INDUSTRIAL DRIVES & APPLICATIONS

MODULE - 2

SELECTION OF MOTOR POWER RATING: Thermal model of motor for heating and cooling, Classes of motor duty, determination of motor rating.

DC MOTOR DRIVES:

(a) Starting braking, transient analysis, single phase fully controlled rectifier, control of dc separately excited motor, Single-phase half controlled rectifier control of dc separately excited motor.

(b) Three phase fully controlled rectifier control of dc separately excited motor, three phases half controlled rectifier control of dc separately excited motor, multi quadrant operation of dc separately excited motor fed form fully controlled rectifier. Rectifier control of dc series motor, chopper controlled dc drives, chopper chopper control of separately excited dc motor. Chopper control of series motor.

SELECTION OF MOTOR POWER RATING

- Thermal model of motor for heating and cooling
- Classes of motor duty
- Determination of motor rating.

INTRODUCTION

1. When a motor operates, heat is produced (losses) in the machine and its temperature rise.

2. As the temperature increases beyond the limit, a portion of heat flows out to the surrounding medium.

3. When temperature reaches a steady state. (i.e. steady state value depends on power loss and output power of the machine).

4. Therefore, temperature rise has a direct relationship with the output power and is termed as thermal loading on the machine.

5. Steady state temperature is not the same at various parts of the machine. It is highest in the windings. (loss density in conductors is high and dissipation is slow)

6. Also because windings are not exposed to cooling air, wrapped with the insulation material and partly exposed in slots.

7. Among the various materials used in machine, the insulation has lowest temperature limit.

When operating for a specific application, motor rating should be carefully chosen to ensure that the insulation temperature never exceeds the prescribed limit. 2. If not lead to thermal breakdown causing short circuit and damage to winding. 3. For loads which operate at a constant power and speed, determination of motor power rating is simple and straightforward.4. Most of the loads operate at variable power and speed and are different for different applications. This chapter has three objectives:

1. Obtain thermal model for the machine – calculation of motor ratings for various classes of motor duty.

2. Categorization of load variation with time. (Classes of duty of motor)

3. Methods for calculating motor ratings for various classes of duty.

CLASSES OF MOTOR DUTY

IEC (the International Electro technical Commission) uses eight duty cycle designations to describe electrical motors operating conditions:

S1 – CONTINUOUS DUTY (A)- The motor works at a constant load for enough time to reach temperature equilibrium. Characterized by a constant motor loss.

Examples: paper mill drives, compressors, pumps.

S2 – SHORT TIME DUTY (B) – it denotes the operation at constant load during a given time, less than that required to reach thermal equilibrium, followed by a rest of sufficient duration to re-establish equality of temperature with the cooling medium.

Examples: motors used for opening and closing lock gates and bridges, motors employed in battery-charging units etc, are rated for such a duty.

S3 - INTERMITTENT PERIODIC DUTY – it denotes a sequence of identical duty cycles, each consisting of a period of operation at constant loadand a rest period, these periods being too short to obtain thermal equilibrium during one duty cycle.

Examples: motors that are used in different kinds of hoisting mechanisms and those used in trolley buses etc. are subjected to intermitted periodic duty.

S4- INTERMITTENT PERIODIC DUTY WITH STARTING – this is intermitted periodic duty cycles where heat losses during starting cannot be ignored. Thus, it consisting of a period of starting, a period of operation at constant load and a rest period, the operating and rest periods being too short to attain thermal equilibrium during one duty cycle.

Examples l*:* motors that drive metal cutting and drilling tool, certain auxiliary equipment of rolling mills.

S5- INTERMITTENT PERIODIC DUTY WITH STARTING AND BRAKING – it denotes a sequence of identical duty cycles each consisting of a period of starting, a period of operation at a constant load, a period of braking and rest period. The operating and rest periods are too short to obtain thermal equilibrium during one duty cycle. In this duty braking is rapid and is carried out electrically.

Examples*:* certain auxiliary equipment used in rolling mills and metal cutting metal lathes offer such operating conditions.

