DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

Subject Name: Solid State Drives **Subject Code: EE T72**

UNIT I:

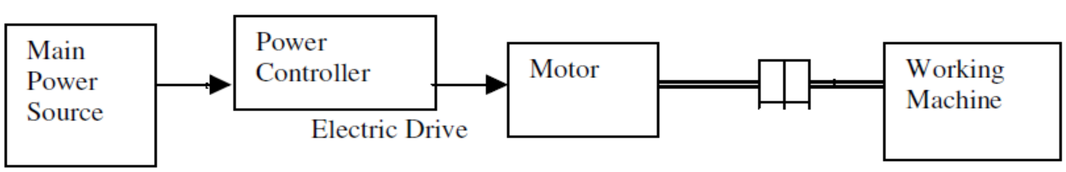
DRIVE CHARACTERISTICS

Characteristics of mechanical system- requirement of drive characteristics -selecting the drive elements- modeling of dc motor-selection of motor rating-P, PI and PID controllers-constant HP and constant torque operations.

TWO MARKS

1. **What is meant by electrical drives?**
Systems employed for motion control are called drives and they employ any of the prime movers such as diesel or petrol engines, gas or steam turbines, hydraulic motors and electric Motors for supplying mathematical energy for motion control. Drives employing electric motion are called electric drives.

2. **Draw the electric drive system?**



3. **Specify the functions of power modulator?**
Power modulator performs one or more of the following four functions.
   a) Modulates flow of power form the source to the motor in such a manner that motor is imparted speed-torque characteristics required by the load.
   b) During transient operations, such as starting, braking and speed reversal, it restricts source and motor currents within permissible values; excessive current drawn from source may overload it or may cause a voltage dip.

4. **Mention the different types of drives and define it?**
   i **Group drive**
   A system where many machines are drived on one shaft and driven by a single electric motor is called group drive.

ii Individual drive

If a single electric motor is used to drive a single machine and all connected mechanisms belonging to the same machine then the system is called individual drive.

iii Multimotor drive

If in a system, a separate motor is provided for driving the separate mechanism, the system is called multimotor drive.

5. What are the advantages of electric drives?

- i They have flexible control characteristics. the steady state and dynamic characteristics of electrical drives can be shaped to satisfy load requirements.
- ii Drives can be provided with automatic fault detection systems, programmable logic controllers and computers can be employed to automatically ctrl the drive operations in a desired sequence.
- iii They are available in which range of torque, speed and power.
- iv It can operate in all the four quadrants of speed-torque plane. Electric braking gives smooth deceleration and increases life of the equipment compared to other forms of braking.
- v Control gear required for speed control, starting and braking is usually simple and easy to operate.

6. What are the functions performed by electric drives?

Various functions performed by electric drives include the following.

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

7. What are the disadvantages of electric drives?

The disadvantages of electric drives.

- i Electric drives system is tied only up to the electrified area.
- ii The condition arising under the short circuits, leakage from conductors and breakdown of overhead conductor may lead to fatal accidents.
- iii Failure in supply for a few minutes may paralyses the whole system.

8. What are the advantages of group drive over individual drive?

The advantages of group drive over individual drive are

- i Initial cost: Initial cost of group drive is less as compared to that of the individual drive.
- ii Sequence of operation: Group drive system is useful because all the operations are stopped simultaneously.
- iii Space requirement: Less space is required in group drive as compared to individual drive.
- iv Low maintenance cost: It requires little maintenance as compared to individual drive.

9. Mention the different factors for the selection of electric drives?

1) Steady state operation requirements.

2) Transient operation requirements.
3) Requirements related to the source.
4) Capital and running cost, maintenance needs life.
5) Space and weight restriction.
6) Environment and location.
7) Reliability.

10. Mention the parts of electrical drives.

1) Electrical motors and load.
2) Power modulator
3) Sources
4) Control unit
5) Sensing unit

11. Mention the applications of electrical drives

Paper mills
Electric traction
Cement mills
Steel mills

12. Mention the types of enclosures

Screen projected type
Drip proof type
Totally enclosed type
Flame proof type

13. What is meant by regenerative braking?

Regenerative braking occurs when the motor speed exceeds the synchronous speed. In this case the IM runs as the induction m\c 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.

14. What is meant by dynamic braking?

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

15. What is meant by plugging?

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

16. What are the methods by which the power rating of the motor is determined?

(i). Average losses method

In this case, the motor having its rated losses equal to the average of the losses of the motor for variable load cycle, is selected for driving the load.

(ii). Equivalent current method

The motor selected should have a current rating more than or equal to the current. It is also necessary to check the overload of the motor. This method of determining the power rating of the motor is known as equivalent current method.

(iii). Method of equivalent power and torque

The motor selected should have a power and torque rating more than or equal to the equivalent power and torque. It is also necessary to check the overload of the motor.

17. Define cooling time constant

It is defined as the ratio between C and A. Cooling time constant is denoted as Tau

Tau = C/A

Where, C=amount of heat required to raise the temp of the motor body by 1 degree Celsius

A=amount of heat dissipated by the motor per unit time per degree Celsius.

18. Define four quadrant operations.

The 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 mathematical energy into electrical energy and thus opposes the motion. Motor can provide motoring and braking operations for both forward and reverse directions.

19. What is meant by mechanical characteristics?

The curve is drawn between speed and torque. This characteristic is called mechanical characteristics.

Eleven Marks

1. DRAW AND EXPLAIN THE BLOCK DIAGRAM OF GENERAL ELECTRIC DRIVE SYSTEM. (APRIL/MAY 2012) & (NOV/DEC 2013)

A drive is a combination of various systems combined together for the purpose of motion control (or) movement control. Especially the drives which employes election motor for motion control are known as Electrical Drives.

An electrical drive which employs solid state devices like thyristors for their control operation are termed as SOLID STATE DRIVES

1. These electrical drives are well established in the industries due to their uncomparable advantages and special features
2. Electrical drives mostly used and placed in starting control, braking, speed control and speed reversal.

GENERAL ELECTRIC DRIVE SYSTEM

The block diagram of electric drive system is shown below

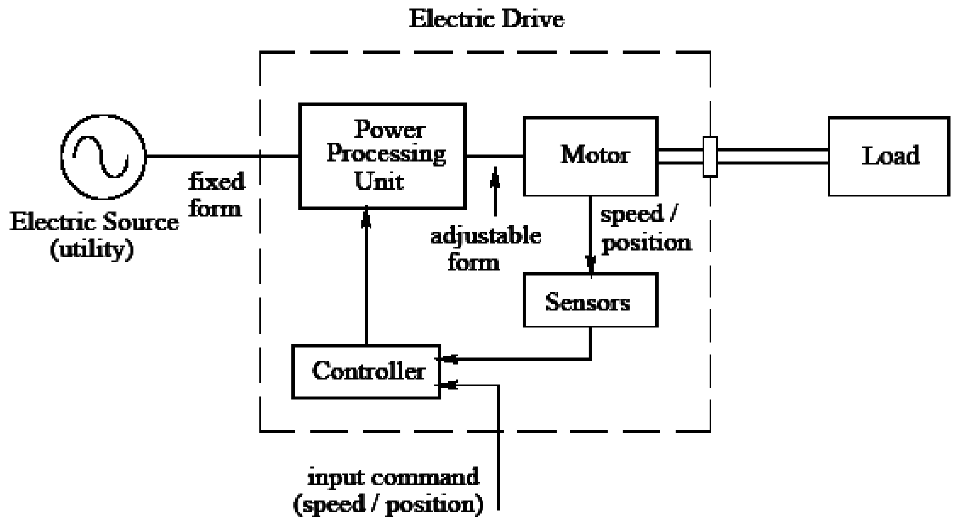


Fig 1.1 General Electrical Drive

COMPONENTS OF ELECTRICAL DRIVES

An electrical drive has the following major components.

1. Electrical motors and load
2. Power modulator
3. Source
4. Control unit
5. Sensing unit

1. ELECTRICAL MOTORS

The possible form of drive motors are
(a). Dc motor fed from DC supply (chopper)
(b) Dc motor fed from AC supply (rectifier)
(c) Ac motor fed from AC supply (AC regulator)
Most commonly used electrical drives are
DC MOTORS

1. Shunt motor
2. Series motor
3. Compound motor
4. Permanent magnet motor

AC MOTORS

INDUCTION MOTORS

1. Squirrel cage IM
2. Wound rotor IM
3. Linear IM

SYNCHRONOUS MOTORS

1. Wound field motor
2. Permanent magnet motor

Brushless dc motors Stepper motors Switched reluctance motors

2. POWER MODULATORS

Power modulators can be classified in to three kinds. Some drives may employ more than one of these modulators.

a. Converters
   1. AC to DC converters (Rectifiers)
   2. AC regulators (AC to AC)
   3. DC to SC converter (choppers)
   4. Inverter (DC to AC)
   5. Cyclo converter (frequency changer)

b. Variable Impedances
   Variable resistors are commonly used for the control of low cost DC and AC drives and also need for dynamic braking of drives.

c. Switching Circuits
   Switching operations are required to achieve any one of the following
   - For changine motor connections to change its quadrant of operations
   - For operating motor circuit parameters in discrete steps for automatic starting and braking control
   - For operating motors and drives according to a predetermined sequence
   - To provide interlocking to prevent mal operation
   - To disconnect motor when abnormal operating conditions occur.

3.SOURCES

- Very low power drives are generally fed from single phase source
- All other drives are power from 3 phase source
- Low and medium power motors are fed from 400 V supply
- Some drives are power from a battery. Eg. Fork lift truck and milk van

4.CONTROL UNIT

Controls for a power modulator are provided in the control unit. Nature of the control unit for a particular drive depends on the power modulator that is used. When semiconductor converter are used, the control unit will consists of firing circuits, which employ linear and digital integrated circuits and transistors and a microprocessor when sophisticated control is required.

5.SENSING UNIT

In this unit, there are two functions are performed i. Speed Sensing ii. Current Sensing

- **SPEED SENSING**

  Speed sensing is required for implementation of closed loop speed control schemes. Speed is usually sensed by Tachometers. When very high speed accuracies required, as in computer peripherals and paper mills, etc., digital tachometers are used

- **CURRENT SENSING**

  Current sensing employs two methods

  1. Use of current sensor employing hall effect

2. It involves the use of a non-inductive resistance shunt in conjunction with an isolation amplifier which has an arrangement for an amplification and isolation between power and control circuits.

ADVANTAGES OF ELECTRICAL DRIVES

1. Availability of simple and easy speed control methods.
2. Electric braking is easily employed
3. Operation is pollution free
4. Efficiency is higher
5. No load losses are less

APPLICATIONS OF SOLID STATE DRIVES

The major industrial applications of solid state drives are

- Steel rolling mills
- Paper mills
- Cement mills
- Oil drilling
- Printing machine
- Induction heating
- Resistance welding equipment
- UPS
- Fore-lift trucks
- Cranes and lifts
- Battery charger
- Fan drives
- DC transmission
- Voltage regulators
- Robots etc

2.DIFFERENTIATE BETWEEN DC AND AC DRIVES IN DETAIL. (APRIL/MAY 2014).

The possible forms of Electric drive motors are

i. DC motors – Dc drives
ii. AC motors – Ac drives

COMPARISON OF DC AND AC DRIVES

DC DRIVES	AC DRIVES
The commutator makes the motor bulky, costly and heavy	Motors are inexpensive, particularly squirrel cage motor
The converter technology is well established.	The power circuit of the converter and its

The power converter is simple and inexpensive	control are complex
Line commutation of the converter is used	Forced commutation is used with induction motor
Line conditions are very poor. Ie. Poor harmonic, poor power factor	For regenerative drives the line power factor is poor. For non regenerative drives the power factor is better
Small power/weight ratio	Large power/weight ratio
Cost doesnot depend on the solid state converter	Solid state converter employed also decides the cost
Fast response and wide speed range smooth control	Response depends upon the type of control with solid state converters, the speed range is wide
Sparkling at the brushes makes it environmentally unsuitablein certain locations. The commutator requires frequeny maintenance.	This kind of problem are not here. Motor is relieable, required little maintenance and can use in all locations.

3. EXPLAIN THE DIFFERENT KINDS OF ELECTRIC DRIVES SYSTEM. (NOV/DEC 2015)

There are three kinds of industrial devices, indicating the trends in the form of advancement. These are

1. Group drive
2. Individual drive
3. Multi-motor drive

GROUP ELECTRIC DRIVE

- This group electric drive has a single motor of sufficient capacity to drive an entire group of machine used. The motor was connected to a line shaft and through the use of belts and pulleys all the machines were driven
- This form of drive was very inefficient, difficult to control and unsafe. Eg. Rice mill machine

INDIVIDUAL ELECTRIC DRIVE

- ✶ In this form of electric drive one motor is connected for each working machine.
- ✶ The electric motor is an internal parts of the machine and can be specially designed to the needs of that machine

MULTI MOTOR DRIVE

- ✶ This type of drive ahs more than one motor for each working machine.
  e.g. metal cutting machine tools, paper making machines and rolling mills, etc.

4. EXPLAIN THE CHOICE (OR) SELECTION FACTORS FOR ELECTRICAL DRIVES (APRIL/MAY 2014)

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

(i) Steady State operation requirements

- Nature of speed-torque characteristics
- Speed Regulation
- Speed range
- efficiency
- Duty cycle
- Quadrants of operation
- Speed fluctuations

(ii) **Transient operation requirements**

– value of acceleration and deceleration
– starting
- braking and reverse operation

(iii) **Requirements related to the source**

- types of source
- magnitude of voltage
- voltage fluctuations
- power factor
- harmonics

(iv) **Other factors**

- capital and running cost
- space& weight restrictions
- environment and location
- reliability

5.ExPLAIN THE FOUR QUADRANT OPERATION OF A DRIVE WITH THE HOIST LOAD. (NOV /DEC 2015) & (APRIL /MAY 2014)

- A motor can be operated in two modes – i. Motoring ii. Braking
- In motoring, it converts electrical energy into mechanical energy which supports its motion
- In braking, it works as a generator which converts mechanical energy into electrical energy which opposes its motion
- This multiquadrant operation of drive will be useful to establish suitable convertions about the signs of torque and speed.
- The power developed by a motor is given by the product of torque and speed

POWER = TORQUE X SPEED

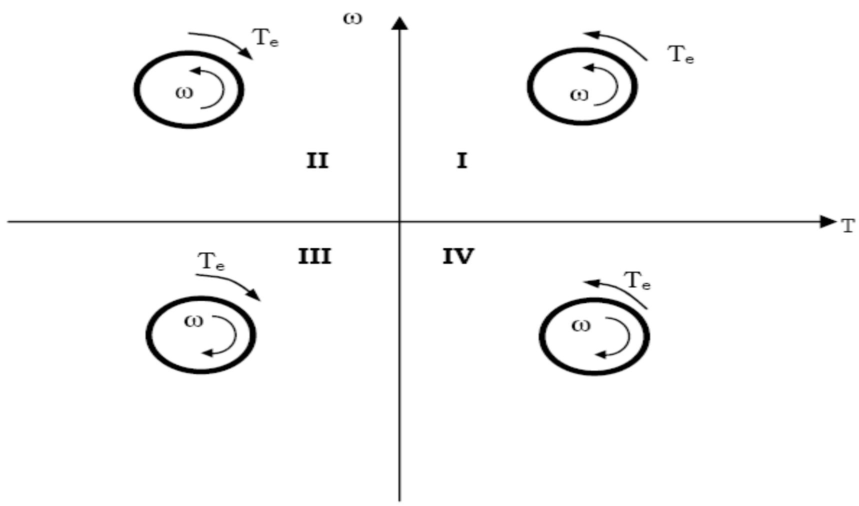


Fig 1.2 Four Quadrant Operation of A Drive

FIRST QUADRANT

Motor drive electrical power to drive the mechanical load in the first quadrant

POWER = Torque * speed

= (+ve) * (+ve)

POWER = +ve* (Forward Motoring)

SECOND QUADRANT:

✶ The operation is braking because in this part of the torque-speed plane, the direction of rotation is positive (+ve) and torque is negative (-ve).

- The machine operates as a generator developing a counter torque which opposes motion

POWER = Torque * speed

= (-ve) * (+ve)

POWER = -ve* (Forward braking)

THIRD QUADRANT

- The operation corresponds to motor action in the reverse direction both speed and torque have negative values, while power is positive. Here, direction of rotation is reversed.

POWER = Torque * speed

= (-ve) * (-ve)

POWER = +ve (reverse motoring)

FOURTH QUADRANT

- In this quadrant, speed will be in negative (-ve). i.e. the direction of rotation is negative, but torque will be positive (+ve)
- The motor must develop a torque which opposes the acceleration due to load. The motor acts as a brake.
- This quadrant corresponds to braking in reverse motoring.

POWER = Torque * speed

= (+ve) * (-ve)

POWER = -ve (reverse braking)

FOUR QUADRANT OPERATION OF A MOTOR DRIVING A HOIST LOAD

HOIST LOAD:

A hoist consists of a rope wound on a drum coupled to the motor shaft. One end of the rope is tied to a hoist box 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 an empty hoist box but lower that of a fully loaded hoist box

- ✶ Forward direction of motor speed will gives upward motion of the cage. Load torque line T_{L1} in quadrant I &IV represents speed- torque characteristic for the loaded hoist. This torque is the difference of torques due to loaded hoist and counter weight.
- ✶ The load torque T_{L2} in quadrant II and III is the speed-torque characteristics of an empty hoist. This torque is difference of torque due to counter weight and empty hoist. It's sign is negative because the counter weight is always higher than that of an empty cage.

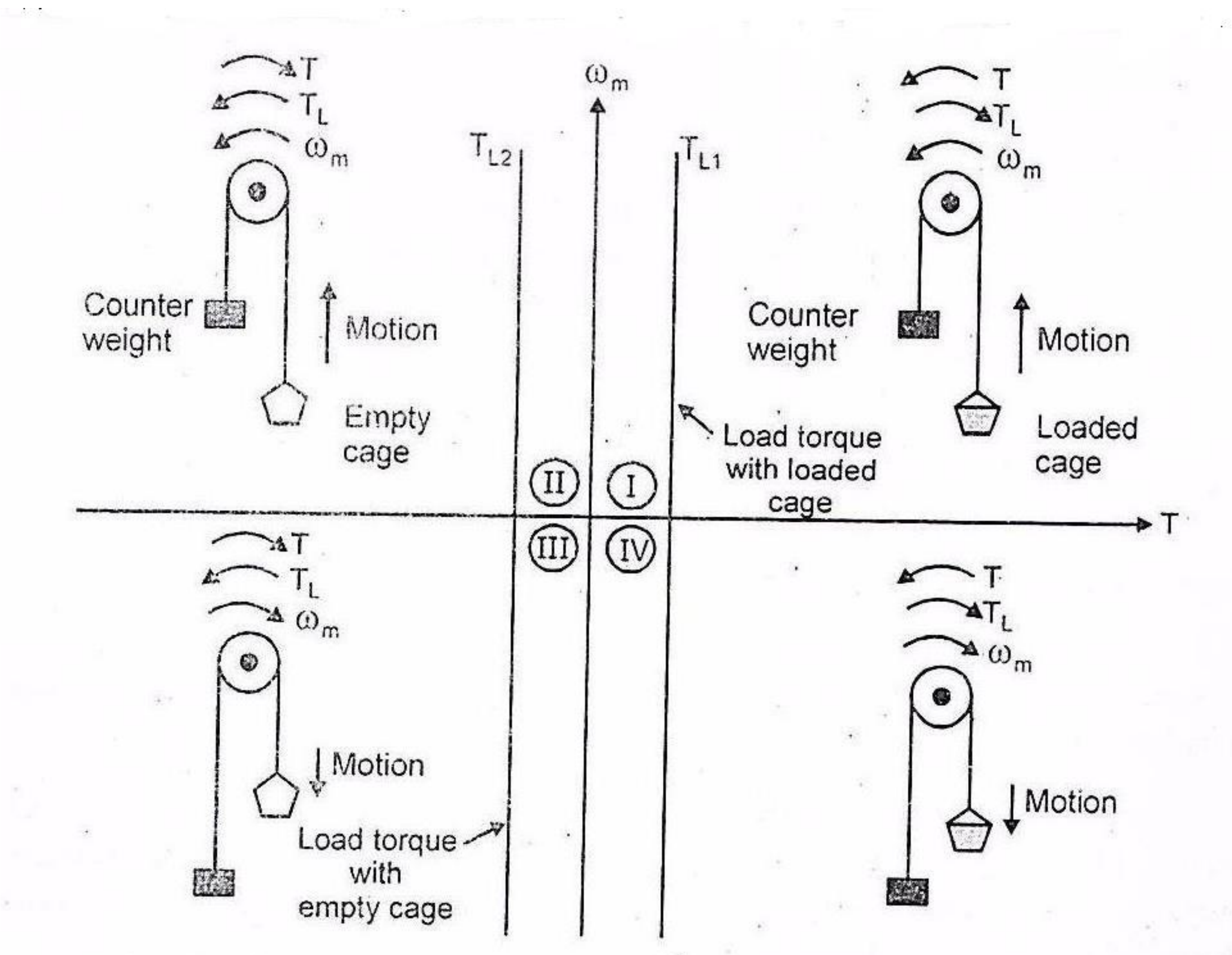


Fig 1.3 Four Quadrant Operation of a Motor Driving A Hoist Load

QUADRANT – I

In first quadrant operation of a hoist required the movement of the hoist box upward, which corresponds to the positive motor speed which is in CCW direction here. This motion will be obtained if the motor produces positive torque in anticlockwise direction equal to the magnitude of load torque T_{L1}. Since developed motor power is positive, this is forward motoring operation.

QUADRANT – II

Quadrant II operation is obtained when an empty cage is moved up. Since a counter weight is heavier than an empty cage, it is able to pull it up. In order to limit the speed within safe value, motor must produce a braking torque equal to T_{L2} in clock wise direction (-ve). Since speed is positive and developed power is negative. It is forward braking operation.

QUADRANT – III

Operation on third quadrant 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 clockwise direction. Since speed is negative and developed power is positive, this is reverse motoring operation.

QUADRANT – IV

This quadrant is obtained when a loaded cage is lowered. Since the weight of a loaded cage is higher than of a counter weight, it is able to come down due to the gravity itself. In order to limit the speed of cage within a safe value, motor must produce a positive torque $T=T_{L2}$ in anticlockwise direction. As both power and speed are in negative, drive is operating in reverse braking.

6. **EXPLAIN THE DIFFERENT LOAD CLASSIFICATION IN DETAIL. (MAY 2015)**

The torque-speed curve normally decides the type of motor, whereas the variation of load with time decides the rating of the motor.

Classification of loads are

1. Continuous constant mode
2. Continuous variable mode
3. Pulsating load
4. Impact load
5. Short time intermittent loads
6. Short time loads

- **CONTINUOUS CONSTANT LOADS**
  This continuous constant load occurs for a long time under the same condition. Eg. Fans
- **CONTINUOUS VARIABLE TYPE LOAD**
  This load is variable over a period of time, but occurs respectively for a longer duration. It occurs in metal cutting lathes, conveyors, etc.
- **PULSATING LOADS**

Certain types of loads exhibits a torque behavior which can be though of as a constant torque superimposed by pulsations. They are present with reciprocating pumps and all loads having crank-shafts.

- **IMPACT LOADS**

  These are peak loads occur at regular intervals at time. Eg. In rolling mills, forging hammers, etc

- **SHORT TIME INTERMITTEND LOAD**

  This load appears periodically in identical duty cycles, each consisting of a period of application of load and one of rest. Cranes and hoisting mechanism are examples

- **SHORT TIME LOADS**

  This is a constant load appears on the drive for a short time and the system rests for the remainder. Battery charging and house hold equipment offer such loads.

7. EXPLAIN THE DIFFERENT TYPES OF SELECTION OF ELECTRIC MOTORS.

- An electric drive consists of an electric motor along with its associated control and a mechanism for transmission of motion to the working machine
- To drive a particular load, choice has to be made about the type of motor, its power rating, type of enclosure, etc
- Selection of a motor has a bearing on the economic interest of the establishment. A motor chosen should neither be too small nor too big to drive a particular load.
- In case of small motor, it may not be able to drive the load satisfactorily and may get unduly overloaded with a temperature rise much greater than the permissible value. Sometimes it may run the risk of damage (or) even burnout
- In case of big motor, the drive motor is not fully loaded, operates with poor efficiency and involves huge capital investment.

KINDS OF MOTORS

A selection of a motor is made from the following options that are commercially available

1. Squirrel cage induction motor
2. Slip ring (or) wound type induction motor
3. Synchronous motor
4. DC shunt (or) compound motor
5. DC series motor
6. AC commutator motor
7. Stepper motor

1.
2.
3.

1. SQUIRREL CAGE INDUCTION MOTOR

This motor is least expensive of all, robust in construction and almost maintenance free. These motors can be directly switched ON to the supply and variation in speed from no load to full load is small.

DRAWBACKS

- Poor power factor
- Low starting torque
- Limited frequency starting

APPLICATIONS

- Fans
- Pumps
- Conveyors
- Stokes
- Lathes,etc

2. SLIP RING INDUCTION MOTOR

This slip ring induction motor is more expensive than the squirrel cage type motor

ADVANTAGES

- Higher starting torque with low starting current
- The rotor losses are mainly in external resistance
- It can be started and stopped as frequently

APPLICATIONS

- Hoists
- Conveyors
- Elevators

3. SYNCHRONOUS MOTOR

Synchronous motors have higher initial cost compare to the cage type motor. However, the running cost of these motors can be reduced by improving, their power factors. The motor have constant speed of operation and do not self start. So, special arrangements are required for starting and therefore these motors are not suitable for driving a load requiring high starting torque.

4. DC MOTORS

The DC motors are delicate, expensive and require periodic maintenance. Since the supply normally available in AC, converters are also required to convert AC into DC. Thus the total cost of system becomes still more. Therefore DC motors are preferred only when AC motors are not suitable to fulfill the special requirements of the load.

5. AC COMMUTATOR MOTORS

This motor are sometimes used in place of DC motors as both their power factor and speed can be controller

6. STEPPER MOTORS

Stepper motors are used in digital systems, these motors can convert input information in digital form to an output which is mechanical.

APPLICATIONS:

- Widely used in computer industry
- Used to drive paped fed mechanisms in line printers
- To drive floppy disc drives and plotters, etc.

KINDS OF ENCLOSURES

The motors used in the electric drives are enclosed within a cover to protect them from dust, water, etc, as well as to protect the operating personnel. Different types of motors require different types of enclosures.

- ✓ Drip proof type enclosure
- ✓ Totally enclosed type
- ✓ Screen protected type
- ✓ Flame proof type

DRIP PROOF TYPE

If the motor is to be used in a location where the atmosphere is damp (or) if it is likely to be submerged (or) if it is to be used outdoor, a drip proof enclosure must be specified. These motors have water tight connection at the entrance and the body is made of rust resistant material.

TOTALLY ENCLOSED TYPE

If the motor is to be used in a very dusty atmosphere, non ventilated type enclosure is used.

SCREEN PROTECTED TYPE

The enclosure of this motor has large opening which are covered by wire mesh screens. This makes ventilation possible, but does not protect the motor from dust. It provides protection from, coming in contact with the motor. Ie. Rats, squirrels and also human beings

FRAME PROOF TYPE

If the motor is to be used in a potential explosive atmosphere, it must be enclosed in special ype of strong covers. These covers must be able to withstand any explosion of gas inside the motor without transmitting the flame to the outside atmosphere. Eg. Motors used in coal mines. Etc.

8. EXPLAIN THE HEATING AND COOLING CURVES OF A DRIVE SYSTEM.

1.7 Heating and Cooling Curves

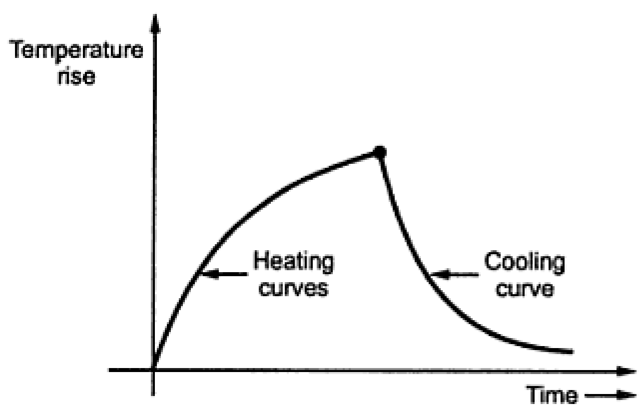
In many of the industrial applications, electric motors are widely used. During the operation of motor, various losses such as copper loss, iron loss and windage loss etc. take place. Due to these losses, heat is produced inside the machine. This increases the temperature of the motor. The temperature when reaches beyond the ambient value, a part of heat produced starts flowing to the surrounding medium. This outflow of heat is function of temperature rise of the motor above the ambient value.

Key Point: *With increase in temperature, the heat outflow rises and the equilibrium is achieved when heat generated is equal to heat dissipated to the surrounding.*

The temperature of motor then attains steady state value. This steady state temperature depends on power loss which in turn depends on power output of the motor. As the temperature rise and power output are directly related, it is called **thermal loading** on the machine.

During the operation of motor, various losses takes place. Due to these losses, heat is produced inside the machine. This increases the temperature of the motor.

Heating time constant, $\theta = \theta_F - (\theta_F - \theta_1)e^{-t/\tau}$



Heating and cooling curves

When the machine is switched off from the main supply or when the load on the motor is reduced, the machine cools. In first case it cools to the ambient temperature while in other it cools to a temperature obtained by power losses at reduced load.

When the machine is switched OFF, there is no heat generation and all the heat stored in the machine is dissipated to surroundings.

Thus cooling will take place, if rate of heat generation is less than rate of heat dissipation.

Cooling time constant, $\theta = \theta_F' - (\theta_0 - \theta_F')e^{-t/\tau'}$

If cooling is not provided then motor can not dissipate heat to surrounding medium. This will increase temperature to a very high value.

Key Point: *Thus cooling is important to limit the maximum temperature rise to a permissible value depending upon class of insulation employed.*

9. EXPLAIN THE P, PI, PD AND PID CONTROLLERS IN DETAIL.

RESPONSE WITH P, PI, PD AND PID CONTROLLERS

In feedback control systems a controller may be introduced to modify the error signal and to achieve better control action. The introduction of controllers will modify the transient response and the steady state error of the system.

Proportional Controller (P-Controller)

The proportional controller produces an output signal which is proportional to error signal. The transfer function of proportional controller is Kp. The term Kpis called the gain of the controller. Hence the proportional controller amplifies the error signal and increases the loop gain of the system. The following aspects of system behavior are improved by increasing loop gain.

- Steady state tracking accuracy.
- Disturbance signal rejection.
- Relative stability.

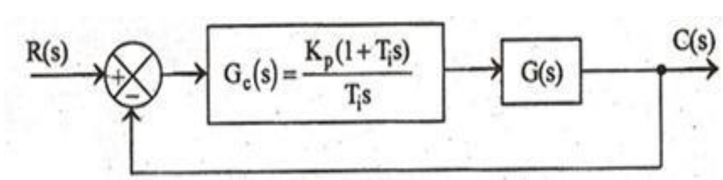
In addition to increase in loop gain it decreases the sensitivity of the system to parameter variations. The drawback in proportional control action is that it produces a constant steady state error.

PI-controller

The proportional plus integral controller (PI-controller) produces an output signal consisting of two terms: one proportional to error signal and the other proportional to the integral of error signal.
Transfer function of PI-controller.

$$G_c(s) = k_p\left(1+\frac{1}{T_i s}\right) = k_p\left(\frac{T_i s+1}{T_i s}\right)$$

Where, Kpis proportional gain and, Ti is integral time The block diagram of unity feedback system with PI-controller is shown in the below fig.



Let the open loop transfer function G(s) be a second order system with transfer function, as shown in equation.
Where

Open loop transfer function, G(s) = $\dfrac{\omega_n^2}{s(s+2\varsigma\omega_n)}$

Now, loop transfer function = $G_c(s)G(s)H(s) = G_c(s)G(s)$

H(S)=1

$$= k_p\left(\frac{1+T_i s}{T_i s}\right)\times\frac{\omega_n^2}{s(s+2\varsigma\omega_n)} = \frac{k_p\omega_n^2(1+T_i s)}{s^2\,\mathrm{T}_i(s+2\varsigma\omega_n)}$$

Now the closed loop transfer function is given by

$$\frac{c(s)}{R(s)} = \frac{G_c(s)G(s)}{1+G_c(s)G(s)} = \frac{\dfrac{k_p\omega_n^2(1+T_i s)}{s^2\,\mathrm{T}_i(s+2\varsigma\omega_n)}}{1+\dfrac{k_p\omega_n^2(1+T_i s)}{s^2\,\mathrm{T}_i(s+2\varsigma\omega_n)}} = \frac{k_p\omega_n^2(1+T_i s)}{s^2\,\mathrm{T}_i(s+2\varsigma\omega_n)+k_p\omega_n^2(1+T_i s)}$$

$$\frac{k_p\omega_n^2(1+T_i s)}{\mathrm{T}_i s^3+2\varsigma\omega_n\,\mathrm{T}_i s^2+k_p\omega_n^2 T_i s+k_p\omega_n^2} = \frac{(k_p/T_i)\omega_n^2(1+T_i s)}{s^3+2\varsigma\omega_n s^2+k_p\omega_n^2 T_i s+\dfrac{k_p}{T_i}\omega_n^2}$$

Where,

$$K_i = \frac{k_p}{T_i}$$

From the closed loop transfer function it is observed that the PI-controller introduces a zero in the system and increases the order by one. The increase in the order of the system results in a less stable system than the original one because higher order systems are less stable than lower order systems. From the loop transfer function equation it is observed that the PI-controller increase the type number by one.

