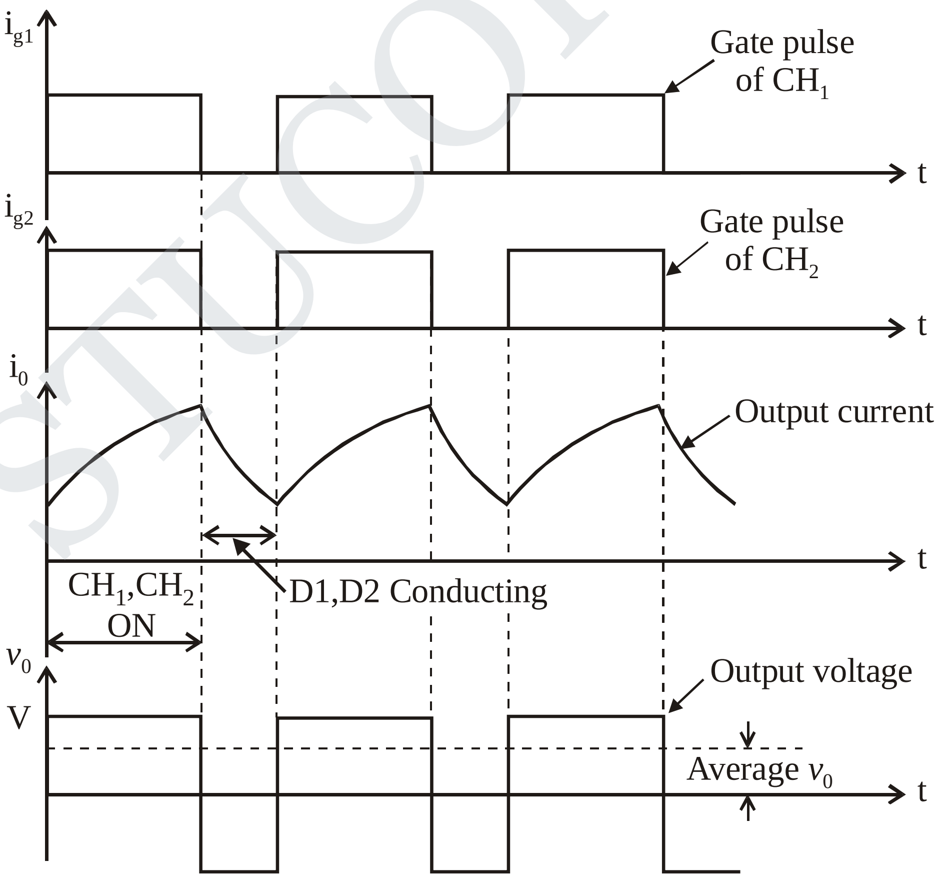


Fig. 2.21: Output Voltage and Current Waveforms for $t_{ON} > t_{OFF}$

DOWNLOADED FROM STUCOR APP
STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

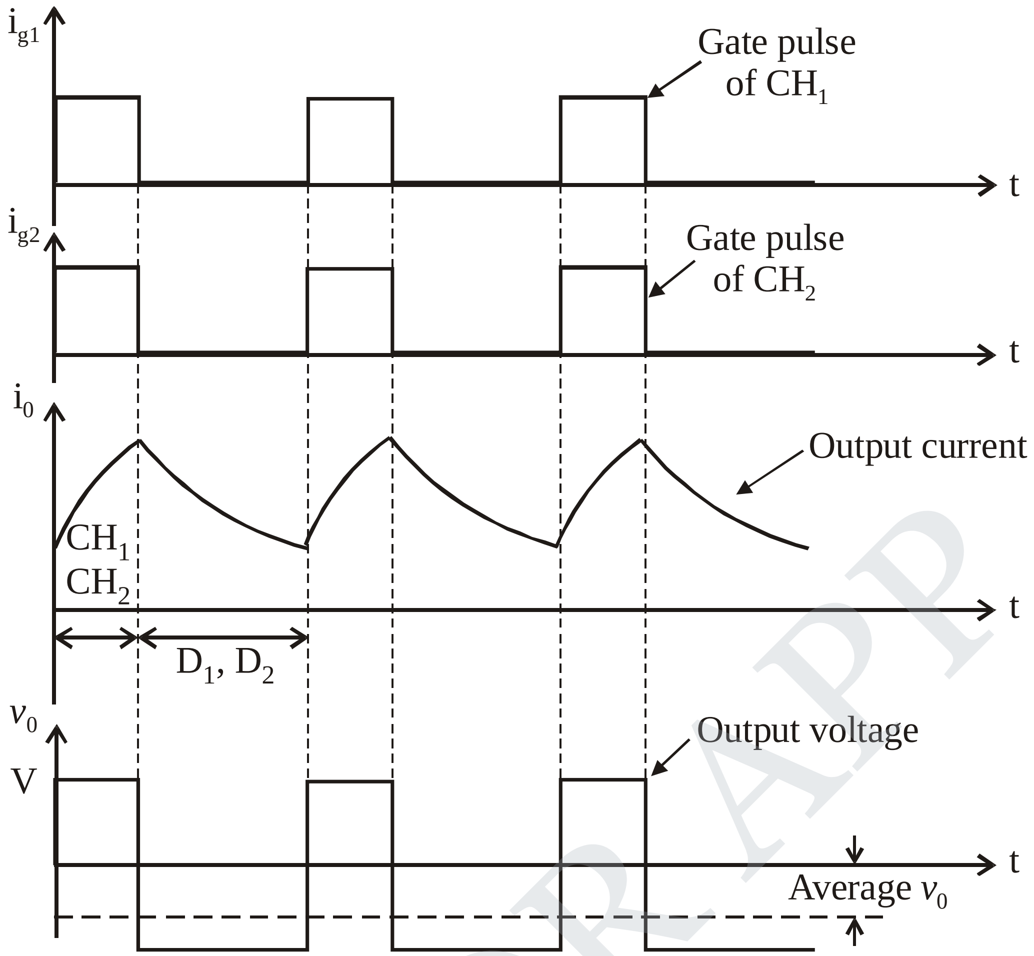


Fig. 2.22: Output Voltage and Current Waveforms for $t_{ON} < t_{OFF}$

CLASS E CHOPPER

The four quadrants or class E chopper fed dc motor circuit is shown in fig.

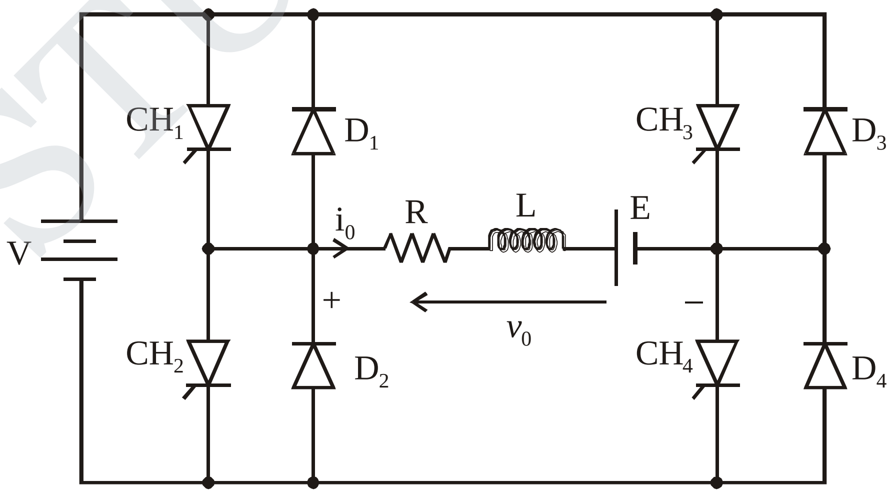


Fig. 2.23: Class E Chopper

DOWNLOADED FROM STUCOR APP

STUCOR APP

DOWNLOADED FROM STUCOR APP
STUCOR APP

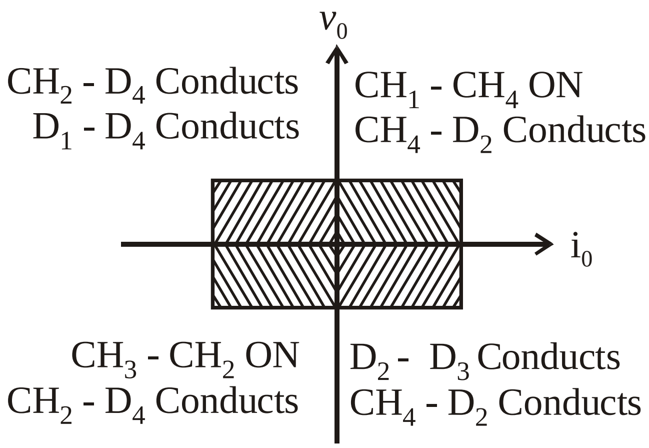


Fig. 2.23(a): Four Quadrant Operation

When CH_1 and CH_4 are triggered, output current i_O flows in positive direction as shown in figure 2.23 through CH_1 and CH_4, with output voltage $v_O = V$. This gives the first quadrant operation. When both CH_1 and CH_4 are OFF, the energy stored in the inductor L drives i_O through D_3 and D_2 in the same direction, but output voltage $v_O = -V$. Therefore the chopper operates in the fourth quadrant. For fourth quadrant operation the direction of battery must be reversed. When CH_2 and CH_3 are triggered, the load current i_O flows in opposite direction and output voltage $v_O = -V$.

Since both i_O and v_O are negative, the chopper operates in third quadrant. When both CH_2 and CH_3 are OFF, the load current i_O continues to flow in the same direction through D_1 and D_4 and the output voltage $v_O = V$. Therefore the chopper operates in second quadrant as v_O is positive but i_O is negative. Figure 2.23(a) shows the devices which are operative in different quadrants.

Comparison between Choppers and Controlled Rectifiers

Sl.No.	Choppers	Controlled Rectifiers
1.	Input is DC	Input is AC
2.	Switching frequency decides the output ripple	Input supply and rectifier decides the output ripple
3.	Small filters are required	Large filters are required
4.	Higher efficiency and power factor	Poor efficiency and poor power factor for inductive loads
5.	Effective regenerative braking	Slow regenerative braking
6.	Small and compact with complex circuit	Costly and bulky with simple circuit
7.	Forced commutation	Natural or line commutation
8.	Control circuit is simple	Control circuit is complex
9.	Pulsating torque is less	Pulsating torque is more

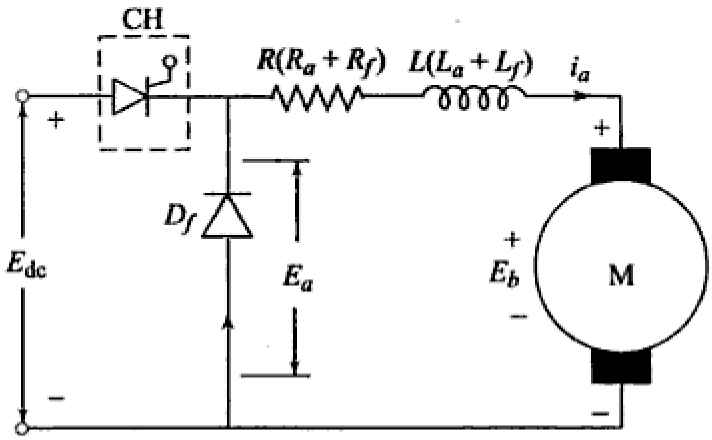
Chopper fed DC Series Motor Speed Control

The chopper fed dc series motor circuit shown in fig. Initially chopper is ON, the armature draw the current I_a from supply and the inductance (series winding) stores the energy. By varying the duty cycle δ or α , voltage across the motor is varied and speed also varied. When switch CH is ON (i.e chopper), the free wheeling diode D_f is reverse biased with respect to motor back emf (see circuit diagram) and it is OFF condition.

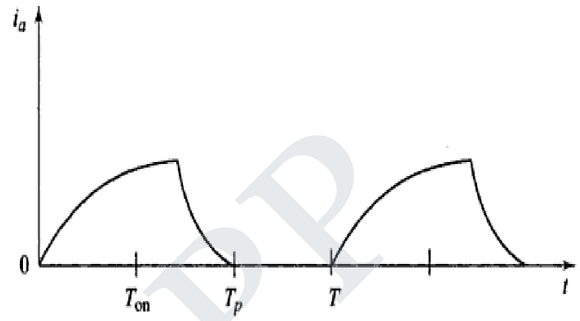
STUCOR APP
STUCOR APP
STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP STUCOR APP

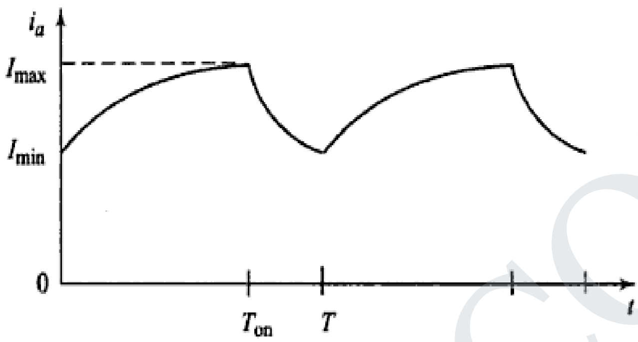
When switch CH is OFF (i.e chopper), then armature is disconnected from the supply and connected to free wheeling diode D_f . The free wheeling diode D_f is now forward biased with respect to motor back emf and it is ON condition. The stored energy in the inductance is discharged through motor and free wheeling diode D_f. The armature carries continuous current due to free wheeling action. The continuous current waveform and discontinuous current waveforms are shown in fig. In the discontinuous mode free wheeling diode is absent.



