Electrical Motor Drives

A.S.Welankiwar

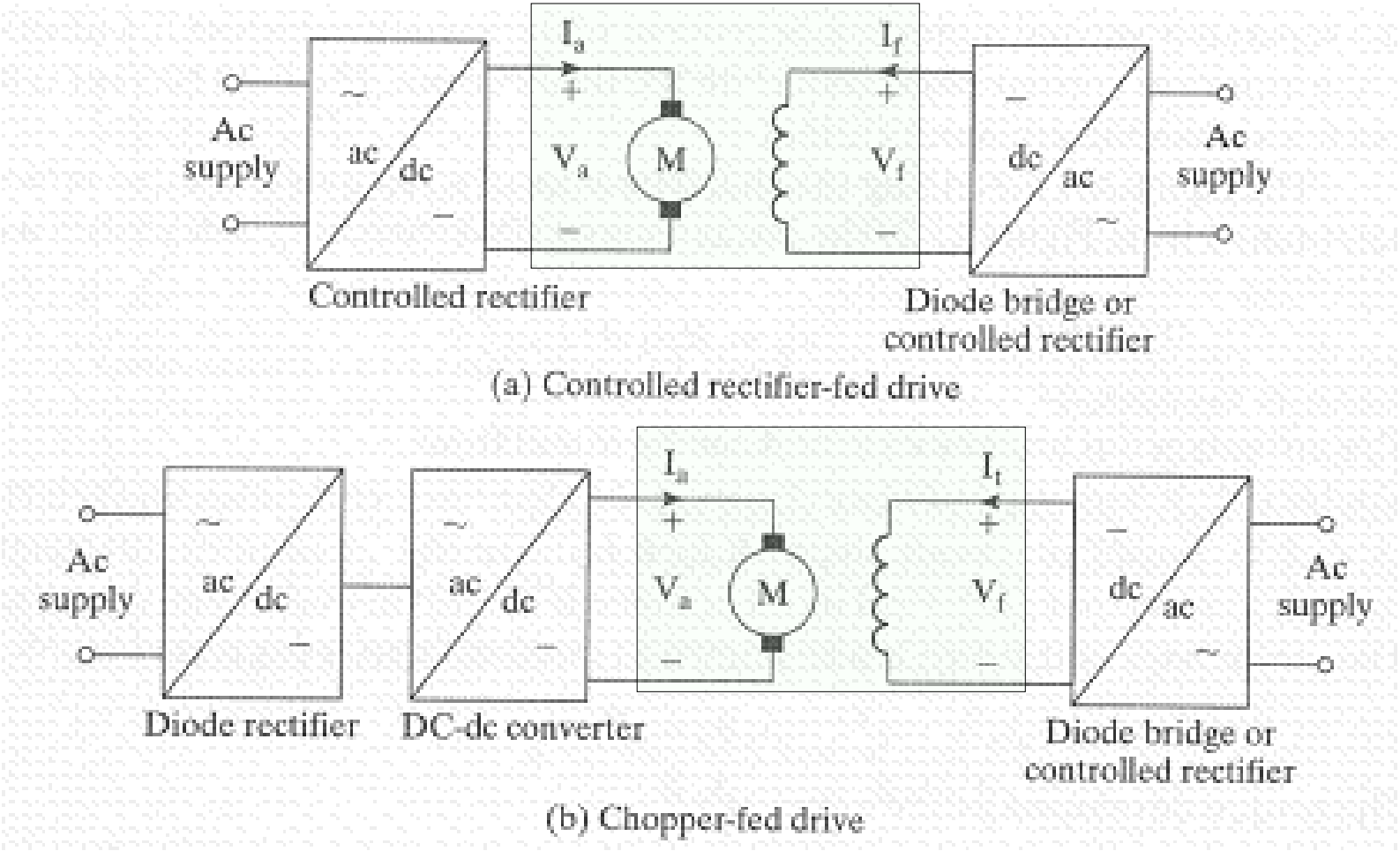
Introduction: DC Motor Drives

- Direct current (dc) motors have variable characteristics and are used extensively 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 industries. It might be a few decades before the DC drives are completely replaced by AC drives.