The increase in type number results in reducing the steady state error. For example if the steady state error of the original system is constant, then the integral controller will reduce the error to zero.

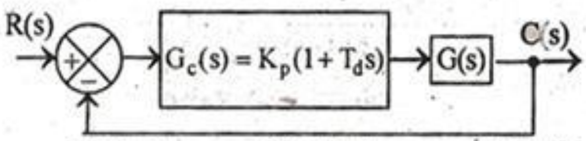
PD-controller

The proportional plus derivative controller produces an output signal consisting to two terms: one proportional to error signal and the other proportional to the derivative of error signal.

The transfer function of PD – controller, $G_c(s) = k_p(1+T_d s)$

Where, k_p is proportional gain and, T_d is integral time.

The block diagram of unity feedback system with PD-controller is shown in fig.



Block diagram of feedback system with PD-controller.

Let the open loop transfer function G(s) be a second order system with transfer function as shown in equation,

Open loop transfer function, G(s) = $\dfrac{\omega_n^2}{s(s+2\varsigma\omega_n)}$

Now, loop transfer function = $G_c(s)G(s)H(s) = G_c(s)G(s)$

H(S)=1

$$= k_p(1+T_d(s)) = \frac{\omega_n^2}{s(s+2\varsigma\omega_n)} = \frac{k_p\omega_n^2(1+T_d s)}{s(s+2\varsigma\omega_n)}$$

Now the closed loop transfer function is given by,

$$\frac{c(s)}{R(s)} = \frac{G_c(s)G(s)}{1+G(s)G_c(s)} = \frac{\dfrac{k_p\omega_n^2(1+T_d s)}{s(s+2\varsigma\omega_n)}}{1+\dfrac{k_p\omega_n^2(1+T_d s)}{s(s+2\varsigma\omega_n)}}$$

$$= \frac{k_p\omega_n^2(1+T_d s)}{s(s+2\varsigma\omega_n)+k_p\omega_n^2(1+T_d s)} = \frac{k_p\omega_n^2(1+T_d s)}{s^2+2\varsigma\omega_n+k_p\omega_n^2+k_p\omega_n^2T_d s}$$

$k_d = k_p T_d$

$$= \frac{k_p\omega_n^2(1+T_d s)}{s^2+(2\varsigma\omega_n+k_p\omega_n^2T_d)s+k_p\omega_n^2} = \frac{\omega_n^2(k_p+k_d s)}{s^2+(2\varsigma\omega_n+k_d\omega_n^2)s+k_p\omega_n^2}$$

From the closed loop transfer function (equation (3.54)) it is observed that the PD-controller introduces a zero in the system and increases the damping ration. The addition of the zero may increase the peak overshoot and reduce the rise time. But the effect of increased damping ultimately reduces the peak overshoot. From the loop transfer function, equation it is observed that the PD controller does not modify the type number of the system. Hence PD-controller will not act modify steady state error

PID-controller

A suitable combination of the three basic modes: proportional, integral and derivative (PID) can improve all aspects of the system performance. The proportional controller stabilizes the gain but produces a steady state error. The integral controller reduces or eliminates the steady error. The derivative controller reduces the rate of change of error. The combined effect of all the three cannot be judged from the parameters Kp, Ki, Kd.

Explain the Electrical and Mechanical characteristics of DC shunt and series motor.

4.12 D.C. Motor Characteristics

The performance of a d.c. motor under various conditions can be judged by the following characteristics

i) Torque-Armature current characteristics (T Vs I_a) :

The graph showing the relationship between the torque and the armature current is called a torque-armature current characteristic. These are also called electrical characteristics.

ii) Speed - Armature current characteristics (N Vs I_a) :

The graph showing the relationship between the speed and armature current characteristics.

iii) Speed - Torque characteristics (N Vs T) :

The graph showing the relationship between the speed and the torque of the motor is called speed-torque characteristics of the motor. These are also called mechanical characteristics.

4.13 Characteristics of D.C. Shunt Motor

i) Torque - Armature current characteristics

For a d.c. motor $T \propto \phi I_a$

For a constant values of R_{sh} and supply voltage V, I_{sh} is also constant and hence flux is also constant.

$$\therefore \quad \boxed{T_a \propto I_a}$$

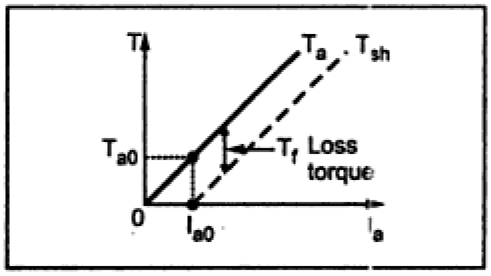


Fig. 4.13 T Vs I_a for shunt motor

The equation represents a straight line, passing through the origin, as shown in the Fig. 4.13. Torque increases linearily with armature current. It is seen earlier that armature current is decided by the load. So as load increases, armature current increases, increasing the torque developed linearly.

Now if shaft torque is plotted against armature current, it is known that shaft torque is less than the armature torque and the difference between the two is loss torque T_f as shown. On no load $T_{sh} = 0$ but armature torque is present which is just enough to overcome stray losses shown as T_{a0}. The current required is I_{a0} on no load to produce T_{a0} and hence T_{sh} graph has an intercept of I_{a0} on the current axis.

To generate high starting torque, this type of motor requires a large value of armature current at start. This may damage the motor hence d.c. shunt motors can develop moderate starting torque and hence suitable for such applications where starting torque requirement is moderate.

ii) Speed - Armature current characteristics

From the speed equation we get,

$$N \propto \frac{V - I_a R_a}{\phi}$$

$$\propto V - I_a R_a \qquad \text{as } \phi \text{ is constant.}$$

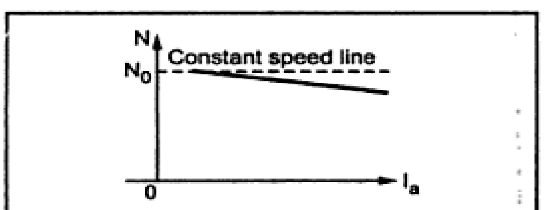


Fig. 4.14 N Vs I_a for shunt motor

So as load increases, the armature current increases and hence drop $I_a R_a$ also increases.

Hence for constant supply voltage, $V - I_a R_a$ decreases and hence speed reduces. But as R_a is very small, for change in I_a from no load to full load, drop $I_a R_a$ is very small and hence drop in speed is also not significant from no load to full load.

So the characteristics is slightly droping as shown in the Fig. 4.14.

But for all practical purposes these type of motors are considered to be a constant speed motors.

iii) Speed - Torque characteristics

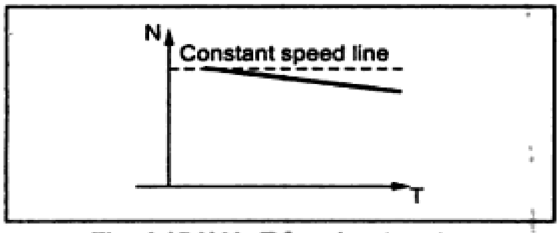


Fig. 4.15 N Vs T for shunt motor

These characteristics can be derived from the above two characteristics. This graph is similar to speed-armature current characteristics as torque is proportional to the armature current. This curve shows that the speed almost remains constant though torque changes from no load to full load conditions. This is shown in the Fig. 4.15.

4.14 Characteristics of D.C. Series Motor

i) Torque - Armature current characteristics

In case of series motor the series field winding is carrying the entire armature current. So flux produced is proportional to the armature current.

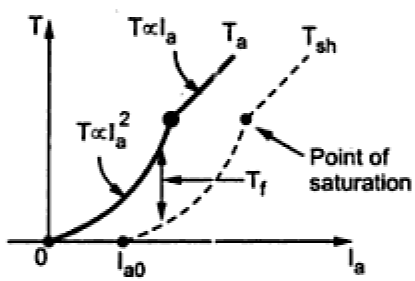
$$\therefore \quad \phi \propto I_a$$

Hence $$\boxed{T_a \propto \phi I_a \propto I_a^2}$$

Thus torque in case of series motor is proportional to the square of the armature current. This relation is parabolic in nature as shown in the Fig. 4.16.

As load increases, armature current increases and torque produced increases proportional to the square of the armature current upto a certain limit.

As the entire I_a passes through the series field, there is a property of an electromagnet called **saturation**, may occur. Saturation means though the current through the winding increases, the flux produced remains constant. Hence after saturation the characteristics take the shape of straight line as flux becomes constant, as shown. The difference between T_a and T_{sh} is loss torque T_f which is also shown in the Fig. 4.16.



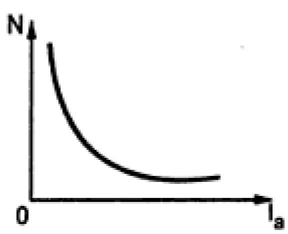


Fig. 4.16 T Vs I_a for series motor

Fig. 4.17 N Vs I_a for series motor

At start as $T \propto I_a^2$, these types of motors can produce high torque for small amount of armature current hence the series motors are suitable for the applications which demand high starting torque.

ii) Speed-armature current characteristics

From the speed equation we get,

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

$$\propto \frac{V - I_a R_a - I_a R_{se}}{I_a} \quad \text{as } \phi \propto I_a \text{ in case of series motor}$$

Now the values of R_a and R_{se} are so small that the effect of change in I_a on speed overrides the effect of change in $V - I_a R_a - I_a R_{se}$ on the speed.

Hence in the speed equation, $E_b \cong V$ and can be assumed constant. So speed equation reduces to,

$$\boxed{N \propto \frac{1}{I_a}}$$

So speed-armature current characteristics is rectangular hyperbola type as shown in the Fig. 4.17.

iii) Speed-Torque characteristics

In case of series motors, $T \propto I_a^2$ and $N \propto \frac{1}{I_a}$

Hence we can write, $\boxed{N \propto \frac{1}{\sqrt{T}}}$

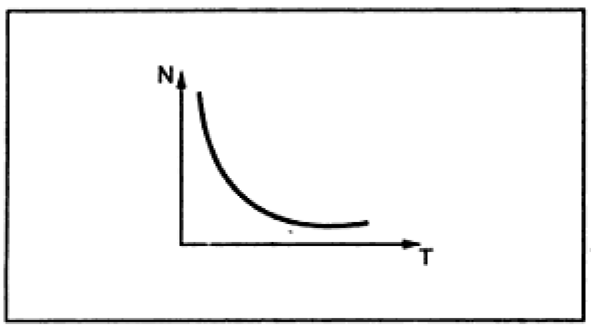


Fig. 4.18 N Vs T for series motor

Thus as torque increases when load increases, the speed decreases. On no load, torque is very less and hence speed increases to dangerously high value. Thus the nature of the speed-torque characteristics is similar to the nature of the speed-armature current characteristics.

The speed-torque characteristics of a series motor is shown in the Fig. 4.18.

Heating and Cooling Curve

UNIT II:

DC DRIVES

Single phase and three phase drives – half controlled and fully controlled- Chopper drives- class A, B, C, D and E chopper drives - braking of dc drives.

TWO MARKS

1. **Mention the types of braking? (NOVEMBER 2010)**

Regenerative braking
Dynamic braking
Plugging

2. **What are the advantage and disadvantages of D.C. drives? (DECEMBER-2014)**

The advantages of D.C. drives are,
a. Adjustable speed
b. Good speed regulation
c. Frequent starting, braking and reversing.
The disadvantage of D.C. drives is the presence of a mechanical commutator which limits themaximum power rating and the speed.

3. **Give some applications of D.C. drives.**

The applications of D.C. drives are,
a. Rolling mills b. Paper mills
c. Mine winders d. Hoists
e. Machine tools f. Traction
g. Printing presses h. Excavators
i. Textile mills j. Cranes.

4. **Why the variable speed applications are dominated by D.C. drives?**

The variable speed applications are dominated by D.C. drives because of lower cost, reliability and simple control.

5. What is the use of flywheel? Where it is used?

It is used for load equalization. It is mounted on the motor shaft in compound motor.

6. What are the advantages of series motor?

The advantages of series motors are,

a. High starting torque

b. Heavy torque overloads.\

7. How the D.C. motor is affected at the time of starting?

A D.C. motor is started with full supply voltage across its terminals, a very high current will flow, which may damage the motor due to heavy sparking at commuter and heating of the winding.Therefore, it is necessary to limit the current to a safe value during starting.

8. Define and mention different types of braking in a dc motor?

In braking the motor works as a generator developing a negative torque which opposes the motion. Types are regenerative braking, dynamic or rheostat braking and plugging or reversevoltage braking.

9. List the drawbacks of armature resistance control?

In armature resistance control speed is varied by wasting power in external resistors that are connected in series with the armature. Since it is an inefficient method of speed control it wasused in intermittent load applications where the duration of low speed operations forms only asmall proportion of total running time.

10. What is static Ward-Leonard drive?

Controlled rectifiers are used to get variable d.c. voltage from an a.c. source of fixe voltage controlled rectifier fed dc drives are also known as static Ward-Leonard drive.

11. What is a line commutated inverter?

Full converter with firing angle delay greater than 90 deg. is called line commutated inverter. such an operation is used in regenerative braking mode of a dc motor in which case aback emf is greater than applied voltage.

12. Mention the methods of armature voltage controlled dc motor?

When the supplied voltage is ac,

i Ward-Leonard schemes

ii Transformer with taps and uncontrolled rectifier bridge

iii Static Ward-Leonard scheme or controlled rectifiers

When the supply is dc:

Chopper control

13. How is the stator winding changed during constant torque and constant horsepower operations?

For constant torque operation, the change of stator winding is made form series – star to parallel – star, while for constant horsepower operation the change is made from series-delta toparallel-star. Regenerative braking takes place during changeover from higher to lower speeds.

14. Define positive and negative motor torque.

Positive motor torque is defined as the torque which produces acceleration or the positive rate of change of speed in forward direction. Positive load torque is negative if it produces deceleration.

15. Write the expression for average o/p voltage of full converter fed dc drives?

Vm=(2Vm/pi)cospi................continuous conduction

Vm=[Vm(cos alpha-cos beta)+(pi+alpha+beta)]/pi]........discontinuous conduction

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

- i Higher initial cost due to use of two additional m\cs.
- ii Heavy weight and size.
- iii Needs more floor space and proper foundation.
- iv Required frequent maintenance.
- v Higher noise and higher loss.

17. Mention the drawbacks of rectifier fed dc drives?

- i Distortion of supply.
- ii Low power factor.
- iii Ripple in motor current

18. What are the advantages in operating choppers at high frequency?

The operation at a high frequency improves motor performance by reducing current ripple and eliminating discontinuous conduction.

19. Why self-commutated devices are preferred over thyristors for chopper circuits?

Self-commutated devices such as power MOSFETs power transistors, IGBTs, GTOs and IGCTs are preferred over thyristors for building choppers because they can be commutated by alow power control signal and don’t need commutation circuit.

20. State the advantages of dc chopper drives?

Dc chopper device has the advantages of high efficiency, flexibility in control, light weight, small size, quick response and regeneration down to very low speed.

21. What are the advantages of closed loop c of dc drives?

Closed loop control system has the adv. of improved accuracy, fast dynamic response and reduced effects of disturbance and system non-linearities.

22. What are the types of control strategies in dc chopper?

i Time ratio control.
ii Current limit control.

23. What is the adv. of using PI controller in closed loop control of dc drive?

i Stabilize the drive
ii Adjust the damping ratio at the desired value
iii Makes the steady state speed error close to zero by integral action and filters out noise again due to the integral action.

Eleven Marks

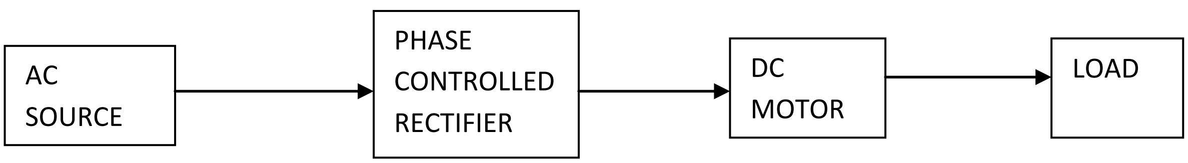
1. EXPLAIN THE SOLID STATE SPEED CONTROL OF DC MOTOR IN DETAIL. (April/May 2014)

The DC motor speed can be controlled through power semiconductor switches. Here the power semiconductor switches are SCR, MOSFET, IGBT, etc..

Types of DC drives:

1. Phase controlled rectifier fed DC drives
2. Chopper fed DC drives

Phase controlled rectifier fed DC Drives



Here AC supply is fed to the phase controlled rectifier circuit. AC supply may be single phase or three phase controlled rectifier converts fixed AC voltage into variable DC voltage. Here the circuit consist of SCRs. By varying the SCR firing angle the output voltage can be controlled.

The variable output voltage is fed to the DC motor. By varying the motor input voltage, the motor speed can be controlled.

Advantages of Thyristorised Drives:

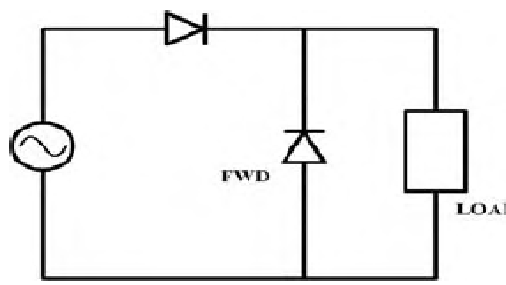
1. Basic operation is simple and reliable
2. Time response is faster
3. Operating efficiency is high about 95%.
4. Small size
5. Less weight
6. Low initial cost

Disadvantages of Thyristorised Drives:

1. Higher ripple content of the converter output adds to the motor heating and commutation problems.
2. The overload capacity is lower.
3. Under certain operating conditions, the power factor in AC supply is low.
4. Om the thyristor converter, complex control circuitry is required to achieve regeneration.

Single phase Half wave converter drives:

Assume armature current I_a is constant. Here the motor is separately excited DC motor. Motor is operated from single phase have wave controlled rectifier. Motor field winding is fed through separate DC source.



(a) 1-PHASE HALF-WAVE

During the positive half cycle SCR is forward biased.

At $\omega t = \alpha$, SCR T is triggered and comes to the ON state. Then +ve voltage is fed to the motor.

At $\omega t = \pi$, free wheeling diode comes to the forward biased, and SCR T comes to the OFF state, because of reverse voltage.

During –ve half cycle of SCR T is OFF state, and free wheeling diode conducts upto$2\pi + \alpha$.

$$\alpha \ to \ \pi - T_{on}$$

$$\pi \ to \ 2\pi + \alpha - F.D \ ON$$

During the period, $\pi \ to \ 2\pi + \alpha$, current is positive, but output voltage is zero because of closed path.

This type of converters are used upto about 1/2KW DC motors.

For single phase half wave controlled rectifier, average output voltage of converter, V_0 = armature terminal voltage V_a.

$$V_0 = V_a = \frac{1}{2\pi}\int_{\alpha}^{\pi} V_s d(\omega t)$$

$$= \frac{1}{2\pi}\int_{\alpha}^{\pi} V_m \sin \omega t \, d\omega t$$

$$V_0 = \frac{V_m}{2\pi}(1 + \cos \alpha)\, , for\ 0 < \alpha < \pi$$

Where,

V_m = max. value of input voltage $= \sqrt{2}V_s$

$\alpha =$ Delay angle

Here by varying the firing angle α, the output voltage can be varied. The variable voltage fed to the motor, and then the motor speed can be changed.

Single Phase Semiconverter Drives:

Assume armature current Ia is constant. DC motor is operated from single phase semiconverter or half controlled rectifier. Semiconverter consists of two SCRs, two diodes and one free wheeling diode (FD). Free wheeling diode is connected across the Load. Here, the load is DC motor.

During +ve half cycle $(0\ to\ \pi)$, $SCR\ T_1$ and diode D_1 is forward biased. At $\omega t = \alpha$. SCR T_1 is triggered. This SCR T_1 and diode D_1 comes to the ON state. During the period $\alpha$to π. SCR T_1 and Diode $D_1$is ON state. In this period we get +ve output voltage and +ve current. At $\omega t = \pi$, SCR T_1 and D_1 is turned OFF.

During –ve half cycle $(\pi\ to\ 2\pi)$, the free wheeling diode conducts. In this period, current flows through FD and motor. Here we can get +ve output current and zero output voltage.

At $\omega t = \pi + \alpha$, SCR T_2 is triggered. Then SCR T_2 and diode D_2 comes to the ON state. During the period $(\pi + \alpha\ to\ 2\pi)$, SCR T_2 and diode D_2 is ON state. Now we can get the +ve output voltage and +ve output current. This voltage is fed to the DC motor. This converter also offers one quadrant converter drive, because the output voltage and current is always positive

This converter is used upto about 15KW DC drives.

Average output voltage $V_0 = V_a = \frac{1}{\pi}\int_{\alpha}^{\pi} V_s d\omega t$

$$V_0 = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m \sin\omega t \; d\omega t$$

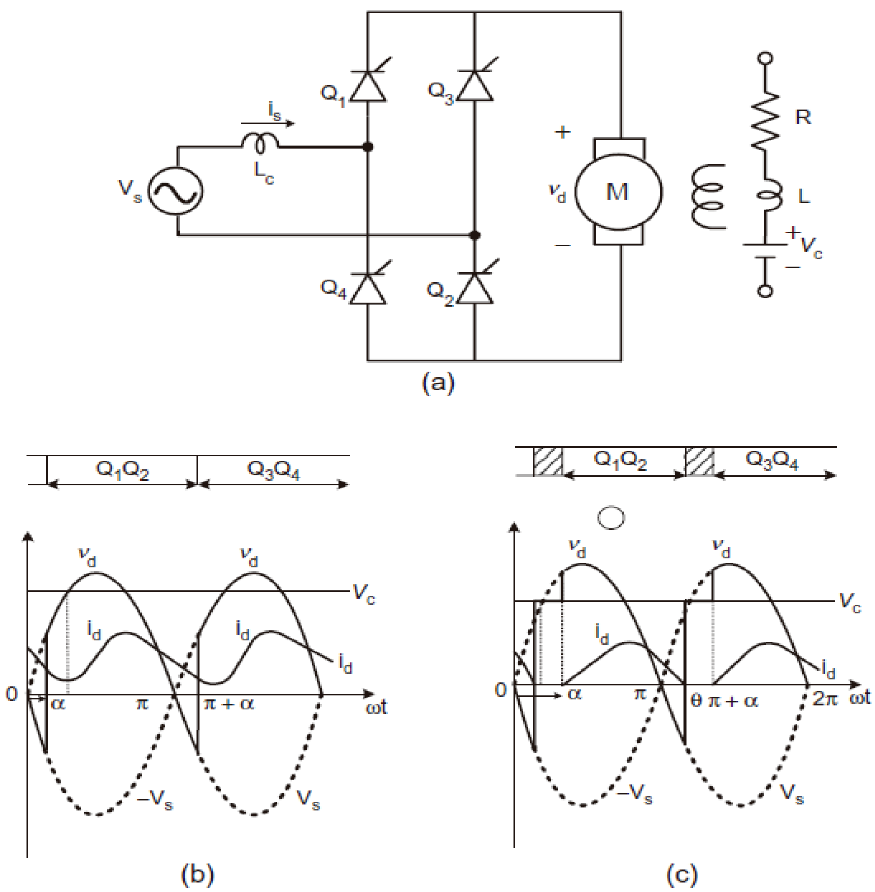
$$V_a = \frac{V_m}{\pi}(1+\cos\alpha)$$

Where, V_m= max value of Input voltage, α = Delay angle.

In this equation, by varying the delay angle, the average output voltage can be changed. By changing the average output voltage, motor speed can be varied.

Single phase Fully controlled Rectifier drives:

(a) Single-phase thyristor bridge with *R-L*-CEMF load, (b) continuous conduction rectification (mode A), and (c) discontinuous conduction rectification (mode B).



Assume armature current I_a is constant. Here the load is DC motor. Full converter consists of 4 SCRs and Load.

During +ve half cycle $(0+\pi)$ SCR T_1 are forward biased. At $\omega t = \alpha$, SCR T_1 and T_2 are triggered and comes to the ON state. These two SCRs conducts upto$\pi+\alpha$. During the period $(\alpha \; to \; \pi+\alpha)$, SCR T_1 and T_2 are ON state.

At $\omega t = \pi + \alpha$, T_3 and T_4 SCRs are triggered. SCRs T_1 and T_2 comes to the OFF state. Now SCRs T_3 and T_4conductsupto$2\pi + \alpha$.

Average output voltage, $V_a = V_0$

$$V_a = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_s \, d\,\omega t$$

$$= \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin \omega t \;\; d\,\omega t$$

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

By varying the firing angle, the output voltage can be changed.

For firing angle,

$\alpha = 0, V_a = 2V_m/\pi$

$\alpha = 90, V_a = 0,$

$\alpha = 180, V_a = \frac{-2V_m}{\pi}$

From the above equation, by changing the firing angle from 0 to 90, we get +ve output voltage and 90 t0 180 we get –ve output voltage.

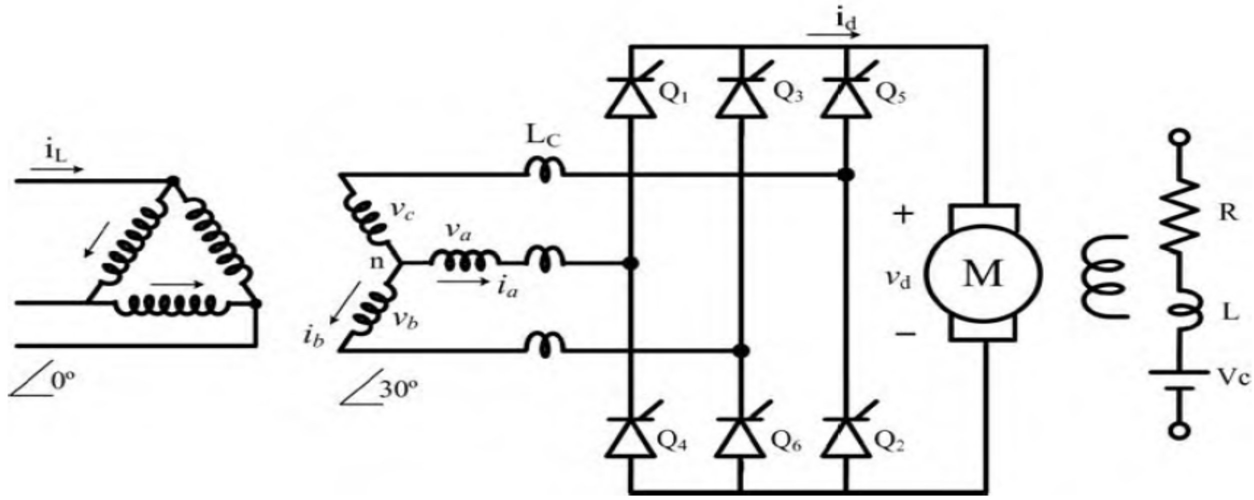
From the above discussion, the full converter is also called two quadrant converter. It means the average output voltage is either positive or negative but output current is always positive.

The converter is used upto 15KW DC motors.

2. EXPLAIN THE THREE PHASE CONTROLLED RECTIFIER CONTROL OF DC SEPARATELY EXCITED MOTOR. (Nov/Dec 2015)

Three phase DC drives.

For large power DC motor drives, three phase controlled rectifiers are used. It gives more number of voltage pulses per cycle of supply frequency. This makes the motor current continuous and filter requirement also less.



It is a one quadrant converter because the average output voltage and current is always +ve. The field winding of the motor is also connected to the three phase semiconverter. It is used upto about 120KW ratings.

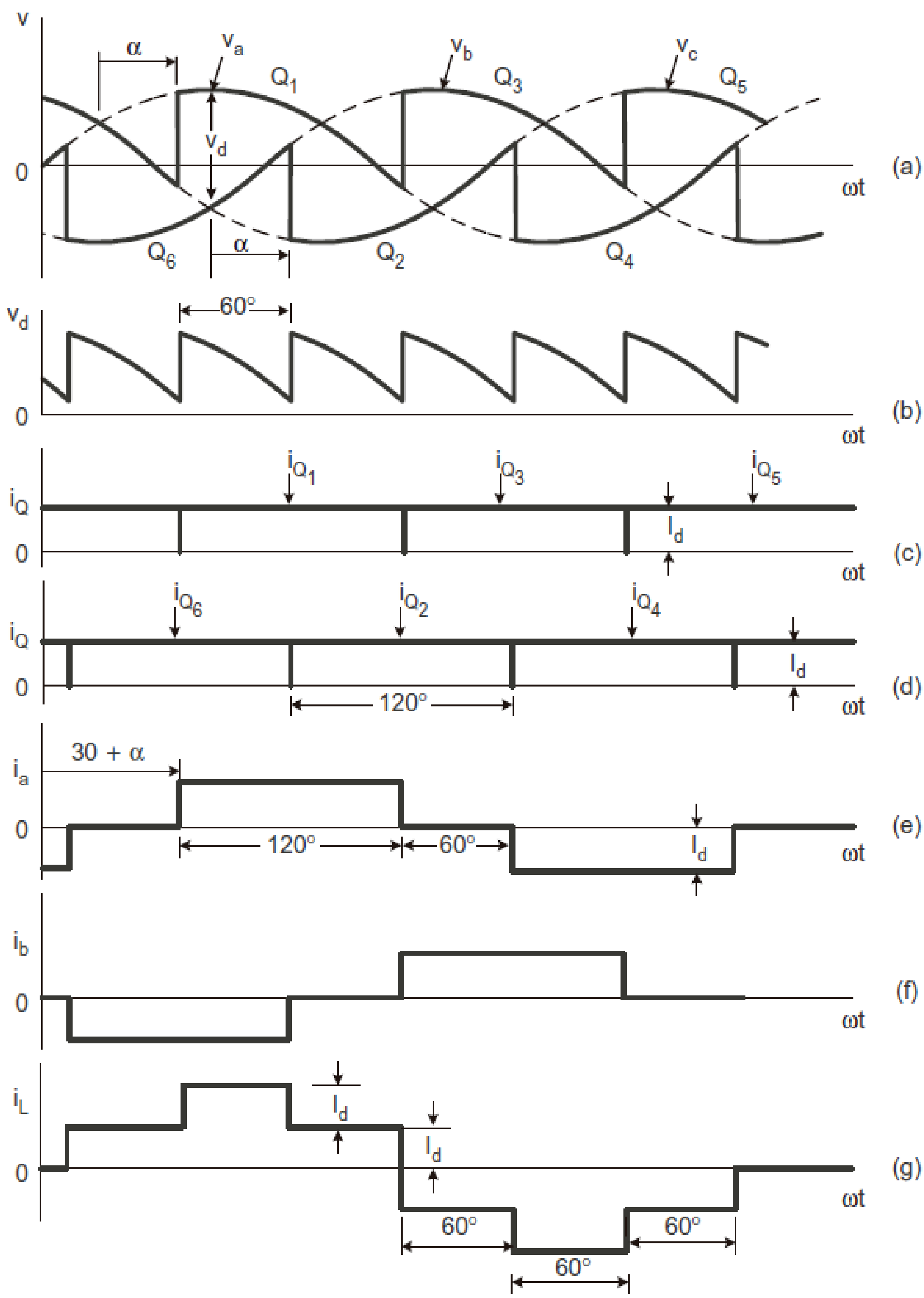
The frequency of the output voltage is 3Fs. The firing angle α, can be varied from 0 to π.

During the period, $\frac{\pi}{6} \leq \omega t \leq \frac{7\pi}{6}$, SCR T_1 is forward biased. If T_1 is triggered at $\omega = \frac{\pi}{6} + \alpha$, SCR T_1 and diode D_1 conduct and line to line voltage V_{ac} appears across the motor terminals.