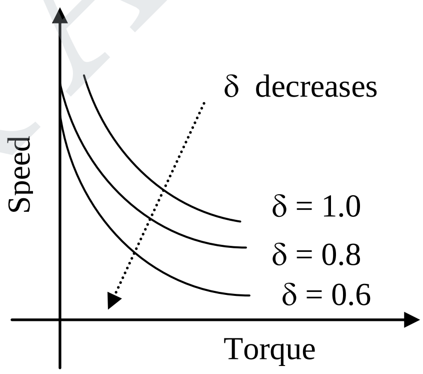
Chopper-fed d.c. series motor



Discontinuous motor current



Continuous motor current



Speed Torque Characteristics

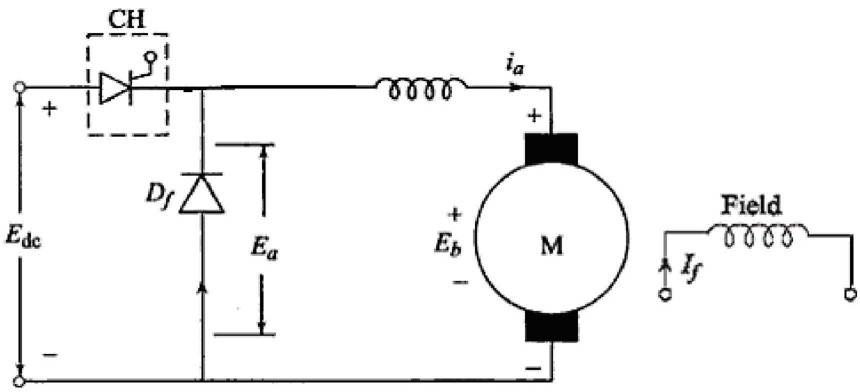
Chopper fed Separately excited DC Shunt Motor Speed Control

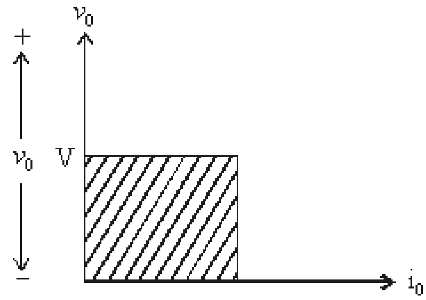
The chopper fed dc shunt motor circuit shown in fig. Initially chopper is ON, the armature draw the current I_a from supply and the inductance (series winding) stores the energy. By varying the duty cycle δ or α , voltage across the motor is varied and speed also varied. When switch CH is ON (i.e chopper), the free wheeling diode D_f is reverse biased with respect to motor back emf (see circuit diagram) and it is OFF condition.

When switch CH is OFF (i.e chopper), then armature is disconnected from the supply and connected to free wheeling diode D_f . The free wheeling diode D_f is now forward biased with respect to motor back emf and it is ON condition. The stored energy in the inductance is discharged through motor and free wheeling diode D_f. The armature carries continuous current due to free wheeling action. The continuous current waveform and discontinuous current waveforms are shown in fig. In the discontinuous mode free wheeling diode is absent.

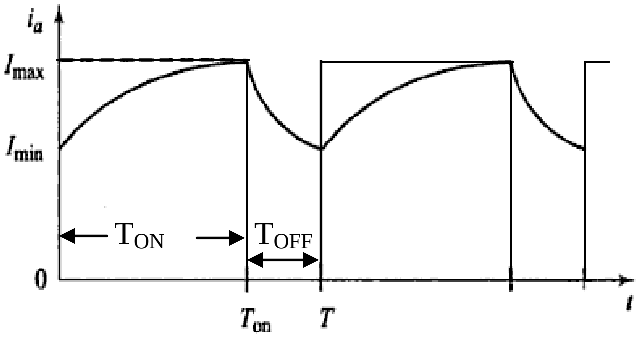
STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP STUCOR APP

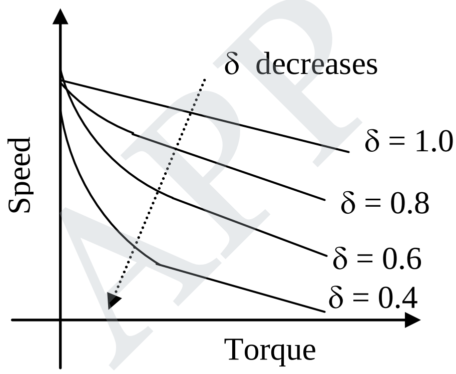




Chopper fed Separately excited DC Shunt Motor Speed Control V – I Characteristics



Continuous motor current



Speed Torque Characteristics

Problem:

The armature and shunt field resistances of a 230 V shunt motor are 0.1Ω and 230Ω respectively. It takes a current of 61 A at 1000 rpm. If the current taken remains unaltered, find the resistance to be included in series with the armature circuit to reduce the speed to 750 rpm.

Solution

$$I_{sh} = \frac{V}{R_{sh}} = \frac{230}{230} = 1 \text{ A}$$

$$I_{a1} = I - I_{sh} = 61 - 1 = 60 \text{ A}$$

Since flux remains constant, $\phi_1 = \phi_2$.

It is given that the current taken by the motor remains constant.

$$\therefore \quad I_{a1} = I_{a2} = 60 \text{ A}$$

$$E_{b1} = V - I_{a1} R_a = 230 - (60 \times 0.1) = 224 \text{ V}$$

$$E_{b2} = V - I_{a2}(R_a + R)$$

$$= 230 - 60(0.1 + R) = 224 - 60R$$

Using the relation,

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \quad (\because \quad \phi_1 = \phi_2)$$

$$\frac{750}{1000} = \frac{224 - 60R}{224}$$

on solving, $R = 0.933 \ \Omega$

STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

Problem:

A 230 V series motor running at a certain speed takes 28A. Its armature and series field resistances are 0.4Ω and 0.1Ω respectively. Assume that the total torque varies as the cube of the speed and flux is proportional to current. Find the resistance to be connected in series with the armature to reduce the speed by 50 percent.

▶ **Solution**

$$\phi \;\alpha\; I_a \quad \text{(given)}$$

$$T_a \;\alpha\; \phi I_a \;\alpha\; I_a^2 \qquad ($$

But,

$$T \;\alpha\; N^3 \quad \text{(given)} \qquad ($$

From equation (4.10) and (4.11),

$$I_{a2} \;\alpha\; N^3$$

$$\therefore \quad \left(\frac{I_{a2}}{I_{a1}}\right)^2 = \left(\frac{N_2}{N_1}\right)^3 = (0.5)^3$$

$$\frac{I_{a2}}{I_{a1}} = 0.354$$

$$\therefore \quad I_{a2} = 0.354\, I_{a1} = 0.354 \times 28 = 9.912 \text{ A}$$

Back emf,

$$E_{b1} = V - I_{a1}(R_a + R_{se})$$

$$= 230 - 28(0.4 + 0.1)$$

$$= 216 \text{ V}$$

$$E_{b2} = V - I_{a2}(R_a + R_{se} + R)$$

where R is the additional series resistance required.

$$= 230 - 9.912(0.4 + 0.1 + R)$$

$$E_{b2} = 225.04 - 9.912\, R$$

Using the relation,

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2}$$

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{I_{a1}}{I_{a2}}$$

$$0.5 = \frac{225.04 - 9.912\, R}{216} \times \frac{28}{9.912}$$

on solving,

$$R = 4.19\ \Omega$$

DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

Problem:

A DC shunt motor drives a centrifugal pump whose torque varies as the square of the speed. The motor is fed from a 200V supply and takes 50A when running at 1000 rpm. What resistance must be inserted in the armature circuit in order to reduce the speed to 800rpm? The armature and field resistances of the motor are 0.1Ω and 200Ω respectively. (AU - Nov/Dec 2003)

Solution

In general, $T \propto \phi I_a$

As per given condition, $T \propto I_a \propto N^2$ [Excitation constant]

$$\therefore \quad I_a \propto N^2$$

$$I_{sh} = \frac{200}{100} = 2\text{ A}$$

$$\therefore \quad I_{a1} = 50 - 2 = 48\text{ A}$$

Let I_{a2} = new armature current at 800 rpm

$$48 \propto N_1^2 \propto 1000^2 \quad \text{and} \quad I_{a2} \propto N^2 \propto 800^2$$

$$\therefore \quad \frac{I_{a2}}{48} = \left(\frac{800}{1000}\right)^2 = 0.8^2$$

Then,

$$I_{a2} = 48 \times 0.64 = 30.72\text{ A}$$

$$E_{b1} = 200 - (48 \times 0.1) = 195.2\text{ V}$$

$$E_{b2} = (200 - 30.72\, R_t)$$

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}}$$

$$\therefore \quad \frac{800}{1000} = \frac{200 - 30.72\, R_t}{195.2}$$

on solving,

$$R_t = 1.42\ \Omega$$

$\therefore$ Additional resistance to be inserted

$$1.42 - 0.1 = 1.32\ \Omega$$

STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

Problem:

A 250V dc series motor takes 40 amperes of current when developing full load torque at 1500 rpm. Its resistance is 0.5 ohm. If the load torque varies as the square of the speed, determine the resistance to be connected in series with the armature to reduce the speed to 1200 rpm. Assume that the flux is proportional to the field current. (November/December 2004)

► Solution

$$\phi \;\alpha\; I_a \quad \text{(given)}$$
$$T_a \;\alpha\; \phi I_a \;\alpha\; I_a^2$$
$$T \;\alpha\; N^2 \quad \text{(given)}$$

From equation (4.12) and (4.13),

$$\left(\frac{I_{a2}}{I_{a1}}\right)^2 = \left(\frac{N_2}{N_1}\right)^2 = \left(\frac{1200}{1500}\right)^2 = (0.8)^2$$

$$\therefore \frac{I_{a2}}{I_{a1}} = 0.8$$

$$\therefore I_{a2} = 0.8 \times I_{a1} = 0.8 \times 40 = 32 \text{ Amps}$$

$$\text{Back emf } E_{b1} = V - I_{a1}(R_a + R_{se}) = 250 - 40(0.5) = 230 \text{ V}$$

$$E_{b2} = V - I_{a2}(R_a + R_{se} + R)$$

where R is the additional series resistance required

$$E_{b2} = 250 - 32(0.5 + R) = 234 - 32R$$

Using the relation,

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2} = \frac{E_{b2}}{E_{b1}} \times \frac{I_{a1}}{I_{a2}}$$

$$\Rightarrow 0.8 = \frac{232 - 22R}{230} \times \frac{40}{32}$$

on solving, $R = 2.65\ \Omega$

Problem:

A DC shunt motor drives a centrifugal pump whose torque varies as square of the speed. The motor is fed from a 220 V supply and takes 60A, when running at 800 rpm. Armature resistance is 0.2Ω and shunt field resistance is 110Ω. What resistance must be inserted in the armature circuit in order to reduce the speed to 600 rpm?

► Solution

$$I_{sh} = \frac{V}{R_{sh}} = \frac{220}{110} = 2 \text{ A}$$
$$I_{a1} = I_1 - I_{sh} = 60 - 2 = 58 \text{ A}$$

Generally, $T \;\alpha\; \phi\, I_a$

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

Since excitation is constant in shunt motors

$$T \;\alpha\; I_a \,\alpha\, N^2$$
$$\therefore \quad I_a \;\alpha\; N^2$$

Let I_{a2} = New armature currnet at $N_2 = 600$ rpm.

Then, $\quad 58 \;\alpha\; N_1^2 \;\alpha\; 800^2$

and $\quad I_{a2} \;\alpha\; N_2^2 \;\alpha\; 600^2$

$$\therefore \quad \frac{I_{a2}}{58} = \left(\frac{600}{800}\right)^2$$

on solving, $\quad I_{a2} = 32.62$ A

$$E_{b1} = V - I_{a1} R_a = 220 - (58 \times 0.2) = 208.4 \text{ V}$$
$$E_{b2} = V - I_{a2}(R_a + R) = 220 - 32.62(0.2 + R)$$
$$= 213.47 - 32.62\,R$$

where R is the additional resistance required.

Using the relation,

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2}$$

since $\quad \phi_1 = \phi_2$

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}}$$
$$\therefore \quad \frac{600}{800} = \frac{213.47 - 32.62\,R}{208.4}$$

on solving, $\quad R = 1.753\ \Omega$

Two Mark Questions:

1. What are the various methods of controlling speed?
2. What are the advantages of flux control method?
3. List out the drawbacks of Rheostatic control method?
4. Why induction motors and DC shunt motors are called as constant speed motors?
5. List out the advantages of Ward-Leonard system.
6. What are the drawbacks of Ward-Leonard system of speed control of DC motors?
7. Where tapped field control method is employed?
8. List out the different ways of obtaining variable flux in the field control method of DC series motors.
9. Where series parallel control method is employed?
10. What are the speed control methods used in DC series motor?
11. List out the advantages of Thyristor controllers.
12. Mention the difference between controlled rectifier and uncontrolled rectifiers.
13. Define holding current of SCR.
14. When the switching action of gate takes place in SCR?
15. What is chopper?
16. Write the expression for average value of load voltage or output voltage in a chopper?
17. What is Time Ratio Control in chopper? How it can be accomplished?