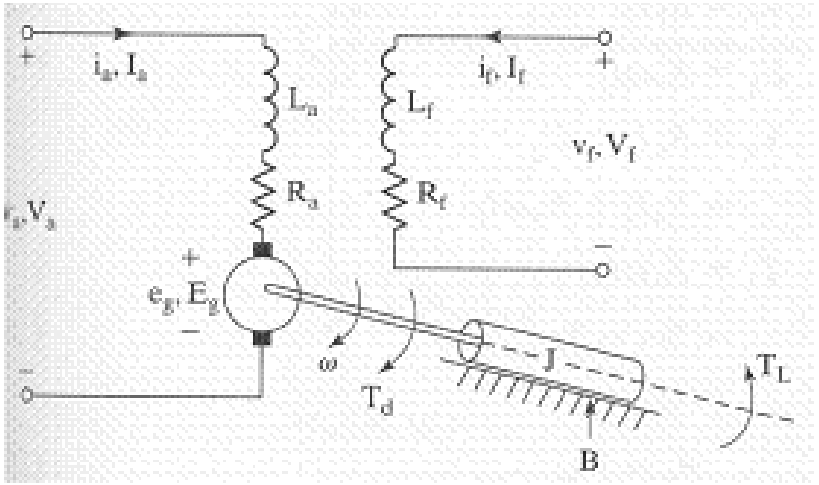
Introduction: DC Motor Drives

- Controlled rectifiers provide a variable dc output voltage from a fixed ac voltage, whereas a dc-dc converter can provide a variable dc voltage from a 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

Controlled Rectifier- and DC-DC Converter-Fed Drives



Basic Characteristics of Shunt DC Motors

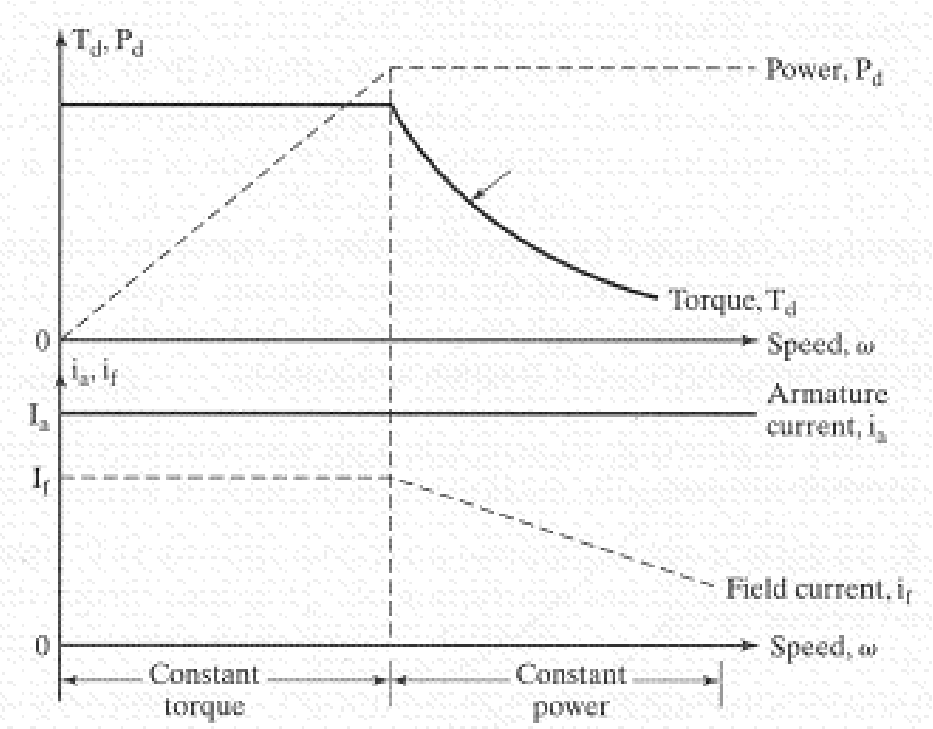


$$\omega = \frac{V_a - R_a I_a}{K_v I_f} = \frac{V_a - R_a I_a}{K_v V_f / R_f}$$

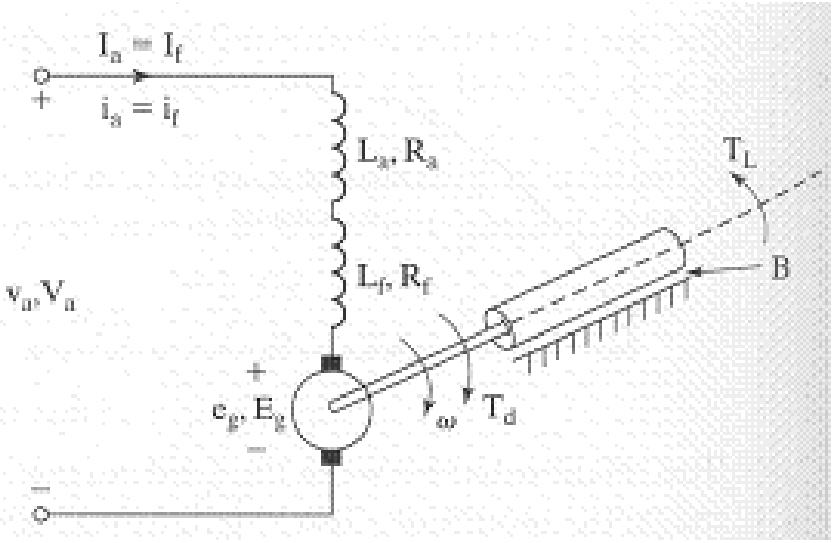
- The motor speed can be varied by
  - controlling the armature voltage V_a, known as voltage control;
  - controlling the field current I_f, known as field control; or
  - torque demand, which corresponds to an armature current I_a, for a fixed field current I_f.
- The speed, which corresponds to the rated armature voltage, rated field current and rated armature current, is known as the rated (or base) speed.