At $\omega t = \frac{7\pi}{6}$, Vac starts to be –ve and free wheeling diode D_f conducts. The motor current continues to flow through D_f and T_1 and D_1 are turned OFF.

In the absence of free wheeling diode SCR T_1 would continue to conduct until SCR T_2 triggered at $\omega t = \frac{5\pi}{6} + \alpha$ and the free wheeling action would be accomplished through T_1 and D_2. At large firing angles the motor current can be continuous or discontinuous depending on the current demand and speed. The motor current may be discontinuous at large firing angles if the current is low and the speed is not low.

FIGURE 3.14 Three-phase thyristor bridge waveforms in rectification mode ($\alpha = 40°$) (mode A).



If we define the three phase line to neutral voltage as

$$V_{an} = V_m \sin \omega t$$

$$V_{bn} = V_m \sin\left(\omega t - \frac{2\pi}{3}\right)$$

$$V_{cn} = V_m \sin(\omega t + \frac{2\pi}{3})$$

The corresponding line to line voltages are

$$V_{ac} = V_{an} - V_{cn} = \sqrt{3}V_m \sin(\omega t - \frac{\pi}{6})$$

$$V_{ba} = V_{bn} - V_{an} = \sqrt{3}V_m \sin(\omega t - \frac{5\pi}{6})$$

$$V_{ab} = V_{an} - V_{bn} = \sqrt{3}V_m \sin(\omega t + \frac{\pi}{6})$$

$$V_{cb} = V_{cn} - V_{bn} = \sqrt{3}V_m \sin(\omega t + \frac{\pi}{2})$$

Where, V_m is the peak phase voltage and continuous conduction.

The motor terminal voltage is

$$V_a = \frac{3}{2\pi} \int_{\pi/6+\alpha}^{7\pi/6} V_{ac}\, d\omega t$$

$$= \frac{3}{2\pi} \int_{\pi/6+\alpha}^{7\pi/6} \sqrt{3}V_m \sin\left(\omega t - \frac{\pi}{6}\right) d(\omega t)$$

$$V_a = \frac{3\sqrt{3}V_m}{2\pi}(1 + \cos\alpha)$$

$$= \frac{3V_m l}{2\pi}(1 + \cos\alpha)$$

Where,

V_{ml}=maximum or peak line voltage

$$V_a = E_b + I_a R_a$$

$$V_a = I_a R_a + K_m \emptyset N$$

$$N = \frac{V_a - I_a R_a}{K_m \emptyset}$$

$$V_a = \frac{3\sqrt{3}V_m}{2\pi}(1 + \cos\alpha)$$

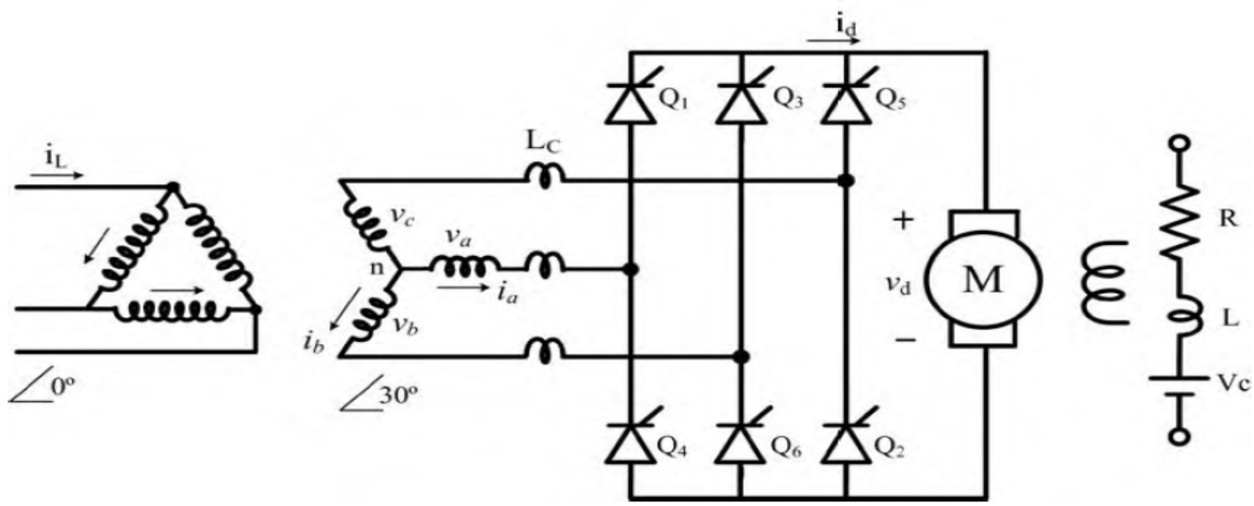
$$V_a = E_b + I_a R_a = K_m \omega_m + I_a R_a$$

$$\omega_m = \frac{V_m - I_a R_a}{K_m}$$

$$\text{Torque}, T = K_m I_a$$

3. EXPLAIN THE THREE PHASE FULLY CONTROLLED RECTIFIER CONTROL OF DC SEPARATELY EXCITED MOTOR. (Nov/Dec 2015)

Three phase full converters are used industrial applications upto 1500KW drives. It is a two quadrant converter.



The SCRs are triggered at an interval of $\pi/3$. The frequency of output ripple voltage is $6F_S$. The filtering requirement is less than that of three phase semi converter.

At $\omega t = \frac{\pi}{6} + \alpha$, SCR T6 is already conducting and SCR T1 is turned ON. During interval $(\frac{\pi}{2} + \alpha) \leq \omega t \leq (\frac{5\pi}{6} + \alpha)$. SCR T1 and T2 conduct and the line to line voltage V_{ac} appears across the load. If the SCRs are numbered in fig. the firing secuence is 12,23,34,45,56 and 61.

For the delay angle α=120, the motor terminal voltage becomes –ve. This is the inversion mode of operation. The power can be transferred from the motor to supply if the motor voltage is reversed with a reversing contactor or by reversing the field current. It is known as regeneration. The motor speed will decrease due to power feed back and thus the motor voltage will decrease.

The average motor terminal voltage is given by

$$V_a = \frac{3}{\pi} \int_{\pi/6+\alpha}^{\frac{\pi}{2}+\alpha} V_{ab} d\omega t$$

$$= \frac{3}{\pi} \int_{\pi/6+\alpha}^{\frac{\pi}{2}+\alpha} \sqrt{3} V_m \sin(\omega t + \pi/6)\, d\omega t$$

$$V_a = \frac{3\sqrt{3}V_m}{\pi} = \frac{3V_m l}{\pi} \cos\alpha$$

The motor speed is given by

$$V_a = E_b + I_a R_a = K_m \emptyset N + I_a R_a$$

$$N = \frac{V_a - I_a R_a}{K_m \emptyset}$$

In separately excited motor,

$$T = K_m \emptyset I_a$$

$$N = \frac{V_a}{K_m \emptyset} - \frac{R_a}{(K_m \emptyset)^2} T$$

When discontinuous conduction is neglected, speed torque curves are obtained.

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4. EXPLAIN THE CLASSIFICATION ,ADVANTAGES, APPLICATIONS AND CONTROL STRATEGIES OF DC CHOPPER DRIVES. (April/May 2013)

DC motor speed can be controlled through DC chopper. Fixed DC voltage is fed to the DC chopper circuit. DC chopper converts fixed DC into variable DC voltage. This variable DC voltage is fed to the motor. By varying the DC voltage, the motor speed can be controlled.

Advantages of DC chopper control

1. High efficiency
2. Flexibility in controls
3. Light weight
4. Small size
5. Quick response

Application of DC chopper drives

1. Battery operated vehicles
2. Traction motors control in electric traction
3. Trolly cars
4. Hoists
5. Electric braking.

Types of DC chopper drives

1. Frist quadrant chopper or class A chopper
2. Second quadrant or type B chopper
3. Two quadrant type A chopper or type C chopper
4. Two quadrant type B chopper or type D chopper
5. Four quadrant chopper or type E chopper

Control Strategies

The output dc voltage can be varied by the following methods.

1) Pulse width modulation control or constant frequency operation.

2) Variable frequency control.

3) Current Limit Control

PULSE WIDTH MODULATION

In pulse width modulation the pulse width (t_{ON}) of the output waveform is varied keeping chopping frequency 'f' and hence chopping period 'T' constant. Therefore output voltage is varied by varying the ON time, t_{ON}. Figure 6 shows the output voltage waveforms for different ON times.

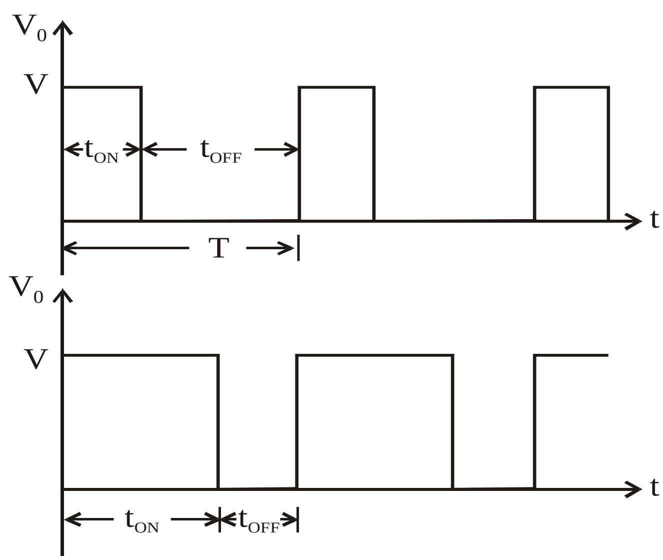


Fig. 6: Pulse Width Modulation Control

VARIABLE FREQUENCY CONTROL

In this method of control, chopping frequency f is varied keeping either t_{ON} or t_{OFF} constant. This method is also known as frequency modulation.Figure 7 shows the output voltage waveforms for a constant t_{ON} and variable chopping period T.

In frequency modulation to obtain full output voltage, range frequency has to be varied over a wide range. This method produces harmonics in the output and for large t_{OFF} load current may become discontinuous.

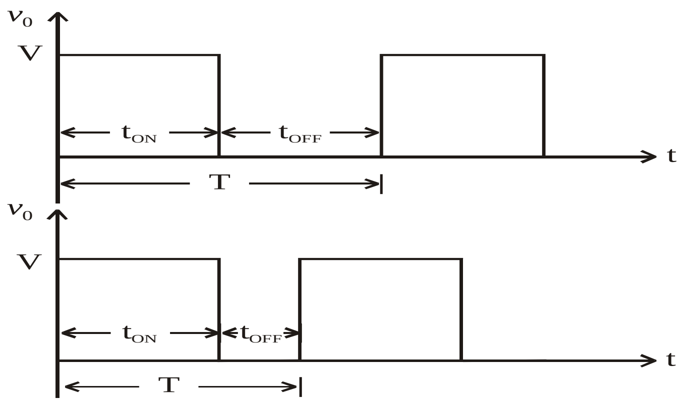


Fig. 7: Output Voltage Waveforms for Time Ratio Control

CURRENT LIMIT CONTROL

As can be observed from the current waveforms for the types of dc-dc converters described earlier, the current changes between the maximum and minimum values, if it (current) is continuous. In the current limit control strategy, the switch in dc-dc converter (chopper) is turned ON and OFF, so that the current is maintained between two (upper and lower) limits. When the current exceed upper (maximum) limit, the switch is turned OFF. During OFF period, the current freewheels in say, buck converter (dc-dc) through the diode,D_F , and decreases exponentially. When it reaches lower (minimum) limit, the switch is turned ON. This type of control is possible, either with constant frequency, or constant ON time,T_{on} . This is used only, when the load has energy storage elements, i.e. inductance, L. The reference values are load current or load voltage. This is shown in Fig. In this case, the current is continuous, varying between I_{max} and I_{min} , which decides the frequency used for switching. The ripple in the load current can be reduced, if the difference between the upper and lower limits is reduced, thereby making it minimum. This in turn increases the frequency, thereby increasing the switching losses.

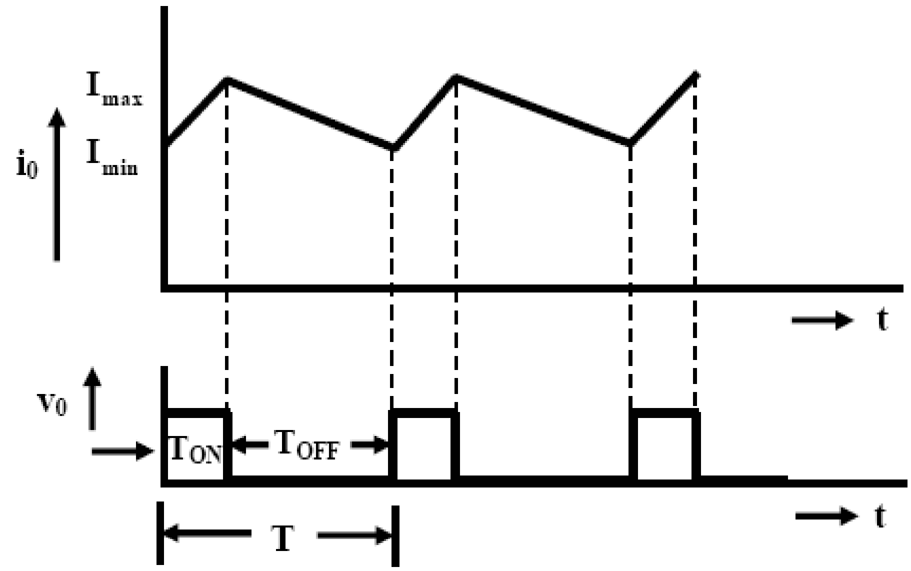


Fig. 8: Output Voltage Waveforms for Current Limit Control.

5.EXPLAIN THE FIRST QUADRANT OR TYPE A CHOPPER OR MOTORING CHOPPER AND SECOND QUADRANT OR TYPE B CHOPPER IN DETAIL. (Nov/Dec -2013)

In this chopper circuit diagram consists of chopping device (SCR, Power MOSFET etc.,) free wheeling diode and motor.

CLASS A CHOPPER

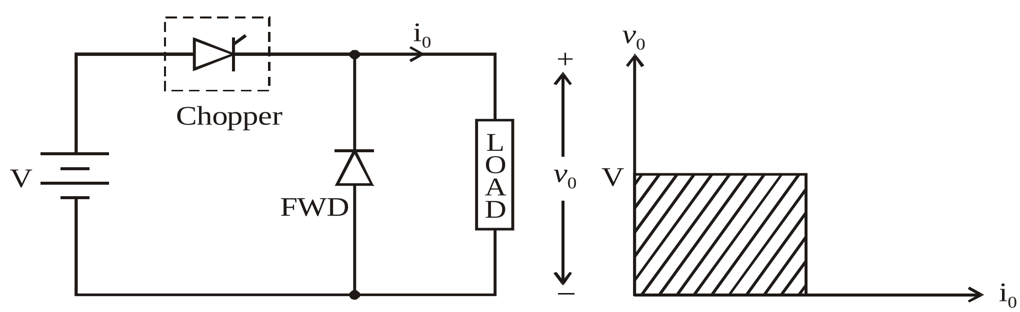
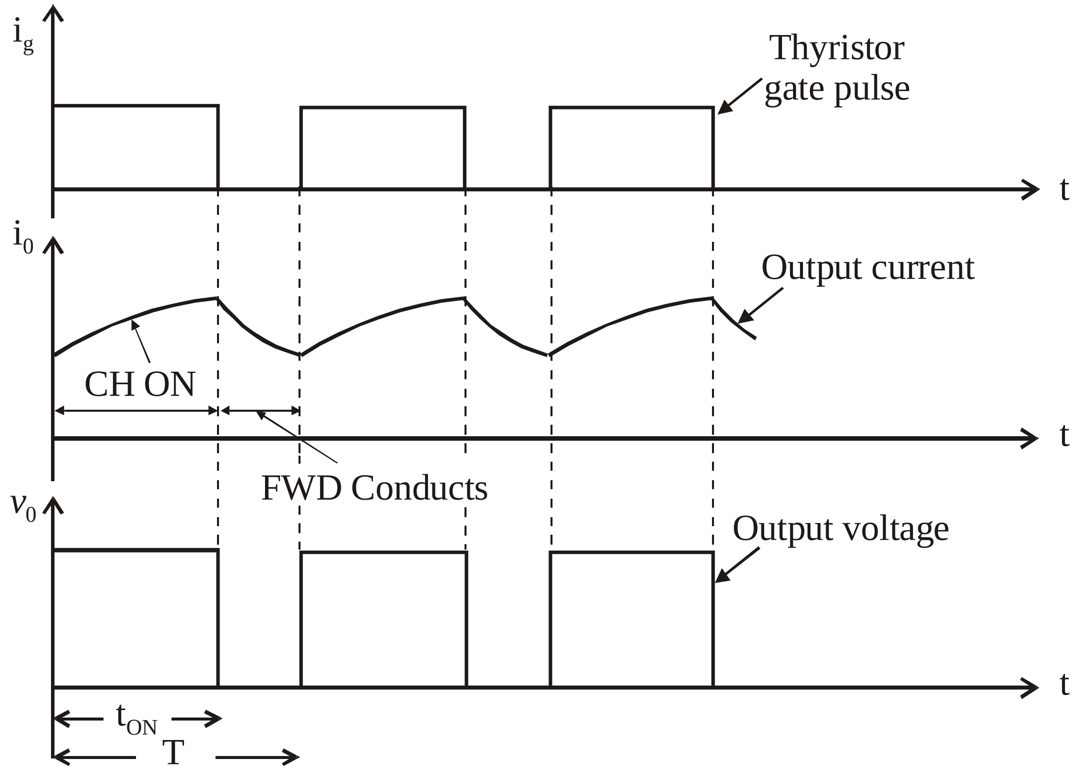


Fig. 8: Class A Chopper and $v_O - i_O$ Characteristics

Input DC supply is fed to the chopper circuit. Then the chopper CH_1 is turned ON by applying trigger pulse. Now the input voltage is fed to the motor. During the ON time (T_{on}) of the chopper output voltage is equal to the input voltage. i.e. $V_0 = V_s$.



First quadrant Chopper – Output Voltage and Current Waveforms

After Ton period, chopper CH_1 is turned OFF. Now the load is disconnected from the supply but the motor current flow through the free wheeling diode. In the turn off period (T_{off}), the output voltage is zero but load current flow through the free wheeling diode. (FD – motor – FD). i.e. V_0=0. Again the chopper CH_1 is turned ON and this cycle is repeated. Here assuming the armature current is constant.

Average output voltage is given by

$$V_0 = V_a = \frac{1}{T}\int_0^T V_s dt = \frac{1}{T}\int_0^{T_{ON}} V_s dt + \int_{T_{ON}}^{T} V_s dt$$

During the ON time period $V_0 = V_s$

During the OFF time period $V_0 = 0$

$$V_0 = V_a = \frac{1}{T}\int_0^{T_{ON}} V_s dt = V_s \frac{T_{ON}}{T}$$

$$V_a = V_s \alpha$$

Where,

α = duty ratio of chopper

$\alpha = \frac{T_{ON}}{T}, \because T = T_{on} + T_{off}$

T_{on} = Turn ON time of chopper

T = Total time

T_{on} = Turn ON time of chopper

T_{off} = Turn OFF time of chopper

T = Total time

T = 1/f

V_s = Supply frequency

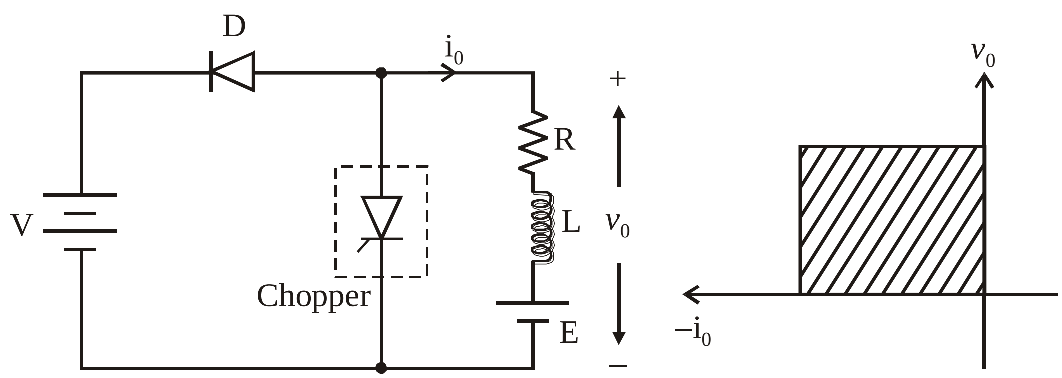
F = chopping frequency

By varying the ON time or OFF time of the chopper, the duty cycle ∝ is change. By changing ∝, the output voltage can be changed. This variable output voltage is fed to the DC motor. Then the DC motor speed can be controlled.

This type of chopper is also called Step down chopper because average output voltage is always less than the input DC voltage.

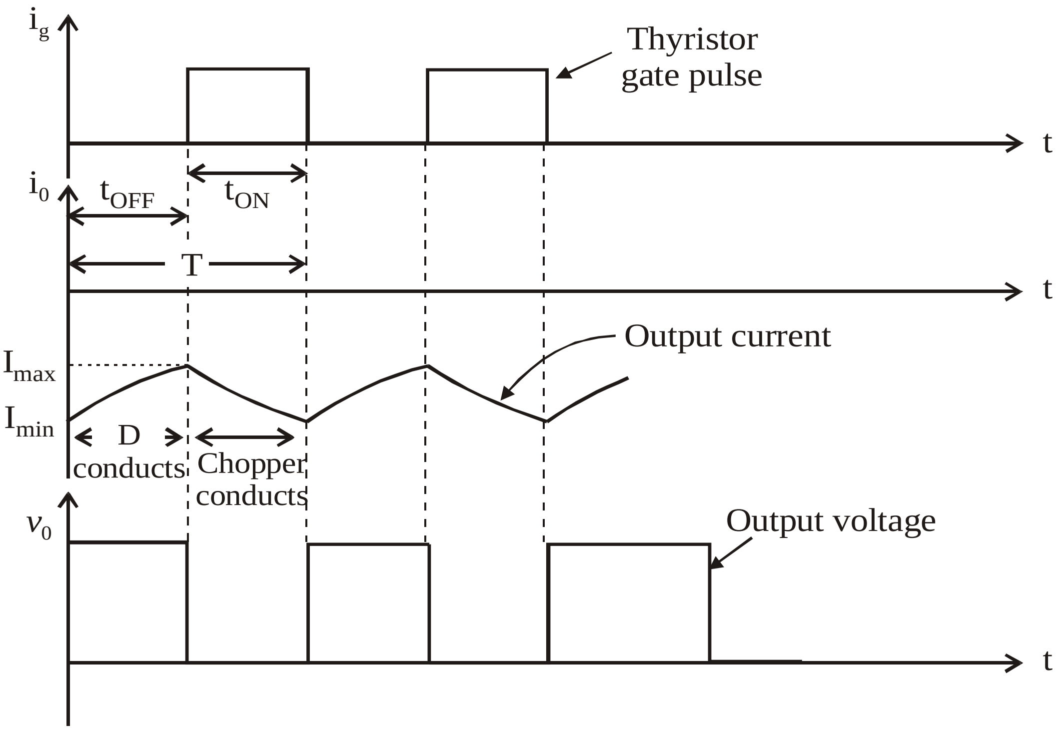
SECOND QUADRANT OR TYPE B CHOPPER

In this chopper the load must contain the DC source E, like a DC motor (or battery).



CLASS B CHOPPER

When CH_2 is ON, output voltage is equal to zero i.e. $V_a = 0$ but load voltage E drives current through L and CH_2. During ON time of chopper (T_{on}), Inductor L stores energy.



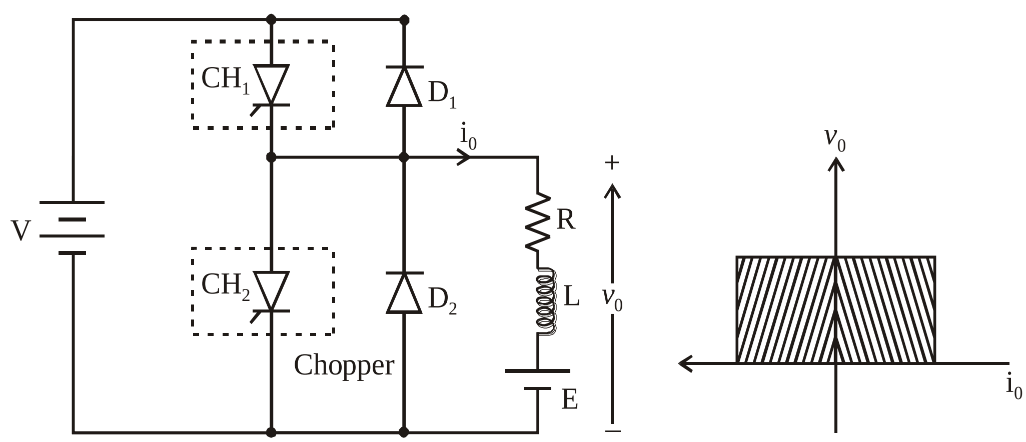
Class B Chopper – Output Voltage and Current Waveforms

When CH_2 is OFF, output voltage $V_a = (E + L\ di/dt)$ exceeds source voltage V_s. As a result, diode D_2 is forward biased and conducts, thus allowing power to flow to the source. Chopper CH_2 may be on or off, load current I0 flows out of the load. Here load current I0 is treated as negative.

The power flows from load to source because output voltage V_a is always +ve and load current I_a is –ve. As load voltage is greater than the source voltage V_s. as load voltage greater

than the source voltage V_s, type B chopper is also called as stepper chopper or boost chopper. It is also called regenerative chopper.

6. EXPLAIN THE TWO QUADRANT TYPE A CHOPPER OR TYPE C CHOPPER:



Type C chopper is obtained by connecting type A and type B chopper in parallel. Here the output voltage V_a is always +ve but the load current I_a is +ve as well as –ve.

When chopper CH_1 or FD conduct, the output voltage and load current is always +ve. In other words CH_1 and FD operate together as type A chopper in first quadrant. When chopper CH_2 or diode D_2 conduct, the output voltage is +ve but the load current is –ve. In other words CH_2 and D_2operates together as type B chopper in second quadrant.

Average load voltage is always +Ve but average load current may be +ve or –ve. Therefore power flow from source to load or from load to source.

Choppers CH1 and CH2 should not be on simultaneously otherwise direct short circuit will occur. This type is used for motoring and regenerative braking of DC motors.

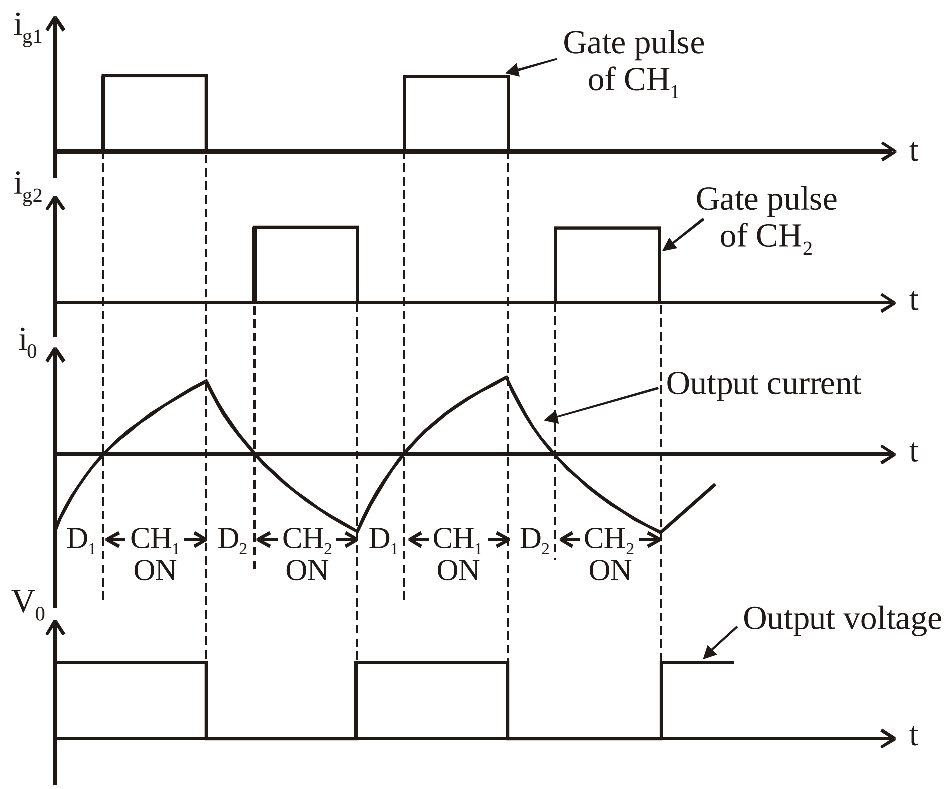
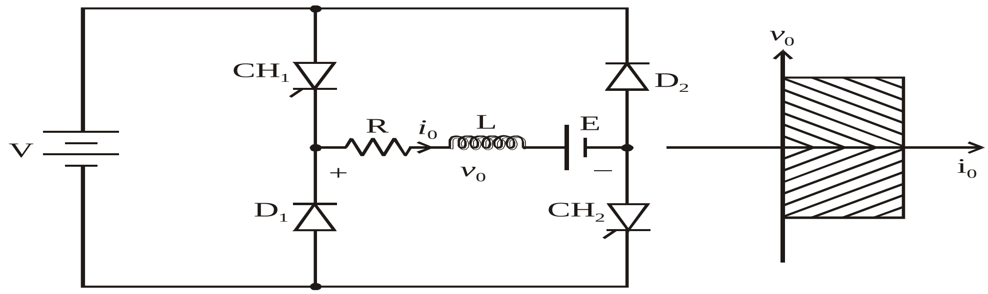


Fig. 13: Class C Chopper – Output Voltage and Current Waveforms

7. EXPLAIN THE TWO QUADRANT TYPE-B CHOPPER OR TYPE-D CHOPPER

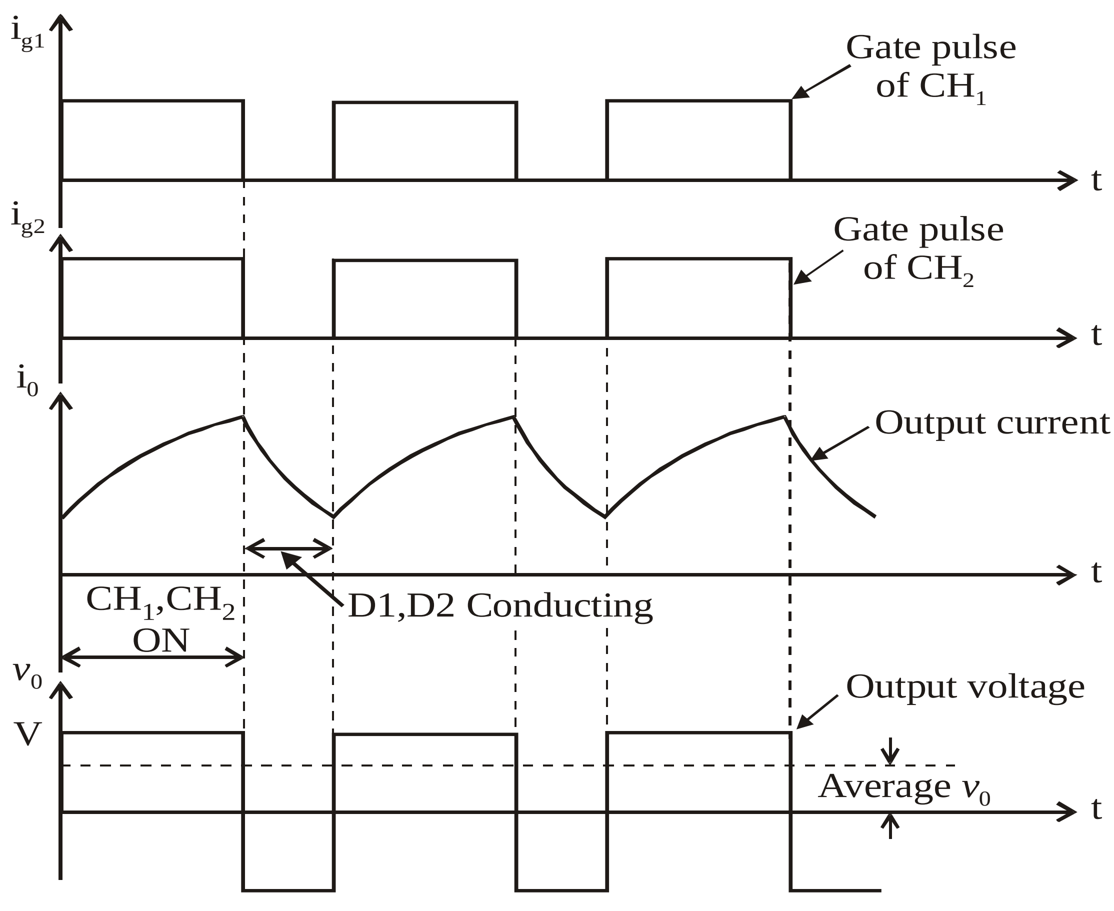
The output voltage is equal to supply voltage i.e. $V_0 = V_s$ when both CH_1 and CH_2 are ON and output voltage is equal to –ve value of supply voltage. i.e. $V_a = -V_s$. when both choppers are OFF but diodes D_1 and D_2 conducts.



