Electric Drives

Electromechanical energy conversion:

Electrical Energy is obtained by the conversion of other forms of energy, based on the principle of conservation of energy. The main advantage of this conversion is that energy in electrical form can be transmitted, utilised and controlled more easily, reliably and efficiently than in any other form.

An electro-mechanical energy conversion device is one which converts electrical energy into mechanical energy (electric motors) or mechanical energy into electrical energy (electric generators). The electro-mechanical energy conversion process is a reversible process. However, devices are designed and constructed to suit one particular process rather than the other. In an energy conversion device, out of the total input energy, some energy is converted into the required form, some energy is stored and rest is dissipated.

For practical application we need to convert electrical energy into the required useful form, such as mechanical energy, heat, light, sound and electromagnetic waves. One of the major applications is electric drives which uses motors.

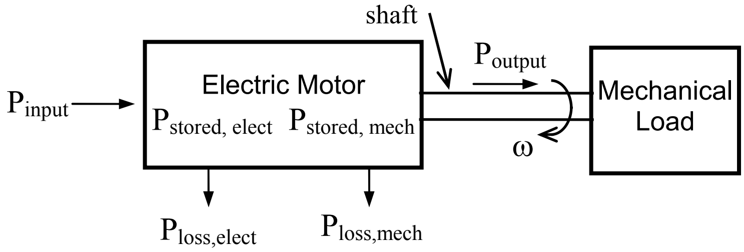


Figure 1 - Power flow in an electric motor

The energy balance for a motor (shown in block diagrammatic form in figure 1) can be written as

Total electrical energy input = mechanical energy output + total energy stored + total energy dissipated

In a motor, energy is stored in the magnetic field and mechanical system. The energy dissipated is in the electric circuit as ohmic losses, in the magnetic circuit as core losses (hysteresis and eddy-current losses), and in the mechanical system as friction and windage losses. [ω is the angular velocity of rotation].

An electric motor provides the driving torque necessary to keep machinery running at the required speed, with provision being made for speed control and reversal of rotation. The electrical motor is required to start, accelerate, drive and decelerate its load, within certain limitations.

There are three main types of motors - Direct Current Motor, Induction Motor and Synchronous Motor

Direct Current (dc) Motors

Direct current (dc) motors operate on a magnetic field produced by the field winding in the stator (stationary part of the motor) interacting with the field produced by the armature winding in the rotor (rotating part). The basic constructional features of a typical two-pole dc motor are shown in the figure 2 and the circuit model in figure 3.

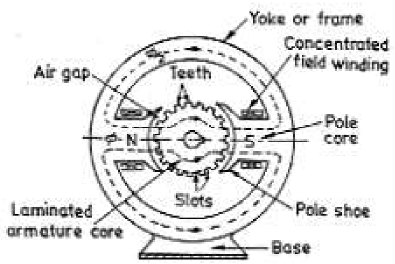
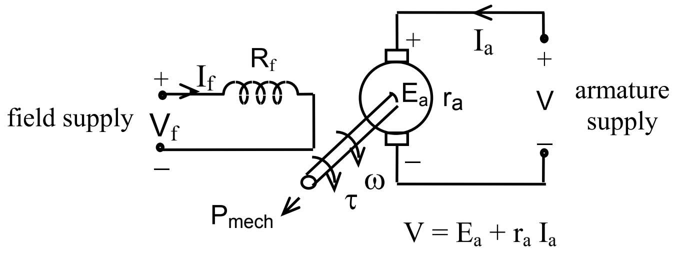


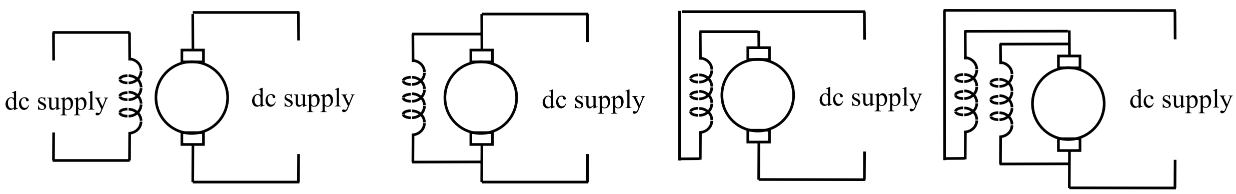
Figure 2 - two-pole dc motor



$V = E_a + r_a I_a$

Figure 3 - Circuit model of a dc motor

The dc motor needs slip rings or split rings (commutator) on the rotor shaft and a set of brushes positioned over them to supply the armature winding. [symbol for the armature basically shows the rotor and a pair of brushes]



(a) separately excited (b) shunt excited (c) series excited (d) compound excited

Figure 4 - categorisation of dc motors

The dc motors can be categorised into four basic types dependent on the method of connection of the field winding (figure 4). These are the (a) separately excited field, (b) shunt connected field, (c) series connected field, and (d) compound connected field.