Basic Characteristics of Shunt DC Motors

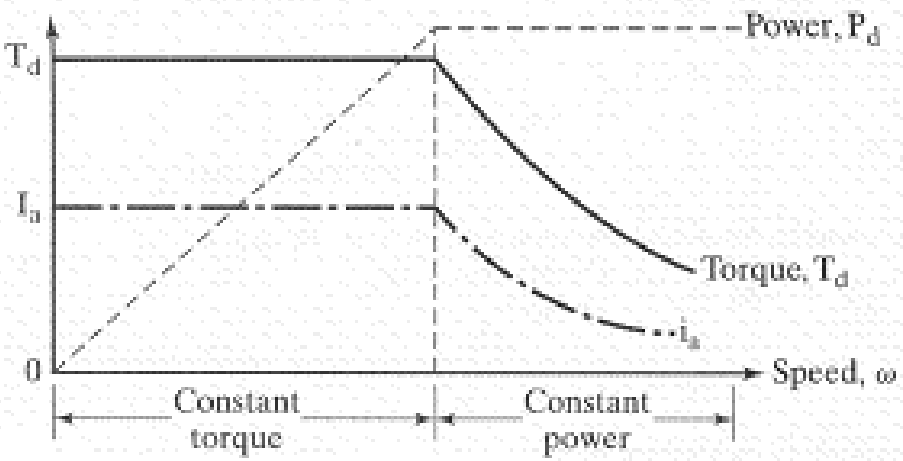
- In practice, for a speed less than the base speed, the armature current and field currents are maintained constant to meet the torque demand, and the armature voltage V_a is varied to control the speed.
- For speed higher than the base speed, the armature voltage is maintained at the rated value and 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.



Basic Characteristics of Series DC Motors



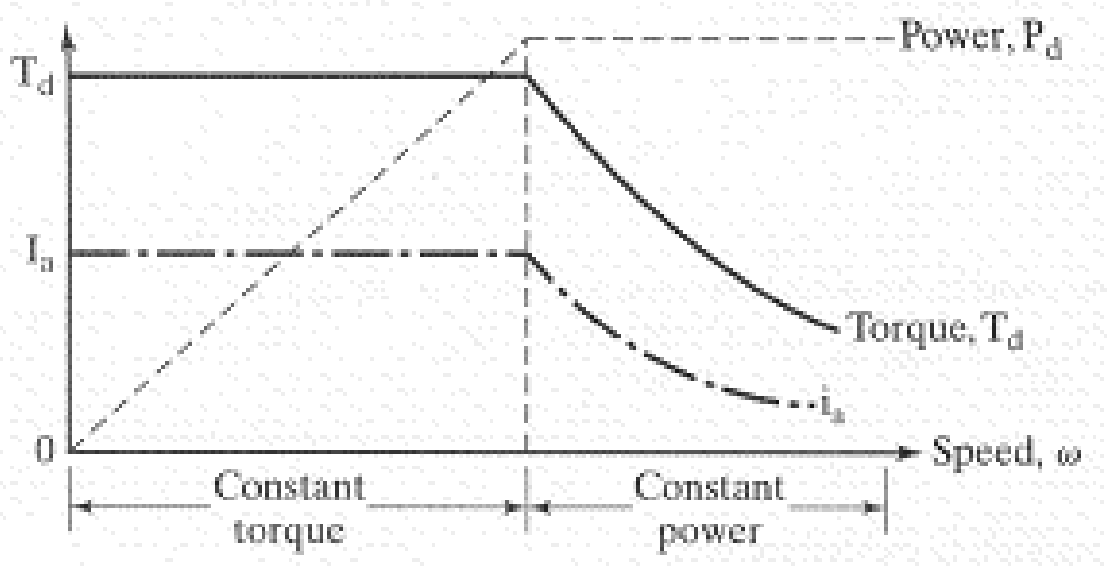
$$\omega = \frac{V_a - (R_a + R_f) I_a}{K_v I_f}$$



- The motor speed can be varied by
  - controlling the armature voltage V_a, known as voltage control;
  - armature current I_a, which is a measure of the torque demand.
- A series motor can provide a high torque, especially at starting; and for this reason, series motors are commonly used in traction applications.