CLASS D CHOPPER

Average output voltage V_a is +ve when ON time of the chopper (T_{on}) is more than their turn OFF time (T_{off}). Average output voltage is –ve when choppers turned OFF time is more than their turn on time.

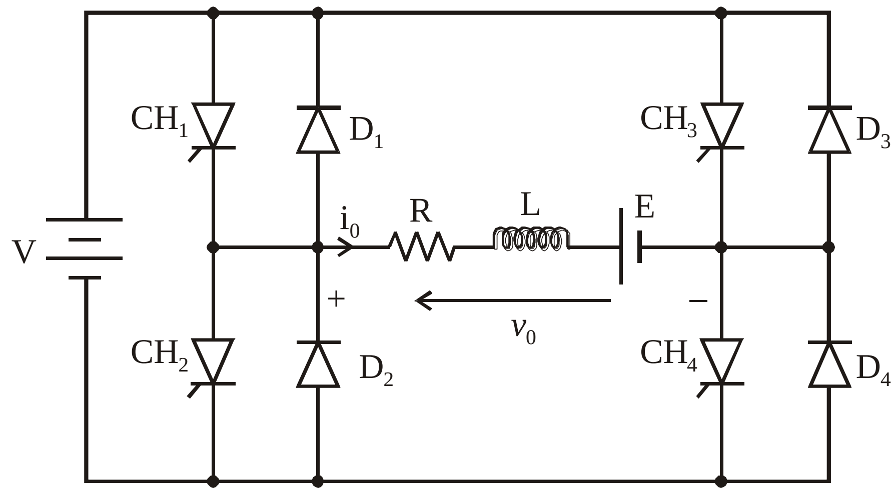
The direction of load is always +ve because choppers and diodes can conduct current only in the direction of arrows shown in figure. Here output voltage V_a is –ve, the power flow from load to source.



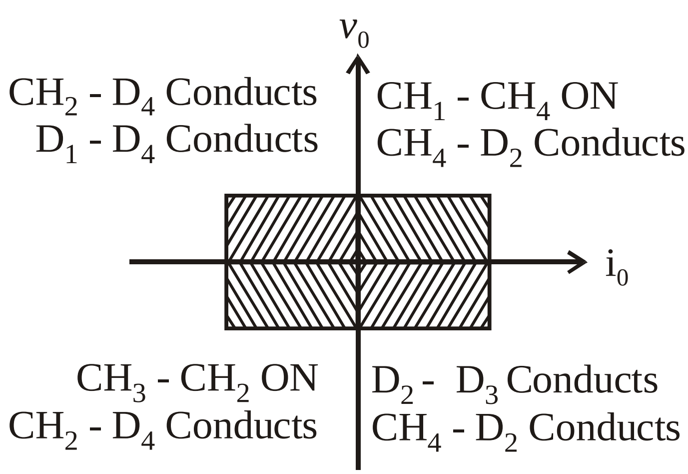
Output Voltage and Current Waveforms for $t_{ON} > t_{OFF}$

8. EXPLAIN THE FOUR QUADRANT CHOPPER OR TYPE E CHOPPER

It consists of four power semiconductor switches CH1 to CH4 and four power diodes D1 to D4 in antiparallel.



CLASS E CHOPPER



FOUR QUADRANT OPERATION

Forward Motoring Mode:

For I quadrant operation CH_4 is kept ON, CH_3 is kept OFF and CH_1 is operated. With CH_1, CH_4 ON, load voltage is equal to supply voltage i.e. $V_a = V_s$ and load current I0 begins to flow. Here both output voltage V_o and load current Io are +ve. When CH_1 is turned OFF, +ve current free wheels through CH_4, D_2, both output voltage V_0 and load current I_0 can be controlled in the first quadrant.

Forward Braking Mode:

Here CH_2 is operated and CH_1, CH_3 and CH_4 are kept OFF. With CH_2 ON, reverse current flow through L, CH_2, D_4 and E. During the ON time of CH_2, the inductor L stores energy. When CH_2 is turned OFF, current is fed back to source through diode D_1, D_4 note that there [E+L di/dt) is greater than the voltage source Vs. As the load voltage V_a is +ve and load current I_a is –ve. It is 2nd quadrant operation of chopper. Also power is flows from load to source.

Reverse Motoring Mode:

For 3rd quadrant operation CH_1 is kept OFF, CH_2 is kept ON and CH_3 is operated. Polarity of load emf E must be reversed for this quadrant operation. With CH_3 ON load gets connected to source V_s, so both output voltage V_a and load current I_a are –ve. It gives third quadrant operation. It is also known as reverse motoring mode. When CH_3 is turned OFF, -ve current free wheels through CH_2, D_4. In this way output voltage V_a and load current I_a can be controlled in third quadrant.

Reverse Braking Mode:

Here CH_4 is operated and other devices are kept OFF. Load emf E, must have its polarity reversed. For operation of fourth quadrant, with CH_4 on, +ve current flows through CH_4, D_2, L and E. During ON time of CH_4, Inductor L stores energy. When CH_4 is turned OFF, current is feedback to source through diodes D_2, D_3. Here load voltage is –ve, but load current is +ve leading to the choppers operation in the fourth quadrant. Also power is flows from load to source. The fourth quadrant operative gives reverse braking mode.

9. EXPLAIN THE DIFFERENT TYPES OF BRAKING IN ELECTRICAL MOTOR DRIVE.

There are 3 types of electrical braking as applicable to electric motors in addition to eddy current braking.

1. Plugging or Reverse voltage braking
2. Dynamic braking or Rheostatic braking
3. Regenerative braking

Plugging

In this case armature connections are reversed, whereas field winding connections remain unchanged with reverse armature connections, the motor develop a torque in the opposite direction. When speed reduces to zero, motor will accelerate in the opposite direction.

Here the arrangement is made to disconnect the motor from the supply as soon as it comes to rest. Fig shows running and reversed connections of shunt motor and series motor. Since with reversed connections V &E_b are in the same direction, voltage across the armature is almost doubled its normal value. In order to avoid excessive current through the armature, additional resistance R is connected in series with armature. This method of braking is wasteful because in addition to wasting kinetic energy of the moving parts, it draws additional energy from the supply during braking.

Braking torque: The electric braking torque is given by

$$T_b \propto \emptyset I_a = k_1 \emptyset I_a$$

We have $I_a = \frac{V+E_b}{R}$

$$T_b = k_1 \emptyset . \frac{V + E_b}{R} = k_1 \emptyset . \frac{V + K_2 \emptyset N}{R} = \frac{k_1 \emptyset V}{R} + \frac{k_1 k_2 \emptyset^2 N}{R} = k_3 \emptyset + k_4 \emptyset^2 N$$

Shunt motor:

Since in this case, ∅ is practically constant

$$T_b = K_S + K_6 N$$

Series motor:

$$T_b = K_3 \emptyset + K_4 \emptyset^2 N = K_5 I_a + K_6 N I_a^2$$

RHEOSTATIC BRAKING (OR) DYNAMIC BRAKING

In this method of electric braking, motor is disconnected from the supply though its field continues to be energized in the same direction. The motor starts working as generator and all kinetic energy of the equipment to be braked is converted into electrical energy and is further dissipated in variable external resistance R connected across the motor during braking period. This external resistance must be less than critical resistance otherwise there will not enough current for generator excitation.

This method has advantage over plugging because in this case, no power is drawn from supply during braking.

RHEOSTATIC BRAKING ON DC MOTORS

In DC shunt motor, for applying rheostatic braking, armature is disconnected from the supply and connected to variable external resistance R while field remains on supply. The motor starts working as a generator whose induced emfE_b depends upon its speed. At start of braking. When speed is high, E_b is large, hence I_a is large. As speed decreases, E_b&I_a decreases. Since $T_b \propto \emptyset I_a$, it will be high at high speeds, low at low speeds. By gradually cutting out R. I_a and T_b is kept constant. Value of $I_a = E_b(R + R_a)$

In DC series motor, for rheostatic braking, the armature is disconnected from supply and it is connected to R_1. However, connections are made that current keeps flowing through series field in same direction otherwise no braking torque would be produced. The motor starts working as a series generator provided R is less than critical resistance.

REGENERATIVE BRAKING

In this method of braking, motor is disconnected from the supply but is made to run as generator by utilizing kinetic energy. Electrical energy is feedback to the supply. The magnetic drag produced on account of generator action offers braking torque. It is the most efficient method of braking. Take the case of a shunt motor. It will run as a generator whenever its E_b becomes greater than V. now,

E_b can exceed in two ways.

1. By increasing field excitation
2. By increasing motor speed beyond its normal value, field current remaining the same. It happens when load on the motor has over hauling characteristics as in the lowering of the cage or a hoist or down gradient movement of electric train.

Regenerative braking can be easily applied to shunt motors though not down to very low speeds because it is not possible to increase field current sufficient.

In case of DC series motor, reversal of current necessary to produce regeneration would cause reversal of the field and hence of Eb. Consequently, modifications are necessary if regenerative braking is to be employed with DC series motors used in electric traction.

It may however be clearly understood the regenerative braking cannot be used for stopping a motor. Its main advantages are i) reduced energy consumption particularly on main-line railways having long gradients and mountain railways ii) reduced wear of brake shoes and wheel types iii) lower maintenance cost for these items.

10. EXPLAIN THE CHARACTERISTICS OF DC MOTOR DRIVES IN DETAIL. (April /May 2014)

Characteristics of DC Drives

The performance of a d.c. motor under various conditions can be judged by the following characteristics.

i) Torque-Armature current characteristics (T Vs I_a) - Electrical characteristics

ii) Speed-Armature current characteristics (N Vs I_a)

iii) Speed-Torque characteristics (N Vs T) - Mechanical characteristics

2.7 Characteristics of D.C. Shunt Motor

i) Torque-Armature current characteristics

For a d.c. motor $T \propto \phi I_a$

For a constant values of R_{sh} and supply voltage V, I_{sh} is also constant and hence flux is also constant.

$$\therefore \quad \boxed{T_a \propto I_a}$$

The equation represents a straight line, passing through the origin, as shown in the Fig. 2.8. Torque increases linearly with armature current. It is seen earlier that armature current is decided by the load. So as load increases, armature current increases, increasing the torque developed linearly.

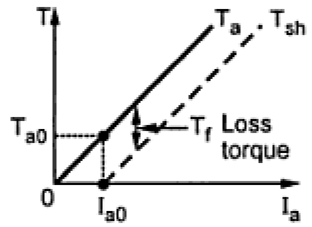


Fig. 2.8 T Vs I_a for shunt motor

Now if shaft torque is plotted against armature current, it is known that shaft torque is less than the armature torque and the difference between the two is loss torque T_f as shown. On no load $T_{sh} = 0$ but armature torque is present which is just enough to overcome stray losses shown as T_{a0}. The current required is I_{a0} on no load to produce T_{a0} and hence T_{sh} graph has an intercept of I_{a0} on the current axis.

To generate high starting torque, this type of motor requires a large value of armature current at start. This may damage the motor hence d.c. shunt motors can develop moderate starting torque and hence suitable for such applications where starting torque requirement is moderate.

ii) Speed-Armature current characteristics

From the seed equation we get,

$$N \propto \frac{V - I_a R_a}{\phi}$$

$$\propto V - I_a R_a \qquad \text{as } \phi \text{ is constant.}$$

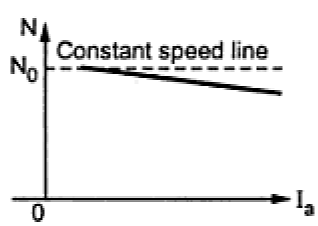


Fig. 2.9 N Vs I_a for shunt motor

So as load increases, the armature current increases and hence drop $I_a R_a$ also increases.

Hence for constant supply voltage, $V - I_a R_a$ decreases and hence speed reduces. But as R_a is very small, for change in I_a from no load to full load, drop $I_a R_a$ is very small and hence drop in speed is also not significant from no load to full load.

So the characteristics is slightly droping as shown in the Fig. 2.9.

But for all practical purposes these type of motors are considered to be a constant speed motors.

iii) Speed-Torque characteristics

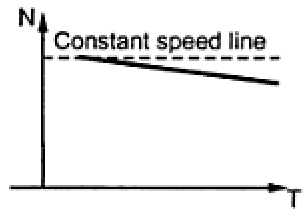


Fig. 2.10 N Vs T for shunt motor

These characteristics can be derived from the above two characteristics. This graph is similar to speed-armature current characteristics as torque is proportional to the armature current. This curve shows that the speed almost remains constant though torque changes from no load to full load conditions. This is shown in the Fig. 2.10.

The modifications in the various characteristics can be obtained by adding a variable resistance in series with armature or field circuit. In some cases, supply voltage also can be varied to modify the characteristics.

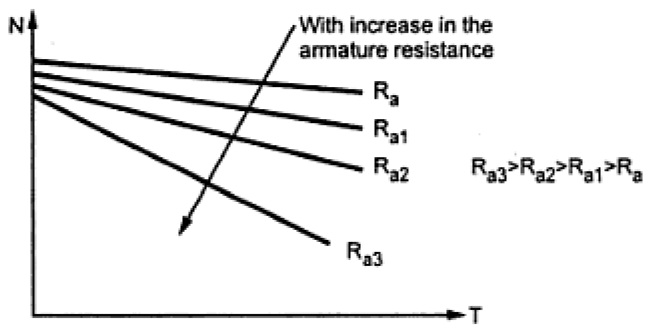


Fig. 2.11 Effect of change in R_a

When the resistance is inserted in the armature circuit, the voltage across the armature decreases and hence the speed from zero to normal speed can be achieved. As voltage decreases, the torque developed also decreases.

Similarly the speeds from zero to twice the normal speed can be obtained by adding resistance in series with the field winding. As the resistance in the field circuit is increased, the current through the field winding decreases decreasing the flux. As the speed is inversely proportional to the flux the speed increases. Such increase in the speed is possible upto twice the normal speed from the mechanical safety point of view.

The modifications in the characteristics by controlling the various parameters discussed above namely armature resistance, field resistance and the supply voltage are shown in the Fig. 2.11, 2.12 and 2.13.

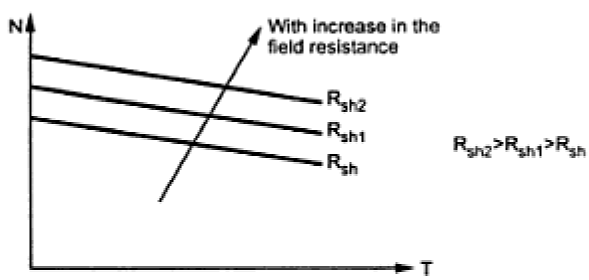


Fig. 2.12 Effect of change of R_{sh}

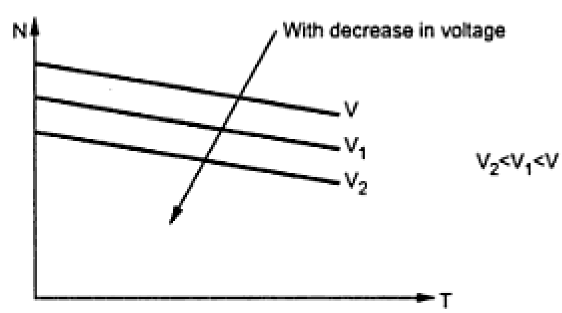


Fig. 2.13 Effect of change in voltage

2.8 Characteristics of D.C. Series Motor

i) Torque-Armature current characteristics

In case of series motor the series field winding is carrying the entire armature current. So flux produced is proportional to the armature current.

$$\therefore \qquad \phi \propto I_a$$

$$\text{Hence} \qquad \boxed{T_a \propto \phi I_a \propto I_a^2}$$

Thus torque in case of series motor is proportional to the square of the armature current. This relation is parabolic in nature as shown in the Fig. 2.14.

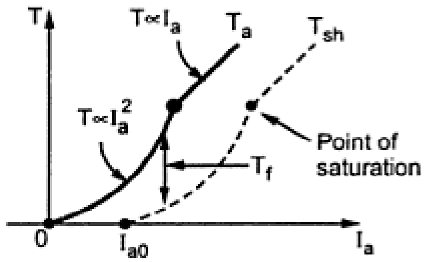


Fig. 2.14 T Vs I_a for series motor

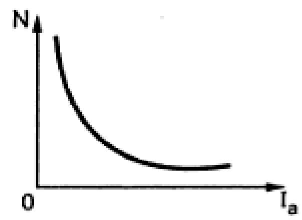


Fig. 2.15 N Vs I_a for series motor

As load increases, armature current increases and torque produced increases proportional to the square of the armature current upto a certain limit.

As the entire I_a passes through the series field, there is a property of an electromagnet called **saturation**, may occur. Saturation means though the current through the winding increases, the flux produced remains constant. Hence after saturation the characteristics take the shape of straight line as flux becomes constant, as shown. The difference between T_a and T_{sh} is loss torque T_f which is also shown in the Fig. 2.14.

At start as $T \propto I_a^2$, these types of motors can produce high torque for small amount of armature current hence the series motors are suitable for the applications which demand high starting torque.

ii) Speed-Armature current characteristics

From the speed equation we get,

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

$$\propto \frac{V - I_a R_a - I_a R_{se}}{I_a} \qquad \text{as } \phi \propto I_a \text{ in case of series motor}$$

Now the values of R_a and R_{se} are so small that the effect of change in I_a on speed overrides the effect of change in $V - I_a R_a - I_a R_{se}$ on the speed.

Hence in the speed equation, $E_b \cong V$ and can be assumed constant. So speed equation reduces to,

$$\boxed{N \propto \frac{1}{I_a}}$$

So speed-armature current characteristics is rectangular hyperbola type as shown in the Fig. 2.15.

iii) Speed-Torque characteristics

In case of series motors,

$$T \propto I_a^2 \qquad \text{and} \qquad N \propto \frac{1}{I_a}$$

Hence we can write,

$$\boxed{N \propto \frac{1}{\sqrt{T}}}$$

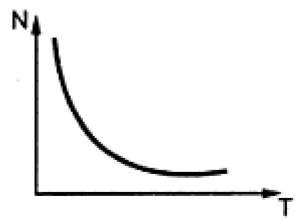
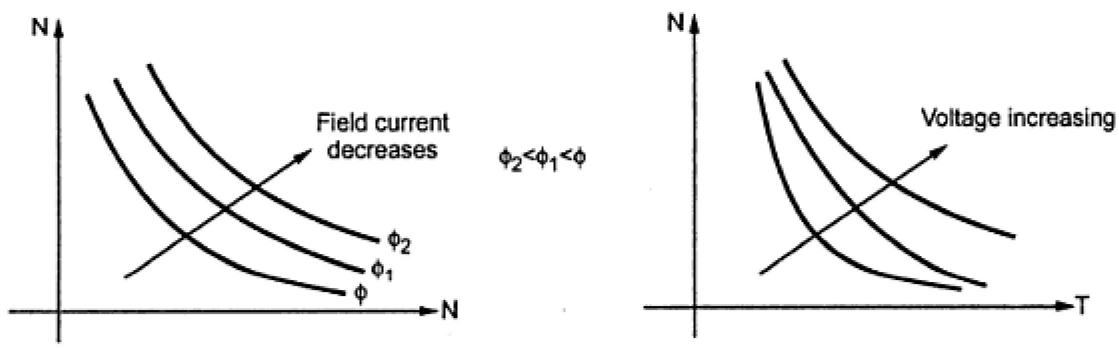


Fig. 2.16 N Vs T for series motor

Thus as torque increases when load increases, the speed decreases. On no load, torque is very less and hence speed increases to dangerously high value. Thus the nature of the speed-torque characteristics is similar to the nature of the speed-armature current characteristics.

The speed-torque characteristics of a series motor is shown in the Fig. 2.16.

The modifications in the various characteristics can be obtained by adding a variable resistance in series with armature due to which armature voltage gets varied. Similarly flux produced by the field winding can be varied by the number of methods such as field divertor, series-parallel grouping of field coils etc. The modifications in the speed-torque characteristics due to change in various parameters like armature voltage, flux are shown in the Fig. 2.17(a) and Fig. 2.17(b).



(a) Effect of change in field current **(b) Effect of change in voltage**

Fig. 2.17

2.9 Characteristics of D.C. Compound Motors

The characteristics of compound motors depend on the nature of the two fluxes ϕ_{sh} produced by shunt field winding and ϕ_{se} produced by series field winding. If the two fluxes are helping each other, the motor is called **cumulatively compound** while if the two fluxes are opposing each other, the motor is called **differentially compound**.

Compound motor characteristics basically depends on the fact whether the motor is cumulatively compound or differential compound. All the characteristics of the compound motor are the combination of the shunt and series characteristic.

Cumulative compound motor is capable of developing large amount of torque at low speeds just like series motor. However it is not having a disadvantage of series motor even at light or no load. The shunt field winding produces the definite flux and series flux helps the shunt field flux to increase the total flux level.

So cumulative compound motor can run at a reasonable speed and will not run with dangerously high speed like series motor, on light or no load condition.

In differential compound motor, as two fluxes oppose each other, the resultant flux decreases as load increases, thus the machine runs at a higher speed with increase in the load. This property is dangerous as on full load, the motor may try to run with dangerously high speed. So differential compound motor is generally not used in practice.

The various characteristics of both the types of compound motors cumulative and the differential are shown in the Fig. 2.18 (a), (b) and (c).

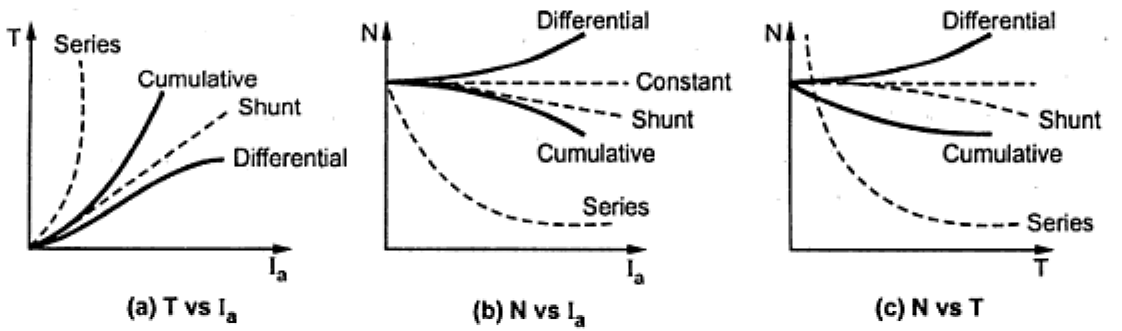


Fig. 2.18 Characteristics of compound motor

The exact shape of these characteristics depends on the relative contribution of series and shunt field windings. If the shunt field winding is more dominant then the characteristics take the shape of the shunt motor characteristics. While if the series field winding is more dominant then the characteristics take the shape of the series characteristics.

Problems

1. **A 500V series motor having armature and field resistance of 0.2 and 0.3ohm respectively runs at 500 rpm when taking 70 amps. Assuming unsaturated field. Find out its speed when field divertor of 0.684 ohm is used constant torque load.**

Given:

V = 500V, R_a = 0.2 ohm, R_{se} = 0.3ohm, I_{a1} = 70A, N_1 = 500rpm, R_{div} = 0.684ohm.

Solution

Back emf $E_{b1} = V - I_{a1}(R_a + R_{se}) = 500 - 70(0.2+0.3) = 465V$

Let I_{a2} be the current taken and $\emptyset_2$ be the flux produced, when a diverter is connected across the series field.

Since torque remains constant

$$\emptyset_1 I_{a1} = \emptyset_2 I_{a2} \ldots\ldots\ldots\ldots (1)$$

but

$\emptyset \propto$ current through series field

$$\emptyset_1 \propto I_{a1}$$

Current through the series field when a divertor is connected

$$= I_{a2} \times R_{div}/(R_{div} + R_{se}) = 0.695\, I_{a2}$$

Flux in this case $\emptyset_2 \propto 0.695\, I_{a2}$ substituting in (1), we get

$$I_{a1}^2 = 0.695 I_{a2}^2$$

$$I_{a2}^2 = \frac{I_{a1}^2}{0.695} = 83.96A$$

Series field current, $I_{se} = 0.695\, I_{a2} = 0.695 \times 83.96 = 58.35A$

Back emf, $E_{b2} = V - I_{a1}R_a - I_{se}R_{se} = 500 - 83.96 \times 0.2 - 58.35 \times 0.3 = 465.703\, V$

Using the relation, $\frac{N_2}{N_1} = \frac{E_{b1}}{E_{b2}} \times \frac{\emptyset_1}{\emptyset_2} \Rightarrow \frac{N_2}{500} = \frac{465.703}{465} \times \frac{70}{83.96} = 418rpm$

2. **A 250V DC series motor takes 40A of current when developing a full load torque at 1500rpm. Its resistance is 0.5ohm. if the load torque varies as the square of speed. Determine the resistance to be connected on series with the armature to reduce the speed to 1500rpm. Assume that the flux is proportional to the field current.**

Given:

Supply voltage, V = 250V, I_{a1} = 40A, Speed N_1 = 1500 rpm

$T \propto N^2$, N_2 = 1200 rpm, Resistance ($R_a + R_{se}$) = 0.5ohm

To find:

Resistance to be connected in series with the armature.

Solution:

Back emf$E_{b1} = V - I_{a1}(R_a + R_{se}) = 250 - (40 \times 0.5) = 230V$

Since $T \propto N^2$

$$\frac{T_2}{T_1} = \left(\frac{N_2}{N_1}\right)^2 = \left(\frac{1200}{1500}\right)^2 = 0.64$$

$$T \propto \emptyset I_a$$

$$T_1 \propto \emptyset I_{a1}$$

$$T_2 \propto \emptyset I_{a2}$$

$$T_1 \propto \emptyset {I_{a1}}^2$$

$$T_2 \propto \emptyset {I_{a2}}^2$$

$$(I_{a2}/I_{a1})^2 = 0.64$$

$$(I_{a2}/40)^2 = 0.64$$

$$I_{a2} = 32A$$

External resistance is connected in series with armature

Back emf= $V - I_{a2}(R + R_a + R_{se}) = 250V - 32(0.5R) = 250 - 16R$

Using the relation, ,$\frac{N_2}{N_1} = \frac{E_{b1}}{E_{b2}} \times \frac{\emptyset_1}{\emptyset_2}$

Here, $\emptyset_1 \propto I_{a1}, \emptyset_2 \propto I_{a2}$

$$\frac{N_2}{N_1} = \frac{E_{b1}}{E_{b2}} \times \frac{I_{a1}}{I_{a2}}$$

$$\frac{1200}{1500} = \frac{250 - 16R}{230} \times \frac{40}{32}$$

$R = 6.425$ohm

3. A 220 V DC shunt motor takes 5A on no-load test and runs at 750rpm. The resistance of armature and shunt field winding are 0.2ohm and 110 ohm respectively. Calculate the speed when motor is loaded and taking a current of 50A. Assume that armature reaction weakens the field by 3%.

Given:

V=220V, I_a = 5A, N_1 = 750rpm, R_a = 0.2ohm, Rsh = 110 ohm, I_L = 50A

Armature reaction weakens the field by 3%. i.e.$\emptyset_2 = 0.97\emptyset$

To find: Speed N_2

Solution:

Shunt field current $I_{sh} = \frac{V}{R_{sh}} = \frac{220}{110} = 2A$

No load armature current, $I_{a0} = I_0 - I_{sh} = 5 - 2 = 3A$

Back emf$E_{b1} = V - I_{a0}R_a = 220 - (3 \times 0.2) = 219.4V$

Load armature current, $I_{a2} = I_L - I_{sh} = 50 - 2 = 48A$

Now back emf, $E_{b2} = V - I_{a2}R_a = 220 - (48 \times 0.2) = 210.4V$

$$\emptyset_2 = 0.97\ \emptyset_1$$

Using the relation, ,$\frac{N_2}{N_1} = \frac{E_{b1}}{E_{b2}} \times \frac{\emptyset_1}{\emptyset_2}$

$$\frac{N_2}{750} = \frac{210.4}{219.4} \times \frac{\emptyset_1}{0.97\emptyset_1}$$

N_2 = 741.5rpm

4. **A 500V DC shunt motor running at 700rpm takes an armature current of 50A, effectivel armature resistance is 0.4ohm. what resistance must be placed series with the armature reduced the speed to 600 rpm. The torque remaining constant.**

Given:

Supply voltage, V = 500V, I_a = 5A. R_a = 0.4ohm, Speed N_1 = 700rpm, Speed N_2 = 600rpm

To find:

External Resistance R_e

Solution:

Back emf, E_{b1} = V – I_aR_a = 500 – (50*0.4) = 480V

R_T = R_a + R_e

SinceI_{sh} is constant.

$$\emptyset_1 = \emptyset_2$$

$$E_{b2} = V - I_a(R_a + R_e) = 500 - 50R_T$$

Using the relation, $\frac{N_2}{N_1} = \frac{E_{b1}}{E_{b2}}$

$$\frac{600}{700} = \frac{500 - 50R_t}{480}$$

$$R_t = 1.77\Omega$$

$$R_t = 0.4 + R_e = 1.77$$

$$R_e = 1.37\Omega$$

5. **A 220V, 15KW, 850rpm shunt motor draws 72.2A while operating at rated condition. The resistance of the armature and shunt fields are 0.25ohm and 100 ohm respectively. Determine the percentage reduction in field flux in order to obtain a speed of 1650 rpm when armature current drawn is 40A.**

Solution:

$$I_{sh} = V/R_{sh} = 220/100 = 2.2A$$

$$I_{a1} = I_a - I_{sh1} = 72.2 - 2.2 = 70A$$

$$E_{b1} = V - I_{a1}R_a = 220 - (70 * 0.25) = 210A$$

Now, $\frac{N_2}{N_1} = \frac{E_{b1}}{E_{b2}} \times \frac{\emptyset_1}{\emptyset_2}$

$$\phi_2 = 0.534\phi_1$$

Reduction in field flux = $\frac{\phi_1 - 0.534\phi_1}{\phi_1} \times 100 = 46.6\%$

Department of Electrical and Electronics Engineering

Subject Name: Solid State Drives **Subject Code: EE T65**

UNIT III: STATOR SIDE CONTROLLED INDUCTION MOTOR DRIVE

Stator voltage controlled induction motor drive - slip torque characteristics- different configuration of controller's input current-closed loop operation. Stator frequency controlled induction motor drive-Slip-torque characteristics; harmonic equivalent Circuit- Rotating magnetic fields-harmonic current-efficiency-torque; stability.

Two Marks

1. What are the different methods of braking applied to the induction motor?

i Regenerative braking

ii Plugging

iii Dynamic braking.

2. What are the different methods of speed control of IM?

Stator voltage control

Supply freq. control

Rotor resistance control

Slip power recovery control.

3. What is meant by stator voltage control?

The speed of the IM can be changed by changing the stator voltage. Because the torque is proportional to the square of the voltage.

4. Mention the application of stator voltage control.

This method is suitable for applications where torque demand reduced with speed, which points towards its suitability for fan and pump drives.

5. Mention the applications of ac drives.

AC drives are used in a no. of applications such as fans, blowers, mill run-out tables, cranes, conveyors, traction.

6. What are the three regions in the speed-torque characteristics in the IM?

Motoring region (0<=s<=1)

Generating region(s<0)

Plugging region (1<=s<=2) where s is the slip.

7. What are the adv. of stator voltage control method?

The ctrl circuitry is

- simple
- Compact size
- Quick response time
- There is considerable savings in energy and thus it is economical method as compared to other methods of speed ctrl.

8. What is meant by soft start?

The ac voltage controllers show a stepless control of supply voltage from zero to rated volt. They are used for soft start for motors.

9. List the adv of squirrel cage IM?

- Cheaper
- Light in weight
- Rugged in construction
- More efficient
- Require less maintenance
- It can be operated in dirty and explosive environment

10. Define slip

The difference between the synchronous speed (Ns)and actual speed(N)of the rotor is known as slip speed. the % of slip is gn by,

%slip s=[(Ns-N)/Ns]x 100

11. Define base speed.

The synchronous speed corresponding to the rated freq is called the base speed.