In the separately excited type, the field winding is connected to a separate or external dc source. In the shunt excited type, the field winding is connected in parallel with the armature winding so that the same dc voltage source is used. In the series excited type, the field winding is connected in series with the armature winding, again making use of the same dc voltage source. Compound excitation involves both the series and shunt excited windings.

In the case of very small motors, the field may be created by a permanent magnet rather than having a field winding. These are known as permanent magnet dc motors.

Speed-torque characteristics of dc motors

The shunt, series and compound motors exhibit distinctive speed-torque characteristics, which are best suited for specific tasks. Thus a study of motor characteristics is essential for one to decide on a specific application using these motors. Figure 5 shows the speed-torque characteristics of dc motors. In addition, other characteristics such as torque-current should be considered when selecting motors.

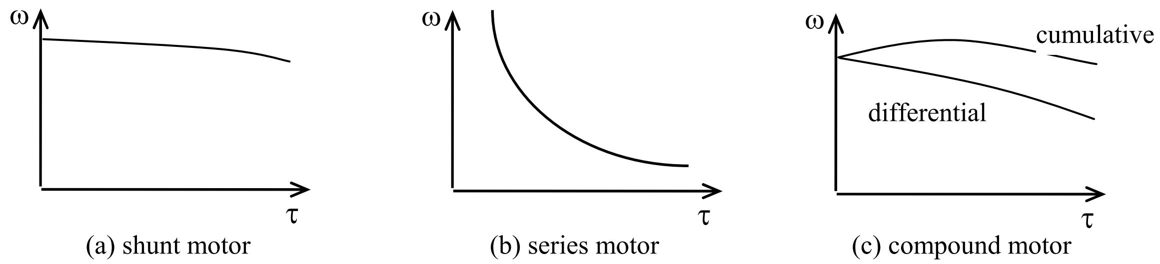


Figure 5 - Speed-torque characteristics of dc motors

DC motor applications

Although ac supplies are now universal, there are many applications, where the dc motor finds its place.

The dc shunt motor has a fairly constant speed against a varying load or torque. Thus, applications include situations where a constant speed is required such as in lathes, conveyors, fans and machine-tool drives. Since the dc series motor is able to create large torques at low speeds (high starting torque), it can be used to accelerate very heavy loads from standstill. Thus, dc series motors are used for driving cranes, electric locomotives, group drive shafts (where the motor is used as a drive for a whole assembly line), steel-rolling mills and so on. Compound motors combine the characteristics of both shunt and series wound motors. The series winding gives good starting torque and shunt winding ensures a comparatively constant speed. The actual characteristics of the compound motor can be varied by varying the ratio of shunt to series field turns. They are used in applications such as planers, shears, guillotines, printing machines and power presses that need peak loads at certain instances (normally used with fly wheels to even out the load). Separately excited motors are used in applications where an independent armature control and field control is required. Examples of their use are in steel and aluminium rolling mills (high power) and control motors (low power).

In addition, permanent magnet motors are used for low power applications. These are specially used in automobiles as starter motors, wiper motors, blowers in heaters and air-conditioners, in raising and lowering windows. They are also used in such other applications as toys, electric tooth-brushes.

Stepper Motors

In certain applications, it is necessary to spin quickly and move to a precise point, such as in computer disk drives. This can be accomplished by using a stepper motor. Stepper motors can be viewed as electric motors without commutators. Typically, all windings in the motor are part of the stator, and the rotor is either a permanent magnet or, in the case of variable reluctance motors, a toothed block of some magnetically soft material. The motors and controllers are designed so that the motor may be held in any fixed position as well as being rotated one way or the other. Most stepper motors can be stepped at audio frequencies, allowing them to spin quite quickly, and with an appropriate controller, they may be started and stopped precisely.

AC Motors

With almost the universal adoption of the ac system of distribution of electric energy for light and power, the field of application of ac motors has widened considerably. There are a number of different types of ac motors, each of which offers certain specific advantages.

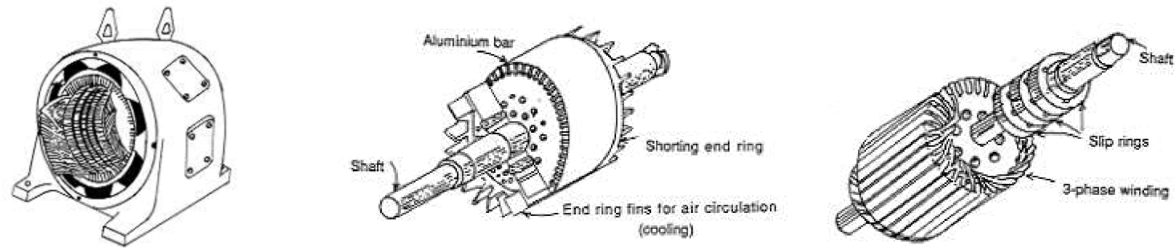
The supply for these motors is either three-phase or single-phase. Three phase motors are found in larger sizes and have mainly industrial applications. Single-phase motors are used mainly for domestic and agricultural applications. In the fractional kilowatt sizes, they are used in large numbers for washing machines, refrigerators and so on.