S6- CONTINUOUS DUTY WITH INTERMITTENT PERIODIC LOADING: it denotes a sequence of identical duty cycles each consisting of a period of operation of constant load and a period of operation at not load, with normal voltage across the exciting windings. The operation and no load periods are too short to attain thermal equilibrium during one duty cycle.

This type of duty is distinguished from intermittent periodic duty by the fact that after a period of operation at constant load follows a period of no load operation instead of rest.

Examples: Pressing, cutting and drilling machine drives are the examples

S7- CONTINUOUS OPERATION WITH STARTING AND BRAKING – it denotes a sequence of identical duty cycles each consisting of a period of starting, a period of operation at constant load and a period of electrical braking. There is no period of rest.

Examples*:* blooming mill

S8- CONTINUOUS DUTY WITH PERIODIC SPEED CHANGES – it consists of periodic duty cycle, each having a period of running at one load and speed, and another period of running at different speed and load; the operating periods being too short to attain thermal equilibrium during one duty cycle. There is no rest period.

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. The heat flow and the temperature distribution within a motor is very difficult to predict because of complexity in the motor geometry. The calculations are also complicated because of loading of the motor. The heat flow direction does not remain same at all loading conditions. The steady state temperature is different at various parts of the motor. It is highest in the windings as loss density in conductors is high and dissipation is slow. A simple thermal model of the motor can be obtained by assuming motor as a homogeneous body with uniform temperature gradient. The heat which is generated at all points has same temperature. The points at which heat is dissipated to the cooling medium are also at same temperature. The heat dissipation is proportional to the difference of the temperatures of the body and surrounding medium. No heat is radiated. Similarly it is also assumed that heat dissipation rate is constant at all temperature. If cooling is not provided then motor can not dissipate heat to surrounding medium.

This will increase temperature to a very high value.

Heating Curves

Let W = Loss taking place in a machine in watts

G = Mass of the machine in kg

S = Specific heat in watt-sec/kg °C

θ = Rise in temperature above ambient temperature in °C

θ_F = Final temperature rise with continuos load in °C

A = Area of cooling surface in m^2

λ = Rate of heat dissipation in watts/sq meter/°C rise in temperature.

Let us consider the small time interval dt in which temperature rise of the machine is $d\theta$ due to the losses taking place in the machine. Total losses in machine during

time interval dt = W dt

Heat dissipation from surface during the same time interval = $A\lambda\theta \cdot dt$

Additional heat stored in the machine = $G.S.d\theta$

We have, heat developed = heat absorbed + heat dissipated

$$W \cdot dt = G.S.d\theta + A\lambda\theta \cdot dt \qquad \ldots(i)$$

$$\therefore \quad W \cdot dt - A\lambda\theta \cdot dt = G.S.d\theta$$

$$\therefore \quad (W - A\lambda\theta)\, dt = G.S.d\theta$$

$$\frac{dt}{G.S.} = \frac{d\theta}{W - A\lambda\theta}$$

$$\frac{dt}{\left(\frac{GS}{A\lambda}\right)} = \frac{d\theta}{\left(\frac{W}{A\lambda} - \theta\right)} \qquad \ldots(ii)$$

When final temperature is reached, there is no heat absorbed. The heat which is generated is totally dissipated.

$$\therefore \quad W \cdot dt = A\,\lambda\,\theta_F\, dt$$

$$\therefore \quad W = A\,\lambda\,\theta_F$$

$$\therefore \quad \theta_F = \frac{W}{A\lambda} \qquad \ldots(iii)$$

Substituting equation (iii) in equation (ii) we get,

$$\frac{dt}{\left(\frac{GS}{A\lambda}\right)} = \frac{d\theta}{\theta_F - \theta}$$