PART – B Questions:

1. Explain with neat sketch the chopper control method of speed control of DC Motors. (16)
2. Explain with neat sketches about the DC Shunt Motor speed control by using single phase fully controlled bridge converter. (16)

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

3. Discuss the Ward-Leonard speed control system with a neat circuit diagram. Also mention its advantages and disadvantages. (16)
4. Explain how the speed of a DC Shunt Motor can be varied both above and below the speed at which it runs with full field current. (16)
5. (i) Explain with neat sketch the operation of chopper fed DC Series Motor drive. Also, derive the expression for average motor current. (10)
   (ii) Explain Time ratio control and Current limit control. (6)
6. Explain the speed control schemes of DC Series Motor. (16)
7. Explain the different methods of speed control employed in DC Shunt Motor. (16)
8. Explain the control of DC drives using rectifiers and choppers. (16)
9. Explain the single phase half wave converter drive speed control for DC drive with waveforms. (16)
10. Explain in detail the single phase semi-converter speed control for DC drive for separately excited motor. (16)

11. A 500V series motor having armature resistance and field resistance of 0.2 Ω and 0.3 Ω respectively runs at 500 rpm when taking 70A. Assuming unsaturated field, find out its speed when field diverter of 0.684 Ω is used constant load torque. (16)

12. A 250V DC Series Motor takes 40A of current when developing a full load torque at 1500 rpm. Its resistance is 0.5 Ω. If the load torque varies as the square of the speed determine the resistance to be connected in series with the armature to reduce the speed to 122 rpm. Assume the flux is proportional to the field current. (16)

13. A 240 V shunt motor has a field resistance of 400 ohms and armature resistance 0.1 ohm. The armature current is 50*A* and the speed is 1350 rpm. Assuming a straight line magnetization curve, determine the additional resistance in the field to increase the speed to 1500 rpm for the same armature current. [Ans: 44.4 ohms]

14. What value of resistance should be inserted in the armature circuit of a 200 V, 1000 rpm shunt motor to reduce its speed to 800 rpm when drawing 20A. Assume resistance to be 0.5 ohms. [Ans: 1.9 Ω]

15. A 230 V DC shunt motor takes an armature current of 20A on a certain load. Resistance of armature is 0.5 ohms. Find the resistance required in series with the armature to halve the speed if (a) the load torque is constant (b) the load torque is proportional to the square of the speed. [Ans: 5.5 Ω, 23.5 Ω]

16. A 230 V shunt motor is taking a current of'50 A. Resistance of the shut field is 46Ω and the resistance of the armature is 0.01 Ω. There is a resistance of 0.6Ω in series with the armature and the speed is 800 rpm. What alteration must be made in the armature circuit to raise the speed to 850 rpm, the torque remaining the same? [Ans: 0.30]

17. A series motor is taking 25A from a 220V supply. The total resistance of the armature and field circuits is 0.5 Ω. Calculate the resistance to be connected in series with the armature to reduce the speed by 40 percent, If the torque is proportional to the square of speed and flux is proportional to current. [Ans: 0.18 Ω]

18. A series motor runs at 500 rpm on certain load. Calculate the resistance of the diverter to raise the speed to 625 rpm, the developed torque reaming constant. Resistance of the field winding is 0.054 ohms. Neglect saturation and ohmic drop in the field and armature. [Ans: 0.09 ohms]

19. Two series motors at a speed of 500 rpm and 550 rpm respectively when taking 50A at 500V. The total resistance of each motor is 0.5 Ω. Calculate the speed of the combination when connected in series and coupled mechanically. The combination is taking 50A on 500V supply. [Ans: 248.1 rpm]

DOWNLOADED FROM STUCOR APP
STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

PANIMALAR ENGINEERING COLLGE

DEPARTMENT OF MECHANICAL ENGINEERING

II YEAR / III SEMESTER

ELECTRICAL DRIVES AND CONTROL

UNIT - V

CONVENTIONAL AND SOLID STATE SPEED CONTROL OF AC DRIVES

DOWNLOADED FROM STUCOR APP

STUCOR APP

DOWNLOADED FROM STUCOR APP

Speed Control of Three Phase Induction Motor:

A 3 phase induction motor is practically a constant speed motor just like a DC shunt motor. The speed of DC shunt motor can be adjusted between wide range with good efficiency and speed regulation by shunt field regulators, but in induction motors, speed cannot be changed without loosing efficiency and good speed regulation.

For the Induction motor, we know that:

$$N = N_s(1-s) = \frac{120\,f}{p}(1-s)$$

It is clear that, speed of the induction motor can be changed either by changing its synchronous speed, N or by changing the slip, s. Also, synchronous speed is given by $N_s = \frac{120\,f}{p}$. By varying *f* and *P*, speed can be controlled.

Torque produced by 3 phase induction motor is given by

$$T \propto \frac{sE_2{}^2 R_2}{R_2{}^2 + (sX_2)^2} \propto E_2{}^2 \propto V^2$$

From this expression, $T \propto E_2{}^2 \propto V^2$ Varying applied voltage will also playa major role in speed change. Hence, to change the speed of an induction motor, it is essential to change at least one of the above factors. Different methods of achieving speed control of induction motors may be grouped under two major headings.

Control from stator side

1. By changing the applied voltage
2. By changing the applied frequency
3. By changing the number of stator poles
4. Voltage / frequency (V/f) control

Control from rotor side

1. Rotor rheostat control
2. By operating two motors in cascade
3. By injection of an emf in the rotor circuit
4. Slip power recovery control

Changing Applied Voltage

Although this is the easiest and most economical, this method is very rarely used due to the following reasons.

A Large change in voltage is required even for a small change in speed. This large change in voltage will result in a larger change in flux density. It will disturb the magnetic conditions of motor, thereby affecting the performance of motor. Based on some approximate relationship at low slip values, the following equations can be written.

$$I_2' = \frac{sV}{R_2'} \text{ and } T = \frac{3}{2\pi n_s}\frac{sV^2}{R_2'}$$

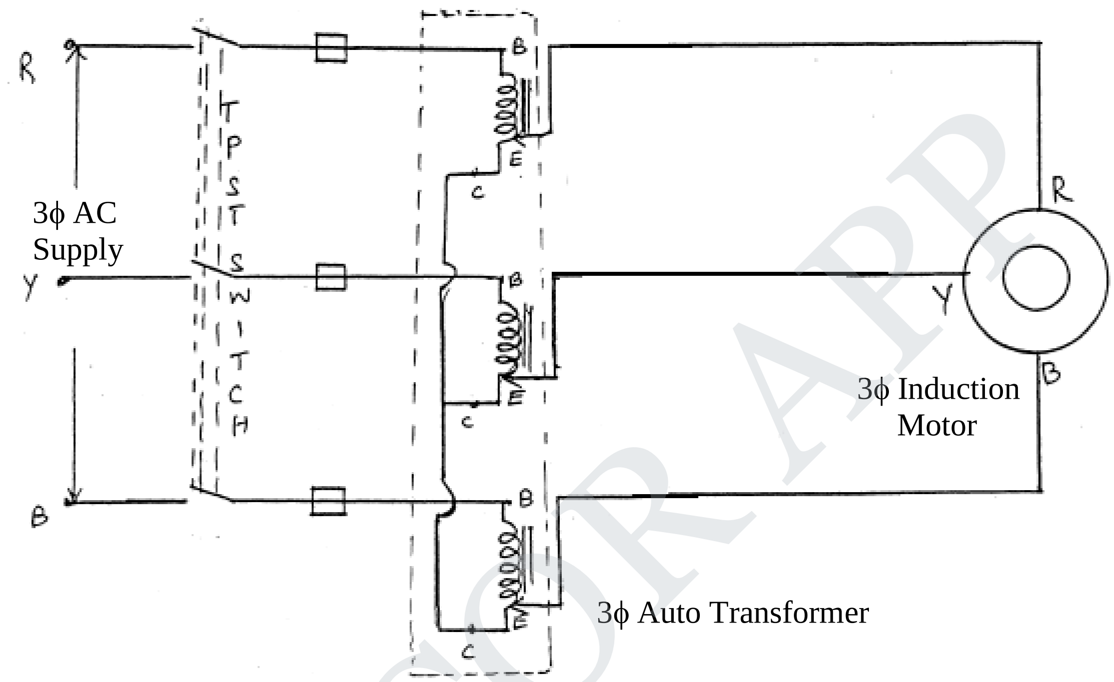
STUCOR APP
STUCOR APP
STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

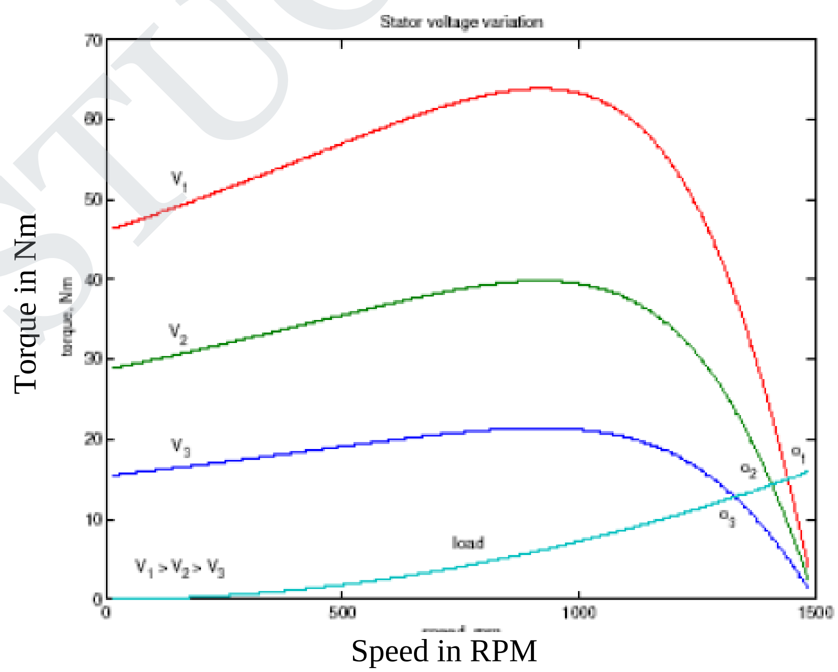
For a motor operating at full load slip, if the slip is to be doubled for constant load torque, based on the above equations, the voltage must be reduced by a factor of $1/\sqrt{2}$ and the corresponding current I_2' rises to $\sqrt{2}$ of the full load value motor, therefore, tends to get overheated. The method, therefore, is not suitable for speed control.

It has a limited use for motors driving fan type loads whose torque requirement is proportional to the square of the speed.

It is a commonly used method for ceiling fans driven by single phase induction motors which have large standstill impedance limiting the current drawn by the stator.



Schematic diagram of Stator Voltage Control of three phase Induction Motor



Speed Torque Characteristics of three phase induction motor with varying Stator Voltage

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

Change in Stator Supply Frequency Control:

In steady state, the induction motor operates in the small-slip region, where the speed of the motor is always close to the synchronous speed of the rotating flux.

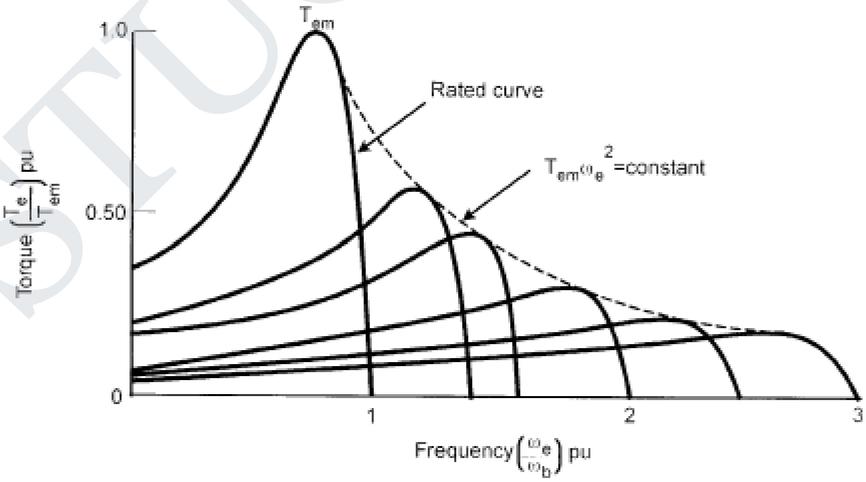
$$N = N_s(1-s) = \frac{120f}{p}(1-s) \qquad \left(\because N_s = \frac{120f}{p}\right)$$

Where *'f'* is the frequency of the stator voltage and '*p'* is the number of poles. Since the synchronous speed is directly proportional to the frequency of the stator voltage, any change in frequency results in an equivalent change in motor speed.

If you plot the motor speed torque characteristics for different values of supply frequencies, you can obtain a family of characteristics.

Frequency manipulation appears to be an effective method for speed control that requires a simple dc/ac converter with variable switching intervals by means of solid state control. Otherwise, the variable frequency achieved conventionally by using rotary converters. However, there are severe limitations to this method: very low frequencies may cause motor damage due to excessive currents, and large frequencies may stall the motor. These limitations are,

1. An increase in the no-load speed (synchronous speed).
2. A decrease in the maximum torque.
3. A decrease in the starting torque.
4. An increase in speed at the maximum torque.
5. A decrease in the starting current.



Speed Torque Characteristics of three phase Induction Motor with varying Stator Supply Frequency

DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP

Changing Number of Stator Poles

This method is easily applicable to squirrel cage motors because the squirrel cage motor adopts itself to any number of stator poles.

It is possible to have one, two or four speeds in steps, by changing the number of stator poles. A continuous smooth speed control is not possible by this method.

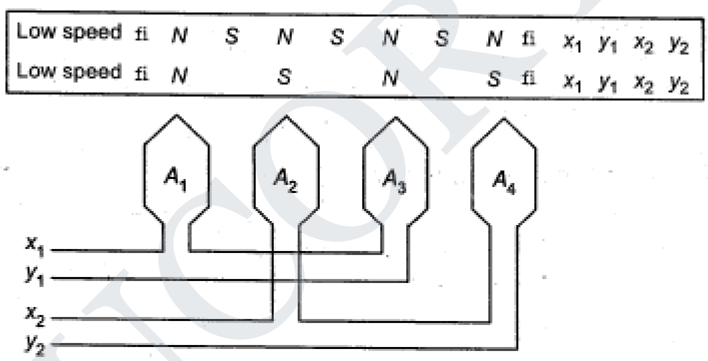
Multiple, stator winding method

The change of number of poles is achieved by having two or more entirely independent stator-windings in the same slots of stator core. Each winding gives a different number of poles and hence different synchronous speeds. Motors with four independent stator winding are also in use and they give four different synchronous speeds.

The various limitations of this method are,

i.. Only step change in speed is possible i.e., no smooth variation of speed.
ii. High cost of the motor.
iii. Design complexity

This method has been used for elevator motors, traction motors and also for small motors driving machine tools.



The drawback of this method is that, only a step change of speed is possible.

Rotor Side Control

Rotor Resistance or Rheostat Control:

This method is similar to the armature resistance control method applied to DC shunt motors. This method is applicable to slip ring induction motors alone and the speed is varied by adding external resistance into the rotor circuit.

It has been already discussed that, for small slip values, $T \propto \frac{s}{R_2}$ Therefore, for the constant torque given, slip can be increased i.e., speed can be decreased by increasing rotor resistance R_2. For this purpose, rotor starter may be used. If itself acts starting rheostat and speed controller. Otherwise, if we do not consider the starting arrangement, for controlling speed, we can use a star connected rheostat as shown in Fig.