Basic Characteristics of Series DC Motors

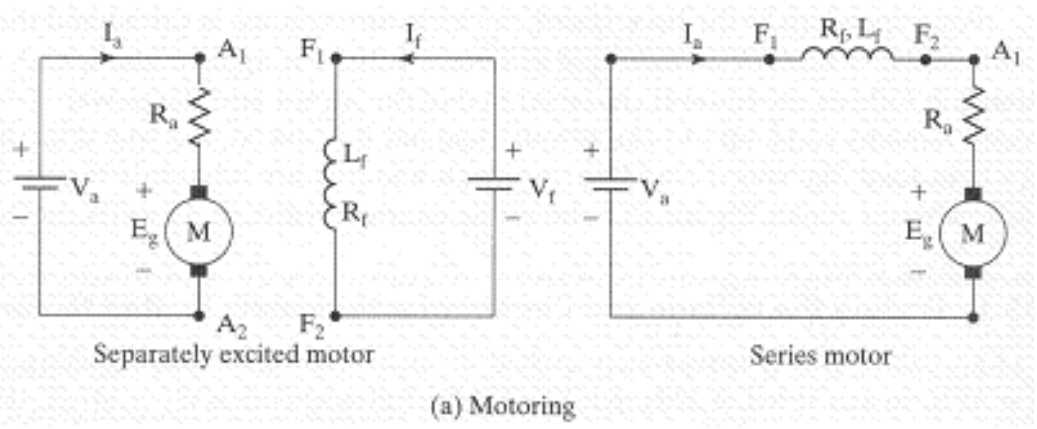
- For a speed up to the base speed, the armature voltage is varied and the torque is maintained constant.
- Once the rated armature voltage is applied, the speed-torque relationship follows the natural characteristic of the motor and the power (= torque X speed) remains constant.
- As the torque demand is reduced, the speed increases.
- At a very light load, the speed could be very high and it is not advisable to run a dc series motor without a load.



Operating Modes

- In variable-speed applications, a dc motor may be operating in one or more modes:
  - motoring,
  - regenerative braking,
  - dynamic braking,
  - plugging, and
  - four quadrants.

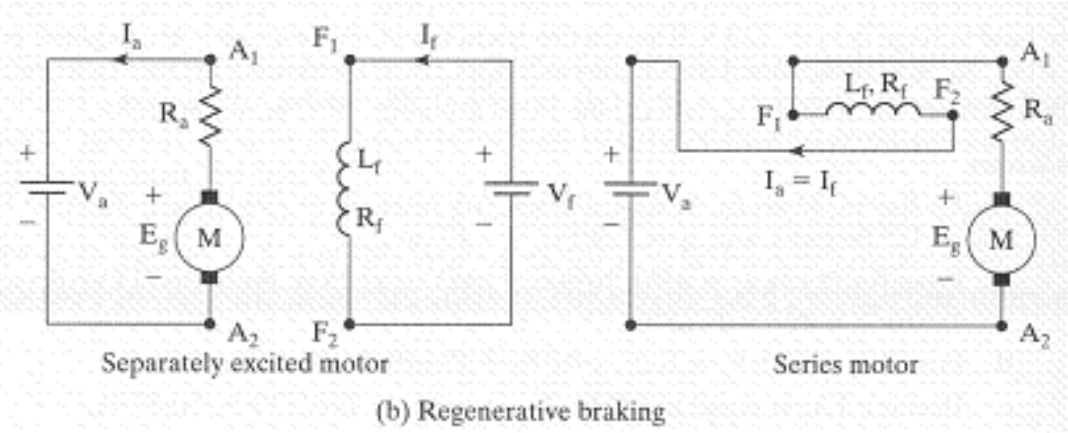
Motoring: The arrangements for motoring are shown in Figure 15.7a. Back emf Eg is less than supply voltage Vy. Both armature and field currents are positive. The motor develops torque to meet the load demand.



Operating Modes

Regenerative braking:

- The arrangements for regenerative braking are shown below Figure.
- The motor acts as a generator and develops an induced voltage E_g. E_g must be greater than supply voltage V_a.
- 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.