Integrating both sides of above equation

$$\int \frac{dt}{\left(\frac{GS}{A\lambda}\right)} = \int \frac{d\theta}{\theta_F - \theta}$$

$$\frac{A\lambda}{GS} \cdot t = -ln(\theta_F - \theta) + K \qquad \text{...(iv)}$$

where K = constant of integration

To find out value of K, let us use initial condition

At $t = 0, \ \theta = \theta_1$

$$\therefore \qquad 0 = -ln(\theta_F - \theta_1) + K$$

$$\therefore \qquad K = ln(\theta_F - \theta_1)$$

Substituting this value of K in equation (iv),

$$\frac{A\lambda}{GS} \cdot t = -ln(\theta_F - \theta) + ln(\theta_F - \theta_1)$$

$$\therefore \qquad \frac{A\lambda}{GS} \cdot t = ln\left(\frac{\theta_F - \theta_1}{\theta_F - \theta}\right)$$

$$\therefore \qquad e^{\frac{A\lambda}{GS}t} = \frac{\theta_F - \theta_1}{\theta_F - \theta}$$

$$\therefore \qquad \theta_F - \theta = (\theta_F - \theta_1)\, e^{-\frac{A\lambda}{GS}t}$$

$$\therefore \qquad \theta = \theta_F - (\theta_F - \theta_1)\, e^{-\frac{A\lambda}{GS}t}$$

The term GS/A λ is called **heating time constant** of the machine and is denoted by τ.

$$\therefore \qquad \boxed{\theta = \theta_F - (\theta_F - \theta_1)\, e^{-t/\tau}}$$

If the machine is started from ambient temperature $\theta_1 = 0°C$ then above equation becomes,

$$\therefore \qquad \boxed{\theta = \theta_F\,(1 - e^{-t/\tau})}$$

Let us consider time period t = τ then

Heating of Electric Motors

An electric motor has various power losses, mainly copper losses in the winding and core losses due to the hysteresis losses and eddy current losses, in the core. These losses appear in the form of heat. The mechanical losses due to the friction and windage also contribute to such heat development. There are some cooling methods provided in an electric motor. The ventilation causes heat to dissipate to the outside media such as air, oil or solids, or cooling medium. However some heat gets stored in the material, causing the temperature rise of an electric motor. Key Point: Under steady state conditions, the final temperature rise is reached when the rate of production of heat and rate of heat dissipation are equal. There is always some limited temperature rise specified for an electric motor. If temperature rises beyond the specified limit, motor is likely to be damaged. The insulating material may get damaged, which may cause a short circuit. Such a short circuit may lead to a fire. If immediate thermal breakdown of insulating material may not occur, the quality of insulation starts deteriorating such that in future for a normal load also thermal breakdown may occur. Hence while selecting an electric motor, such thermal restriction must be considered. Key Point: In fact the continuous rating of a machine is that rating for which the final temperature rise is just below the permissible value of temperature rise. The insulating material used to protect the conductors decides the permissible temperature rise for an electric motor. The following table gives various classes of insulating materials and the corresponding permissible temperatures.

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. The heat flow and the temperature distribution within a motor is very difficult to predict because of complexity in the motor geometry. The calculations are also complicated because of loading of the motor. The heat flow direction does not remain same at all loading conditions. The steady state temperature is different at various parts of the motor. It is highest in the windings as loss density in conductors is high and dissipation is slow. A simple thermal model of the motor can be obtained by assuming motor as a homogeneous body with uniform temperature gradient The heat which is generated at all points has same temperature. The points at which heat is dissipated to the cooling medium are also at same temperature. The heat dissipation is proportional to the difference of the temperatures of the body and surrounding medium. No heat is radiated. Similarly it is also assumed that heat dissipation rate is constant at all temperature. 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. It is important to know about the heating and cooling curves. The detailed analysis about these curves is made in subsequent sections.

Heating Curves Consider a homogenous machine developing heat internally at a uniform rate and gives it to the surroundings proportional to temperature rise. It can be proved that the temperature rise of a body obeys exponential law.

Determination of motor rating

For a drive motor which is driving a constant load for sufficiently longer period till it reaches thermal equilibrium, its rating must be sufficient to drive it without exceeding the specified temperature. The rating of the motor selected for such type of duty is called continuous or design rating. The continuous rating specifies the maximum load that the motor can take over a period of time without exceeding the temperature rise. It is also expected that the motor should carry momentary overloads. Hence the motor which is selected sometimes has a rating slightly more than the power required by the load.