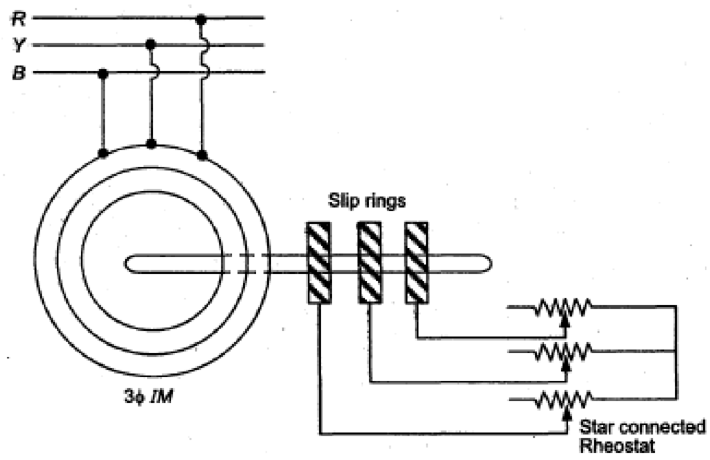
Drawbacks

1. With increase in rotor resistance, I^2 R losses also increases. It will result in decrease in efficiency.
2. Speed not only depends on rotor resistance R_2, but also on the load.

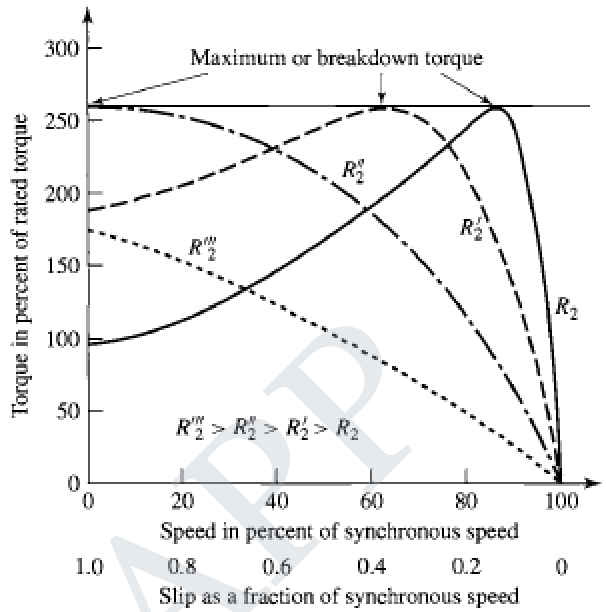
STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

There is double dependence of speed. Because of this accurate control is not possible.
Due to the above points, this method is used where speed changes are needed for short periods only.



Rotor Resistance Control of Slip Ring Induction Motor



Speed Torque Characteristics of Rotor Resistance Control in Wound Rotor IM

Rotor Slip Power Control

A slip ring induction motor can be operated at reduced speeds by inserting external resistances in the rotor circuit through slip rings. In this method, certain amount of slip power i.e., the rotor power at slip frequency is lost as heat in the external resistances.

As a logical extension of this, an interesting method of speed control of slip ring motor is developed based on economical use of slip power through suitable slip power converters.

The principal methods of speed control of wound rotor motors by slip power control are

1. Cascade operation
2. Injecting an emf into rotor circuit

1. Cascade operation

When multiple speeds are required, motors are sometimes operated in tandem or in cascade mode. In this mode, two motors are coupled to the same shaft (Fig.).

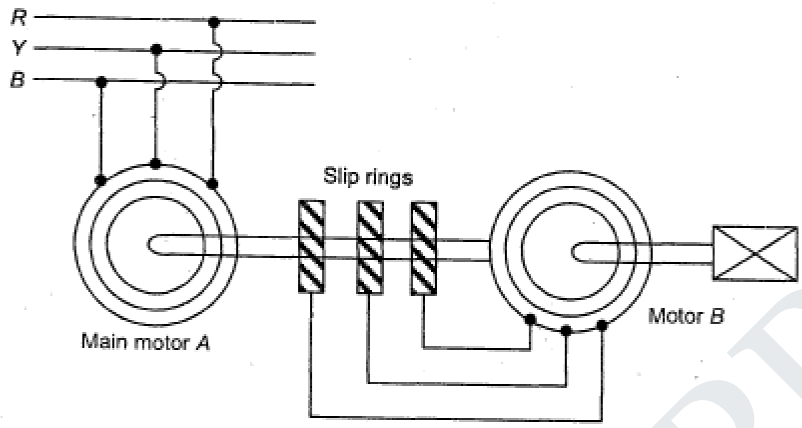
The stator winding of the first main motor is connected to the mains in the usual way, while that of the second stator is fed from the rotor winding of the first. The first motor necessarily be of slip ring motor and the second one may be either squirrel cage motor (or) slip ring motor.

The motors maybe so connected that both tend to run in the same direction or the phase rotation of one motor may be reversed, thus tending it to make it rotate in the reverse direction. In either case, the set win run after it is started, but in the latter case, no starting torque is developed and for this reason, this connection is rarely used.

STUCOR APP
STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

The first case is called as cumulative cascade and the second case is called as differential cascade. If P_1 and P_2 are not equal, four synchronous speeds are possible, two with tandem operation and one for each motor separately.



The expression for speed of the set is derived as follows:

Let the frequency of the supply voltage be f_1 and let the machines M_1 and M_2 have P_1 and P_2 number of poles respectively.

Let the two machines, M_1 and M_2 run with slip of S_1 and S_2 respectively.

$$\text{speed in rpm of } M_1 \text{ is } N_1 = \frac{120\, f_1}{P_1}(1 - s_1) \quad (5.1)$$

$$\text{speed in rpm of } M_2 \text{ is } N_2 = \frac{120\, f_2}{P_2}(1 - s_2) \quad (5.2)$$

But the shaft are mechanically coupled, therefore

$$N_1 = N_2 = N \quad \text{i.e., speed of the set}$$

Also,

$$f_2 = s f_1$$

DOWNLOADED FROM STUCOR APP

STUCOR APP

DOWNLOADED FROM STUCOR APP

Hence, substituting the value of f_2, we get

$$N_2 = \frac{120\, s_1\, f_1}{P_2}(1 - s_2)$$

Equating the expression for N_1 and N_2 and solving for s_1, we get

$$\frac{120\, f_1}{N_1}(1 - s_1) = \frac{120\, s_1\, f_1}{P_2}(1 - s_2)$$

$$\therefore \quad s_1 = \frac{P_2}{P_1 - P_1 s_2 + P_2} = \frac{P_2}{P_1(1 - s_2) + P_2}$$

But when the rheostat is short circuited, s_2 approaches zero, the above expression then reduces

$$s_1 = \frac{P_2}{P_1 + P_2}$$

But $$s_1 = \frac{N_{s1} - N_1}{N_{s1}}$$

where N_{s1} is the synchronous speed of M_1

$$\therefore \quad \frac{N_{s1} - N_1}{N_{s1}} = \frac{P_2}{P_1 + P_2}$$

Solving for N_1, we have

$$N_1 = N_{s1} \cdot \frac{P_1}{P_1 + P_2}$$

However, $N_{s1}\, P_1 = 120\, f_1$, so substituting the value of $N_{s1}\, P_1$ in the above expression it becomes

$$N = N_1 = \frac{120\, f_1}{P_1 + P_2} \text{ rpm} \tag{5.3}$$

Similarly, it can be proved that, for differential cascade mode

$$N = N_1 = \frac{120\, f_1}{P_1 - P_2} \tag{5.4}$$

Hence four different speeds are possible i.e., equation (5.1), (5.2), (5.3) and (5.4), two speeds with operating M_1 and M_2 separately and two speeds with tandem operation.

Disadvantages

1. It requires two motors which makes the set expensive.
2. Smooth speed control is not possible.
3. Operation is complicated,
4. Set cannot be operated if $P_A = P_B$

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

5. The starting torque is not sufficient to start the set especially in differential cascade.

Points to be noted

There are atleast 4 ways in which the combination may be run.

1. Main motor A may be run separately from the supply i.e., $N_{sa} = \frac{120\ f}{P_a}$.
2. Auxiliary motor B may be run separately from the mains (motor A being disconnected) i.e., $N_{sb} = \frac{120\ f}{P_b}$.
3. The combination may be connected in cumulative cascade i.e., $N_{sc} = \frac{120\ f}{P_a+P_b}$.
4. The combination may be connected in differential cascade. i.e., $N_{sc} = \frac{120\ f}{P_a-P_b}$.

Also, it can be proved that

i. $s = s_1 \cdot s_2$

ii. Mechanical outputs are in the ratio of the number of poles of the motor.

2. Injection of an EMF into Rotor Circuit:

In this method, an emf is injected into the rotor circuit. The frequency of rotor circuit is at slip frequency and hence the emf to be injected must be at slip frequency. If the injected emf is in phase with the rotor induced emf, effective rotor resistance decreases. If the injected emf is in direct phase opposition to the rotor induced emf, effective rotor resistance increases. So, by controlling the magnitude of the injected emf, rotor resistance and hence the effective speed can be controlled.

Two methods are available using this principle. They are

i. Kramer System

ii. Scherbius System

Kramer system

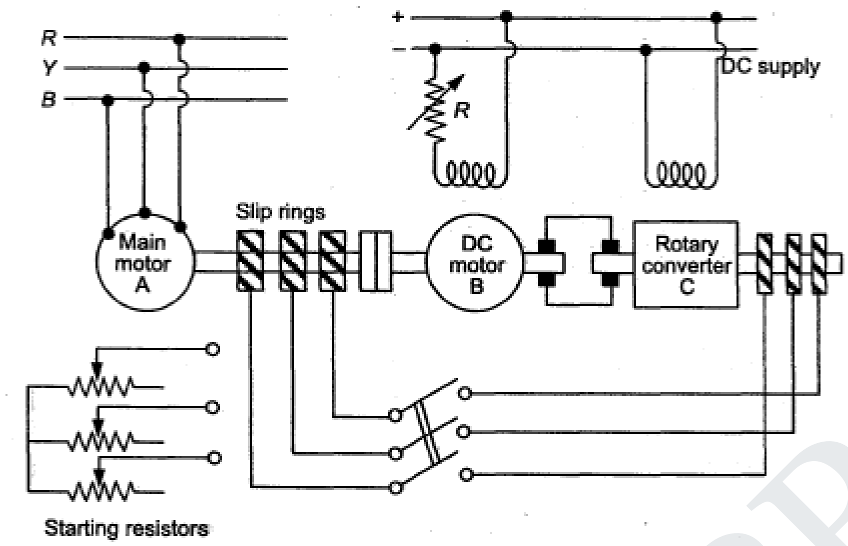
This method is applicable to larger rating motors of 4000 kW or above. The main advantage of this method is that, any speed within the working range i.e., smooth step less speed control is possible.

The objective is to control the speed of main motor *A*. Auxiliary equipments needed are DC motor and rotary converter. A separate DC supply is required to excite the field winding of dc motor and exciting winding of rotary converter. The variable resistance introduced in the field circuit of de motor acts as field regulator (Fig.).

The rotary converter converts the low slip frequency ac power into de power which is used to drive a de shunt motor *B*, mechanically coupled to the main motor *A*. The main motor is coupled to the shaft of de shunt motor *B*. The slip rings of *A* are connected to the rotary converter C. The de output of C is used to drive *B*. Both C and *B* are excited from the de bus bar. When the field resistance *R* is changed, back emf of motor *B* changes. Thus, the dc voltage at the commutator of C changes.

STUCOR APP
STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP



Schematics Arrangement of Conventional Kramer System

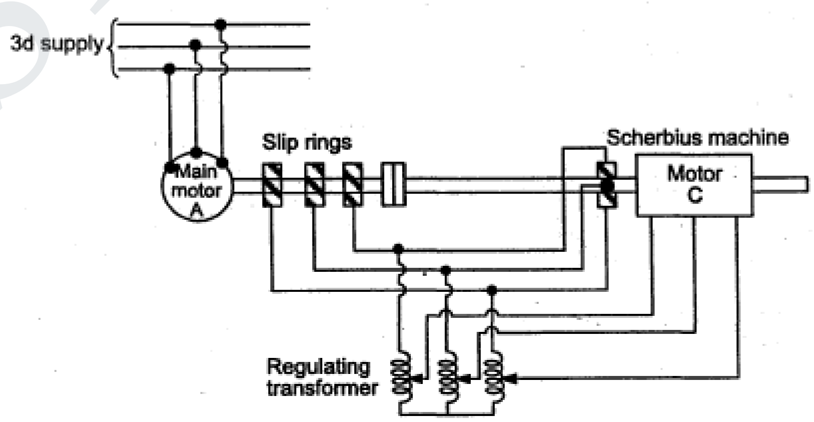
The rotary converter has a fixed ratio between ac side and de side voltages. Thus voltage on its ac side also changes. This ac voltage is given to the slip rings of main motor *A*. So, the voltage injected in the rotor of main motor changes which produces the required speed control.

Another advantage of this system is that, if rotary converter is over excited, it draws leading current which compensates for the lagging current drawn by main motor *A* and hence power factor improvement is also possible.

Scherbius System

In this method, a special 3 phase or 6 phase AC commutator motor, called as Scherbius machine is used. The Scherbius machine is excited at slip frequency from the rotor of main motor, through a regulating transformer. Either by varying the tap settings on the regulating transformer or by changing the position of brushes of special machine, or by changing both, voltage developed in the rotor of Scherbius machine can be varied. This is injected into the rotor of main motor. This controls the speed of main motor (Fig.).

The main difference between the above two systems is that, here, slip energy is not converted into de. The slip energy is directly fed to the Scherbius machine.
The only disadvantage of these methods is that it can be applied for slip ring induction motors only.



Schematics Arrangement of Conventional Scherbius System

STUCOR APP
STUCOR APP
STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

Solid State Control of Three-Phase Induction Motor

The control of de motors requires providing a variable de voltage, which can be obtained from de choppers or controlled rectifiers. These voltage controllers are simple and less expensive. De motors are relatively expensive and require more maintenance, due to the brushes and commutators. The speed control of ac drives generally requires complex control algorithms that can be performed by microprocessors and/or microcomputers along with fast switching power converters.