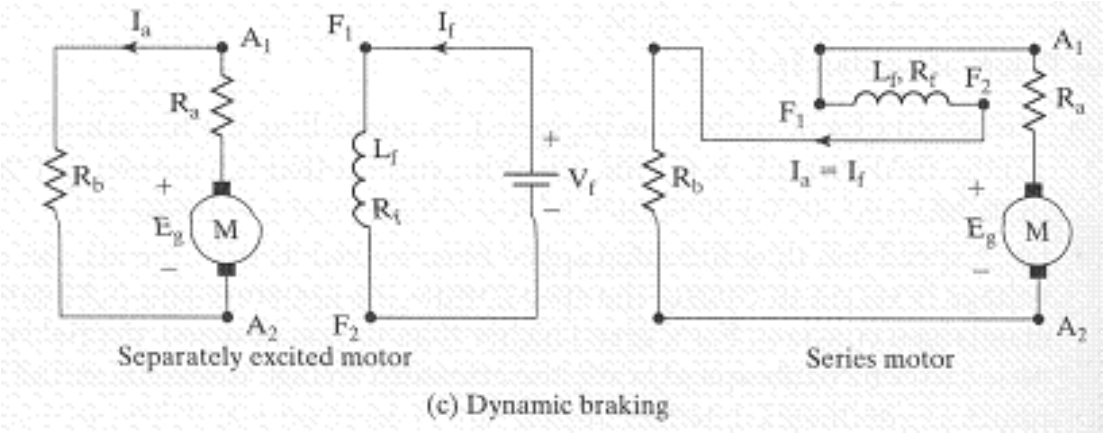


(b) Regenerative braking

Operating Modes

Dynamic braking:

- The arrangements shown in Figure are similar to those of regenerative braking, except the supply voltage V_a is replaced by a braking resistance R_b,.
- The kinetic energy of the motor is dissipated in R_b.

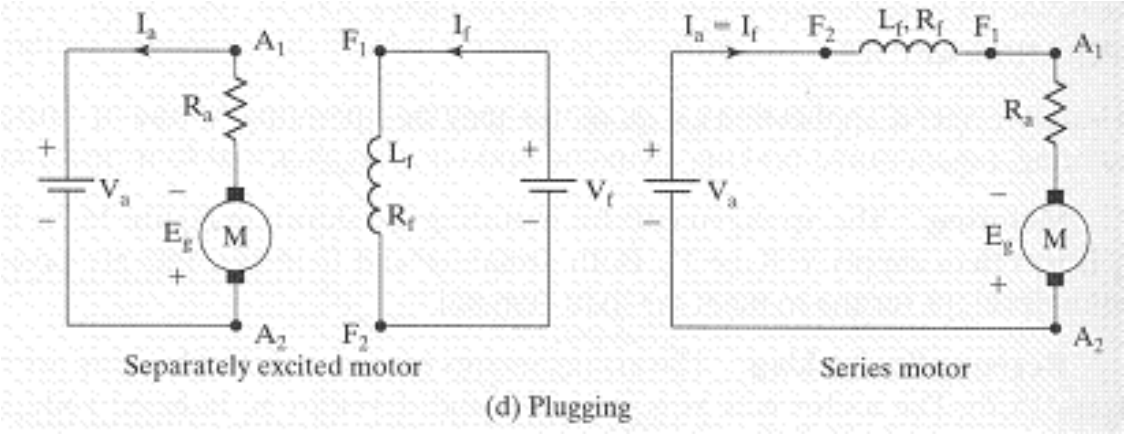


(c) Dynamic braking

Operating Modes

Plugging:

- Plugging is a type of braking. The connections for plugging are shown in Figure .
- The armature terminals are reversed while running. The supply voltage V_a and the induced voltage E_g 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.