The efficiency of motor varies considerably with type of drive, bearings etc. Centrifugal pumps, fans, conveyors and compressors are some types of loads where the continuous duty at constant load is required. Selection of motor for such duty class is simple. Based on the load characteristics or specific requirements, the continues input required for mechanical load can be obtained. A suitable motor can be then selected from manufacture's catalogue. The thermal or overload capacities for selected motors should not be checked again as the design rating takes care of heating and temperature rise and the motor normally has short time overloading capacity. In case of such motors, the losses occurring during starting even though more than at rated load should not be given much importance as such motors does not require frequent starting. But it should be checked that whether the motor is able to provide enough starting torque or not if the load has considerable moment of inertia.

Method based on Average Losses

A method based on average losses of motor is suitable for selecting a motor for continuous duty, variable load. 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. Here the final steady state temperature rise under variable load is same as the temperature rise with constant load. Let us consider a load-time graph as shown in the Fig. 1.10. The load torque goes on varying as per different intervals of time. In the last time period motor is de-energized from supply which is period of rest. T,

Key Point: The losses are zero in the last interval as motor is disconnected from supply. Consider equivalent constant current Li which causes same average losses over the time period considered. Average losses = W, c+1, .2.q12 where Wc, are core losses and R is the resistance of armature. LolI1 be current in time interval t 1, 12 be current in time interval 12 and so on.

D C MOTOR DRIVES:

- Starting braking, transient analysis, single phase fully controlled rectifier
- Control of dc separately excited motor
- Single-phase half controlled rectifier control of dc separately excited motor.
- Three phase fully controlled rectifier control of dc separately excited motor
- Three phases half controlled rectifier control of dc separately excited motor Multiquadrant operation of dc separately excited motor fed form fully controlled rectifier. Rectifier control of dc series motor
- Chopper controlled dc drives, chopper control of separately excited dc motor.
- Chopper control of series motor.

Introduction

It is seen that due to various advantages, electric motors are used as drive motors in various industrial applications. The various industrial loads have different types of mechanical characteristics, which mainly include speed-torque characteristics. When an electric motor is to be selected as a drive motor, first the speed-torque requirement of the load is determined. Then an electric motor is selected having speed-torque characteristics same as that required by the load. Thus it is necessary to know the various types of electric motors used as drive motors and their mechanical characteristics. This helps to select the proper motor for driving the load. The electric motors are classified based on the nature of the electric supply used to drive the motor. Accordingly, the electric motors are basically classified as, 1. D.C. Motors which require d.c. supply. 2. AC. motors which require a-c. supply. This chapter explains the various types of electric motors and their characteristics.

D.C. Motors

The motors which require d.c. supply to drive them are called d.c. motors. In d.c. motors, there are two types of windings, 1. Field winding: 'this is used to produce the main operating flux. This is also called exciting winding. The dc. supply is used to pass exciting current through the field winding. The field current products necessary working flux. Key Point: Before saturation, the flux ON produced by the field winding is directly proportional to the field current (lf) 2. Armature winding: The armature winding is placed on armature, which is a rotating part of the d.c. motor. The armature winding is connected to the commutator and the supply to the armature winding is given through the bushes which are resting against the commutator. When supply is given to the armature, it carries an armature current (I,,) and produces the flux called armature flux.

Principle of Operation

DC motor operates on the principle that when a current carrying is placed in a magnetic field, it experiences a mechanical force given by F = BIL newton. Where the current and ‘L’ is the length of the conductor. The direction of force can be found by left hand rule. Constructionally, there is no difference between a DC generator and DC motor. Conductors. The collective force produces a driving torque which sets the armature into rotation.The function of a commutator in DC motor is to provide a continIn DC generator the work done in overcoming the magnetic drag is converted into electrical energy.
Conversion of energy from electrical form to mechanical form by a DC motor takes place by the work done in overcoming the opposition which is called the BACK EMF: is the dynamically induced emf in the armature conductors of a dc motor when the armature is rotated. The direction of the induced emf as found by Flemings right hand rule is in Opposition to the applied voltage. Its value is same as that This emf is called as back opposition is converted into mechanical energy.