Some of the advantage of ac motors over de motors is:

1. A.C. motors are lightweight (20 to 40% lighter than equivalent de motors).
2. A.C. motor drives are built for high speeds in large power ratings and due to low inertia they have a fast response.
3. They are inexpensive, and require low maintenance compared to de motors.

One of the disadvantages of a.c. motors is getting an efficient smooth speed control is a problem. The advantages of ac drives outweigh the disadvantages.

In order to obtain variable speed in an ac drive, the supply frequency, voltage or current have to be varied. The power converters, inverters and ac voltage controllers can control the frequency, voltage and/or current to meet the drive requirements.

There are two types of ac drives:

(i) Induction motor drives

(ii) Synchronous motor drives

The speed and torque of induction motors can be varied by one of the following methods

1. Stator Voltage Control
2. Voltage and frequency control
3. Slip power recovery scheme

The stator voltage can be varied by

1. Three-phase ac voltage controllers or Regulators
2. Voltage-fed variable dc-link inverters
3. Pulse-width modulation (PWM) inverters.

Stator Voltage Control

Stator voltage control for three phase induction motors of both squirrel cage as well as slip ring induction motor can be implemented by using three phase AC Voltage controllers.

A simple method of controlling speed in a cage-type induction motor is by varying the stator voltage at constant supply frequency. Stator voltage control is also used for “soft start” to limit the stator current during periods of low rotor speeds. Fig. shows the torque-speed curves with variable stator voltage. Often, low-power motor drives use this type of speed control due to the simplicity of the drive circuit. The fig. shows two commonly used symmetrical three phase ac voltage controller for delta and star connected stators. For small size motors, TRIACs may be used.

Three-phase motors usually drive industrial fans and pumps. A phase controlled thyristorised ac controller is used for getting a variable stator voltage at constant frequency. This thyristor voltage controller for speed control of 3-phase Induction motors is shown in Fig. Motor may be connected in star or delta. In delta connection, third harmonic voltage produced by motor back emf causes circulating current through the windings which increases losses and thermal loading of motor, Speed control is obtained by varying

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

conduction period of thyristors. For low power ratings, anti-paralleled thyristor pair in each phase can be replaced by TRIACs. Since voltage controllers, both single and three phases, allow a stepless control of voltage from its zero value, they are also used for soft start of motors.

Torque produced by 3 phase induction motor is given by

$$T \propto \frac{sE_2{}^2 R_2}{R_2{}^2 + (sX_2)^2} \propto E_2{}^2 \propto V^2$$

From this expression, $T \propto E_2{}^2 \propto V^2$ Varying applied voltage will also play a major role in speed change.

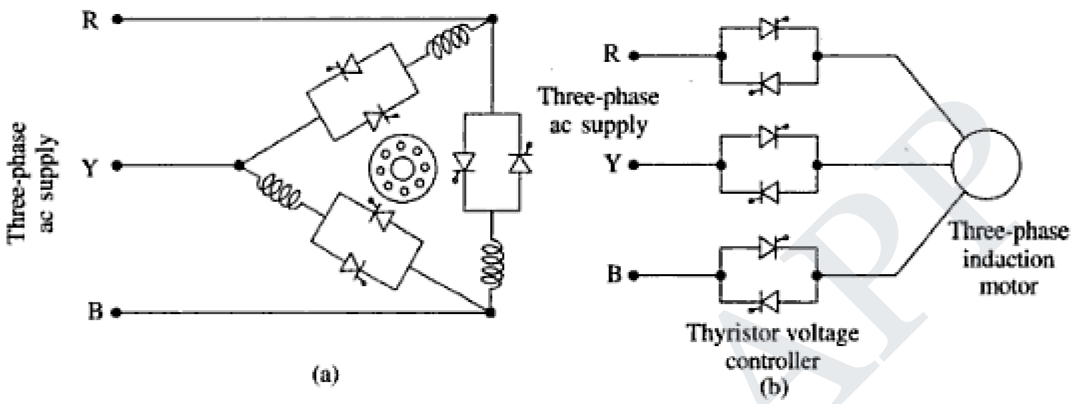


Fig. 7.15 Variable stator voltage controlled three-phase induction motor.

The figure 7.15.(a) is Delta connected ac voltage controller and (b) Star connected ac voltage controller.

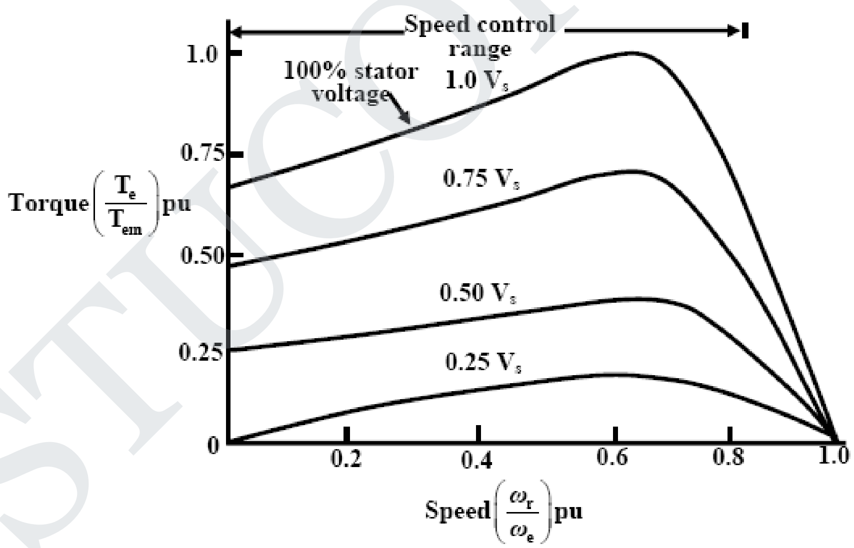


Fig. 34.3 Torque-speed curves at variable supply voltage

Advantages

1. The ac voltage controllers are very simple.

Disadvantages

1. Due to limited speed range requirements,
2. The harmonic contents are high
3. The input PF of the controllers is low.
4. Starting torque is low

They are used mainly in low-power applications, such as fans, blowers, and centrifugal pumps.

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

Applications of AC Voltage Controllers

- Lighting / Illumination control in ac power circuits.
- Induction heating.
- Industrial heating & Domestic heating.
- Transformer tap changing (on load transformer tap changing).
- Speed control of induction motors (single phase and poly phase ac induction motor control).
- AC magnet controls

Constant V/f (Volt/Hertz) Control of Induction Motor:

Let,

V = rated voltage of the motor

f = rated frequency of the motor

When the motor is operated in constant v/f control with the base speed.

– For a frequency kf
– The motor terminal voltage will be kV

Where k is a factor such that 0< k <1,

The frequency is changes from 0 to rated frequency , voltage changes from o to rated voltage V, k changes from 0 to 1

For an induction motor the emf equation is

$E_1 = 4.44\, K_w\, N_{ph}\, f\, \phi_r$

Where, V- Stator supply voltage

K_w – Stator winding factor

N_{ph} – Stator series turns per phase

f - Stator supply frequency

ϕ_r – Resultant air gap flux per phase

E_1 – Stator induced emf per phase

Neglecting losses $E_1 \cong V$

Also $\phi_r = \dfrac{1}{4.44\, N_{ph}\, K_w}\left(\dfrac{V}{f}\right)$

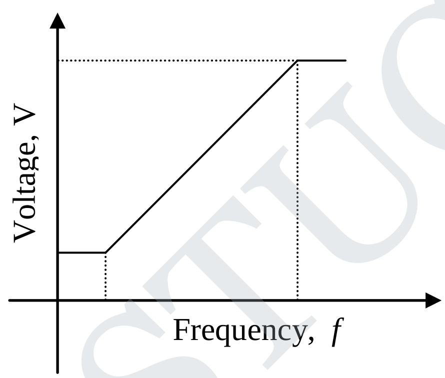
Therefore, if supply frequency is changed, the value of air gap flux also gets affected. This may result into saturation of stator and rotor cores. Such a saturation leads to the sharp increase in the no load current of the motor. Hence it is necessary to maintain air gap flux constant when supply frequency is changed. To achieve this, when *f* is varied, *V* must be also varied such that (*V/f*) remains constant.

- The speed control of 3ϕ induction motor mostly prepares this control method.
- The increase in the supply frequency increases the motor speed and also reduces the max torque of the motor.
- But the increase in voltage results in an increase in the max torque of the motor.
- If we combine these two features
  – We can achieve a control design by which the speed increases and torque is kept the same. This is known as V/f control.
- The change in V/f is a powerful method for speed control of induction motor.

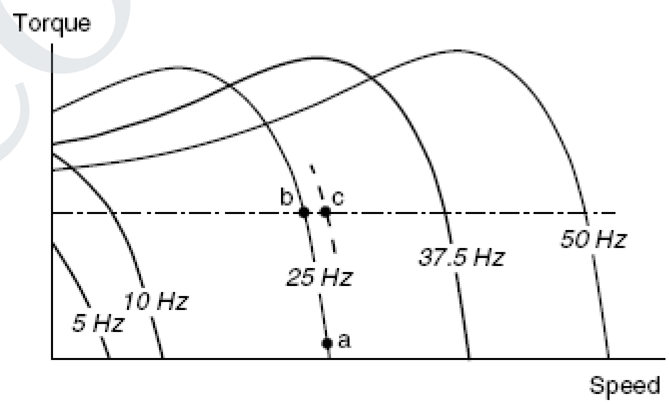
STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

- There are several variations where the V/f ratio is also adjusted to provide a special operating performance.
- The most common method is the fixed V/f ratio.
- Fig shows the N-T char., for fixed V/f ratio.
- From the fig,
- Tm should be constant by keeping fixed V/f ratio
  - The relation between max torque and V/f is, $T_{max} = k\,(V/f)^2$
- From this equation,
  - (V/f) is maintained constant, T_{max} also remains constant and air gap flux is also constant.
  - Therefore motor operates in constant torque mode
- **The low frequency operation** at a constant V/f is not satisfactory particularly at very low frequency.
- Due to this very low frequency
  - **Starting torque** and **breaking torque** considerably **decreases** and **no - load current increases.**
  - **The air gap flux** cannot be maintained constant at low frequency maintaining at constant V/f ratio
  - Therefore we can maintain the **V/f ratio constant**, **the supply voltage should be increasing**.
- The V/f control method,
  - One must be careful not to increase the voltage magnitude beyond the rating of the motor.
  - The increased voltage can cause instant damage to the insulations of the motor winding.
  - Normally the voltage should be kept below 110% of the rated value.
- The main features are,
  - The max torque should be constant.
  - The starting current is also constant



Constant V/ f Control



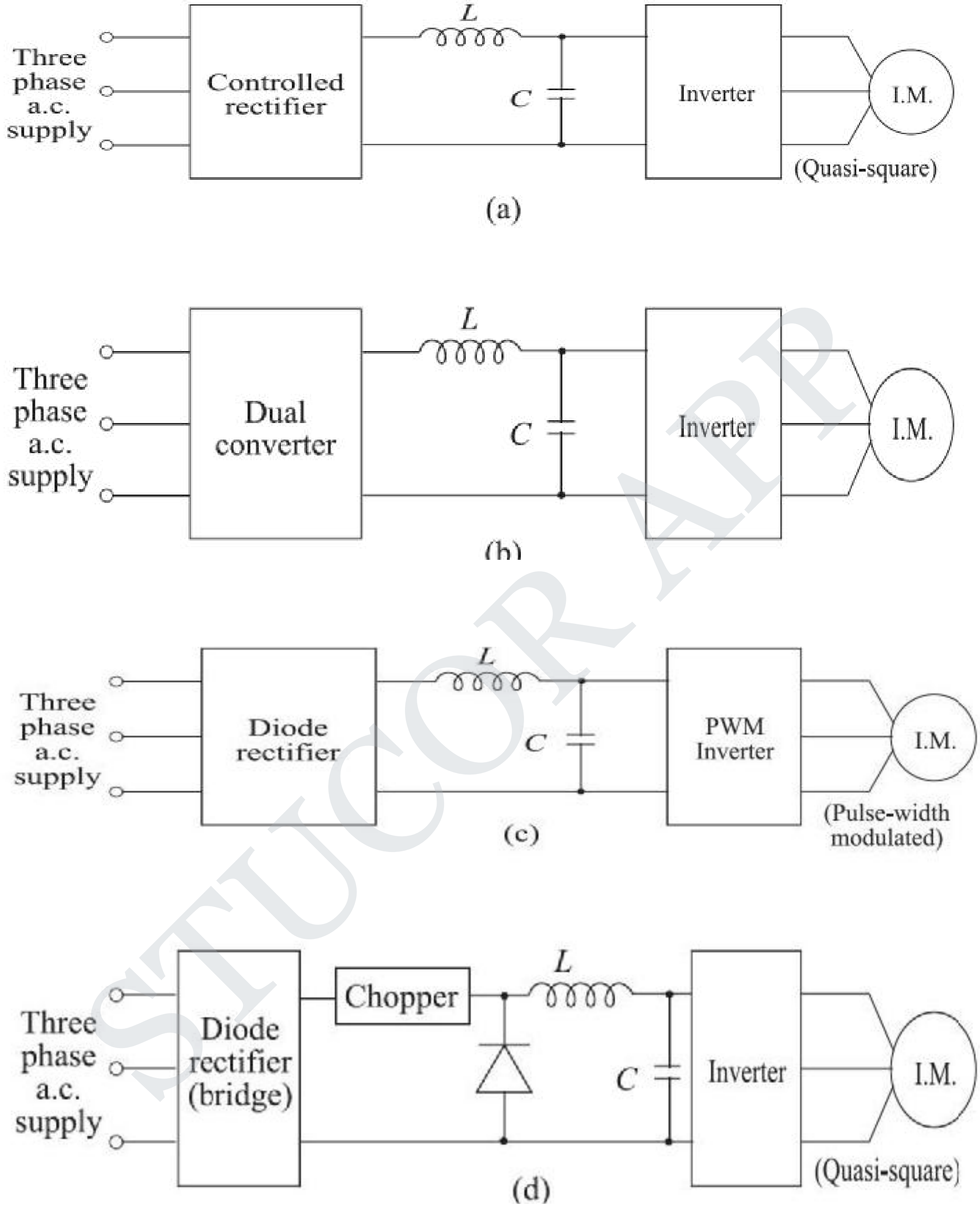
Speed torque characteristics of Constant V/ f Control

- The torque and speed of induction motors can be controlled by changing the supply frequency.
- We can notice from Eq. that at the rated voltage and rated frequency, the flux is the rated value.
- If the voltage is maintained fixed at its rated value while the frequency is reduced below its rated value, the flux increases.
- This would cause saturation of the air-gap flux, and the motor parameters would not be valid in determining the torque-speed characteristics.
- At low frequency, the reactances decrease and the motor current may be too high. This type of frequency control is not normally used.