(d) Plugging

Operating Modes

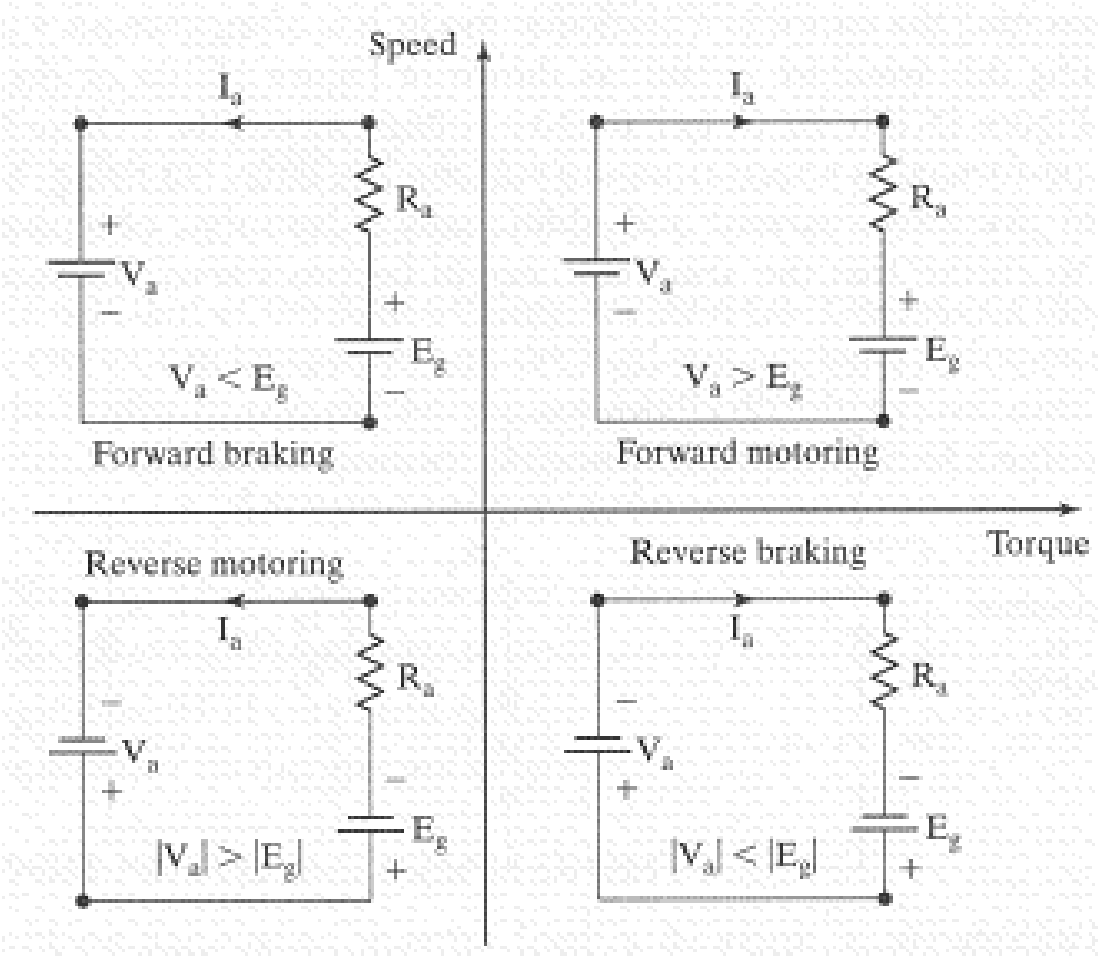
Four Quadrants:

- Figure shows the polarities of the supply voltage V_a, back emf E_g, and armature current I_a for a separately excited motor.
- In forward motoring (quadrant I), V_a, E_g, and I_a are all positive. The torque and speed are also positive in this quadrant.
- During forward braking (quadrant II), the motor runs in the forward direction and the induced emf E_g continues to be positive. For the torque to be negative and the direction of energy flow to reverse, the armature current must be negative. The supply voltage V_a should be kept less than E_g.
- In reverse motoring (quadrant III), V_a, E_g, and I_a are all negative. The torque and speed are also negative in this quadrant. To keep the torque negative and the energy flow from the source to the motor, the back emf E_g must satisfy the condition $|V_a| > |E_g|$. The polarity of E_g can be reversed by changing the direction of field current or by reversing the armature terminals.
- During reverse braking (quadrant IV), the motor runs in the reverse direction. V_a, and E_g continue to be negative. For the torque to be positive and the energy to flow from the motor to the source, the armature current must be positive. The induced emf Eg must satisfy the condition $|V_a| < |E_g|$.

Operating Modes

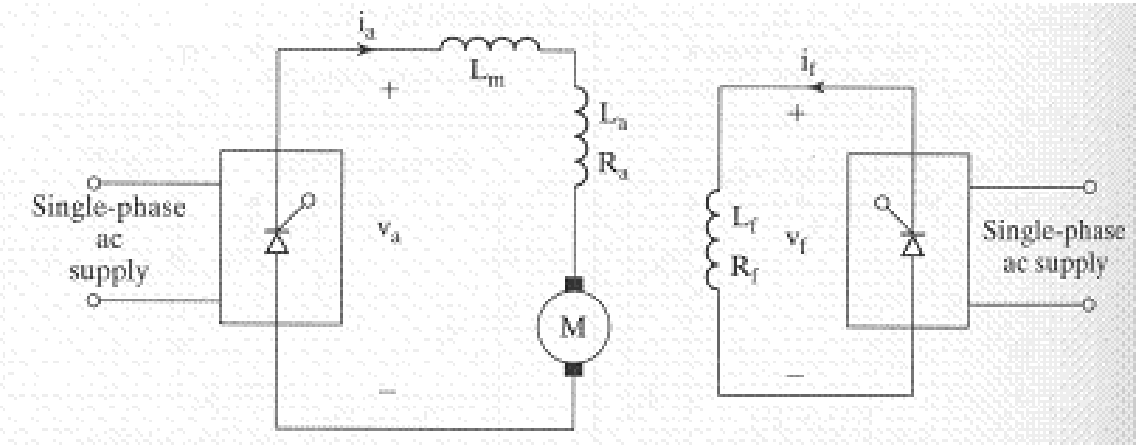
Four Quadrants:

- Blow Fig. shows the polarities of the supply voltage V_a, back emf E_g, and armature current I_a for a separately excited motor.