Starting braking

DC motor operates on the principle that when a current carrying is placed in a magnetic field, it experiences a mechanical force given by F = BIL newton. Where 'B' = flux density in wb/ is the length of the conductor. The direction of force can be found by

left hand rule. Constructionally, there is no difference between a DC generator and DC motor. Armature conductors are carrying current downwards under North Pole and upwards under South Pole. When the field coils are excited, with current carrying armature conductors, a force is experienced by each armature conductor whose direction can be found by Fleming's left hand rule. This is shown by arrows. The collective force produces a driving torque which sets the armature into rotation. The function of a commutator in DC motor is to provide a continuous and unidirectional torque.

In DC generator the work done in overcoming the magnetic drag is converted into electrical energy. Conversion of energy from electrical form to mechanical form by a DC motor takes place by the work done in overcoming the opposition which is called the 'back emf'. is the dynamically induced emf in the armature conductors of a dc motor when the armature is rotated. The direction of the induced emf as found by Flemings right hand rule is in opposition to the applied voltage. Its value is same as that of the induced emf in a DC generator volts. This emf is called as back emf′. The work done in overcoming this opposition is converted into mechanical energy.

The direction of force can be found by Fleming's left hand rule. Constructionally, there is no difference between a DC generator and DC motor. Shows a multipolar DC motor. Armature conductors are carrying current downwards under North Pole and upwards under South Pole. When the field coils are excited, with current carrying armature conductors, a force is experienced by each armature hose direction can be found by Fleming's left hand rule. This is shown by arrows on top of the. The collective force produces a driving torque which sets the armature into rotation

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armature is rotated. The direction of the induced emf as found by Flemings right hand rule is in of the induced emf in a DC generator . The work done in overcoming this
The rotating armature connected across a supply voltage of ‘V’.Direct current (dc) motors have variable characteristics and are usedextensively in variable-speed drives.

• DC motors can provide a high starting torque and it is also possible to obtain speed control over a wide range.

• The methods of speed control are normally simpler and less expensive than those of AC drives.

• DC motors play a significant role in modern industrial drives.

• Both series and separately excited DC motors are normally used in variable- speed drives, but series motors are traditionally employed for traction applications.

• Due to commutators, DC motors are not suitable for very high speed applications and require more maintenance than do AC motors.

• With the recent advancements in power conversions, control techniques, and microcomputers, the ac motor drives are becoming increasingly competitive with DC motor drives.

• Although the future trend is toward AC drives, DC drives are currently used in many might be a few decadesControlled rectifiers provide a variable dc output voltage from a fixed acvoltage, whereas a dc-dc converter can provide a variable dc voltage froma fixed dc voltage.

• Due to their ability to supply a continuously variable dc voltage, controlled rectifiers and dc-dc converters made a revolution in modern industrial control equipment and variable-speed drives, with power levels ranging from fractional horsepower to several megawatts.

• Controlled rectifiers are generally used for the speed control of dc motors.

• The alternative form would be a diode rectifier followed by dc-dc converter.