 STUCOR APP
DOWNLOADED FROM STUCOR APP STUCOR APP

DOWNLOADED FROM STUCOR APP

Different configuration Inverter fed three phase induction motor



Various Configuration of Inverter fed three phase Induction Motor Drive

- In the stepped wave inverter the o/p frequency can be varied by varying T.
  - o/p voltage can be varied by varying i/p DC voltage.
- When the i/p voltage is DC
  - Variable DC i/p voltage is obtained by connecting a chopper b/w DC supply and inverter.

STUCOR APP
STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

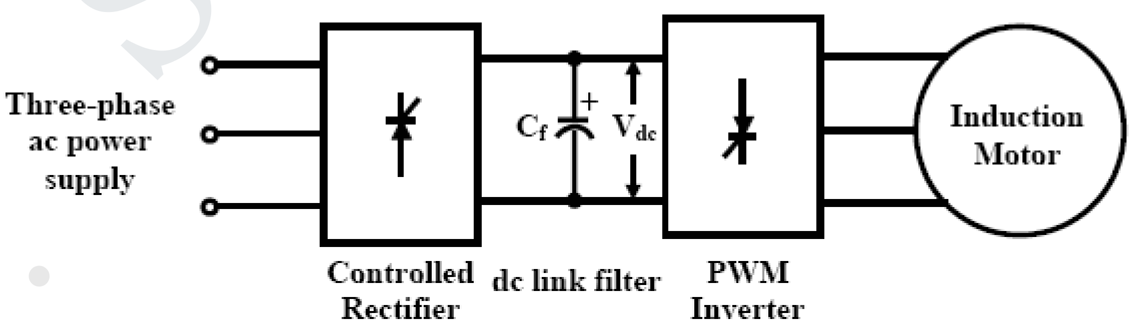
- Shown fig
- Here dc supply is given to the DC chopper
  - DC chopper – fixed DC to variable DC voltage
  - This voltage is fed to the filter
  - Filter – filter out the harmonics in DC link voltage
  - The DC voltage is fed to the six step inverter.
- The Inverter o/p voltage is variable fz variable voltage
  - It is fed to the 3Φ IM
- When the i/p voltage is **AC**
  - Variable DC i/p voltage is obtained by connecting a controlled rectifier b/w AC supply & inverter
  - It is shown in fig
- Here 3Φ AC supply is fed to the controlled rectifier
  - It converts fixed AC in to variable DC voltage
  - This voltage is fed to the filter
  - Filter reduces the harmonics
- The filtered o/p is fed to the inverter,
  - The inverter o/p voltage can be varied by varying DC voltage.
- The o/p frequency can be varied by time period of the inverter.

Variable voltage variable frequency (VVVF) Control

The VVVF AC drive is the power electronic controller used to control the speed of 3phase AC motors (Synchronous or Induction) by varying the frequency and the voltage applied to the motor terminals. Voltage and frequency relationship is decided based on the motor name plate data and the load characteristics.

Typical power circuit configuration involves three phase diode rectifier at the input, which converts the AC input to DC voltage. LC or C filter reduces the ripple in the DC voltage. Three phase IGBT AC drive stage converts this DC voltage into variable voltage variable frequency output as per the desired pattern

The variable voltage variable frequency supply (VVVF) for an induction motor drive consists of a uncontrolled (Fig.) or controlled rectifier (Fig.) (fixed voltage fixed frequency ac to variable/fixed voltage dc) and an inverter (dc to variable voltage/variable frequency ac). If rectification is uncontrolled, as in diode rectifiers, the voltage and frequency can both be controlled in a pulse-width-modulated (PWM) inverter as shown in Fig. The dc link filter consists of a capacitor to keep the input voltage to the inverter stable and ripple-free.



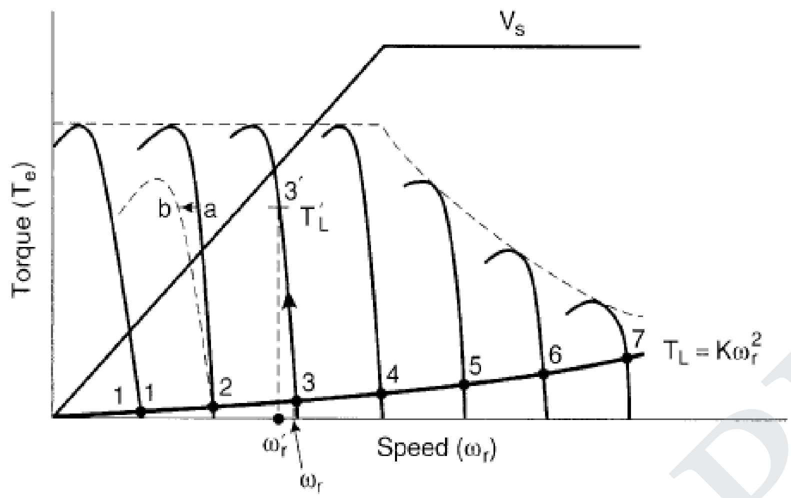
Variable Voltage Variable Frequency (VVVF) Induction Motor Drive

On the other hand, a controlled rectifier can be used to vary the dc link voltage, while a square wave inverter can be used to change the frequency. This configuration is shown in Fig. Variable Voltage Variable

STUCOR APP STUCOR APP STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

Frequency (VVVF) drive suitable for a motor operating at low speed where both voltage and frequency are simultaneously varied linearly.



Torque-speed curves showing effect of frequency variation, load torque, and supply voltage changes

Voltage Source Inverter Fed Three Phase Induction Motor (VSI)

- An inverter is defined as converter that **converts DC into AC.**
  - An inverter called VSI
  - If viewed from load side, the **AC terminals of the inverter function as a voltage source**. i.e., the i/p voltage should be constant
- The VSI has **low internal impedance.**
  - Because of this the terminal voltage of a VSI remains constant with variations in load
- VSI allows a variable fz supply to be obtained from a DC supply.
- MOSFETs is used in low voltage & power inverters
  - Power transistor & IGBT – medium power level
  - GTOs, IGCTs – high power level
- Fig shows a VSI employing IGBTs
- Voltage source inverter can be operated as a
  - **Stepped wave inverter or**
  - **PWM inverter**
- Inverter operated as a stepped wave inverter,
  - IGBTs are switched in the sequence of **T/6**
  - Each IGBT is kept an duration **T/2**

  - Fig shows stepped wave inverter line voltage waveform

One of the most common converter topologies that is very widely used in industry is shown in this figure. It consists of a three-phase bridge inverter with a three-phase diode rectifier in the front end or Battery Source. The rectifier (which can be single or three-phase) converts ac to uncontrolled dc. The harmonics in the dc link are filtered by an *LC* or *C* filter to generate smooth voltage V_d for the inverter. The inverter consists of three half-bridges or phase legs to generate three-phase ac for industrial motor drives or other applications.

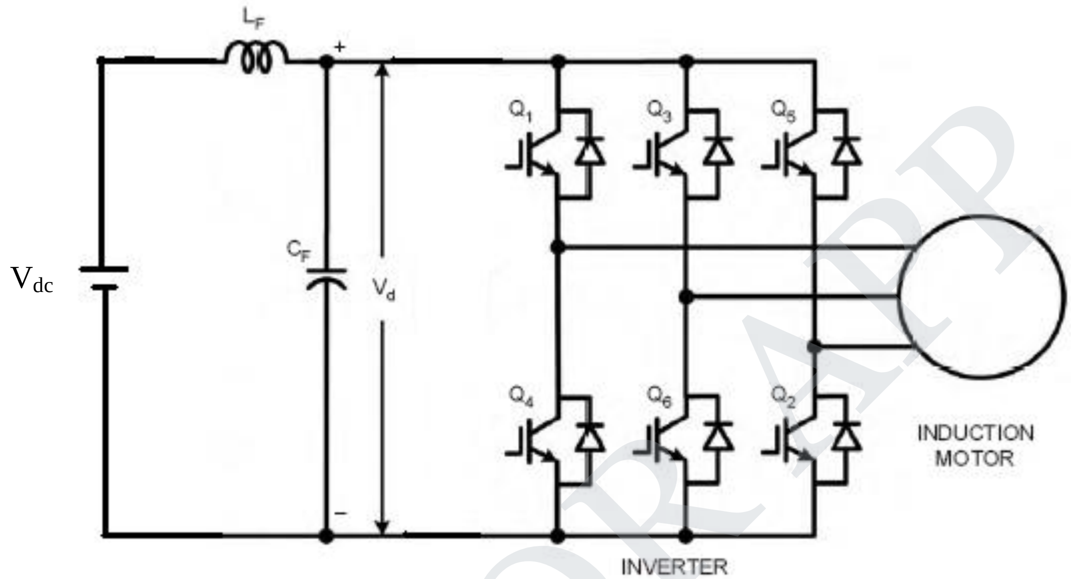
In all such cases, V_d is usually unregulated. The battery-fed inverter drive is commonly used for electric/hybrid vehicle drives. Note that because of the diode rectifier in the front end, the converter system

DOWNLOADED FROM STUCOR APP STUCOR APP

DOWNLOADED FROM STUCOR APP

cannot regenerate power. The filter capacitor C_F sinks the harmonics from the rectifier as well as inverter sides.

The three-phase inverter of Fig. can be operated in either the square-wave or PWM mode. The waveforms in square-wave mode are explained in this figure. Three phase legs of the inverter generate square waves at 120° mutual phase-shift angle, where the output phase voltage magnitudes ($\pm 0.5V_d$) are shown with respect to the artificial dc link center point. The line voltages v_{ab}, v_{bc}, and v_{ca} are constructed by subtracting the adjacent phase voltages.



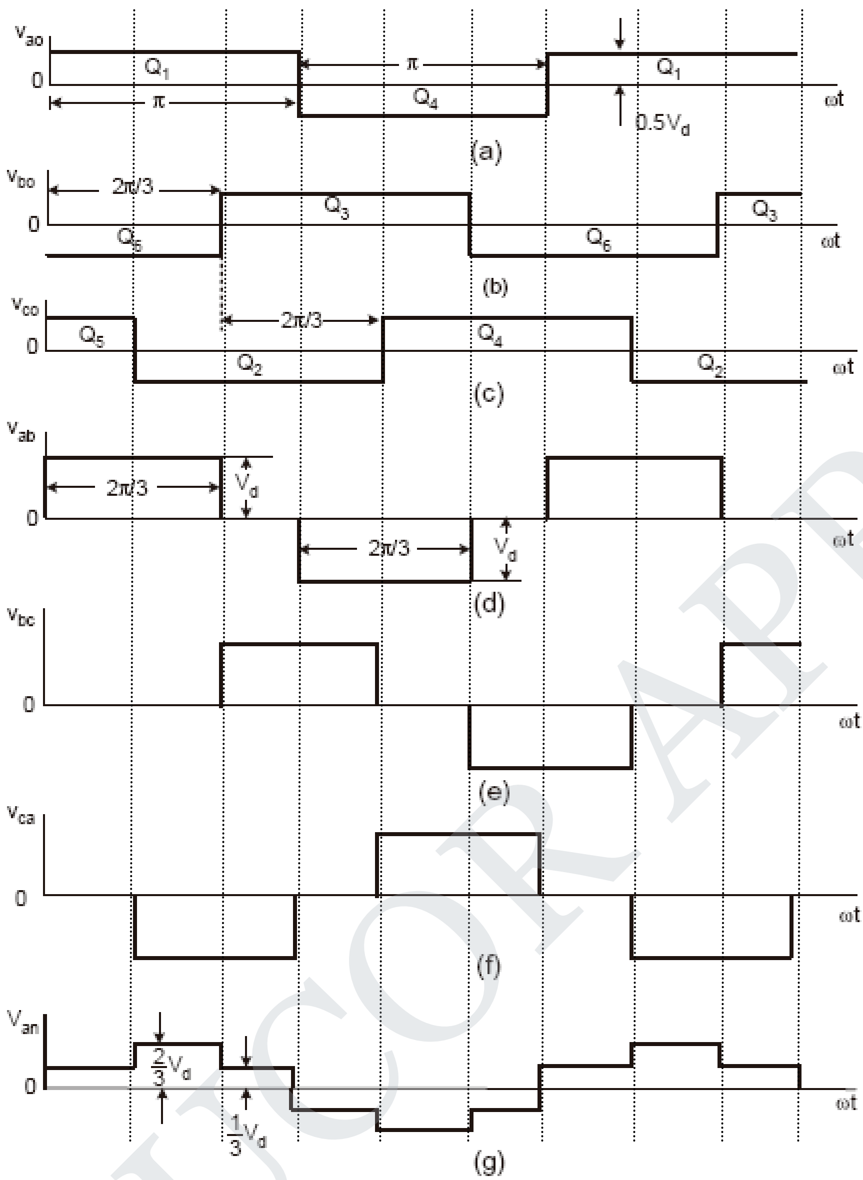
Voltage source inverter fed three phase induction motor

For an isolated neutral Y-connected load, the phase voltage wave v_{an} due to the absence of triplen (third or multiple of third) harmonics. The line and load phase voltages have characteristic six-step wave shapes with suppression of triplen harmonic voltages. With three-phase balanced load, the line currents are also balanced but may be rich in harmonics. In the square-wave mode, output voltage control is not possible by the inverter and V_d variation reflects to the output.

$$v_{an} = \frac{2}{3}v_{ao} - \frac{1}{3}v_{bo} - \frac{1}{3}v_{co}$$

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP



Three-phase bridge inverter output voltage waves in square-wave (or Six-step) mode.