12. What is meant by frequency control of IM?

The speed of IM can be controlled by changing the supply freq because the speed is directly proportional to supply frequency. This method of speed ctrl is called freq control.

13. What is meant by V/F control?

When the freq is reduced the i/p 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 IM behavior is similar to the working of dc series motor.

14. What are the advantages of V/F control?

Smooth speed ctrl

Small i/p current and improved power factor at low freq. start

Higher starting torque for low case resistance

15. What is meant by stator current control?

The 3 phase IM speed can be controlled by stator current control. The stator current can nbe varied by using current source inverter.

16. What are the 3 modes of region in the adjustable-freq IM drives characteristics?

Constant torque region

Constant power region

High speed series motoring region

17. What are the two modes of operation in the motor?

The two modes of operation in the motor are, motoring and braking. In motoring, it converts electrical energy to mechanical energy, which supports its motion. In braking, it works asa generator converting mechanical energy to electrical energy and thus opposes the motion.

18. How will you select the motor rating for a specific application?

When operating for a specific application motor rating should be carefully chosen that the insulation temperature never exceed the prescribed limit. Otherwise either it will lead to its immediate thermal breakdown causing short circuit and damage to winding, or it will lead to deterioration of its quality resulting into thermal breakdown in near future.

19. What is braking? Mention its types.

The motor works as a generator developing a negative torque which opposes the motion is called barking. It is of three types. They are,

a. Regenerative braking.

b. Dynamic or rheostat braking.

c. Plugging or reverse voltage braking.

20. What are the three types of speed control? (NOVEMBER 2011, 13)

The three types of speed control as,

a. Armature voltage control

b. Field flux control

c. Armature resistance control.

21. What are the advantages of armature voltage control? (NOVEMBER 2013)

The advantages of armature voltage control are,

a. High efficiency

b. Good transient response

c. Good speed regulation.

22. What are the methods involved in armature voltage control?

When the supply in A.C.

a. Ward-Leonard schemes

b. Transformer with taps and an uncontrolled rectifier bridge.

c. Static ward Leonard scheme or controlled rectifiers when the supply in D.C.

d. Chopper control.

23. Give some drawbacks and uses of Ward-Leonard drive.

The drawbacks of Ward Leonard drives are.

a. High initial cost

b. Low efficiency

The Ward-Leonard drive is used in rolling mills, mine winders, paper mills, elevators, machine tools.

24. **Give some advantages of Ward-Leonard drive**.

The advantages of Ward-Leonard drive are,

a. Inherent regenerative braking capability

b. Power factor improvement.

25. What is called continuous and discontinuous conduction?

A D.C. motor is fed from a phase controlled converter the current in the armature may flow in discrete pulses in called continuous conduction.

A D.C. motor is fed from a phase controlled converter the current in the armature may flow continuously with an average value superimposed on by a ripple is called discontinuous conduction.

26. What are the three intervals present in discontinuous conduction mode of single phase half and fully controlled rectifier?

The three intervals present in half controlled rectifier are,

a. Duty interval

b. Free, wheeling interval

c. Zero current intervals.

The two intervals present in fully controlled rectifier are

a. Duty interval

b. Zero current intervals.

27. What are the advantages of induction motors over D.C. motors?

The main drawback of D.C. motors is the presence of commutate and brushes, which require frequent maintenance and make them unsuitable for explosive and dirty environments. On the other hand, induction motors, particularly squirrel-cage are rugged, cheaper, lighter, smaller, more efficient, require lower maintenance and can operate in dirty and explosive environments.

28. Give the applications of induction motors drives.

Although variable speed induction motor drives are generally expensive than D.C. drives, they are used in a number of applications such as fans, blowers, mill run-out tables, cranes, conveyors, traction etc., because of the advantages of induction motors. Other applications involved are underground and underwater installations, and explosive and dirty environments.

29. How is the speed controlled in induction motor? (NOVEMBER 2011)

The induction motor speed can be controlled by supplying the stator a variable voltage, variable frequency supply using static frequency converters. Speed control is also possible by feeding the slip power to the supply system using converters in the rotor circuit; Basically one distinguishes two different methods of speed control.

i Speed control by varying the slip frequency when the stator is fed from a constant voltage, constant frequency mains.

ii Speed control of the motor using a variable frequency variable voltage motor operating at constant rotor frequency.

30. How is the speed control by variation of slip frequency obtained? (NOVEMBER 2012)

Speed control by variation of slip frequency is obtained by the following ways.

a. Stator voltage control using a three-phase voltage controller.

b. Rotor resistance control using a chopper controlled resistance in the rotor circuit.

c. Using a converter cascade in the rotor circuit to recover slip energy.

d. Using a cyclconverter in the rotor circuit.

31. Mention the effects of variable voltage supply in a cage induction motor.

When a cage induction motor is fed from a variable voltage for speed control the following observation may be made.

i The torque curve beyond the maximum torque point has a negative shape. A stable operating point in this region is not possible for constant torque load.

ii The voltage controlled must be capable of withstanding high starting currents. The range of speed control is rather limited.

iii The motor power factor is poor.

32. Classify the type of loads driven by the motor.

The type of load driven by the motor influences the current drawn and losses of the motor as the slip varies. The normally occurring loads are

a. Constant torque loads.

b. Torque varying proportional to speed.

c. Torque varying preoperational to the square of the speed.

33. What are the disadvantages of constant torque loads?

The constant torque loads are not favored due to increase in the losses linearly with slip and becoming maximum at s= 1.0. This is obvious form the variation of flux as the voltage is varied for speed control.

To maintain constant torque the motor draws heavy current resulting in poor torque/ampere, poor efficiency and poor power factor at low speeds.

34. In which cases, torque versus speed method is suitable.

Torque versus speed method is suitable only for the following cases.

a. For short time operations where the duration of speed controls is defined.

b. For speed control of blowers or pumps having parabolic or cubic variations of torque with speed.

This is not suitable for constant torque loads due to increases and heating.

c. For speed control of motor having poor efficiencies under normal operation.

35. How is the speed of a squirrel cage induction motor controlled?

The speed of a squirrel cage induction motor can be controlled very effectively by varying the stator frequency. Further the operation of the motor is economical and efficient, if it operates at very small slips. The speed of the motor is therefore, varied by varying the supply frequency and maintaining the rotor frequency at the rated value or a value corresponding to the required torque on the linear portion of the torque-speed curve.

36. Why the control of a three-phase indication motor is more difficult than D.C. motors.

The control of a three-phase induction motor, particularly when the dynamic performance involvedis more difficult than D.C. motors. This is due to

i Relatively large internal resistance of the converter causes voltage fluctuations following load fluctuations because the capacitor cannot be ideally large.

ii In a D.C. motor there is a decoupling between the flux producing magnetizing current and torque producing armature current. They can be independently controlled. This is not the case with induction motors.

iii An induction motor is very poorly damped compared to a D.C. motor.

37. Where is the V/f control used?

The V/f control would be sufficient in some applications requiring variable torque, such as centrifugal pumps, compressors and fans. In these, the torque varies as the square of the speed. Therefore at small speeds the required torque is also small and V/f control would be sufficient to drive these leads with no compensation required for resistance drop. This is true also for the case of the liquid being pumped with minimal solids.

38. What are the components of the applied voltage to the induction motor?

The applied voltage to the induction motor has two components at low frequencies. They are

a. Proportional to stator frequency.

b. To compensate for the resistance drop in the stator.

The second component deepens on the load on the motor and hence on rotor frequency.

39. What is indirect flux control?

The method of maintaining the flux constant by providing a voltage boost proportional to slip frequency is a kind of indirect flux control. This method of flux control is not desirable if very good dynamic behaviour is required.

40. What is voltage source inverter?

Voltage source inverter is a kind of D.C. link converter, which is a two stage conversion device.

41. What is the purpose of inductance and capacitance in the D.C. link circuit?

The inductance in the D.C. link circuit provides smoothing whereas the capacitance maintains the constancy of link voltage. The link voltage is a controlled quality.

42. What are the disadvantages of square wave inverter in induction motor drive?

Square wave inverters have commutation problems at very low frequencies, as the D.C. link voltage available at these frequencies cannot charge the commutating capacitors sufficiently enough to commutate the thrusters. Those put a limit on the lower frequency of operation. To, extend the frequency towards zero, special charging circuits must be used.

43. What is slip controlled drive?

When the slip is used as a controlled quantity to maintain the flux constant in the motor the drive is called slip enrolled drive. By making the slip negative (i.e., decreasing the output frequency of the inverter) the machine may be made to operate as a generator and the energy of the rotating parts fed back to the mains by an additional line side converter or dissipated in a resistance for dynamic barking. By keeping the slip frequency constant, braking at constant torque and current can be achieved. Thus braking is also fast.

44. What are the effects of harmonics in VSI fed induction motor drive?

The motor receives square wave voltages. This voltage has harmonic components. The harmonics of the stator current cause additional losses and heating. These harmonics are also responsible for torque pulsations. The reaction of the fifth and seventh harmonics with the fundamental gives rise to the seventh harmonic pulsations in the torque developed. For a given induction motor fed from a square wave inverter the harmonic content in the current tends to remain constant independent of input frequency, with the rang of operating frequencies of the inverter.

45. What is a current source inverter?

In a D.C. link converter, if the D.C. link current is controlled, the inverter is called a current source inverter, the current in the D.C. link is kept constant by a high inductance and the capacitance of the filter is dispensed with. A current source inverter is suitable for loads which present low impedance to harmonic currents and have unity p.f.

46. Explain about the commutation of the current source inverter.

The commutation of the inverter is load dependent. The load parameters form a part of the commutation circuit. A matching is therefore required between the inverter and the motor. Multimode operation is not possible. The inverter must necessarily be a force commutated one as the induction motor cannot provide the reactive power for the inverter. The motor voltage is almost sinusoidal with superimposed spikes.

47. Give the features from which a slip controlled drive is developed.

The stator current of an induction motor operating on a variable frequency, variable voltage supplyis independent of stator frequency if the air gap flux is maintained constant. However, it is a function of the rotor frequency. The torque developed is also a function of rotor frequency. The torque developed is also a function of rotor frequency only. Using these features a slip controlled drive can be developed employing a current source inverter to feed an induction motor.

48. How is the braking action produced in plugging?

In plugging, the barking torque is produced by interchange any two supply terminals, so that the direction of rotation of the rotating magnetic field is reversed with respect to the rotation of the motor. The electromagnetic torque developed provides the braking action and brings the rotor to a quick stop.

Eleven Marks

1. Explain the various open loop speed control techniques employed for three phase induction motor.

The induction motor speed can be controlled by varying the stator voltage. This method of speed control is known as stator voltage control.

The rotor circuit power can be varied either by having a variable resistance or by feeding back to the mains through appropriate power conditioning circuits. In the case of variable resistance, the power associated with the rotor circuit is wasted. This scheme is utilized in the rotor resistance control. This method is used in slip power recovery scheme

Thus the above mentioned various methods of speed control scheme of the induction motor can be listed as follows

1. Slip control
   a. Stator voltage control
   b. Rotor resistance control
   c. Slip power recovery scheme
2. Stator frequency control

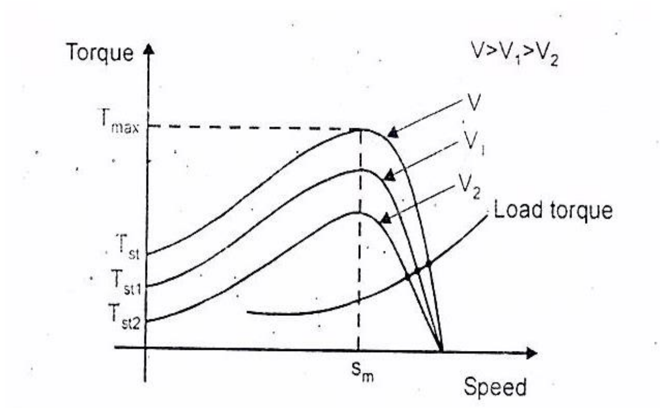


Fig speed –Torque Characteristics of Stator voltage control

Here the supply frequency is constant. Torque equation indicate; that the torque is proportional to the square of its stator voltage i,e., $T \alpha V^2$. For the same slip and frequency, a small change in stator voltage results in a relatively large change in torque, A 10% reduction in voltage causes a 19% reduction in developed torque as well as the starting and maximum torque.

Figure shows speed torque characteristics of induction motor under stator voltage control. This characteristic is based on the torque equation. This shows two curves for two different values of the' stator voltage. Here the slip at the maximum torque remains unchanged since it is not a function of voltage. For a low slip motor, the speed range is very narrow. So this method is not used for wide range of speed control and constant torque load. This is applicable for requiring low starting torque and a narrow speed range at relatively low slip.

lf the stator copper loss and the friction, windage and core losses are neglected, from equation, the motor efficiency is given by

$\eta_m = P_m / P_{ag} = (1-S)$

This equation, increasing the slip i.e very low speeds the motor efficiency is poor.

It is an excellent method for reducing starting current and increasing the efficiency during light load conditions. The starting current is reduced since it is directly proportional to the input voltage. The losses are decreased, mainly core losses, which are proportional to the square of the voltage. The terminal voltage cannot exceeds rated value to prevent the damage of the winding's insulation. Thus, this method is only suitable for speed control below the rated speed.

1. Conventional Method
2. Solid State control Method

3.2 Conventional method

The stator voltage can be controlled by two methods

1. Using auto transformer
2. Primary resistors connected in series with stator winding.

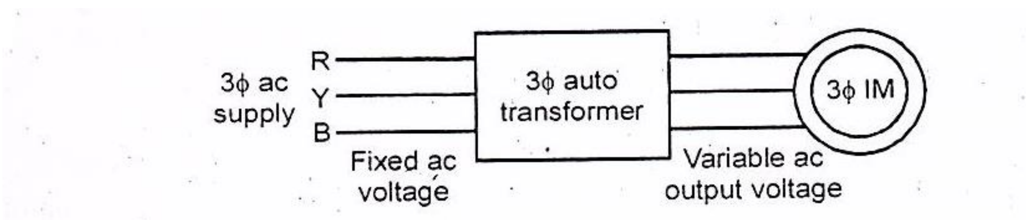


Fig (3.2.1) Conventional method using auto Transformer

The speed of the induction motor can be controlled by using auto transformer. It is shown in figure. The input to the auto transformer is a fixed ac voltage.

By varying the auto transformer we can get variable ac output voltage without change in supply frequency. The variable voltage is fed to the induction motor. Then the induction motor speed also changes.

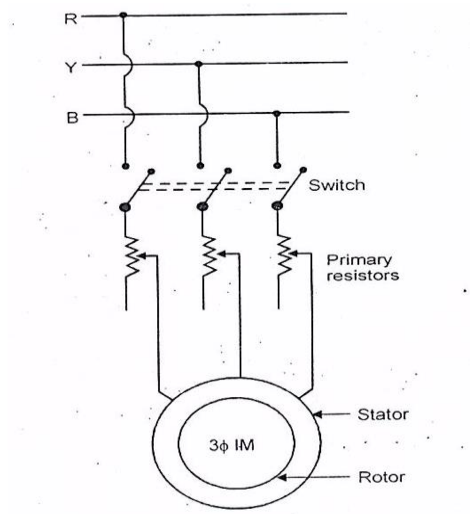


Fig Primary resistor connected in series with stator winding

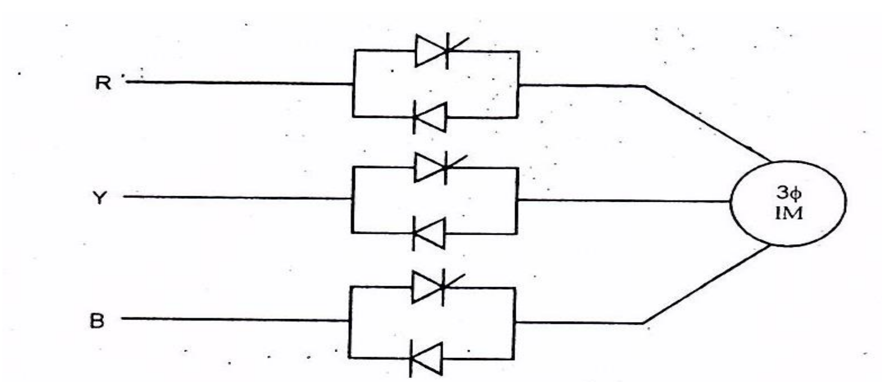
The primary resistors are connected in series with stator windings as shown in figure, By varying the primary resistance, the voltage drop across the motor terminals is reduced. That is, reduced voltage is fed to the motor. Then the motor speed can be reduced. It is one method of conventional speed control of induction motor, The control method is very simple. The main disadvantage is that more power loss occurs in the primary resistors

AC voltage controller for 3-phase induction Motor

The stator voltage is controlled in these speed control systems by means of a power electronic controller. There are two methods of control as follows

(a) on-off control

(b) phase control.



(a) Half wave ac voltage controller

In on off control, the thyristors are employed as switches to connect the load circuit to the source for a few cycles of source voltage and then disconnect it for another few cycles Here thyristors acts as high speed switch (contactor). This method is known as integral cycle control In phase control the thyristors are employed as switches connect the load to the ac source for a portion of each cycle of input voltage. The power circuit configuration for on off control and phase control do not differ in any manner. Normally thyristors in phase control modes are used.

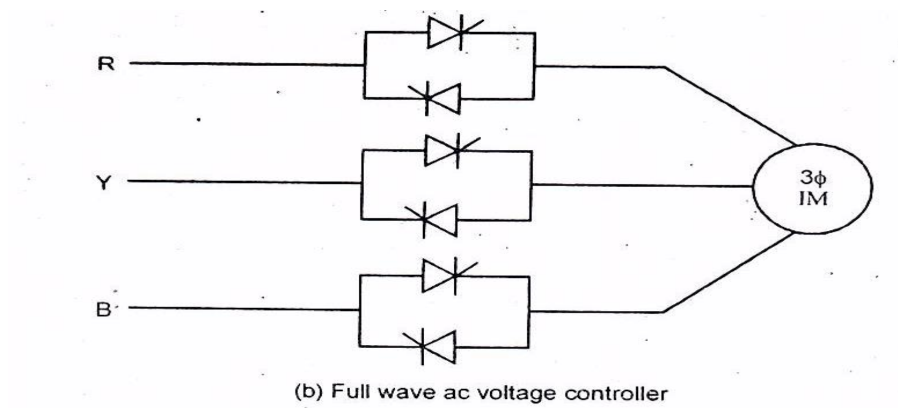


Fig AC voltage controller for 3-phase induction Motor

The various schemes are

(1) single phase or 3 phase half wave ac voltage controller
(ii) l-φ or 3-φ full wave ac voltage controller

Figure (a) and (b) shows the circuits of three phase half wave and full wave ac voltage controllers for star connected stators. In half wave ac 'voltage controller consists of 3 SCRs and 3 diodes Here one SCR and one diode in anti parallel are connected between the line and motor in a phase., The full wave ac voltage controller consists of 6 SCRs Here two SCRs in anti parallel are connected_ between die line and motor in a phase The main advantage of half wave controller is a 'saving the cost of system The disadvantage is that it introduces more harmonics into the line current. The effective load voltage in three phase ac circuit can be varied by varying the thyristor tiring angles.

Advantages of stator voltage control

1. The control circuit is very simple

2. More compact and less weight

3. lts response time is quick

4. There is a considerable savings in energy and thus it is a economical method

Disadvantages

1. The input power factor is very low.

2. Voltage and current waveforms are highly distorted due to harmonics, which affects the efficiency of the machine.

3. Performance is poor under running condition at low speed

4. Operating efficiency is low as resistance losses are high.

5. Maximum torque available from the motor decreases with decreases in stator voltage.

6. At low speeds, motor currents are excessive and special arrangements should be provided to limit the excessive currents.

Applications

1. They are mainly used in low power applications such as fans, blowers and centrifugal pumps where the starting torque is low.
2. They are also used for starting high power induction motors to limit the in-rush

Explain the closed loop speed control of Induction Motor drives. (Nov – 2014)

Feedback loops in an electrical drive may be provided to satisfy one or more of the following requirements,

1. Protection
2. Improvement of speed response
3. To improve steady state accuracy

Closed loop speed control

This system consists of a power circuit, 3¢ IM, tacho generator and control circuits, A DC tacho-generator is coupled with induction motor shaft. This tacho-generator generates a voltage proportional 'to the motor speed. The generated voltage is equal to the actual speed of the motor. This voltage is compared with dc reference voltage (reference speed). The difference between these two voltages is compared in comparator and output voltage is error signal voltage. This voltage is amplified by amplifier and fed to the thyristor gating circuits. This controls the thyristor tiring angles and thereby changes the terminal voltage and hence the motor speed changes.

If the reference speed is greater than actual speed, the conduction periods of the SCRs are increased. The increased stator voltage allows the development of an increased motor torque and hence the motor speed also increases, lf the actual speed is greater than the reference speed, the conduction angle of SCRS are reduced and the motor torque decreases as well as reduces the motor speed. When the motor speed is equal to the reference speed, the conduction angles are just sufficient to allow the development of a motor torque.

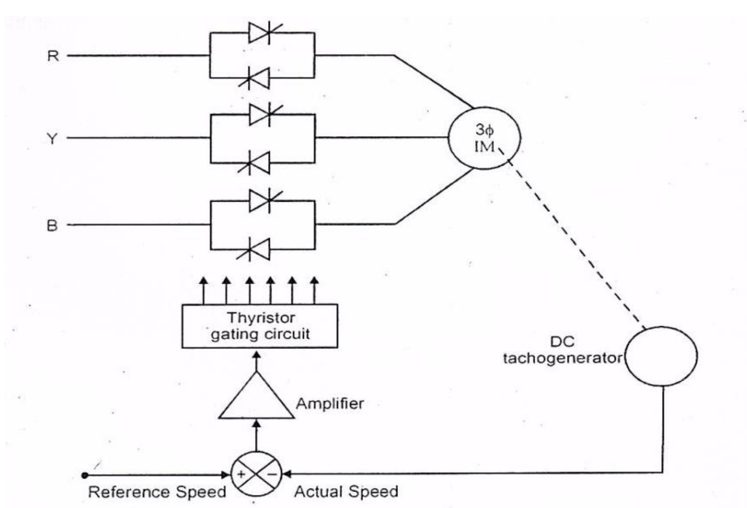


Fig Closed loop speed control

This motor torque is equal to the load torque. In a high-gain feedback system the desired speed can be maintained and there is no necessity for the motor to have a flat speed-torque characteristic, since the output speed is determined by the reference (desired) signal rather than the open-loop characteristics of the motor. The stable operation may be obtained at any point of the induction motor speed-torque characteristic.

3. Describe the Stator Frequency Control for speed control of three phase Induction motor. (April – 2014)

The stator frequency control is the one of the speed control of 3 phase induction motors. Here we can vary the input frequency of the motor. Under steady state condition, the induction motor operates in the small-slip region, where the speed of the induction motor is always close to the synchronous speed of the rotating flux

The synchronous speed of the induction motor is given by

$$Ns = 120f / P$$

Where

f- Frequency of the supply voltage

P – Number of poles

In this equation, synchronous speed of the motor is directly proportional to the frequency of the supply voltage. Here, the supply frequency is changes, the motor speed also changes. Since the emf V1 induced in the stator winding of the induction motor is equal to

$$V1 = 4.44 f \varphi T_{ph} K_w$$

Φ – flux /pole

K_w- winding factor

f- Frequency of stator (input) supply

T_{ph} – Number of turns in the stator winding

lf the frequency of the stator supply IS changes the magnitude of V1 should also be changed to maintain the same value of flux .Here we consider two cases

1) Low frequency operation at constant voltage

2) High frequency operation at constant voltage

<u>1. Low frequency operation at constant voltage</u>

By decreasing the supply frequency at constant voltage V1, the value of air gap flux increases and the induction motor magnetic circuits also gets saturated For considering the emf equatlon,

V_1 constant; f decreases; φ increases

Due to this low frequency operation the following effects are given below

l) It draws more magnetizing current

2) Line currents and line voltages are distorted .Increase the core loss and stator copper loss .produce a high pitch acoustic noise.

3) Very low efficiency.

2. High frequency operation at constant voltage (field weakening mode)

With the constant input voltage, if the stator frequency is increased, the motor speed also increases. Due to increase in frequency, flux and torque are reduces.

V_1 constant; f increases; φ decreases

By increasing the supply frequency of the motor, the following effects are given below,

1. The no load speed increases
2. The maximum torque decreases
3. Starting torque reduces
4. Starting current decreases

The base speed ω_b is defined as the synchronous speed corresponding to the rated frequency. The synchronous speed at any other frequency is equal to
$\omega_s = K\ \omega_b$

$K = \omega_s / \omega_b = f / f_{rated}$

f = Operating frequency

f_{rated} = Rated Frequency

K = Perunit Frequency

$$Slip\ , s = \frac{\omega_s - \omega_m}{\omega_s} = \frac{k\omega_b - \omega_m}{k\omega_b} = 1 - \frac{\omega_m}{K\omega_b}$$

Torque equation for rated voltage and rated frequency is given by

$$T = \frac{3}{sK\omega_b} \frac{V^2 R_r'}{\left(\frac{R_r'}{s}\right)^2 + (KX_s + KX_r')^2}$$

The slip at which the maximum torque occurs is given by

$$s_m = \frac{R_r'}{k(X_s + X_r')} \qquad [when\ Rs\ is\ neglected]$$

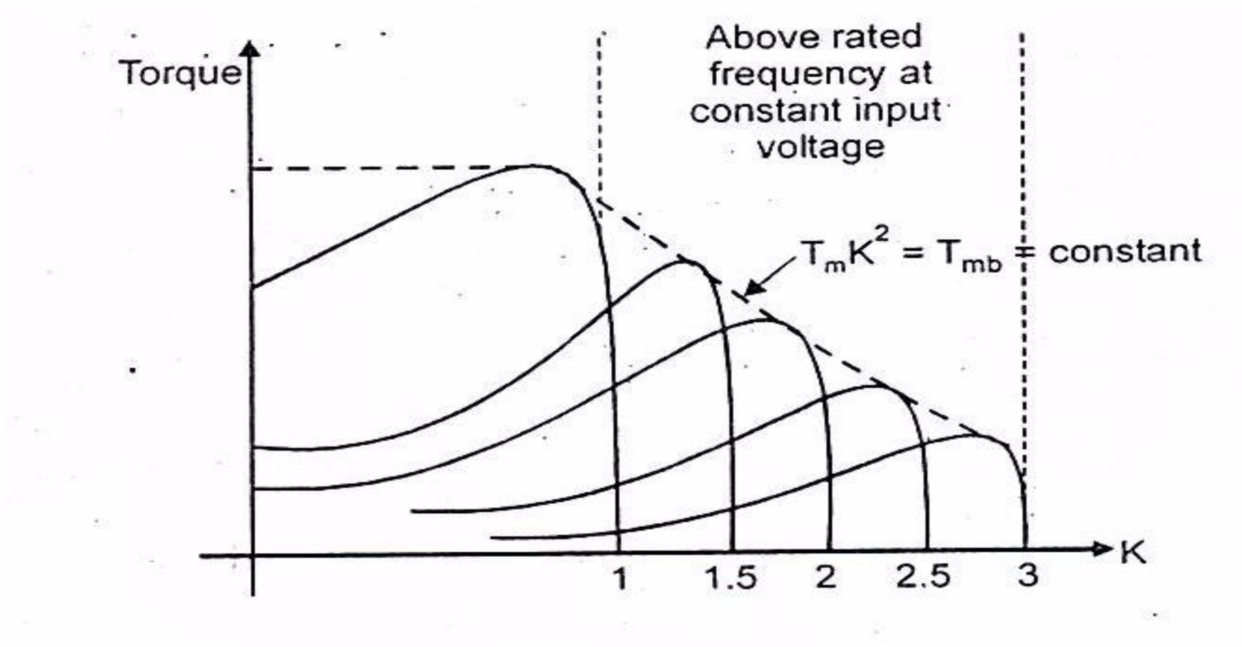
Maximum torque is given by

$$T_m = \frac{3}{2\omega_b(X_s + X_r')}\left(\frac{V}{K}\right)^2$$

When K =1, we can get maximum torque at the base speed.

$$T_{mb} = \frac{3V^2}{2\omega_b(X_s + X_r')}$$

Torque –speed characteristics for stator frequency control at constant voltage.



During this mode of operation of induction 'motor behavior is similar to the working of a dc series motor. It is also known as field weakening mode because the air gap flux gets reduced. Here the maximum torque also reduced.

For K > l, the induction motor is operated at constant terminal voltage, air gap flux is reduced and torque capability of the motor is limited. 'For 1 < K < 1.5, the relation between Tm and K can be approximately linear. For K < 1, the induction motor is normally operated at constant flux by reducing supply voltage along with the supply voltage.

4. **Explain the variable frequency speed control of induction motor using variable frequency Voltage source. (Nov – 2013)**

The induction motor speed can be controlled by varying the supply frequency This method is mainly applied to the squirrel cage induction motor. The variable frequency control allows good running and transient performance to be obtained from a squirrel cage induction motor.

The variable frequency induction motor drives are very popularly because of

i) Special applications requiring maintenance free operation, such as underground and under water installations.

ii) Applications involving explosive and contaminated environments such as in mines and the chemical industry.

The variable frequency AC drives applications are in

I) Pumps 2) Fans 3) Mill run out tables

4) Blowers 5) Compressors 6) Spindle drives

7) Conveyors 8) Machine tools and so on

Due to availability of power semiconductor devices such as power transistors, power MOSFETs, IGBTS and GTOs with improved ratings and characteristics, general purpose medium and high power variable frequency drives are available. The cost of the equipment is less compared to the drives. The variable frequency conversion can be made by using,

1. Voltage source inverter
2. Current source inverter
3. Cycloconverter

Voltage source inverter fed AC drives

An inverter is defined as converter that converts DC into AC. An inverter called voltage source inverter, if viewed from the load side, the AC terminals of the inverter function as a voltage source i.e`., the input 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. The VSI are capable of supplying variable frequency variable voltage for the speed control of induction motors.

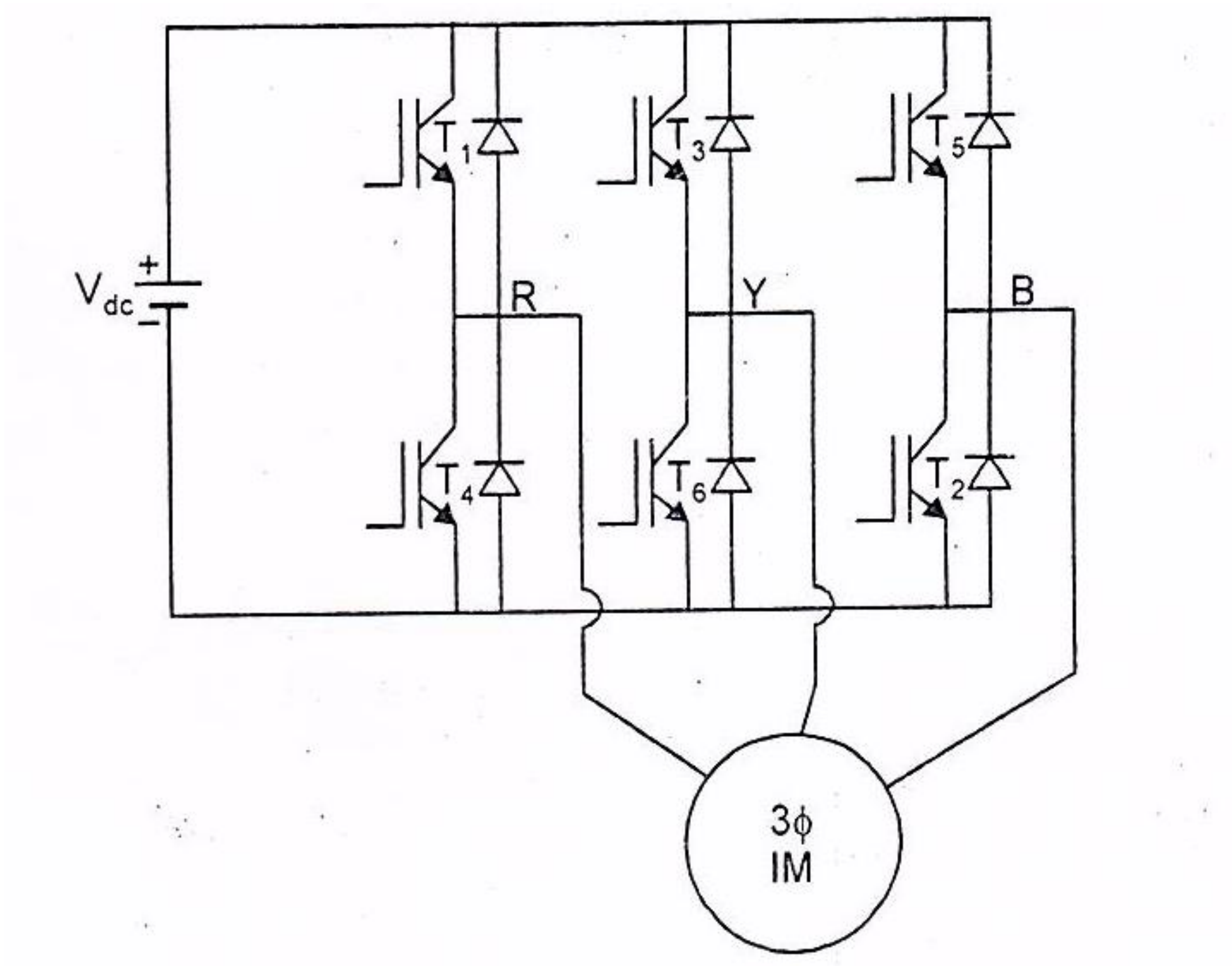


Fig VSI employing IGBT's

VSI allows a variable frequency supply to be obtained from a DC supply. MOSFET is used in low voltage and low power inverters. Power transistors and IGBTS are used for medium power level of inverters.