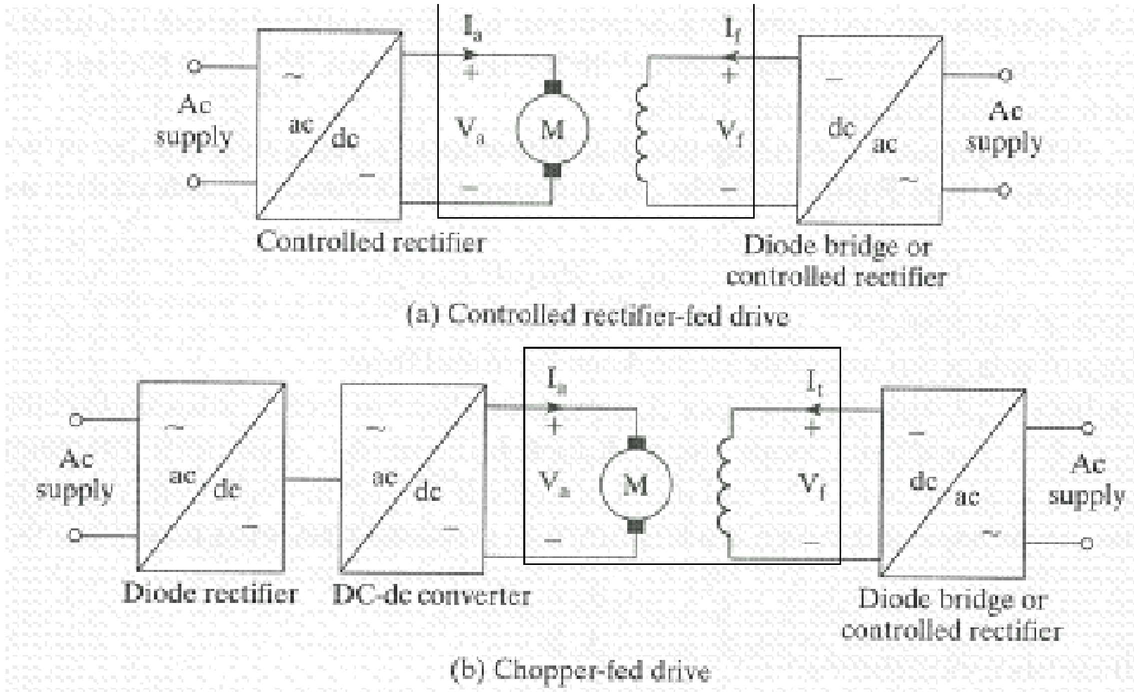
• DC drives can be classified, in general, into three types:

– 1. Single-phase drives

– 2. Three-phase drives

– 3. DC-DC converter drives

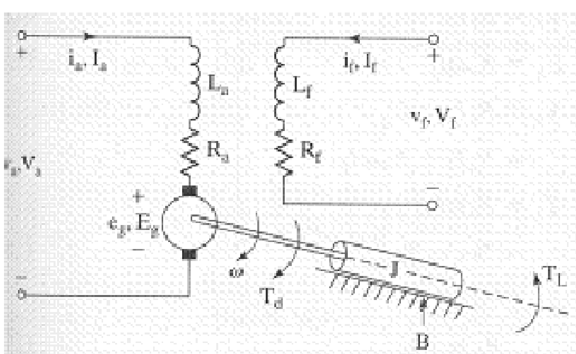
Single phase fully controlled rectifier



(a) Controlled rectifier-fed drive

(b) Chopper-fed drive

Control of dc separately excited motor



$$\omega = \frac{V_a - R_a I_a}{K_v I_f} = \frac{V_a - R_a I_a}{K_v V_f / R_f}$$

The motor speed can be varied by

– controlling the armature voltage Va, known as voltage control;

– controlling the field current If, known as field control; or

– torque demand, which corresponds to an armature current Ia, for a fixed field current If.

The speed, which corresponds to the rated armature voltage, rated field current and rated armature current, is known as the rated (or base) speed.

In practice, for a speed less than the base speed, the armature current and field currents are maintained constant to meet the torque demand, and the armature voltage Va is varied to control the speed. For speed higher than the base speed, the armature voltage is maintained at the rated value and the field current is varied to control the speed. However, the power developed by the motor (= torque X speed) remains constant.

Figure below shows the characteristics of torque, power, armature current, and field current against the speed.

Operating Modes

In variable-speed applications, a dc motor may be operating in one or more modes: motoring,

Regenerative braking,

Dynamic braking,

Plugging

Motoring: The arrangements for motoring are shown in Figure 15.7a. Back emf Eg is less than supply voltage Vy. Both armature and field currents are positive. The motor develops torque to meet the load demand.