Cycloconverter Fed Induction Motor Control

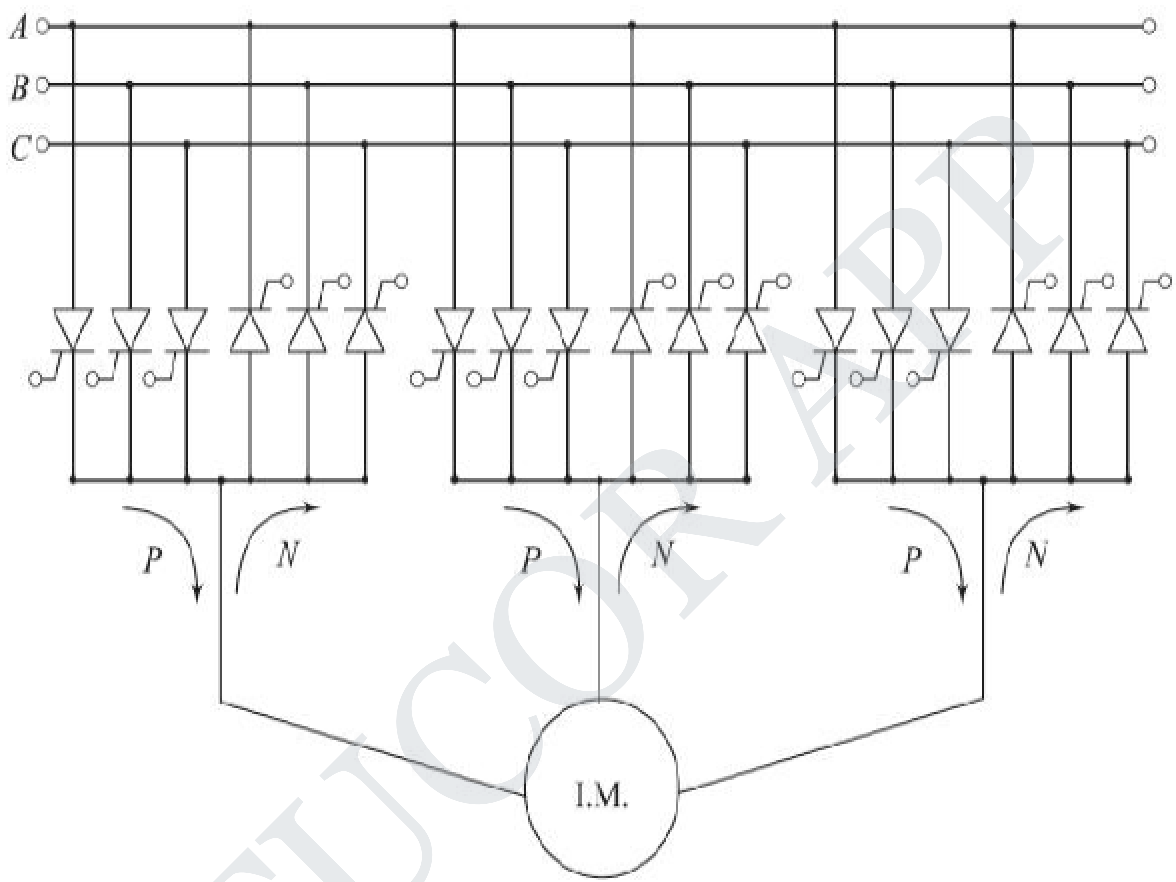
Variable frequency supply to an induction motor may be obtained using a cycloconverter. A three phase three pulse cycloconverter feeding a three phase induction motor is shown in fig.

- AC power at one frequency is converted directly to an AC power at another frequency without any intermediate DC stage.
- The output of cycloconverter provides ac power at a lower frequency than input.
- Bidirectional power-flow is possible.
- Able to operate with loads of any power factor.
- Generally, output frequency is lower than source frequency.
- Input power factor is worse if the fabricated output voltage is decreased.
- The voltage control is possible in the converter itself, so that the machine operates at its rated flux conditions.

DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

- The output frequency of the cycloconverter is limited to 1/3 of input frequency. A speed control range of 0-33% of base speed is possible.
- It requires many thyrister and it operates by means of line commutation. No need of forced commutation.
- The cycloconverter fed induction motor drive show that it provides a very smooth low speed operation with the least torque ripple.
- The cycloconverter is capable of power transfer in either direction between an ac source and motor load.



Cycloconverter Fed Induction Motor Control

During first half cycle P-converter alone (P - positive) ON state, hence output is positive and during second half cycle N-converter alone (N - negative) ON state, hence output is negative.

The output frequency $f_0 = \frac{1}{T_0}$ whrer T_0 – is time period

The firing angle of P-converter is $\alpha_P = T_0 / 2$
The firing angle of N-converter is $\alpha_N = T_0 / 2$
Total firing angle $\alpha_P + \alpha_N = \pi$ Also, $\alpha_N = \pi - \alpha_P$

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

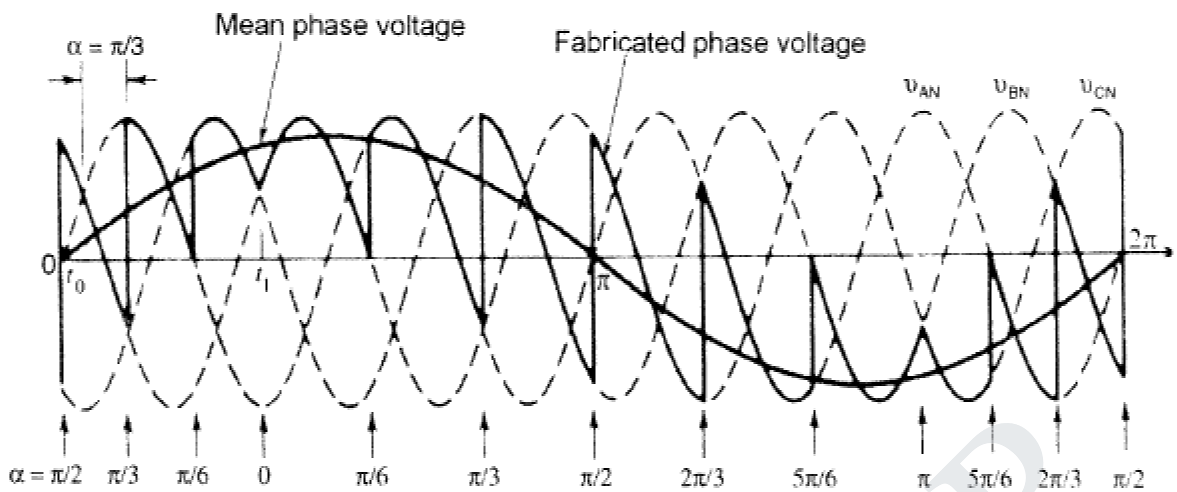


Figure 4.12 Phase-controlled fabrication of output voltage wave in three-phase, half-wave cycloconverter

Advantages of Cycloconverter

- Direct frequency conversion without any intermediate stage.
- Natural commutation – Compact system.
- Power transfer in either direction.
- Operates in any p.f.
- Capable of regeneration over the complete speed range, down to standstill.
- Commutation failure leads only to blown-off of individual fuses only.
- Delivers a high quality sinusoidal waveform at low output frequencies - since it is fabricated from a large number of segments of the supply waveform.
- This is often preferable for very low speed applications.

Disadvantages of Cycloconverter

- Large number of thyristors are required in a cycloconverter.
- Complex control circuitry.
- The output frequency is limited to one third of the input frequency. (For reasonable power output and
- efficiency)
- The power factor is low, particularly at reduced output voltages.

Applications

- Speed control of drives.
- Variable input frequency, constant frequency output. (constant frequency power supplies)
- Induction heating. (Low frequency 3- phase to high frequency 1-phase AC)

Drawbacks of stepped wave (VSI) inverter:

- Large harmonics of low fz in the o/p voltage.
- Because of low fz harmonics, the motor losses are increased.
- Motor develops pulsating torque due to 5th, 7th, 13th harmonics.
- Harmonic content in motor current increases at low speed and the m/c saturated at light loads at low speeds due to high (V/f) ratio.
    - These two effects overheat the m/c at low speeds.
- The above drawbacks are eliminated by using PWM inverter.

STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

The advantages of PWM inverters are,

- Harmonics are reduced
- Losses are reduced
- Smooth motion is obtained at low speeds.

- Fig shows o/p voltage waveform for sinusoidal PWM
- By using this method, the inverter o/p voltage and fz can be controlled.
  - There is no need of external control
  - V/f can be controlled inverter itself.
- When the i/p voltage is DC, it is directly connected to the PWM inverter.
  - It is shown in fig
- When the i/p voltage is AC, DC supply is get from a diode bridge rectifier.
  - It is shown below
- Here 3Φ supply is fed to the diode bridge rectifier
  - It converts fixed AC to fixed DC voltage
  - This voltage is fed to the filter and then PWM inverter
  - PWM inverter gives variable an V & f
  - By changing the v & f the motor speed can be controlled.

Static Rotor Resistance Control

If the three phase resistor in the circuit of Fig. replaced by a three phase bridge rectifier and chopper, then it is possible to vary the speed of the induction motor by varying the duty cycle of the chopper. The fraction of the air gap power which is not converted to mechanical power is known as slip power. This power is dissipated in the resistor *R*. The slip power control of induction motors in illustrated in Fig. When the chopper is OFF (is blocked)? then the effective rotor resistance is *R*. When the chopper is ON (i.e. conducting switch) the effective rotor resistance is $R = 0$. If T_{on} and T_{off} are the 'ON' and 'OFF' time periods respectively, then the effective value of resistance is *R*

$R_{eff} = (1-\delta)R$ Where, δ or α is duty cycle or ratio = T_{on} / T $(\because T = T_{ON} + T_{OFF})$

The effective rotor resistance can be adjusted by varying the time periods T_{on} and T_{off}. Speed control below synchronous speed is obtained, by controlling the slip power. If the slip power is made to return to the mains, then the speed control system can become an efficient one and the capacity of the drive can be increased.

- They are also used for starting high-power induction motors to limit the in-rush current.
- This method increases the starting torque while limiting the starting current.
- However, this is an inefficient method and there would be imbalances in voltages and currents if the resistances in the rotor circuit are not equal.
- A wound-rotor induction motor is designed to have a low-rotor resistance so that the running efficiency is high and the full-load slip is low.
- The increase in the rotor resistance does not affect the value of maximum torque but increases the slip at maximum torque.
- The wound-rotor motors are widely used in applications requiring frequent starting and braking with large motor torques (e.g., crane hoists).
- Because of the availability of rotor windings for changing the rotor resistance, the wound rotor offers greater flexibility for control.
- However, it increases the cost and needs maintenance due to slip rings and brushes.
- The wound-rotor motor is less widely used as compared with the squirrel-case motor.

DOWNLOADED FROM STUCOR APP STUCOR APP

DOWNLOADED FROM STUCOR APP

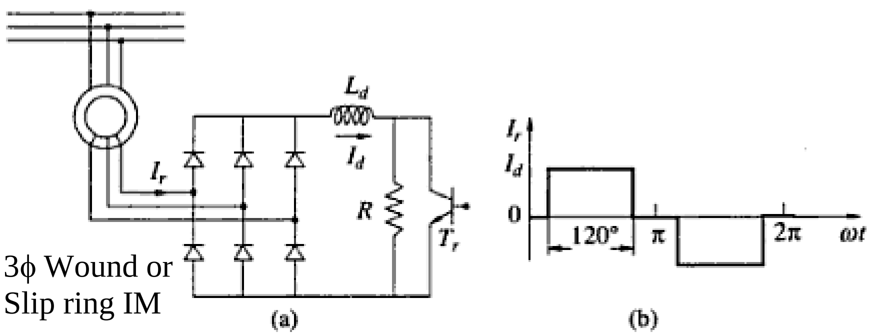
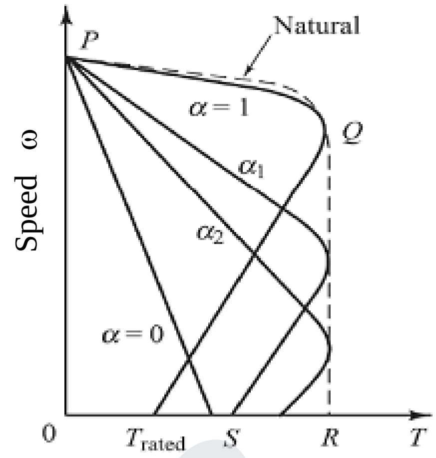


Fig. 7.17 Chopper control of rotor resistance.



$1 > \alpha_1 > \alpha_2 > 0$

Advantages

1. High initial torque at lower values of initial current
2. Wide rang of speed control
3. Improved power factor
4. Smooth speed and resistance control

Static Kramer drive

The slip power in the rotor circuit of an induction motor can be returned to the supply by replacing the chopper and resistance R_o in Fig. with a three-phase full converter as shown in Fig.