For high power level of inverters thyristors,-GTOs and IGCTs (insulate Gate Commutated Thyristor) are used.

Voltage source inverter can be operated as a stepped wave inverter or a Pulse Width Modulated (PWM) inverter, Inverter operated as a stepped wave inverter IGBTS are switched in the sequence of their numbers with a time difference of T/6 and each IGBT is kept an for the duration T/2 where T is the time period of the one cycle.

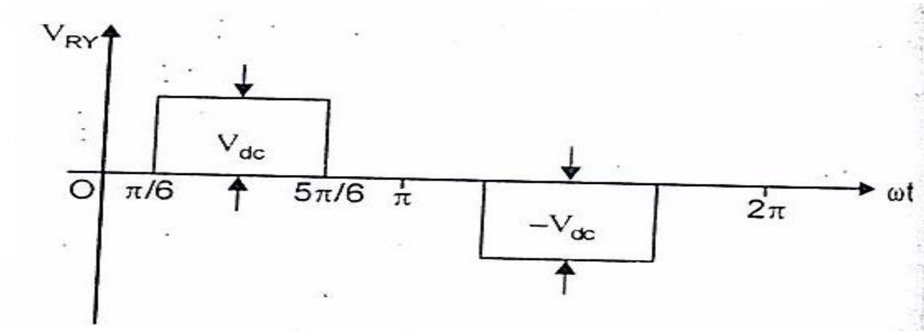
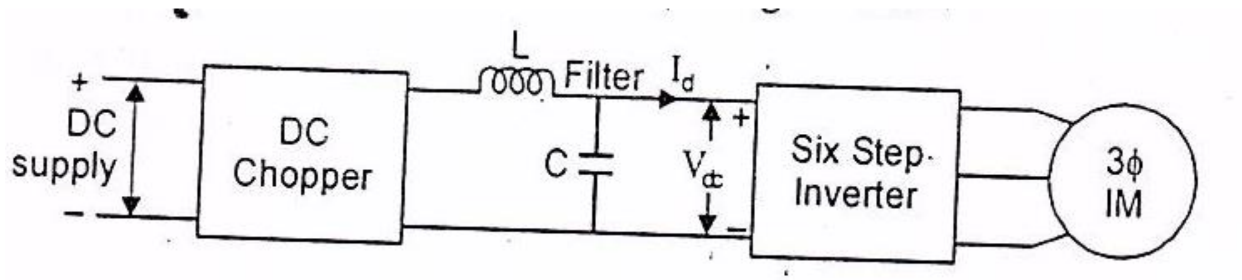
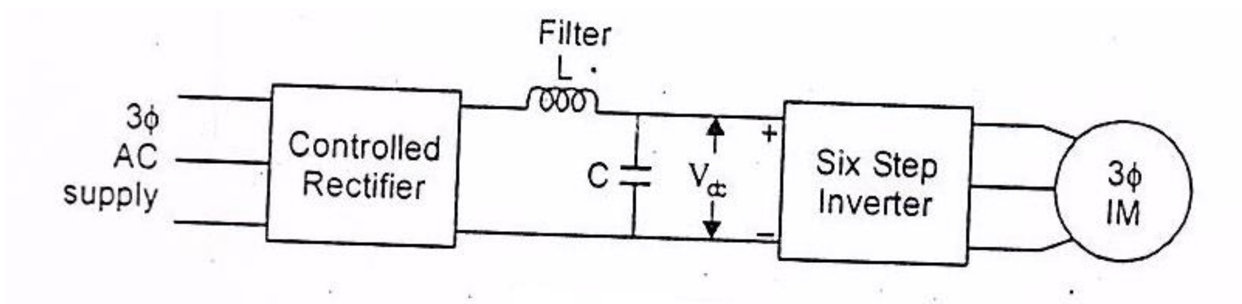


Figure shows stepped wave inverter line voltage waveform. In the stepped wave inverter the output frequency can be varied by varying T. Output voltage can be varied by varying input DC voltage. When the input voltage is DC, variable DC input voltage is obtained by connecting a chopper between DC supply and inverter. It is shown in figure



Here DC supply is given to the chopper. The DC chopper converts fixed DC to variable DC voltage, This voltage fed to the filter. It is used to filter out harmonics in DC link voltage. The DC voltage is fed to the six step inverter. The inverter output voltage is variable frequency variable voltage. It is fed to the 3¢ induction motor.



When the input voltage is AC, variable DC input voltage is obtained by connecting a controlled rectifier between AC supply and inverter; It is shown in above figure. Here 3¢ AC supply is fed to the controlled rectifier; It converts fixed AC into variable DC. This voltage is fed to the filter. Filter reduces the harmonics.

The filtered output is fed to the inverter. The inverter output voltage can be varied by varying DC voltage; It is done by controlled rectifier. The output frequency can be varied by time period of the inverter, the main disadvantages of stepped wave inverter is the large harmonics of low frequency in the output voltage. A stepped wave inverter fed induction motor drives suffers from the following disadvantages.

1. Due to low frequency harmonics, the motor losses are increased at all speeds causing derating of the motor.

2. Motor produces pulsating torques because of fifth, seventh, eleventh and thirteenth harmonics which cause jerky motion of the rotor at low speeds.

3. Harmonic content in induction motor current increases at low speeds. The machine saturates at low speeds due to high (V/f) ratio. These two effects overheat the motor at low speeds, thus limiting lowest speed to around 40% of base speed.

The above drawbacks are eliminated by using of Pulse Width Modulated inverter

(PWM). The advantages PWM inverters are

l. Harmonies are reduced.

2. Losses are reduced.

3. Smooth motion is obtained at low speeds,

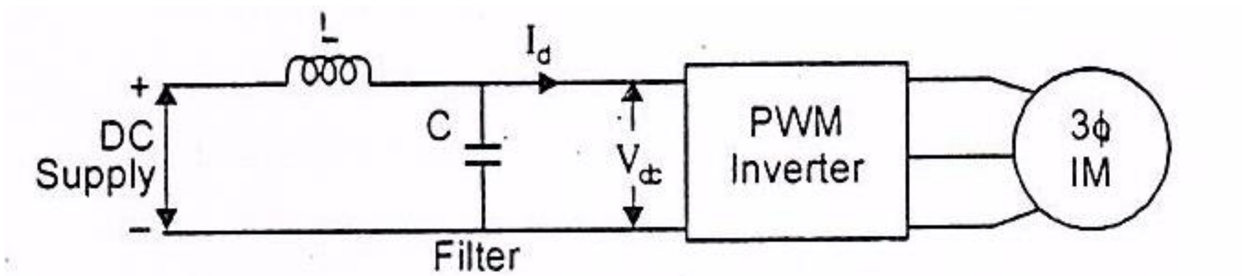


Fig PWM inverter

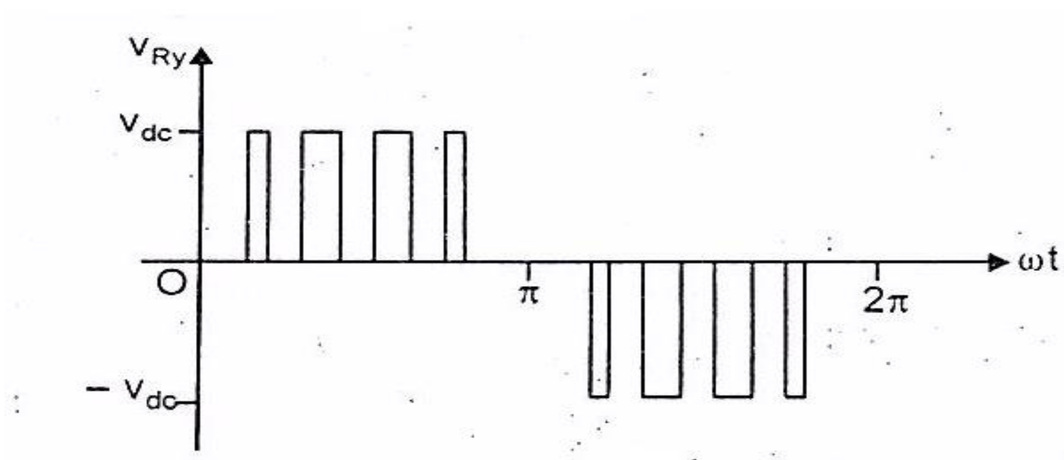
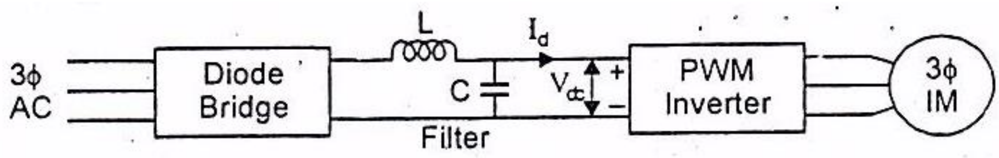


Figure shows output voltage waveform for sinusoidal pulse width modulation. By using this method, the inverter output voltage and frequency can be controlled. There is no need of external control. Voltage and frequency can be controlled inverter itself. When the input voltage is DC, it is directly connected to the PWM inverter. It is shown in figure

When the input voltage is AC , DC supply is get from a diode bridge rectifier, shown in below fig.



Here 3φ supply is fed to the diode bridge rectifier. It converters fixed AC voltage into fixed DC voltage, this voltage is fed to the filter and then PWM inverter. PWM inverter gives variable an voltage and frequency. By changing the voltage and frequency the motor speed can be controlled.

Department of Electrical and Electronics Engineering

Subject Name: Solid State Drives **Subject Code: EE T72**

UNIT IV: ROTOR SIDE CONTROLLED INDUCTION MOTOR DRIVE

Rotor Resistance Control: slip-torque characteristics- equivalent chopper resistance- chopper circuit filter-constant current operation. Slip Power Recovery Scheme: Slip power recovery scheme-sub synchronous operation; performance prediction- input power factor.

1. **How is the resistance in the output terminals of a chopper varied?**

   The resistance connected across the output terminals of a chopper can be varied from O to R by varying the time ratio of the chopper. When the chopper is always OFF, the supply is always connected to the resistance R. The time ratio in this case is zero and the effective resistance connected in R. Similarly when the chopper is always ON, the resistance is short circuited. The time ratio in the case is unity and the effective resistance connected is 0. Hence by varying the time ratio from 0 to 1, the value of resistance can be varied from R to O.

2. **What is the function of inductance L and resistance R in the chopper resistance circuit?**

   A smoothing inductance L is used in the circuit to maintain the current at a constant value. Any short circuit in the chopper does not become effective due to L.The value of R connected across the chopper is effective for all phases and its value can be related to the resistance to be connected in each phase if the conventional method has been used. The speed control range is limited by the resistance.

3. **What are the disadvantages and advantages of chopper controlled resistance in the rotor circuit method?**

   The method is very inefficient because of losses in the resistance. It is suitable for intermittent loads such as elevators. At low speeds, in particular the motor has very poor efficiency. The rotor current is non-sinusoidal. They harmonics of the rotor current produce torque pulsations. These have a frequency which is six times the slip frequency. Because of the increased rotor resistance, the power factor is better.

4. **How is the range of speed control increased?**

The range of speed control can be increased if a combination of stator voltage control and rotor resistance control is employed. Instead of using a high resistance rotor, a slip ring rotor with external rotor resistance can be used when stator voltage control is used for controlling the speed.

5. Why the static scherbius drive has a poor power factor?

Drive input power is difference between motor input power and the power fed back. Reactive input power is the sum of motor and inverter reactive power. Therefore, drive has a poor power factor throughout the range of its options.

6. How is super synchronous speed achieved? (MAY-2014)

Super synchronous speed can be achieved if the power is fed to the rotor from A.C. mains. This can be made possible by replacing the converter cascade by a cycloconverter. A cycloconverter allows power flow in either direction making the static sherbets drive operate at both sub and supper synchronous speeds.

7. Give the features of static scherbius drive. (DECEMBER-2014)

The torque pulsations and other reactions are minimal. The performance of the drive improves with respect to additional losses and torque pulsations. A smooth transition is possible from sub to super synchronous speeds without any commutation problems. Speed reversal is not possible. A step up transformer may be interposed between the lines and the converter, to reduce the voltage rating of the converter.

8. Where is Kramer electrical drive system used?

Some continuous rolling mills, large air blowers, mine ventilators, centrifugal pumps and any other mechanisms including pumps drives of hydraulic dredgers require speed adjustment in the range from 15 to 30% below or above normal . If the induction motor is of comparatively big size (100 to 200 KW) it becomes uneconomical to adjust speed by mean' s pf external resistances due to copper losses as slip power is wasted as heat in the retort circuit resistance. In these case , the Kramer electrical drive system is used , where slip power recovery takes places.

9. What is the use of sub synchronous converter cascades?

Sub synchronous converter cascades have been used, till now, in applications requiring one quadrant operation. These can be employed for drives where at least one electrical barking is required. A four quadrant operation can also be made possible in these cascades, using suitable switching.

10. How is the speed control obtained in static Kramer drive?

For speed control below synchronous speed, the slip power is pumped back to the supply, whereas for the case of speed above synchronous speed, additional slip power is injected into the rotor circuit.

11. What is static Kramer drive?

Instead of wasting the slip power in the rotor circuit resistance, it can be converted to 60 Hz A.C. and pumped back to the line. The slip power controlled drive that permits only a sub synchronous range of speed control through a converter cascade is know as static Kramer drive.

12. What is the use and functions of step down transformer is static Kramer drive?

For a restricted speed range closer to synchronous speed, the system power factor can be further improved by using a step –down transformer.

The step-down transformer has essentially two functions: besides improving the line power factor, it also helps to reduce the converter power ratings.

13. What are the advantages of static Kramer drive?

The static Kramer drive has been very popular in large power pump and fan-type drives, where the range of speed control is limited near, but below the synchronous speed. The drive system is very efficient and the converted power rating is low because t has to handle only the slip power, In fact, the power rating becomes lower with a more restricted range of speed control. The additional advantages are that the drive system has D.C. machine like characteristics and the control is very simple.

14. What are the causes of harmonic currents in static Kramer drive?

The rectification of slip power causes harmonic currents in the rotor, and these harmonics are reflected to the stator by the transformer action of the machine. The harmonic currents are also injected into the A.C. line by the inverter. As a result, the machine losses are increased and some amount of harmonic torque is produced. Each harmonic current in the rotor will create a reading magnetic field and its direction of rotation will depend on the order pf the harmonic.

15. Give the four modes of operation of a Scherbius drive

The four modes of operation of static Scherbius drive are,

Sub synchronous motoring.

Sub synchronous regeneration

Super synchronous motoring

Super synchronous regeneration

16. How is the static Scherbius drive operated in super synchronous motoring mode?

In super synchronous motoring mode, the shaft speed increases beyond the synchronous speed, the slip becomes negative and the slip power is absorbed by the rotor. The slip power supplements the air gap power for the total mechanical power output. The line therefore supplies slip power in addition to stator input power. At this condition, the phase sequence of slip frequency is reversed so that the slip current – induced rotating magnetic field is opposite to that of the stator.

17. Where is rotor resistance control used?

Where the motors drive loads with intermittent type duty, such as cranes, ore or coal unloaders, skip hoists, mine hoists, lifts, etc. slip-ring induction motors with speed control by variation of resistance in the rotor circuit are frequently used. This method of speed control is employed for a motor generator set with a flywheel (Ilgner set) used as an automatic slip regulator under shock loading conditions.

18. What are the advantages and disadvantages of rotor resistance control? (November 2012)

Advantage of rotor resistance control is that motor torque capability remains unaltered even at lowspeeds. Only other method which has this advantage is variable frequency control. However, cost of rotor resistance control is very low compared to variable frequency control.

Major disadvantage is low efficiency due to additional losses in resistors connected in the rotor circuit.

19. What are the advantages and disadvantages of rotor resistance control?

Advantage of rotor resistance control is that motor torque capability remains unaltered even at low speeds. Only other method which has this advantage is variable frequency control. However, cost of rotor resistance control is very low compared to variable frequency control.

Major disadvantage is low efficiency due to additional losses in resistors connected in the rotor circuit.

Eleven Marks

1. Explain about the different rotor resistance control technique.

ROTOR RESISTANCE CONTROL

The induction motors are widely used in industrial applications. The stator side control is applicable to both squirrel cage and slip ring induction motors .Because of more advantages, squirrel cage motor is always preferred. The speed control of slip ring induction motor i.e. rotor side control. The slip ring induction motor has a number of disadvantages compared to squirrel cage motor such as

1. Wound - rotor machine is heavier
2. Higher cost
3. Higher rotor inertia
4. Higher speed limitation
5. Maintenance and reliability problems due to brushes and slip rings

However, a wound-rotor (SRIM) machine speed control method is very simplest and oldest method. The speed can be controlled by mechanically varying rotor circuit rheostat.

The main feature of this machine is that slip power becomes easily available from the slip rings, which can be electronically controlled to control speed of the motor. For limited range speed control applications, where, the slip power is only a fraction of the total power rating of the machine, the converter cost should be reduced. The main applications of slip power recovery drives are,

1. Variable speed wind energy systems.
2. Large - capacity wind energy systems.
3. Shipboard VSCF (Variable - Speed/Constant - Frequency) systems.
4. Utility system flywheel storage system.
5. Variable- speed hydro pumps / generators.

Types

1. Conventional rotor resistance control
2. Static rotor resistance control
3. Slip power recovery scheme (Energy efficient drives)

Conventional Rotor Resistance Control

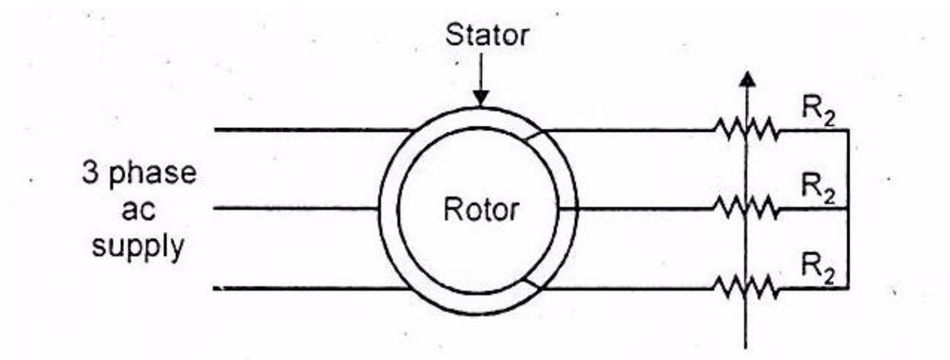


Fig conventional Rotor Resistance Control

This method is only applicable for slip ring or wound-rotor induction motor. Here, 3-phase ac supply is fed to the stator and a variable resistance R2 is connected in the rotor side. Here r2 is rotor resistance.

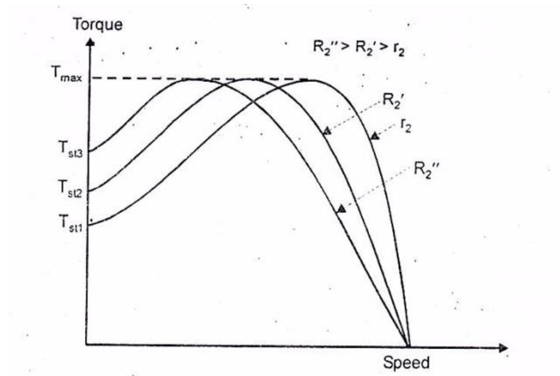


Fig Speed –torque characteristics of rotor resistance control

By varying the rotor circuit resistance R2 the starting torque and starting current can be controlled. Figure shows the speed - torque characteristics and speed - stator current characteristics.

In this curve, by increasing the rotor circuit resistance, the maximum torque remains constant but the starting torque increases and the speed decreases.

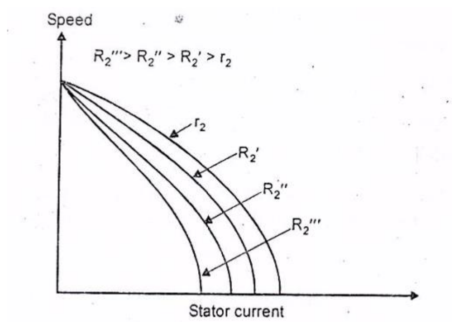


Fig Speed –Stator current characteristics of rotor resistance control

From this curve, by increasing the rotor circuit resistance, the stator current decreases and the speed decreases.

Advantages of this method

1. Absence of in-rush starting current
2. Availability of full-rated torque at starting
3. High live power factor
4. Absence of line current harmonics
5. Smooth and wide range of speed control

Main drawbacks of this speed control

1. Reduced efficiency because the slip energy is wasted in the rotor circuit resistance.
2. Speed changes very widely with load variation

3. Unbalance in voltage and current if rotor circuit resistance are not equal.

Slip ring induction motor speed control with rotor circuit chopper or static rotor resistance control

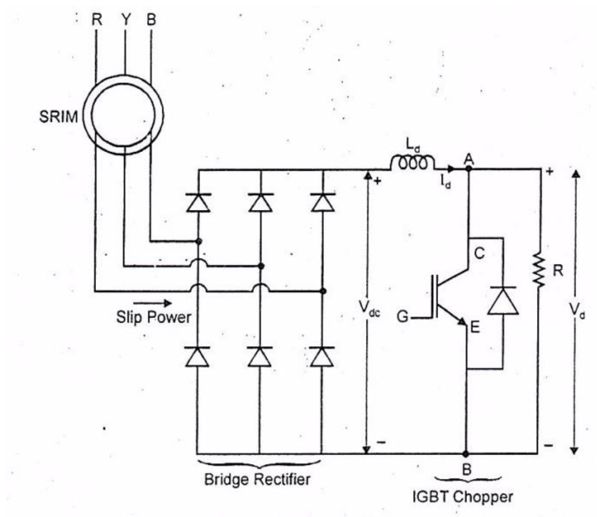


Fig Slip ring induction motor speed control with rotor circuit chopper or static rotor resistance control.

The speed of a wound rotor induction motor can be varied by varying the rotor circuit resistance; The rotor resistance can be varied sleeplessly by using a diode bridge rectifier and chopper as shown in fig

This method of speed control is very inefficient because the slip energy is wasted in rotor circuit resistance. However, advantages are that high starting torque is available at low starting current and improved power 'factor is possible with wide range of speed control.

The stator of the machine is directly connected to the line power supply and in the rotor circuit; slip voltage is available across the slip rings. This slip voltage is rectified by the three phase diode bridge rectifier. The dc voltage is convened to current source Id by connecting a large series inductor L_d. It is then fed to shunt chopper with resistance R as shown figure . The chopper circuit may use IGBT, GTO, thyrister or any other power semiconductor devices. Here the dc chopper circuit consists of an IGBT.

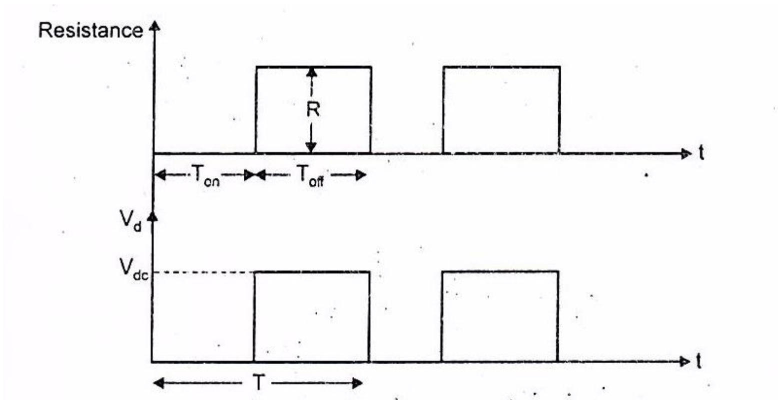
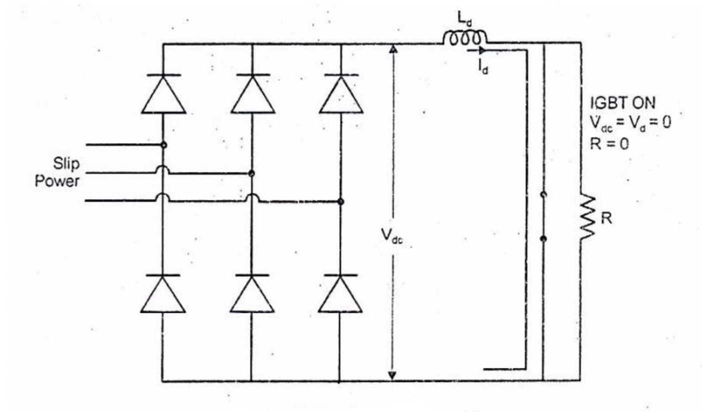
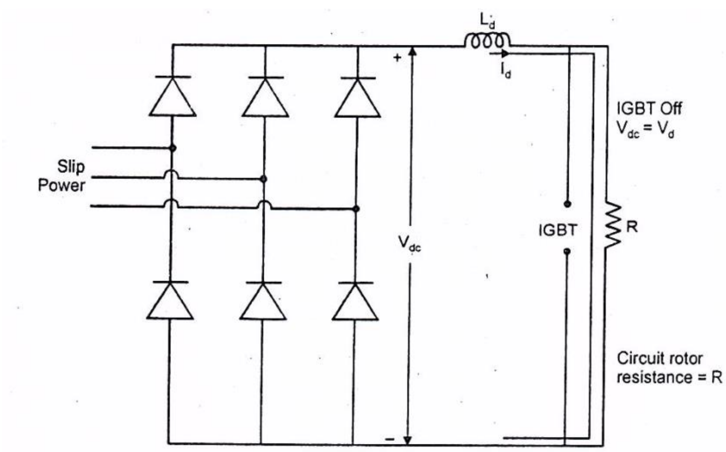


Fig Slip ring induction motor speed control with rotor circuit chopper or static rotor resistance control

The chopper periodically connects and disconnects the resistance R. When the IGBT chopper is on, the resistance is short-circuited and the current I_d is passed through it. i.e. V_{dc} = Vd., = 0 and R = O. It is indicated as shown in figure.



When the lGB'I` chopper is off; the resistance is connected in the circuit and the ‘ dc link current I, flows through it. i.e. Vdc = Vd, and resistance in the rotor circuit is R. lt is indicated as shown in figure



The effective external resistance Re is

$$R_e = \frac{1}{T}\int_0^T R\,dt = \frac{1}{T}\left[\int_0^{T_{on}} R\,dt + \int_{T_{on}}^{T} R\,dt\right]$$

During on time of the chopper R= 0 i.e

$$R_e = \frac{1}{T}\int_0^T R\,dt = \frac{R}{T}(T - T_{on}) = R\left(\frac{T}{T} - \frac{T_{on}}{T}\right)$$

The effective resistance between terminals A and B is given by

$$R_e = R(1-\alpha)$$

$$\alpha = \frac{T_{on}}{T} = duty\ cycle\ of\ the\ chopper$$

$$T_{on} = on - time\ of\ the\ chopper$$

$$T_{off} = off - time\ of\ the\ chopper$$

$$T = total\ time\ of\ the\ chopper$$

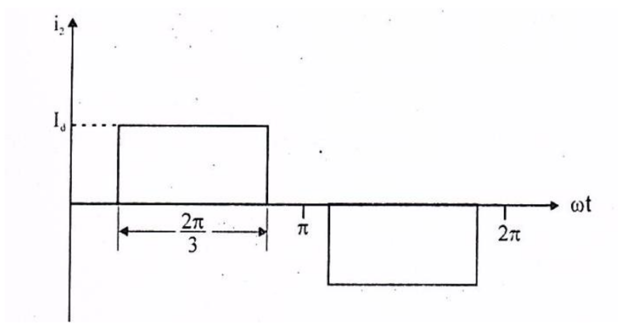
The effective rotor circuit resistance Re can be varied by varying the duty cycle of the chopper .Therefore the developed torque and speed of the machine can be controlled by the variation of the duty cycle of the chopper.

Power consumed by effective resistance Re is

$$P_{AB} = I_d^2 R_e = I_d^2 R(1-\alpha)$$

The rotor current waveform is shown in fig, when the ripple is neglected, the RMS value of rotor current is

$$I_2 = \left[\frac{1}{\pi}\int_0^{2\pi/3} I_d^2 d(wt)\right]^{1/2} = \left[\frac{I_d^2}{\pi}\left[\frac{2\pi}{3} - 0\right]\right]^{1/2}$$



Current waveform

$$I_2 = \left[\frac{I_d^2}{\pi}\frac{2\pi}{3}\right]^{1/2} = I_d\sqrt{\frac{2}{3}}$$

$$I_d = \sqrt{\frac{3}{2}} I_2$$

The per phase power consumed by resistance Re*

$$P_e = \frac{1}{3} I_d^2 [R_d + (1-\propto)R] \qquad -(4)$$

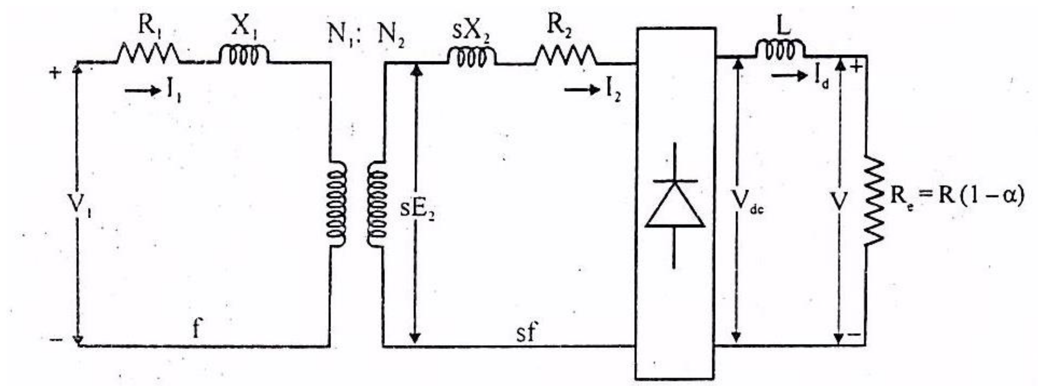
Substituting the value of I_d in equation (4), we get

$$P_e = \frac{1}{2}[R_d + (1-\propto)R] I_2^2$$

Hence effective value of resistance per phase is given by

$$R_e^* = 0.5[R_d + (1-\propto)R]$$

2. Explain in details of harmonic current in three phase induction motor with equivalent circuit. (Nov – 2012)



The equivalent circuit for 3 phase induction motor, diode bridge rectifier and chopper-circuit is shown in figure. The stator and rotor leakage impedances are neglected as compared to inductor Ld. It is indicated as shown in the equivalent circuit of figure.