Regenerative braking:

• The motor acts as a generator and develops an induced voltage E g. Eg must be greater than supply voltage Va.

• The armature current is negative, but the field current is positive.

• The kinetic energy of the motor is returned to the supply.

• A series motor is usually connected as a self-excited generator.

• For self-excitation, it is necessary that the field current aids the residual flux. This is normally accomplished by reversing the armature terminals or the field terminals.

Dynamic braking:

• The arrangements shown in Figure 15.7c are similar to those of regenerative braking, except the supply voltage Va is replaced by a braking resistance Rb,.

• The kinetic energy of the motor is dissipated in Rb.

Plugging:

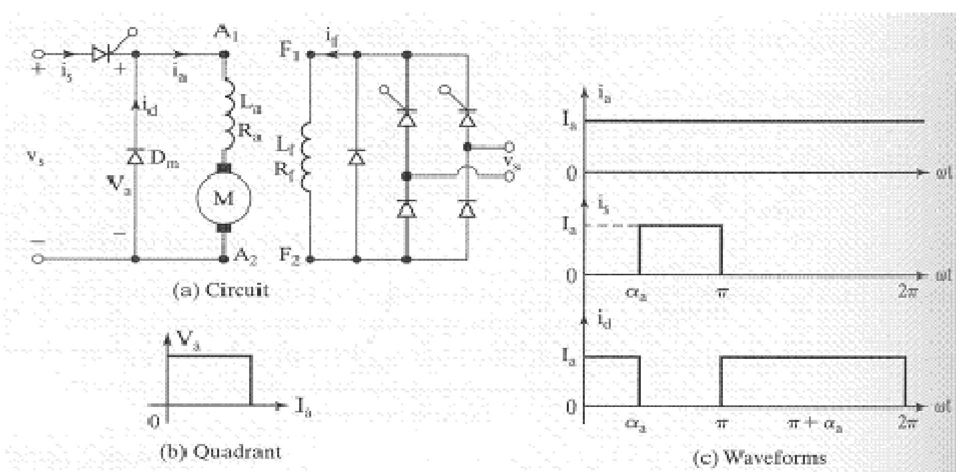
• Plugging is a type of braking. The connections for plugging are simple

• The armature terminals are reversed while running. The supply voltage Va and the induced voltage Eg act in the same direction.

• The armature current is reversed, thereby producing a braking torque. The field current is positive.

• For a series motor, either the armature terminals or field terminals should be reversed, but not both.

Single-phase half controlled rectifier control of dc separately excited motor



A single-phase half-wave converter feeds a dc motor, as shown

• The armature current is normally discontinuous unless a very large inductor is connected in the armature circuit.

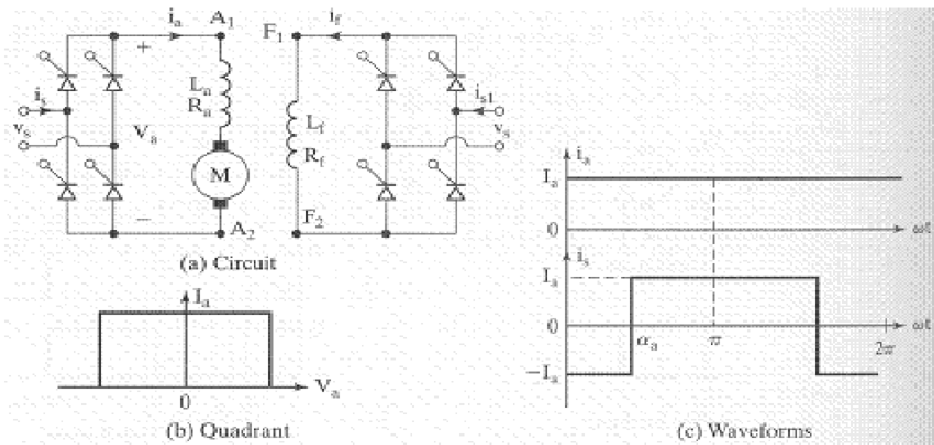
• A freewheeling diode is always required for a dc motor load and it is a one-quadrant drive.