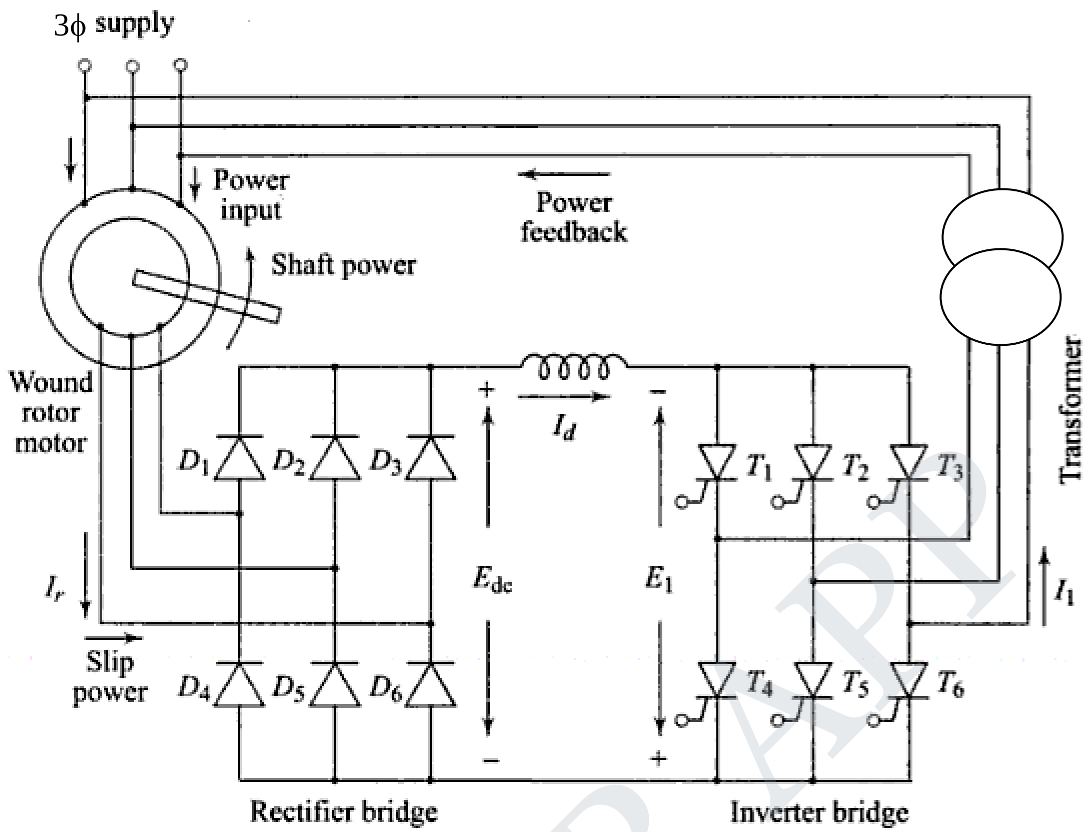
The combination of the diode rectifier and phase controlled inverter is called a converter cascade (or) sub synchronous cascade. The diode rectifier rectifies the slip frequency voltage of the rotor. The output of this rectifier is connected to the phase controlled thryristor bridge which operates as an inverter. The slip power is returned back to the supply through the transformer.

Rectifier is connected to inverter through a smoothing inductor L. The phase control of the inverter brings in speed control. For the inverter, the firing angle α will be large so that substantial power is fed back to the AC power bus. A large value of α will result in a poor operating power factor. As the slip power is returned to the mains, the machine has fairly good efficiency. The machine always operators with nearly constant air gap flux, as decided by the fixed stator voltage-and frequency.

The losses in the circuits cause a slight reduction in efficiency. This efficiency is further affected by additional losses due to the non- sinusoidal nature of the rotor current. Therefore the drive motor must be slightly over dimensioned. The motor used must have a rating 20% higher than the required power. Constant power control is obtained by Static Kramer Drive.

STUCOR APP
DOWNLOADED FROM STUCOR APP
STUCOR APP

DOWNLOADED FROM STUCOR APP



Static Kramer Drive

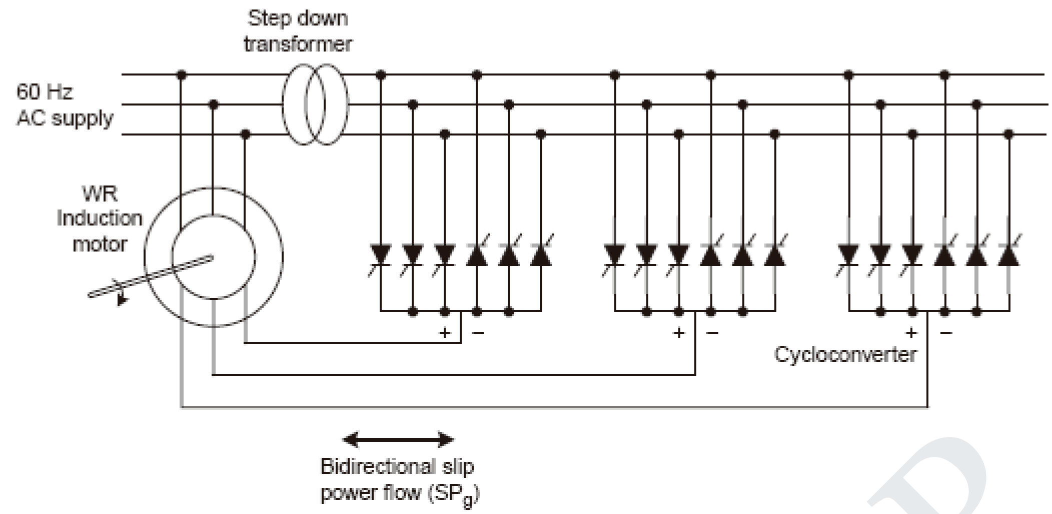
Static Scherbius drive

In a Scherbius drive, as shown in this figure, the converter system in the Kramer drive is replaced by a phase-controlled cycloconverter (CCV) so that slip power can be controlled to flow in either direction. With bidirectional power flow capability, the drive cannot only be controlled for motoring and regeneration, but for sub-synchronous as well as super synchronous speed regions as well. The range of speed, however, typically remains limited within •}50% of synchronous speed. The speed reversal is not possible (as is Kramer drive) because it requires reversal of stator supply voltage phase sequence.

The CCV is expensive and has control complexity, but the advantages are a near-sinusoidal rotor current that gives reduced harmonic loss and a machine over excitation capability that permits leading power factor operation on the stator side. In fact, CCV's input lagging DPF can be canceled by machine leading DPF so that the line PF can be unity or leading. In addition, true synchronous speed operation of the drive is possible when the CCV operates as a rectifier to generate dc excitation current for the machine. During the drive operation, the CCV output frequency and phase should closely track those of the rotor output. The step-down transformer at the input reduces the input voltage so that CCV can operate at the best DPF for the speed range of operation. Unfortunately, like a Kramer drive, the drive also requires separate resistive starting.

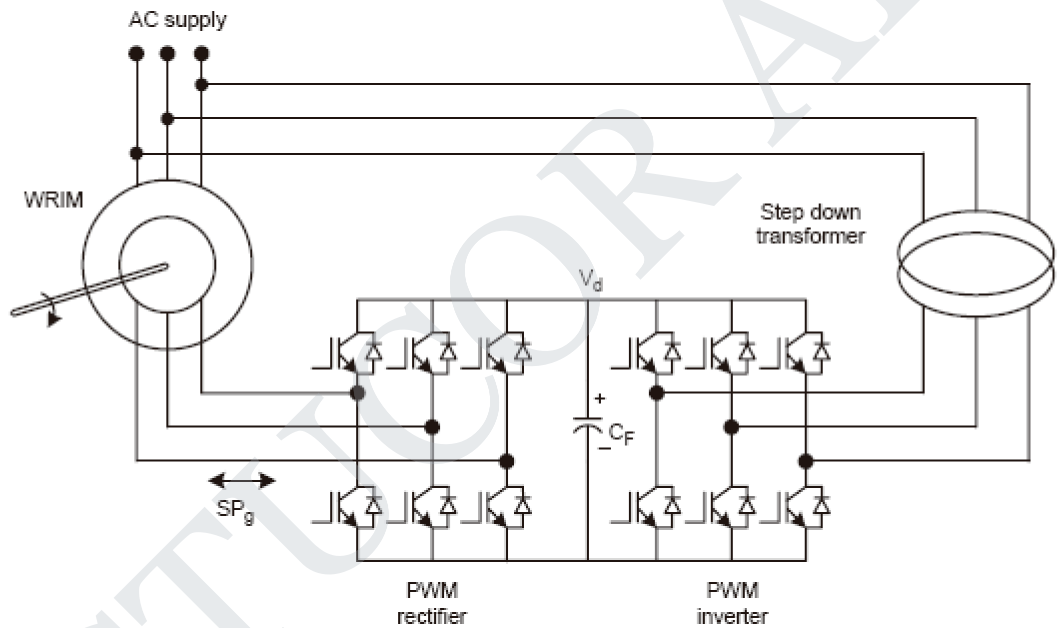
STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP



Cycloconverter Fed Static Scherbius Drive

PWM Converter fed Static Scherbius drive



PWM Converter fed Static Scherbius drive

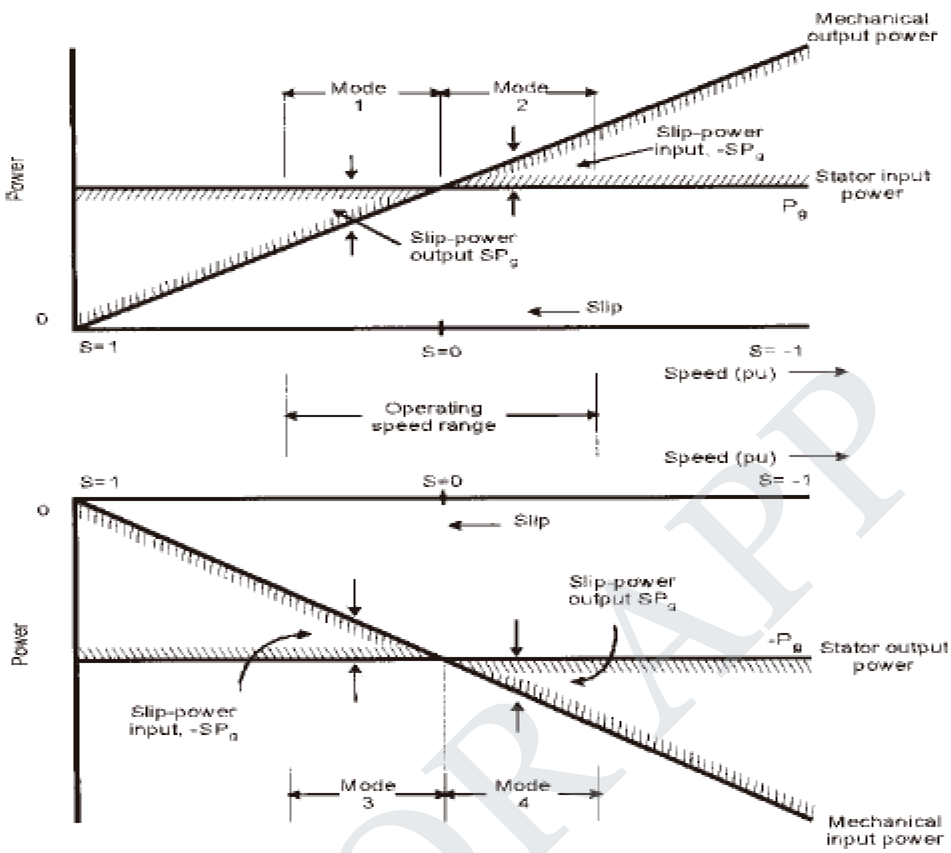
The CCV-based Scherbius drive system discussed in earlier figures can offer improved performance if the CCV is replaced by the two-sided PWM voltage-fed converter system shown in this figure. The slip power can be controlled to flow in either direction and vector control can be easily applied to both converters. DC link voltage V_d should be sufficiently high so that both the line-side and machine-side converters can always operate in under modulation mode (buck mode with respect to the dc link) to fabricate sinusoidal machine and line currents.

The PWM rectifier can easily track the variable frequency, variable-magnitude slip voltage including the ideal dc condition at synchronous speed. This is basically dc-dc converter mode operation of the rectifier. The line-side step-down transformer helps keep the converter rating low with reasonably low V_d. Note that the machine stator-side DPF is always lagging, but the line-side converter can be controlled to be leading so that the total DPF can be maintained at unity.

STUCOR APP
STUCOR APP
DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

FIGURE 7.46 Modes of operation of a static Scherbius drive.



MODE 1: SUBSYNCHRONOUS MOTORING
MODE 2: SUPERSYNCHRONOUS MOTORING
MODE 3: SUBSYNCHRONOUS REGENERATION
MODE 4: SUPERSYNCHRONOUS REGENERATION

Two Mark Questions

1. What are the methods of speed control which can be applied from stator side of induction motor?
2. What are the methods of speed control which cannot be applied from rotor side of induction motor?
3. Why the variable voltage method is very rarely used?
4. Mention one application area of variable frequency control.
5 Mention the types of schemes under slip power control. .
6. What are the limitations of the method of speed control by changing number of poles?
7. What is slip power control?
8. What are the three methods used in cascading of induction motors.
9. What is Slip Power Recovery Scheme?
10. Mention the two types of schemes under Slip power recovery.
11 Where and when stator voltage control is employed.
12. What is V*If* control scheme applied to 3-phase Induction motor?.
13. What is the drawback of V*If* control scheme?

DOWNLOADED FROM STUCOR APP

DOWNLOADED FROM STUCOR APP

Part – B Questions

1. Draw the power circuit arrangement of three phase variable frequency inverter for the speed control of three phase induction motor and explain its working. (16)
2. Explain the V/f control method of AC drive with neat sketches. (16)
3. Discuss the speed control of AC motors by using three phase AC Voltage regulators. (16)
4. Explain the speed control schemes of phase wound induction motors. (16)
5. Explain the concatenation operation of three phase induction motors. Hence derive the speed experienced for the cascaded set. (16)
6. Explain in detail about Slip power recovery scheme. (16)
7. Explain the different methods of speed control used in three phase induction motors. (16)
8. Explain the working of following methods with neat circuit diagram.
   i) Kramer system ii) Scherbius system (16)
9. Explain in detail rotor resistance method of speed control of a slip ring induction motor. (16)
10. (i) Explain the operation of Pole changing method of speed control. (8)
    (ii) Explain the pole amplitude modulation method. (8)
11. Explain the static Kramer method and static Scherbius method of speed control of three phase induction motor. (16)
12. Explain in detail about the various methods of solid state speed control techniques by using inverters. (16)
13. Explain the solid state stator voltage control technique for the speed control of three phase induction motor. (16)
14. Explain the various methods of speed control of a three phase induction motor when fed through semiconductor devices.

STUCOR APP

 STUCOR APP
DOWNLOADED FROM STUCOR APP