The stator voltage V1 when referred to rotor circuit gives slip-frequency voltage as

$$S.\frac{V_1}{N_1}N_2 = sbV_1 = sE_2$$

sE2 = rotor induced emf per phase at stand still

V1 =stator voltage per phase

$$b = \frac{\text{rotor effective turns} \quad N2}{\text{Stator effective turns} \quad N1}$$

= per phase turns ratio of rotor to stator

Voltage sE2 = sbV1 is applied to the three phase diode bridge rectifier and the rectified output voltage is,

$$V_{dc} = \frac{3V_{lm}}{\pi} = \frac{3\sqrt{3}V_{pm}}{\pi}$$

$$V_d = \frac{3\sqrt{3}}{\pi}\sqrt{2}.sbV_1 = 2.339sbV_1 \qquad \dots(6)$$

V_{pm} = maximum value of phase voltage = $\sqrt{2}sbV_1$

Total slip power = 3sPag. For no losses in the rectifier, this is equal to V_dI_d.

$$\therefore 3sP_{ag} = V_dI_d$$

Per phase developed power, P_m

$$P_m = (1-s)P_{ag} = (1-s)\frac{V_d I_d}{3s} \qquad \ldots\ldots(7)$$

$$P_m = T_e\omega_m = T_e\omega_s(1-s) \qquad \ldots\ldots\ldots(8)$$

From equation (7) and (8), we get

$$V_d I_d \frac{(1-s)}{3s} = T_e\omega_s(1-s)$$

$$I_d = \frac{T_e\omega_s 3s}{V_d}$$

Substituting the value of V_d from equation (6), we get

$$I_d = \frac{3sT_e\omega_s}{2.339\ sbV_1} = 1.2826\ \frac{T_e\omega_s}{bV_1}$$

Load torque $T_L = 3T_e$

Where T_e = motor developed torque per phase

$$I_d = \frac{T_L\omega_s}{2.339\ bV_1} \qquad \ldots\ldots\ldots(9)$$

Equation (9) indicates that inductor current Id is independent of motor speed (ω_m). assuming inductor to be ideal, dc voltage at the bridge rectifier output is

$$V_d = I_d\ R\ (1-\propto)$$

From equation (6), $V_{dc} = 2.339\ sbV_1 = I_d\ R\ (1-\propto)$

$$\therefore Slip\ s = \frac{I_d\ R\ (1-\alpha)}{2.339\ b\ V_1}$$

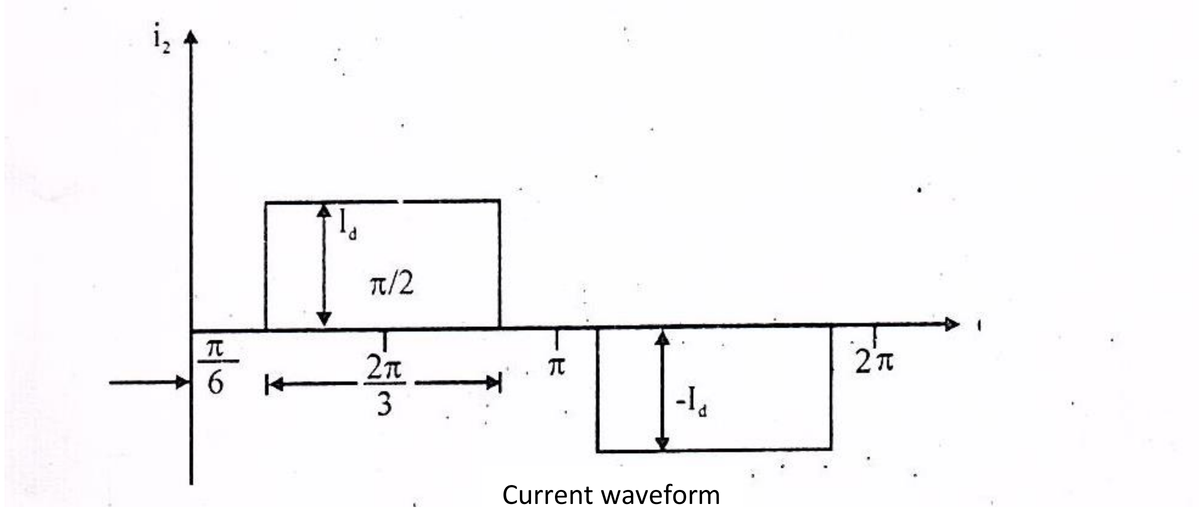
Motor speed, $\omega_m = \omega_s(1-s) = \omega_s\left[1-\frac{I_d R(1-\propto)}{2.339\ bV_1}\right] \quad \ldots.(9a)$

Also $N_r = N_s\left[1-\frac{I_d R(1-\propto)}{2.339\ bV_1}\right]$

Substituting the value of I_d from equation (9) in equation (9a) we get

$$\omega_m = \omega_s\left[1-\frac{T_L\omega_s\ R(1-\propto)}{(2.339\ bV_1)^2}\right] \qquad \ldots\ldots.(10)$$

For fixed value of duty cycle($\propto$), speed falls as load torque T_L is increased.



Current waveform

In figure each diode conducts for 120 degree. The waveform of rotor current i_1 shown in figure.

The rms value of rotor current

$$I_r = I_2 = \sqrt{I_d^2 \frac{2\pi}{3} \frac{1}{\pi}} = \sqrt{\frac{2}{3}} I_d \qquad \dots\dots\dots\dots(11)$$

Rotor current referred to stator,

$$I_r' = \frac{N_2}{N_1} I_2 = bI_2 = bI_d \sqrt{\frac{2}{3}} \qquad \dots\dots\dots\dots\dots(12)$$

Fourier analysis of the waveform

$$A_1 = \frac{2}{\pi} \int_{\pi/6}^{5\pi/6} I_d \sin \omega t \; d(\omega t) = \frac{2}{\pi} I_d [-\cos \omega t]_{\pi/6}^{5\pi/6} = \frac{2\sqrt{3}}{\pi} I_d$$

This gives fundamental component of rotor current as

$$I_{r1} = \frac{A_1}{\sqrt{2}} = \frac{2\sqrt{3}}{\sqrt{2}\pi} I_d = \frac{\sqrt{2}\sqrt{3}}{\pi} I_d = \frac{\sqrt{6}}{\pi} I_c \qquad \dots\dots\dots\dots\dots(13)$$

Fundamental component of rotor current referred to stator

$$I_{r1}' = \frac{N_2}{N_1} I_{21} = bI_{21} = \frac{\sqrt{6}}{\pi} bI_d \qquad \dots\dots\dots\dots\dots\dots(14)$$

3. **Explain the operation of closed loop control of induction motor with static rotor resistance control. (Nov – 2014)**

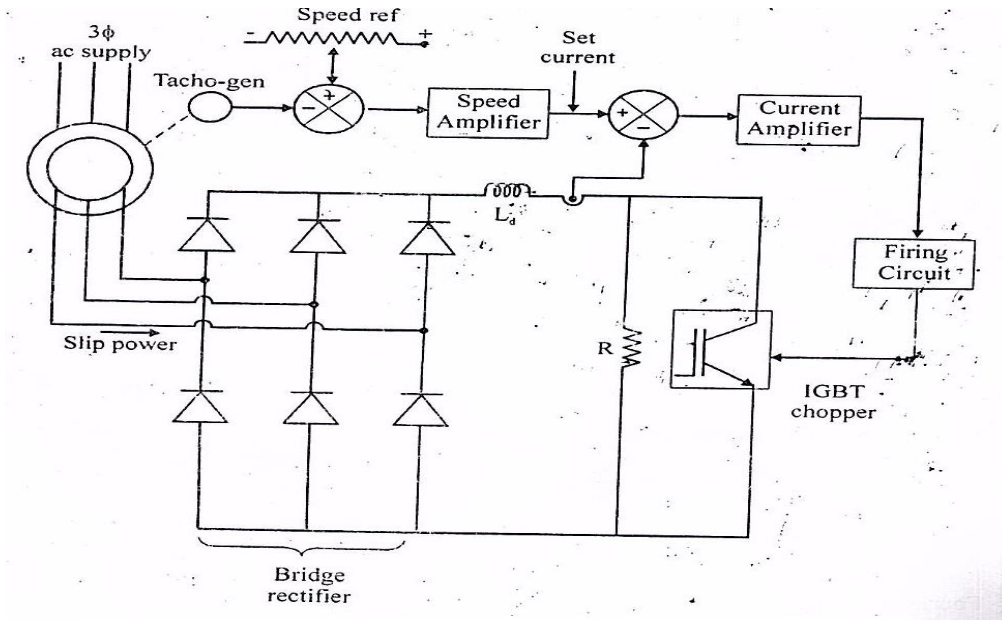


Fig (4.3) Closed loop control for static rotor resistance control

For satisfying the transient and steady state performance of induction motors, a closed loop control is normally used. The IGBT chopper circuit allows the external rotor resistance to be varied statistically and steplessly, and provides a low cost variable speed drive with a good dynamic response. Figure shows closed loop control for rotor resistance chopper circuit control. The rotor slip power is converted into dc by using diode bridge rectifier and fed through a smoothing inductor Ld to a resistor R. A single IGBT chopper is connected across the resistor. The IGBT chopper is on and off by control circuit. When the chopper is on, the resistance is short circuited. When the chopper is off, the resistance is included in the circuit. By varying the duty cycle Ton / T of the IGBT chopper the effective resistance can be varied. Due to the variation of the rotor resistance the motor speed also varied. The control signal (pulse) can be obtained from sensing of speed and current. The actual speed is fed back from a tacho-generator coupled to the slip ring induction motor and compared with a reference voltage (set speed). The error voltage is amplified by the speed amplifier and set the desired current reference.

The actual current can be obtained from current sensing circuit and compared with actual current and set current. The error output goes to the current amplifier and driver circuit. The current feedback loop adjusts the current of the system by controlling the IGBT chopper. By controlling on and off times of chopper, the effective value of rotor resistance can be determined and thus controls the motor speed by altering its torque-speed characteristics. By connecting a capacitor in series with the external resistance, it is possible to obtain a variation in the effective resistance from zero to unity, thus permitting a wider range of speed control. The rotor resistance control is used in the high-torque range.

4. Describe the static Kramer drive for the open loop and closed loop speed control of three phase induction motor. (April – 2014)

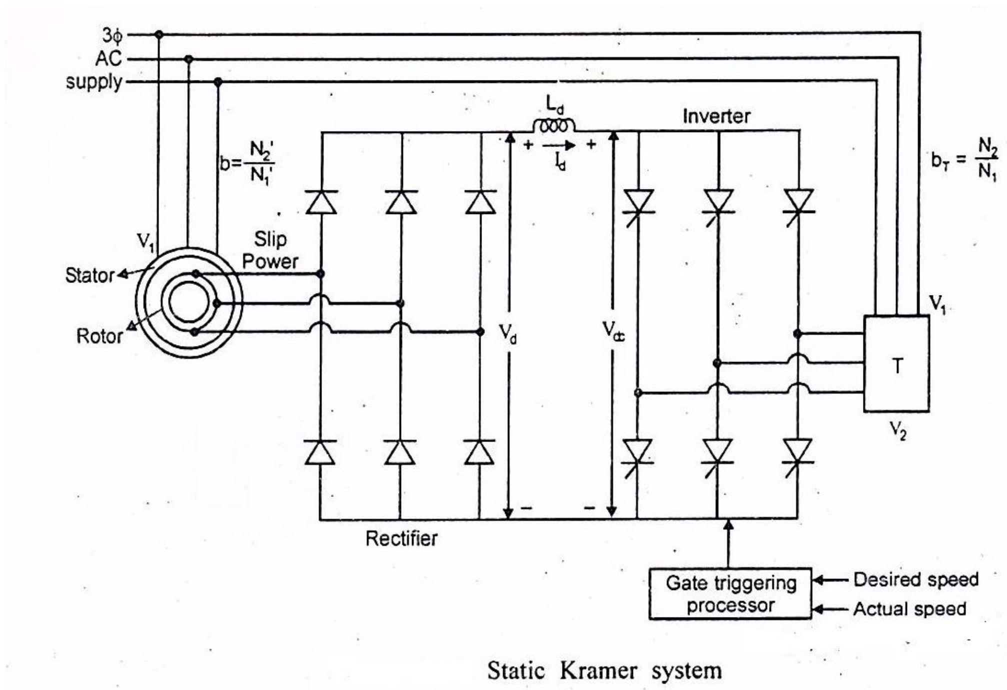


Fig Static Kramer system

In rotor resistance control method the slip power is wasted in the rotor circuit resistance. Instead of wasting the slip power in the rotor circuit resistance, it can be converted to 50 Hz ac and pumped back to the line. Here, the slip power can flow only in one direction. This method of drive is called static Kramer drive. It is shown in figure . The static Kramer drive offers speed control only for sub-synchronous speed. i.e. speed can be control only less than the synchronous speed is possible.

In this method, the slip power is taken from the rotor and it is rectified to dc voltage by 3-phase diode bridge rectifier. Inductor L_d smoothens the ripples in the rectified voltage Vd. This dc power is converted into ac power by using line - commutated inverter. The rectifier and inverter are both line commutated by alternating emfs appearing at the slip rings and supply bus bars respectively. Here, the slip power flows from rotor circuit to supply, this method is also, called as constant - torque drive.

The static Kramer drive has been very popular in large power pump and fan type drives, where the range of speed control is limited near, but less than the synchronous speed. This method of speed control is economical because the rectifier and inverter only have to carry the slip power of the rotor, which is considerably less than the input power to the stator.

Closed loop control for Kramer system

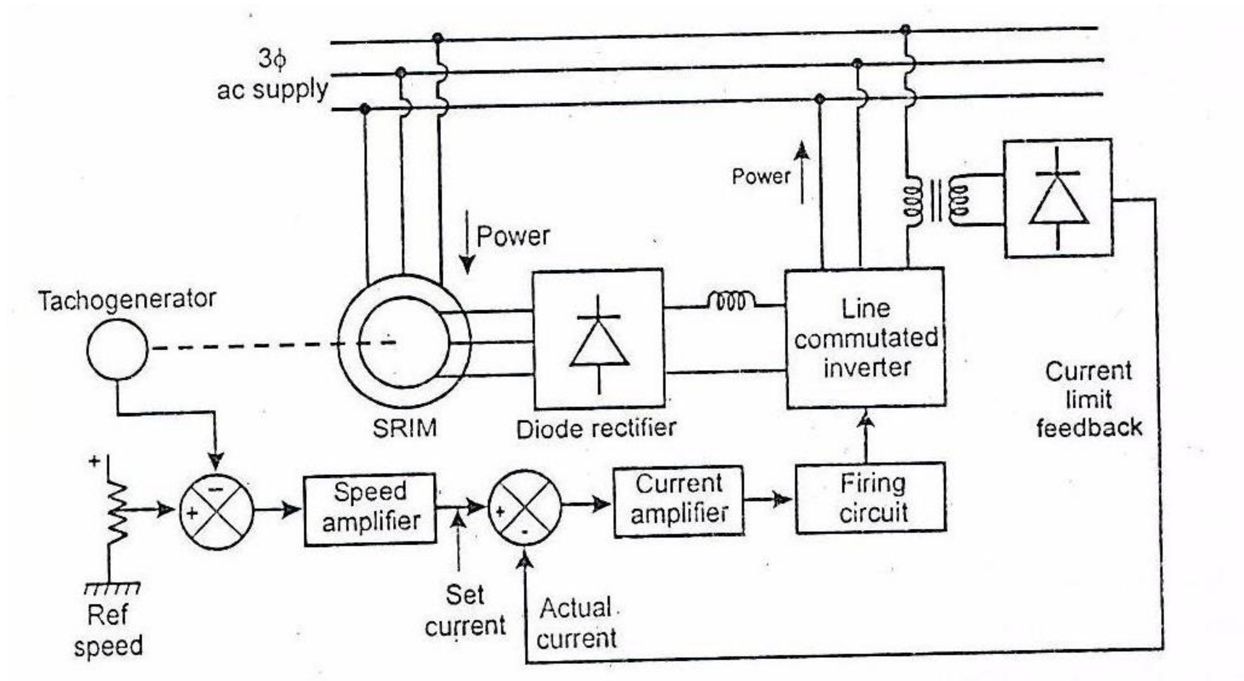


Fig Closed loop control for Kramer system

The actual speed is feedback from a tacho-generator, which is coupled to the SRIM. This actual speed is compared with a reference voltage (ref Speed). The error voltage is amplified by the speed amplifier and set the desired current reference. The current feedback loop adjusts the current of the system by controlling the firing angles of the inverter. This current determines the motor torque. The current signal is proportional to the ac current of the inverter. This is compared with the current reference set by the speed amplifier.

The error voltage is amplified by the current amplifier and fed to the firing angle control circuit of the inverter. Thus, in this system, speed error produces a motor torque which again reduces the error. The maximum current limit can be set to any desired value by setting the current reference through the speed - error amplifier. Thus the current can be limited to any desired value even under the stalled condition.

The acceleration and deceleration is fairly smooth. The cascade drive control system is much simpler and stable than any other variable - speed slip ring induction motor drive system in which the rotor slip is measured and controlled.

5. **Describe the scherbius drive for the speed control of three phase Induction Motor. (April – 2015)**

The scherbius system is similar to Kramer system but only the difference is that in the Kramer system the feedback is mechanical and in the scherbius system the return power is electrical. The different types of scherbius system are

1. Conventional scherbius System

2. Static Scherbius drive

4.9 Conventional Scherbius Drive

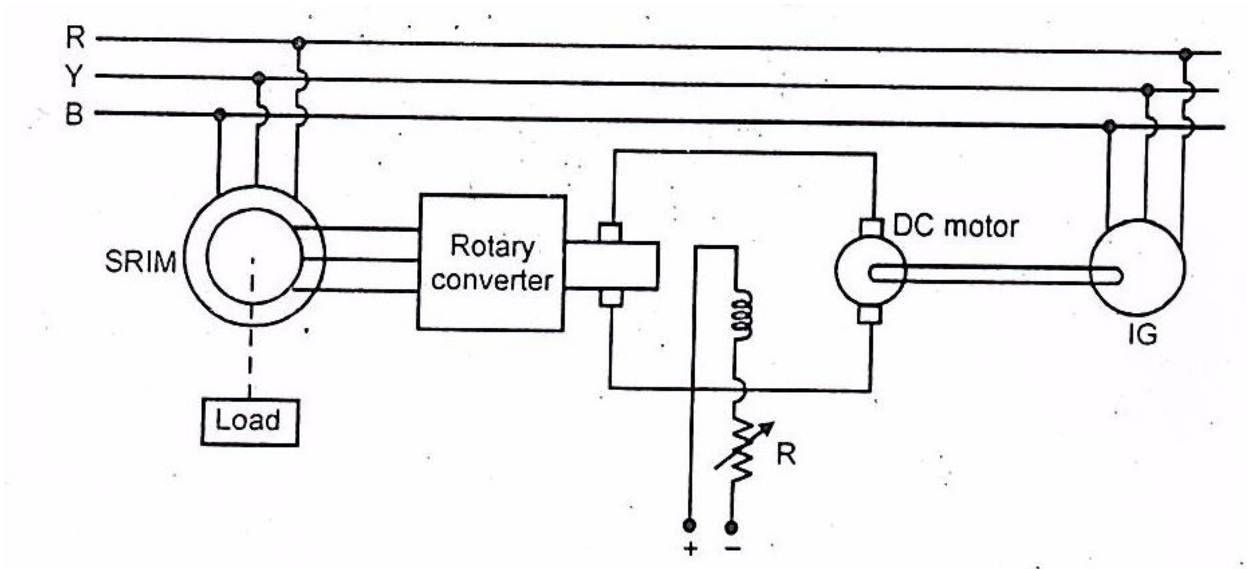


Fig Conventional Scherbius Drive

Here the rotary converter converts slip power into dc power and the dc power fed to the dc motor. The dc motor is coupled with induction generator. The induction generator converters the mechanical power into electrical power and return it to the supply line. The SRIM speed can be controlled by varying the field regular of the dc motor.

Static Scherbius System

For the speed control of SRIM both below and the above synchronous speed,static scherbius drive system is used. This system can again be classified as

1. DC link static scherbius drive

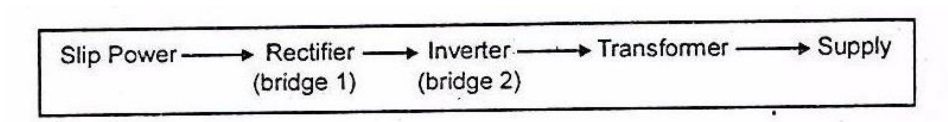
2. Cyclo-converter static scherbius drive

DC link static scherbius drive

This system consists of SRIM,2 no of phase controlled bridges, smoothing inductor and step up transformer. This system is used for both sub-synchronous speed and super-synchronous speed operation.

Sub-Synchronous speed operation

In sub-synchronous speed -control of SRIM, slip power is removed from the rotor circuit and is pumped back into the ac supply. Figure shows the dc link static Scherbius system. ln the Scherbius system, when the machine is operated at sub- synchronous speed, phase controlled bridge l operates in the rectifier mode and bridge 2 operates in the inverter mode. In other words, bridge l has firing angle less than 90° whereas bridge 2 has firing angle more than 90°. The slip power Flows from rotor circuit to bridge l, bridge 2, and transformer and returned to the supply i.e.



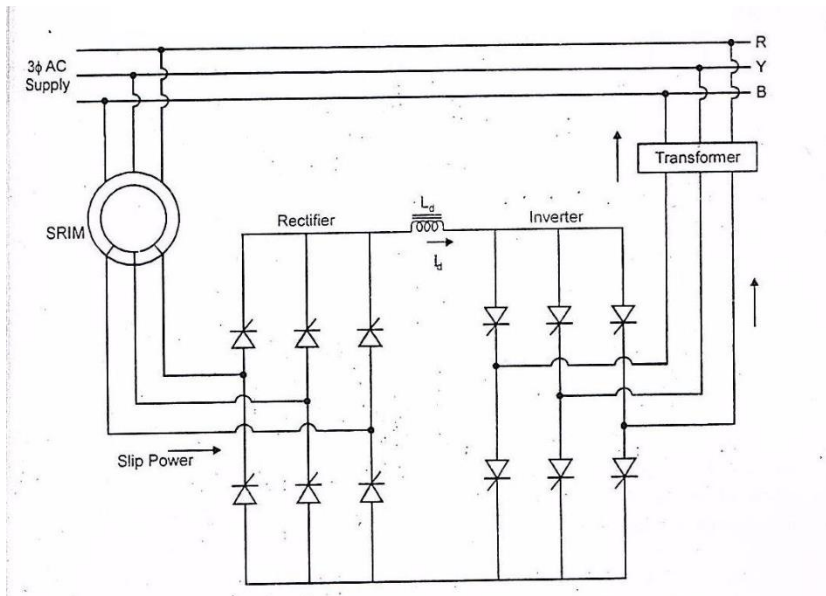
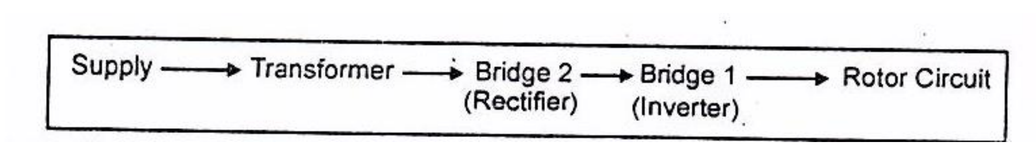


Fig Sub-Synchronous speed operation

Super Synchronous Speed operation

In super synchronous speed operation, the additional power is fed into the rotor circuit at slip frequency. Figure shows super synchronous speed operation ofa DC link static Scherbius system. In the Scherbius system, when the machine is operated at super synchronous speed, phase controlled bridge 2 should operate in rectifier mode and bridge l in inverter mode.

In other words, the bridge 2 has firing angle less than 90° whereas bridge l has tiring angle more than 90°. The slip power flows from the supply to transformer, bridge 2 (rectifier), bridge l (line commutated inverter) and to the rotor circuit.



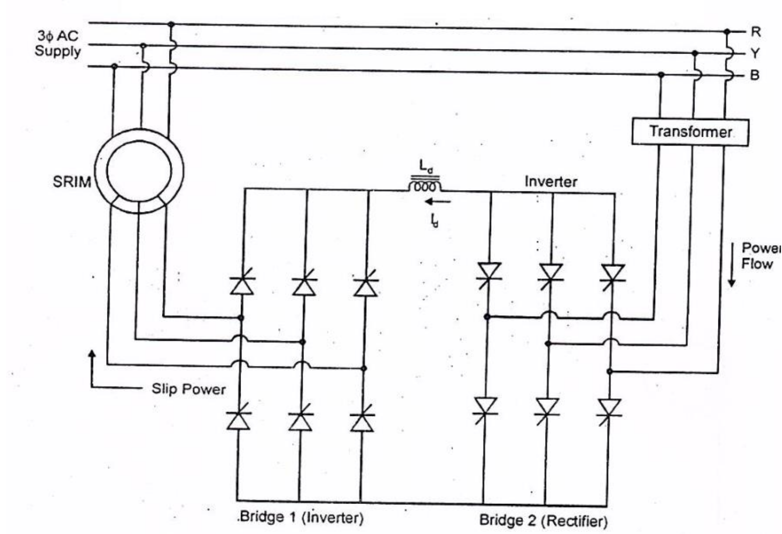


Fig Super Synchronous Speed operation

Near synchronous speed, the rotor voltage is low, and forced commutation must be employed in the inverter, which makes the scheme less attractive. The replacement of sirt diodes by six thyristors increases the converter cost and also necessitates the introduction of slip frequency gating circuit.

Difficulty is experienced near synchronous when the slip frequency emfs are insufficient for line or natural commutation and special connections or forced commutation methods are necessary for the passage through synchronism Thus, the provision of super synchronous speed control unduly complicates the static converter cascade system and nullifies the advantages of simplicity and economy.

Cycloconverter Static Scherbius Drive

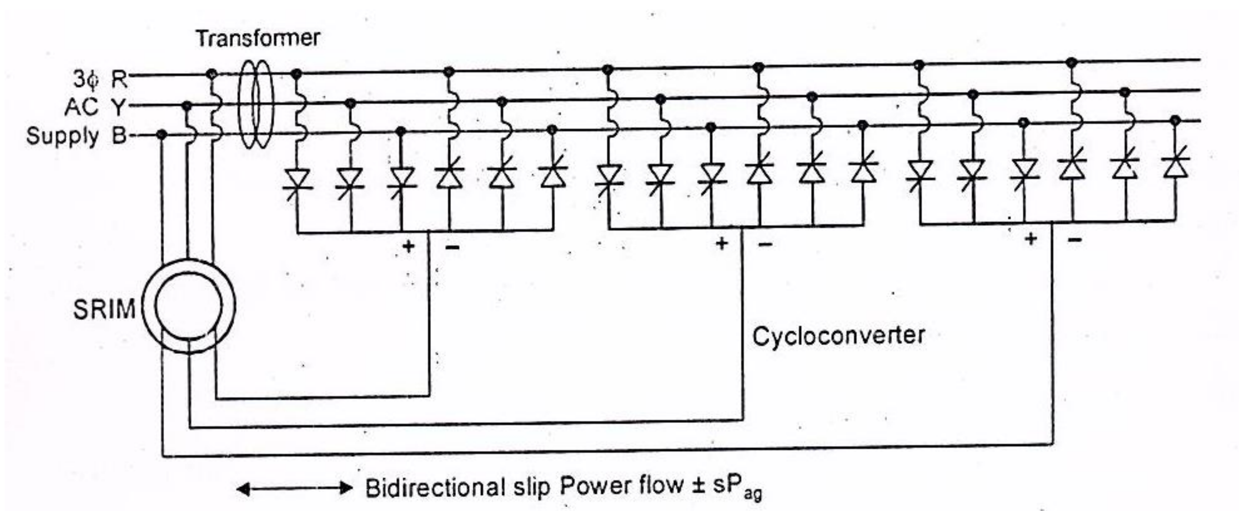


Fig Cyclo-converter Static Scherbius Drive

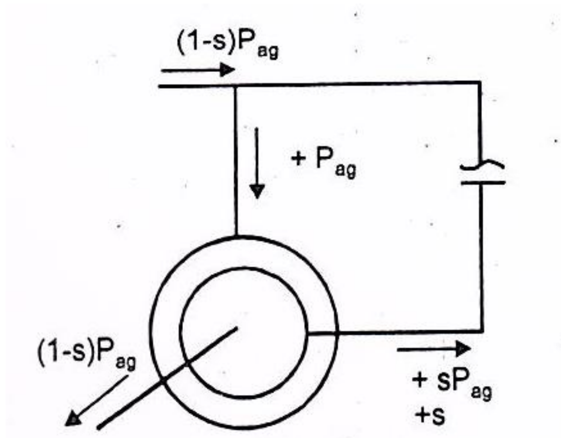
The Kramer drive system has only a forward motoring mode (one quadrant) of operation But this system is applicable 'for both motoring and regenerating in both sub-synchronous and super synchronous ranges of speed.

The dual bridge convener system in figure can be replaced by a three phase controlled line commutated cylco-converter, as shown in figure Here the slip power flow in either direction.

The various modes of operation shown in figure can be explained as follows. Assuming motor shaft torque is constant and the losses in the motor and cyclo-converter are negligible.

Mode –I Sub Synchronous motoring

This mode, shown in figure (a) is similar to that of the static Kramer system. The stator input or air gap power P_{ag} remains constant and the slip power sP_{ag}, which is proportional to the slip (which is positive), is returned back to the line through the cyclo-converter.



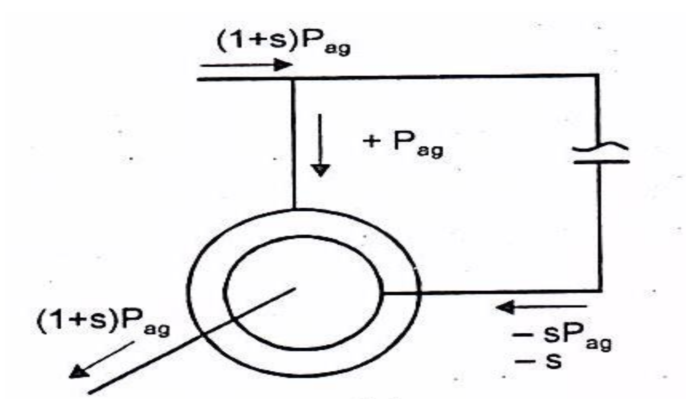
(a)

Therefore the line supplies the net mechanical power Pm = (1-s) Pag consumed by the shaft.

The slip frequency power in the rotor creates the rotating filed in the direction as in the stator and the rotor speed ωr corresponds to the difference (ω_s-ω_{sl}) between these two frequencies.

At slip is equal to zero, the cyclo-converter supplies dc excitation to the rotor and the machine behave like a standard synchronous motor.

Mode 2 : Super Synchronous Motoring

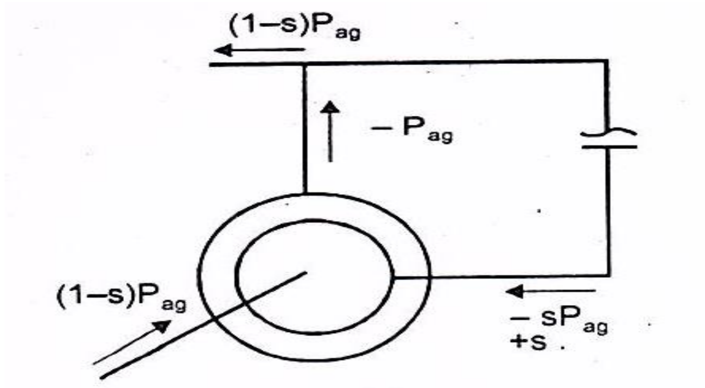


(b)

In this mode, as shown in figure (b), the shaft speed increases beyond the synchronous speed, the slip becomes negative and the slip power is a absorbed by the rotor. The slip power sP_{ag} supplements the air gap power P_{ag} for the total mechanical power output (l + s) P_{ag}. The line therefore supplies slip power in addition to stator input power.

During this condition, the slip voltage is reversed, so that the slip frequency- induced rotating magnetic field is opposite to that of the stator.

Mode 3: Sub –synchronous Regeneration



(c)

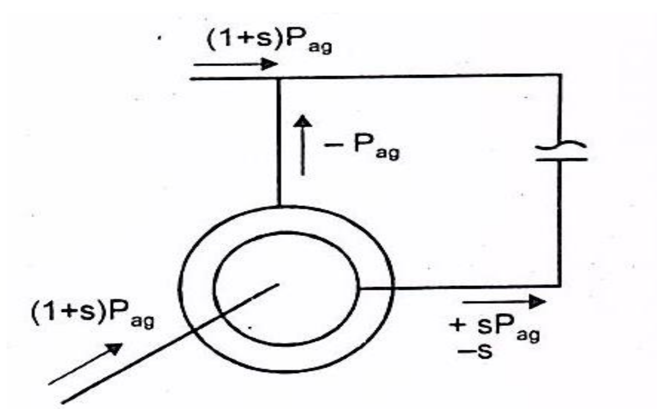
In regenerative braking condition, as shown in figure (c), the shaft is driven by the load and the mechanical energy is converted into electrical energy.

With constant negative shaft torque, the mechanical power input to the shaft Pm = (l-s) Pag increases with speed and this equals the electrical power fed to the line.

In the sub-synchronous speed range, the slip s is positive and the air gap power P_{ag} is negative. The slip power sP_{ag} is fed to the rotor from the cyclo-converter so that the total air gap power is constant. The slip voltage has a positive phase sequence.

At synchronous speed, the cyclo-converter supplies dc excitation current to the rotor circuit and the machine behaves as a synchronous generator. The main application in this is a variable-speed wind generation system.