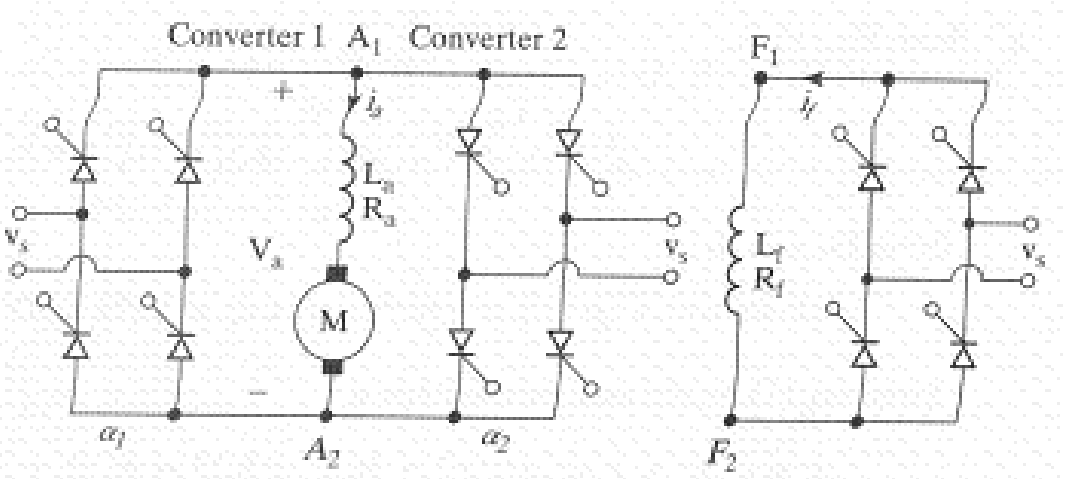
Single-Phase Drives

- If the armature circuit of a dc motor is connected to the output of a single-phase controlled rectifier, the armature voltage can be varied by varying the delay angle of the converter α_a.
- The basic circuit agreement for a single-phase converter-fed separately excited motor is shown in Figure.
- At a low delay angle, the armature current may be discontinuous, and this would increase the losses in the motor.
- A smoothing inductor, L_m, is normally connected in series with the armature circuit to reduce the ripple current to an acceptable magnitude.
- A converter is also applied in the field circuit to control the field current by varying the delay angle α_f.