• The applications of this drive are limited to the 0.5 kW power level.

• Figure shows the waveforms for a highly inductive load.

• A half-wave converter in the field circuit would increase the magnetic losses of the motor due to high ripple content on the field excitation current.

Single-Phase Full-Wave-Converter Drives

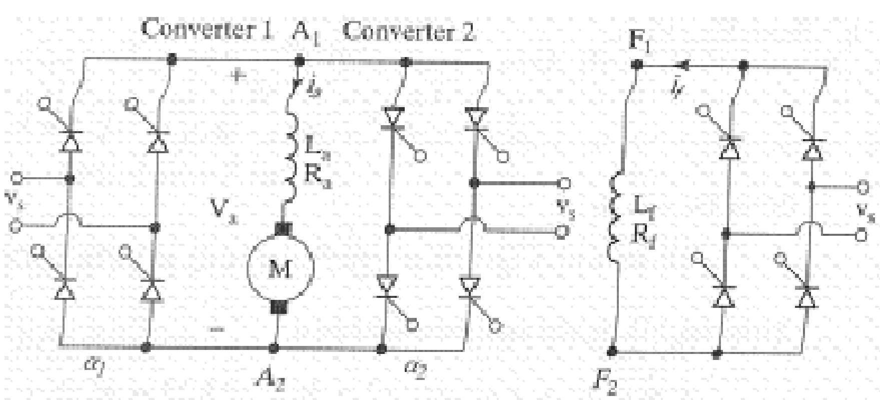


The converter in the field circuit could be a full, or even a dual converter.

• The reversal of the armature or field allows operation in the second and third quadrants.

• The current waveforms for a highly inductive load are shown in Figure for powering action.

Single-Phase Dual-Converter Drives



• Two single-phase full-wave converters are connected.

• Either converter 1 operates to supply a positive armature voltage, Va, or converter 2 operates to supply a negative armature voltage, - Va.

• Converter 1 provides operation in the first and fourth quadrants, and converter 2, in the second and third quadrants.

• It is a four-quadrant drive and permits four modes of operation: forward powering, forward braking (regeneration), reverse powering, and reverse braking (regeneration).

• It is limited to applications up to 15 kW. The field converter could be a fill-wave or a dual converter.

Chopper controlled dc drives

DC to DC converters operating under certain conditions. The use of such converters is extensive in automotive applications, but also in cases where a DC voltage produced by rectification is used to supply secondary loads. The conversion is often associated with stabilizing, i.e. the input voltage is variable but the desired output voltage stays the same. The converse is also required, to produce a variable DC from a fixed or variable source. The issues of selecting component parameters and calculating the performance of the system will be addressed here. Since these converters are switched mode systems, they are often referred to as choppers. The basic circuit of this converter is shown in figure connected first to a purely resistive load. If we remove the low pass filter shown and the diode the output voltage vo(t) is equal to the input voltage Vd when the switch is closed and to zero when the switch is open, giving an average output voltage Vo: Ts = D, the duty ratio. The low pass filter attenuates the high frequencies (multiples of the switching frequency) and leaves almost only the DC component. The energy stored in the filter inductor (or the load inductor) has to be absorbed somewhere other than the switch, hence the diode, which conducts when the switch is open. We'll study this converter in the continuous mode of operation i.e. the current through the inductor never becomes zero. As the switch opens and closes the circuit assumes one of the topologies of figures.

If the source of supply is dc. a chopper-type converter is The basic operation of a single-switch chopper and Drives ,where it was shown that the average output voltage could be varied by periodically switching the battery voltage on and off for varying intervals. The principal difference between the thyristor-controlled rectifier and the chopper is that in the forrner the motor current always flows through the supply, whereas in the latter, the motor current only flows from the supply terminals for part of each cycle. A single-switch chopper using a transistor, IvIOSFET or IGBT can only supply positive voltage and current to a dc. Motor, and is therefore restricted to quadrant 1 motoring operation.