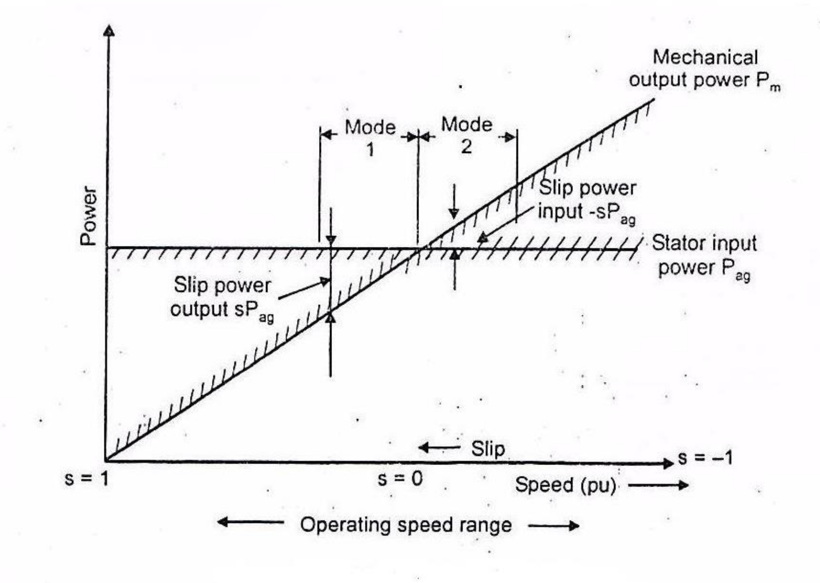
Mode 4: Super synchronous regeneration

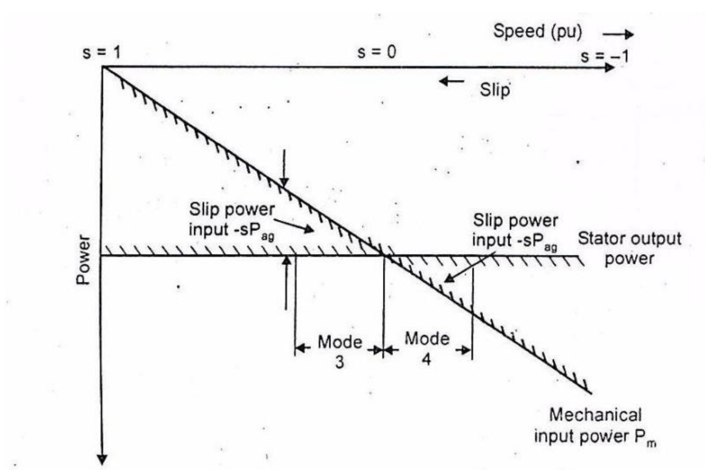


(d)

The super synchronous regeneration is indicated as shown in figure (d). Here, the stator output power remains constant, but the additional mechanical power input is reflected as slip power output Now the rotor field rotates in the opposite direction because the cyclo-converter phase sequence' is reversed.

Power distribution as a function of slip in sub-synchronous and super-synchronous speed ranged is summarized for all four modes in figure below, where the operating speed range of ± 50 percent about the synchronous speed is indicated.





Advantages of static Scherbius Drive

1. In this method, the problem of communication near synchronous speed disappears.

2. The cyclo-converter can easily operates as a phase controlled rectifier, supplying dc current in the rotor and permitting true synchronous machine operation.

3. The near-sinusoidal current waves in the rotor, which reduce harmonic loss and a machine over excitation capacity that permits leading power factor operation on the stator side so the line's power factor is unity.

4. The cyclo-converter is to be controlled so that its output frequency tracks precisely with the slip frequency.

Disadvantages

1. The cyclo-converter cost is increases
2. The control of the scherbius drive is somewhat complex.

Applications

1. Multi-MW, variable-speed pumps / generators
2. Flywheel energy storage systems.

UNIT V: SYNCHRONOUS MOTOR DRIVES

Open loop volts/hertz control and self-control of synchronous motor: Marginal angle control and power factor control. Introduction to vector control - Principles and types.

Two Marks

1. Give the use of synchronous motors.

Synchronous motors were mainly used in constant speed applications. The development of semiconductor variable frequency sources, such as inverters and cycloconverters, has allowed their use in draft fane, main line traction, servo drives, etc.

2. How are the stator and rotor of the synchronous motor supplied?

The stator of the synchronous motor is supplied from a thyristor power converter capable ofproviding a variable frequency supply. The rotor, depending upon the situation, may beconstructed with slip rings, where it conforms to a conventional rotor. It is supplied with D.C.through slip rings. Sometimes rotor may also be free from sliding contacts (slip rings), in whichcase the rotor is fed from a rectifier rotating with rotor.

3. What is the difference between an induction motor and synchronous motor?

An induction motor operates at lagging power factor and hence the converter supplyingthe same must invariable is a force commutated one. A synchronous motor, on the other hand, canbe operated at any power factor by controlling the field current.

4. List out the commonly used synchronous motors.

Commonly used synchronous motors are,

b. Wound field synchronous motors.

c. Permanent magnet synchronous motors

d. Synchronous reluctance synchronous motors.

e. Hysterias motors.

5. Mention the main difference between the wound field and permanent magnet motors.

When a wound filed motor is started as an induction motor, D.C. field is kept off. In case of a permanent magnet motor, the field cannot be ‘turned off.

6. Give the advantages and applications of PMSM.

The advantages of PMSM are,

b. High efficiency

c. High power factor

d. Low sensitivity to supply voltage variations.

The application of PMSM is that it is preferred of industrial applications with large duty cycle such as pumps, fans and compressors.

7. Give the uses of a hysteresis synchronous motor.

Small hysteresis motors are extensively used in tape recorders, office equipment and fans. Because of the low starting current, it finds application in high inertia application such as gyro compasses and small centrifuges.

8. Mention the two modes employed in variable frequency control

Variable frequency control may employ and of the two modes.

a. True synchronous mode

b. Self-controlled mode

9. Which machine is said to be self-controlled?

A machine is said to be self-controlled if it gets its variable frequency from an inverterwhose thrusters are freed in a sequence, using the information of rotor position or statorvoltages. In the former a rotor position sensor is employed which measures the rotor position with respect to the stator and sends pulses to the thyristors. Thus frequency of the inverter output is decided by the rotor speed.

10. What is Commutator Less Motor (CLM)?

The self-controlled motor has properties of a D.C. Motors both under steady state and dynamic conditions and therefore is called commutator less motor(CLM). These machines have better stability behaviours. They do not fall out of step and do not have oscillatory behaviours, asin normal synchronous motors.

11. Give the application of self-controlled synchronous motor.

A self-controlled synchronous motor is a substitute for a D.C. motor drive and finds application where a D.C. motor is objectionable due to its mechanical commutator, which limits the speed range and power output.

12. Define load commutation

Commutation of thyristors by induced voltages pf load is known as load commutation,

13. List out the advantages of load commutation over forced commutation.

Load commutation has a number of advantages over forced commutation

It does not require commutation circuits

Frequency of operation can be higher

It can operate at power levels beyond the capability of forced commutation.

14. Give some application of load commutated inverter fed synchronous motor drive.

Some prominent applications of load commutated inverter fed synchronous motor drive are high speed and high power drives for compressors, blowers, conveyers, steel rolling mills, main-line traction and aircraft test facilities.

15. How the machine operation is performed in self-controlled mode?

For machine operation in the self-controlled mode, rotating filed speed should be the same as rotor speed. This condition is realised by making frequency of voltage induced in the armature. Firming pulses are therefore generated either by comparison of motor terminal voltages or by rotor position sensors.

16. What is meant by margin angle of commutation?

The difference between the lead angle of firing and the overlap angle is called the margin angleof commutation. If this angle of the thyristor, commutation failure occurs. Safe commutation is assured if this angle has a minimum value equal to the turn off angle of the thyristor.

17. What are the disadvantages of VSI fed synchronous motor drive?

VSI synchronous motor drives might impose fewer problems both on machine as well ason the system design. A normal VSI with 180o conduction of thyristors required force dcommutation and load commutation is not possible.

18. How is PNM inverter supplied in VSI fed synchronous motor?

When a PWM inverter is used, two cases may arise the inverter may be fed from a constant D.C. source in which case regeneration is straight forward. The D.C. supply to the inverter may beobtained from a diode rectifier. In this case an additional phase controlled converter is required onthe line side.

19. What is D.C. link converter and cycloconverter?

D.C. link converter is a two stage conversion device which provides a variable voltage,variable frequency supply.

Cycloconverter is a single stage conversion device which provides a Variable voltage,variable frequency supply.

20. What are the disadvantages of cycloconverter?

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

21. What are the applications of cycloconverter?

A cycloconverter drive is attractive for law speed operation and is frequently employed inlarge, low speed reversing mils requiring rapid acceleration and deceleration. Typicalapplications are large gearless drives, e.g. drives for reversing mills, mine heists, etc.

22. Give the application of CSI fed synchronous motor.

Application of this type of drive is in gas turbine starting pumped hydroturbine starting,pump and blower drives, etc.

23. What are the disadvantages of machine commutation?

The disadvantages of machine commutation are,

a. Limitation on the speed range.

b. The machine size is large

c. Due to overexciting it is underutilized.

24. What is the use of an auxiliary motor?

Sometimes when the power is small an auxiliary motor can be used to run up thesynchronous motor to the desired speed.

25. What are the advantages of brushless D.C. motor?

The brushless D.C. motor is in fact an inverter-fed self-controlled permanent synchronousmotor drive. The advantages of brushless D.C. motor are low cost, simplicity reliability andgood performance.

Eleven Marks

1. Explain the Voltage/ hertz speed control of synchronous motor. (Nov – 2013)

Synchronous speed is directly proportional to frequency, similar to induction motors constant flux operation below base speed is achieved by operating the synchronous motor with constant (V / f) ratio.

The synchronous motor either run at synchronous speed (or) it will not run at all.

Hence variable frequency control may employ any of the following two modes

1. True synchronous mode
2. Separate controlled mode
3. Self controlled mode

SEPARATE CONTROLLED MODE

This method can also be used for smooth starting and regenerative braking. An example for true synchronous mode is the open loop (V/f) speed control shown in fig

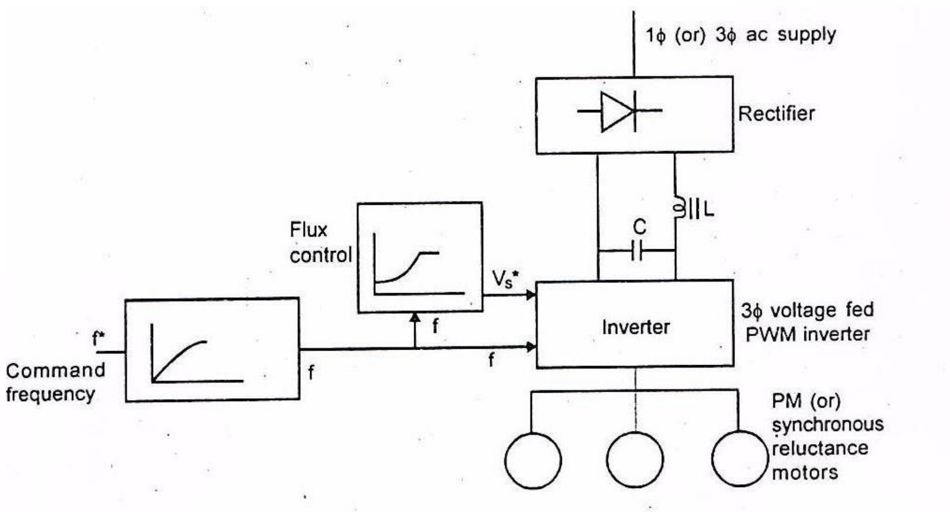


Fig (5.3) Separate Controlled Mode

Here all the machines are connected in parallel to the same inverter and they move in response to the command frequency f* at the input.The frequency command f* after passing through the delay circuit is applied to the voltage source inverters (or) a voltage fed PWM inverter.This is done so that the rotor source is able to track the change in frequency.

A flux control black is used which changes the stator voltage with frequency so as to maintain constant flux for speed below base speed and constant terminal voltage for speed above base speed.

The front end of the voltage fed PWM inverter is supplied from utility line through a diode rectifier and LC filter.the machine can be built with damper winding to prevent oscillations.

SELF CONTROLLED MODE

In self controlled mode, the supply frequency is changed so that the synchronous speed is same as that of the rotor speed.Hence, rotor cannot pull-out of slip and hunting eliminations are eliminated. For such a mode of operation the motor does not require a damper winding.

Fig shows a synchronous permanent magnet machine with self control.The stator winding of the machine is fed by an inverter that generates a variable frequency voltage sinusoidal supply.

Here the frequency and phase of the output wave are controlled by an absolute position sensor mounted on machine shaft, giving it self-control characteristics. Here the pulse train from position sensor may be delayed by the external command as shown in fig.

In this kind of control the machine behavior is decided by the torque angle and voltage/ current. Such a machine can be looked upon as a dc motor having its commutator replaced by a converter connected to stator. The self controlled motor run has properties of a dc motor both under steady state and dynamic conditions and therefore, is called commutator less motor (CLM).These machines have better stability behavior.

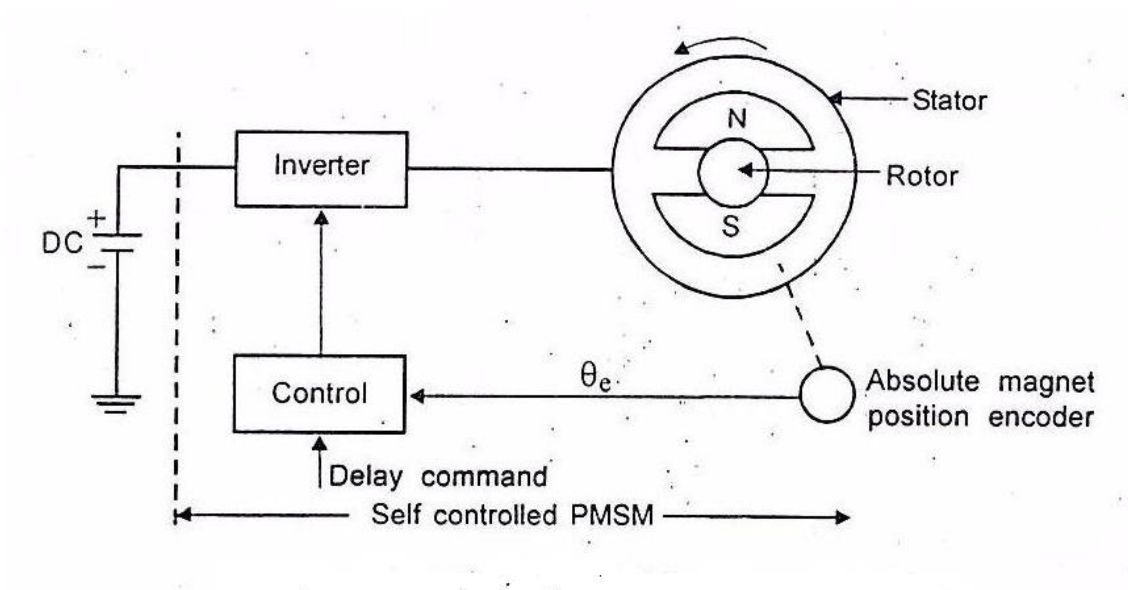


Fig (5.4)Self Controlled Mode

Alternatively, the firing pulses for the inverters can also be obtained from the phase position of stator voltages in which case the rotor position sensor can be dispensed with.

When synchronous motor is over excited they can supply the reactive power required for commutation thyristors. In such a case the synchronous machine can supply with inverter works similar to the line commutated inverter where the firing signals are synchronized with line voltages.

Here, the firing signals are synchronized with the machine voltages then these voltages can be used both for control as well as for commutation. Hence, the frequency of the inverter will be same as that of the machine voltages. This type of inverters are called load commutated inverter (LCI).Hence the commutation has simple configurations due to the absence of diodes, capacitors and auxiliary thyristors.

But then this natural commutation its not possible at low speeds upto 10% of base speed as the machine voltage are insufficient to provide satisfactory commutation. At that line some forced commutations circuit must be employed.

Self controlled synchronous motor Drive empolying load commuated Thyristor Inverter

In fig wound field synchronous motor is used for large power drives. Permanent magnet synchronous motor is used for medium power drives. This drive consists of two converters i.e source side converter and load side converter.

The source side converter is a 3 phase 6 pulse line commutated fully controlled rectifier .When the firing angle range $0 \leq \alpha s \leq 90^{\circ}$,it acts as a commutated fully controlled rectifier.

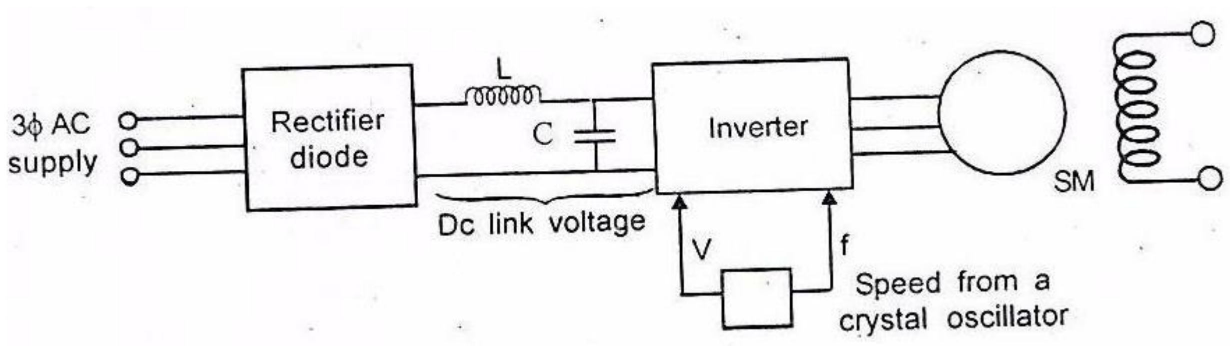


Fig (5.5) Separate control of SM fed from PWM inverter

During this mode ,output volatge Vds and output current Ids is positive.When the firing angle range is $90^{\circ} \leq \alpha s \leq 180^{\circ}$,it acts as an line commutated inverter.During this mode,output voltage Vds is negative and output current Ids is positive.

When synchronous motor operates at a leading power factor ,thyristors of the load side 3φ converter can be commutated (turn off) by the motor induced voltages in the same way,as thyristors of a 3φ line commutated converter are commutated by supply voltage .Load commutation is defined as commutation of thyristors by induced voltages of load (here load is synchronous motor).

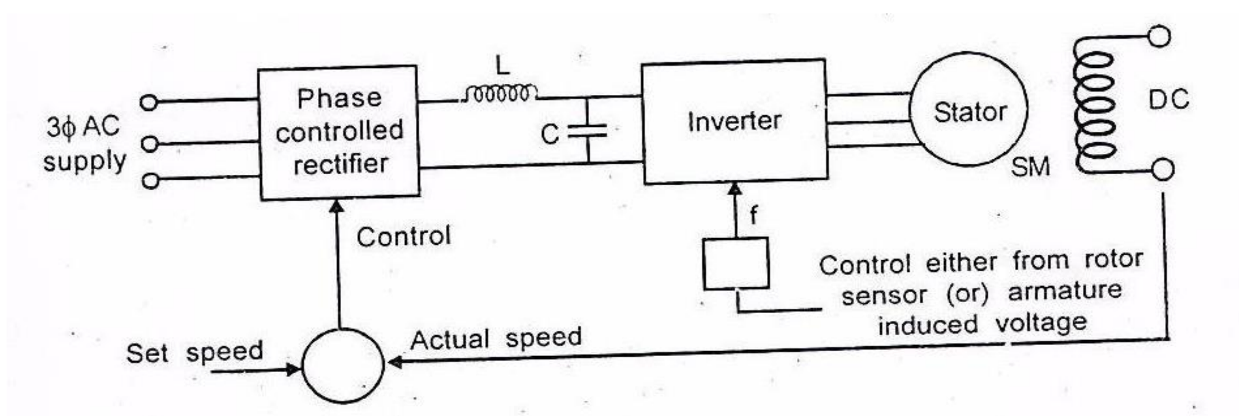


Fig (5.5.1) Self control of SM fed square wave inverter

Triggering angle is measured by comparison of induced voltage in the same way as by the comparison of supply voltages in a line commutated converter.Loas side converter operates as a rectifier when the firing angle range is $0 \le \alpha l \le 90^{\circ}$.It gives positive Vdl and Id.When the firing angle range is $90^{\circ} \le \alpha l \le 180^{\circ}$,it gives negative Vdl and positive Id.

For $0 \le \alpha s \le 90^{\circ}$, $90^{\circ} \le \alpha l \le 180^{\circ}$ and with Vds >Vdl,the source side converter works as a line commutated rectifier and load side converter,causing power flow from ac source to the motor,thus giving motoring operation.

When firing angles are changed such that $90^{\circ} \le \alpha s \le 180^{\circ}$ and $0^{\circ} \le \alpha l \le 90^{\circ}$,the load side converter operates as a rectifier and source side converter operates as an inverter.In this condition ,the power flow reverses and machine operates in regerative braking.The magnitude of torque value depends on (Vds – Vdl).Synchronous motor speed can be changed by control of line side converter firing angles.

When working as an inverter, the firing angle has to be less than 180º to take care of commutation overlap and turn off of thyristors. The commutation lead angle for load side converter is

$$\beta_l = 180^0 - \alpha_l$$

if commutation overlap is neglected ,the input ac current of the converter will lag behind input ac voltage by angle αl.Here synchronous motor input current has an opposite phase to converter input current,the motor current will lead its terminal voltage by a commutation lead angle βl.

Therefore the synchronous motor operates at a leading power factor. The commutation lead angle is low value, due ti this higher the motor power factor and lower the inverter rating.

2. Explain the constant margin angle control of Synchronous motor. (Nov – 2013)

The operation of the inverter at the minimum safe value of the margin angle gives the highest power factor and the maximum torque per ampere of the armature current, thus allowing the most efficient use of both the inverter and motor.

Fig shows the constant margin angle control for a wound field motor drive employing a rotor position encoder. This drive has an outer speed loop and an inner current loop. The rotor position can be sensed by using rotor position encoder. It gives the actual value of speed ωm.This signal is fed to the comparator. This comparator compares ω_m and ω_m^* (ref value).

The output of the comparator is fed to the speed controller and current limiter. It gives the reference current value Id*.Id is the DC link current. It is sensed by current sensor and fed to the comparator. The comparator compares Id and Id*.The output of the comparator is fed to the current controller. It generates the trigger pulses.

It is fed to the controlled rectifier circuit. In addition, it has an arrangement to produce constant flux operation and constant margin angle control.

From the value of dc link current command Id*,Is and 0.5u are produced by blocks (1) and (2) respectively .The signal φ is generated from γ_{min} and 0.5u in adder (3).

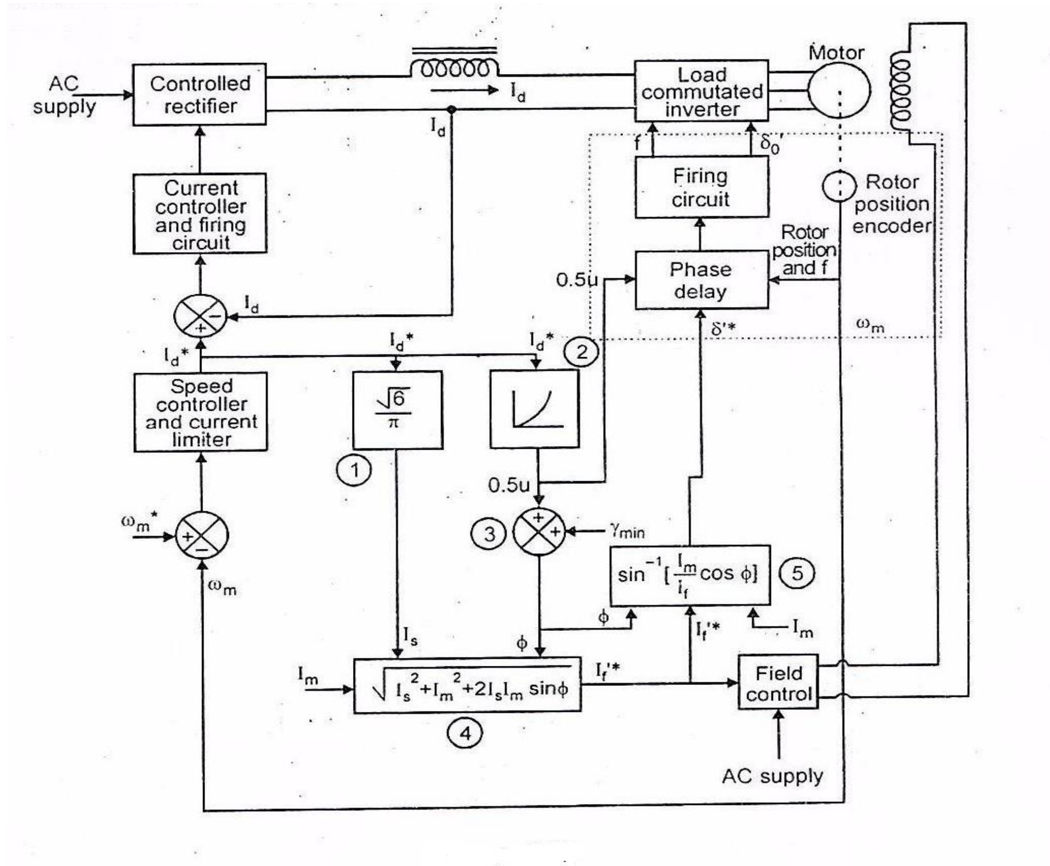


Fig Constant Marginal Angle Control

In block (4) If' is calculated from the known values of Is,φ and I_m. Note that the magnetizing current Im is held constant at its rated value Im to keep the flux constant.

If* sets reference for the closed loop control of the field current I_F. Blocks (5) calculates δ'* from known, values of φ and I_f*

The phase delay circuit suitably shifts the pulses produced by the encoder to produce the desired value of δ_0'.This signal is fed to the load commutated inverter.

The load commutated inverter drives are used in medium power, high-power and very high power drives, and high speed drives such as compressors, extractors ,induced and forced draft fans, blowers, conveyers, aircraft test facilities, steel rolling mills, large ship propulsion, main line traction ,flywheel energy storage and so on.

This drive also used for the starting of large synchronous machines in gas turbine and pumped storage plant.

High power drives employ rectifiers with higher pulse numbers, to reduce torque pulsations. The converter voltage ratings are also high so that efficient high voltage motors can be employed.

3. Explain the constant margin angle control of Synchronous motor. (Nov – 2014)

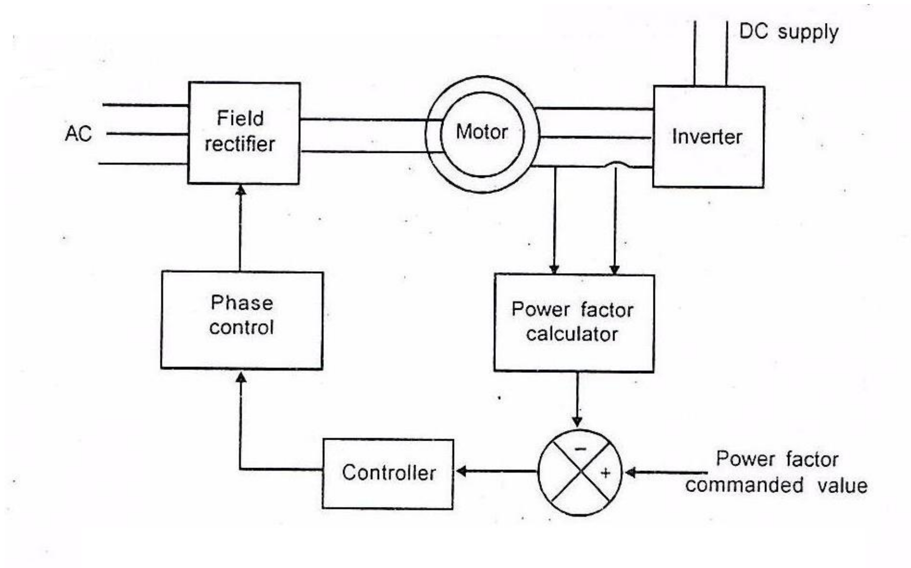


Fig Power Factor Control

Fig shows the block diagram of automatic closed loop adjustment of power factor. The main aim of adjustment of power factor is the variation of the field current. This is possible in a wound field machine. If the motor is operated at a power factor of unity, the current drawn by it will have the lowest magnitude for a given power input and therefore the lowest internal copper losses.

From this diagram, the motor voltage and current are sensed and fed to the power factor calculator. The power factor calculator computes the phase angle between the two and therefore the power factor. It is the actual power factor value. The computed power factor value is compared against the power factor commanded value by using error detector. The error is amplified by the error amplifier and its output varies the field current power factor confirm to the commanded value.

4. Explain the vector control of Induction Motor (April –2015, Dec –2014)

The vector control decouples the two components of stator current, one providing the air gap flux and the other producing the torque.

It provides independent control of flux and torque and the control characteristic is linearized.

Operating principles of vector control

Generally ,a vector controlled induction motor drive can operate as a separately excited dc motor drive.fig shows separately excited dc motor diagram.

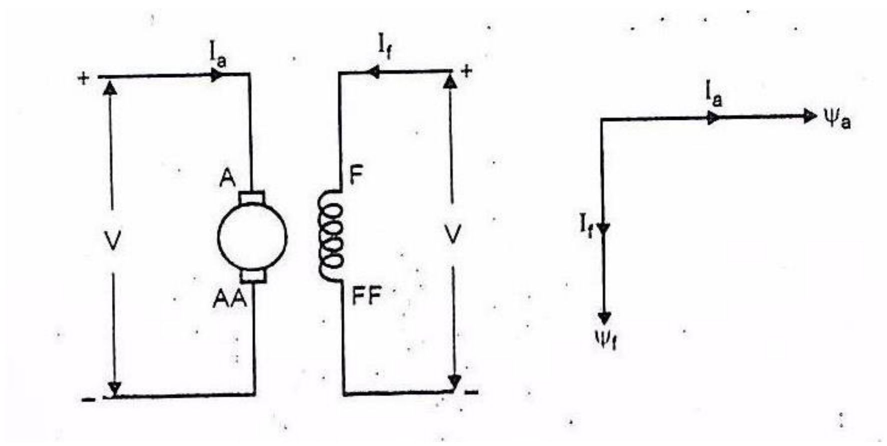


Fig (5.8) circuit diagram of vector control

In a DC machine, the developed torque is given by

$T_d = K_t I_a I_f$

Where

Kt – torque constant

Ia – Armature current (torque component)

If – Field current (Field component)

The construction of a DC machine is such that the field flux linkage Ψf produce by If is perpendicular to the armature flux linkage Ψa produced by Ia.

These space vectors, which are stationary in space, are orthogonal or decoupled in nature, Due to this ,a dc motor has fast transient response. But, an induction motor cannot give such fast transient response due to its inherent coupling problem.

DC machine –like performance can also be extended to an induction motor if the machine is controlled in s synchronously rotating reference frame (d^e-q^e),where the sinusoidal variables appear as DC quantities in the steady state.

Fig shows simple block diagram of vector controlled induction motor .

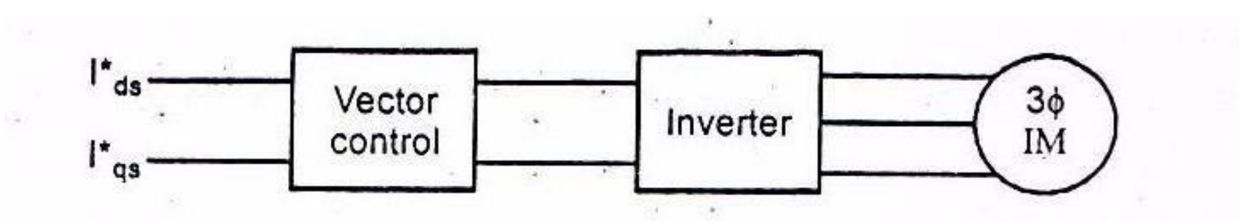


Fig (5.8.1) Block diagram of vector controlled induction motor

There are two current inputs are fed to the vector control. one is i*ds and other i*qs.

i*ds= direct –axis component of stator current

i*qs = quadrature –axis component of stator current these currents are synchronously rotating reference frame.with vector control ,ids is analogous to the field current If and iqs is analogous to armature current Ia of dc motor .therefore the torque developed in an induction motor is given by

$Td = Km\ \Psi r \overline{I}f$

$= Kt\ ids\ iqs$

$\overline{\Psi r}$ = absolute peak value of the sinusoidal space flux linkage vector $\overline{\Psi r}$

ids = field component

iqs = torque component