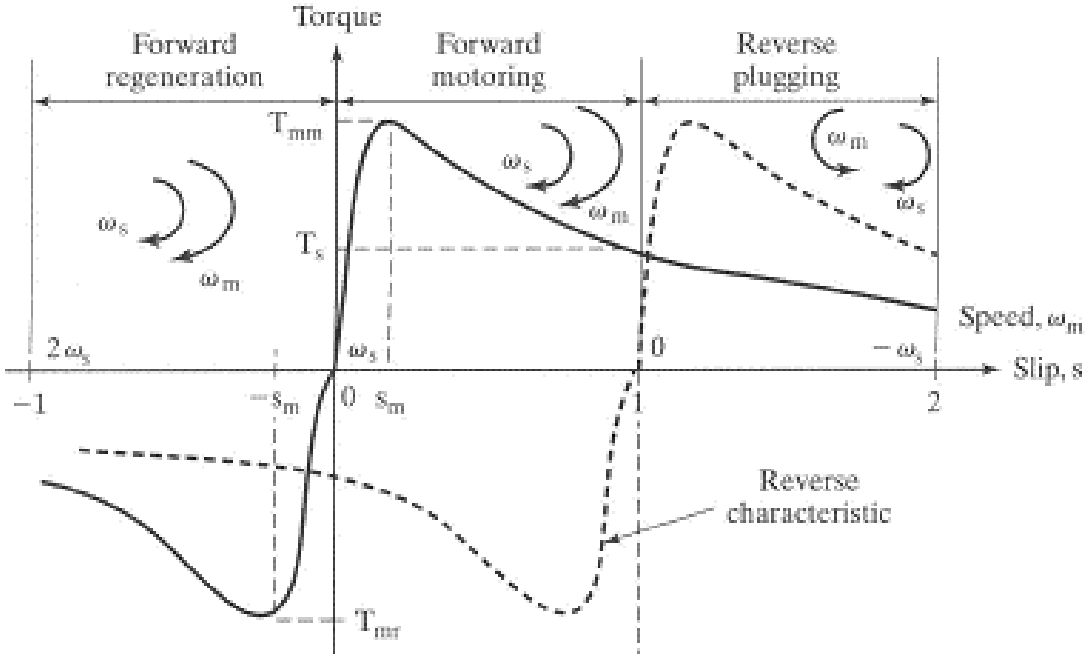


Single-Phase Dual-Converter Drives

- Two single-phase full-wave converters are connected.
- Either converter 1 operates to supply a positive armature voltage, V_a, or converter 2 operates to supply a negative armature voltage, $-V_a$.
- 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 full-wave or a dual converter.



Induction Motor Drives



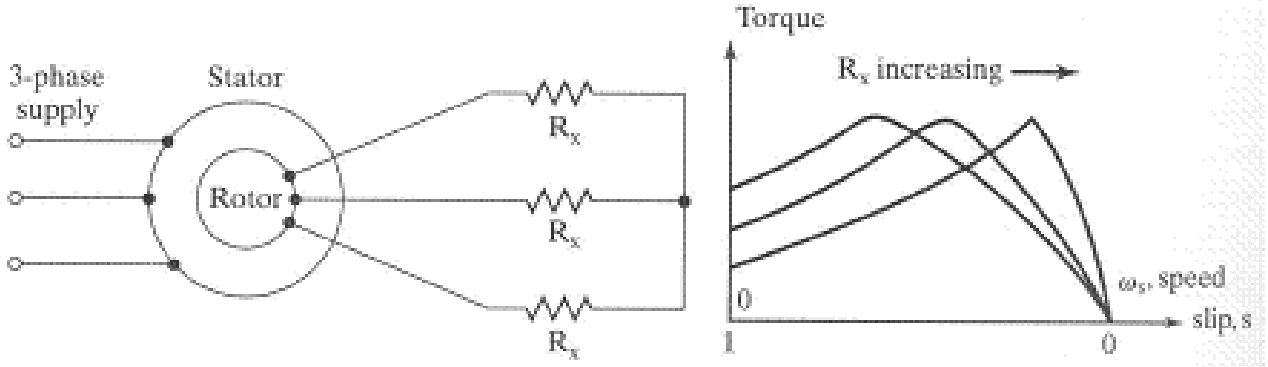
- The speed and torque of induction motors can be controlled by
  - Stator voltage control
  - Rotor voltage control
  - Frequency control
  - Stator voltage and frequency control
  - Stator current control
- To meet the torque-speed duty cycle of a drive, the voltage, current, and frequency control are normally used.

Induction Motor Drives: Stator Voltage Control

- The stator voltage can be varied by three-phase
  - ac voltage controllers,
  - voltage-fed variable de-link inverters, or
  - pulse-width modulation (PWM) inverters.
- However, due to limited speed range requirements, the ac voltage controllers are normally used to provide the voltage control.
- The ac voltage controllers are very simple.
- However, the harmonic contents are high and the input PF of the controllers is low.
- They are used mainly in low-power applications, such as fans, blowers, and centrifugal pumps, where the starting torque is low.
- They are also used for starting high-power induction motors to limit the in-rush current.

Induction Motor Drives: Rotor Voltage Control

- In a wound-rotor motor, an external three-phase resistor may be connected to its slip rings, as shown in fig.
- The developed torque may be varied by varying the resistance R_x. If R_x is referred to the stator winding and added to R_r, Eq. (16.18) may be applied to determine the developed torque.
- The typical torque-speed characteristics for variations in rotor resistance are shown in Figure 16.5b.



(a) Rotor resistance

(b) Increasing R_x

FIGURE 16.5

Speed control by motor resistance.

Induction Motor Drives: Rotor Voltage Control

- This method increases the starting torque while limiting the starting current.
- However, this is an inefficient method and there would be imbalances in voltages and currents if the resistances in the rotor circuit are not equal.
- A wound-rotor induction motor is designed to have a low-rotor resistance so that the running efficiency is high and the full-load slip is low.
- The increase in the rotor resistance does not affect the value of maximum torque but increases the slip at maximum torque.
- The wound-rotor motors are widely used in applications requiring frequent starting and braking with large motor torques (e.g., crane hoists).
- Because of the availability of rotor windings for changing the rotor resistance, the wound rotor offers greater flexibility for control.
- However, it increases the cost and needs maintenance due to slip rings and brushes.
- The wound-rotor motor is less widely used as compared with the squirrel-case motor.