AC motors are classified to various groups based on their principle of operation; most common are the induction motor and synchronous motor.

Induction Motors

As the name implies, the induction motor is based on the induced voltage in a winding in the rotor. The rotor does not receive electric power by conduction but by induction in exactly the same way as the secondary of a transformer receives its power from the primary. Of all the ac motors, the three-phase induction motor is the one which is extensively used for various kinds of industrial drives.

An induction motor consists essentially of two main parts, namely (a) a stator and (b) a rotor (figure 6).



(a) stator (b) squirrel cage rotor (c) wound rotor

Figure 6 - rotor construction of induction motors

In the three phase induction motor the stator carries a 3-phase winding fed from a 3-phase supply. The stator windings, when supplied with 3-phase currents, produce a magnetic flux which is of constant magnitude but which revolves (or rotates) at a constant speed (at synchronous speed). On a 50 Hz supply, the synchronous speed for a 2-pole machine is 3000 rpm and for a 4-pole machine is 1500 rpm.

This revolving magnetic flux induces an emf in the rotor by mutual induction. This causes a current to flow through the rotor conductors and produce a torque with the interaction of stator magnetic field. This torque causes the rotor to start rotating to drive a load. The rotor-load combination settles at a lower speed than the synchronous speed (typically around 2850 – 2975 rpm for a 3000 rpm synchronous speed) as power can be transferred only when there is a relative speed. The difference between synchronous speed and rotor speed is termed as the “slip”. Slip is usually defined as a ratio or percentage of the speed to the synchronous speed. Typically, slip is about 1-5 %.

$$slip = \frac{synchronous\ speed - rotor\ speed}{synchronous\ speed}, \quad s = \frac{N_s - N}{N_s}.$$

The rotor of an induction motor can be of two types, namely (a) squirrel cage and (b) wound rotor as seen in figure 6(b) and 6(c).

(a) *Squirrel cage rotor*

About 90% of induction motors are squirrel cage type, because this type of rotor has the simplest and most rugged construction and is almost indestructible. The rotor consists of a cylindrical core with parallel slots for carrying the rotor conductors which are not wires but heavy bars of copper, aluminium or alloys. The rotor bars are permanently short-circuited at the ends to form the winding.

Because of the absence of moving parts in the circuitry, the motor is useful for duties in hazardous areas. It finds applications for most industrial drives, where speed control is not required. These are specially used with loads requiring low starting torque and substantially constant speeds. It can be shown that by increasing the effective rotor resistance, the torque-speed characteristic can be modified such that the starting torque is increased. However the operating slip also increases. With low rotor resistance, these are used in fans, centrifugal pumps, most machine tools and wood working tools. With high rotor resistance, they are used in compressors, crushes, reciprocating pumps etc. With very high rotor resistance, are used in punching presses, shears, hoists and elevators.

(b) *Wound rotor*

Unlike the cage rotor type, the wound rotor type is provided with a three-phase winding in the rotor. Usually, the three phases are connected internally as a star. The other three winding terminals are brought out and connected to three insulated slip-rings mounted on the shaft with brushes resting on them. This makes possible the introduction of additional resistance in the rotor circuit during the starting period for increasing the starting torque of the motor and for changing its speed-torque/current characteristics. When running under normal conditions, the slip-rings are automatically short-circuited and the brushes lifted from the slip-rings. Hence, it is seen that under normal running conditions, the wound rotor is short-circuited on itself just like the squirrel cage rotor. Applications of the wound rotor type include high-inertia drives requiring variable speed, fly wheel machine drives, air-compressors, ram pumps, crushing mills, cranes, hoists, winches and lifts.

Typical Torque-speed characteristics of an induction motor are shown in figure 7. The effect of increasing the rotor resistance on the characteristic is also shown.

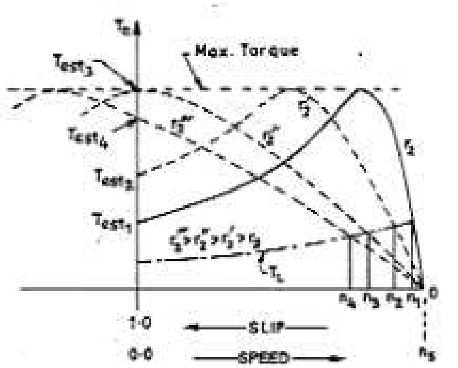


Figure 7 - Torque-speed characteristics of an induction motor

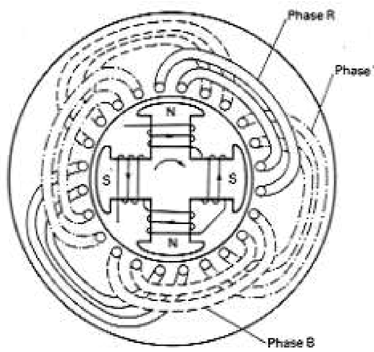


Figure 8 - Synchronous Motor

Synchronous Motors

Synchronous motors operate on the same fundamental principles of electromagnetic induction as dc motors. They usually consists of a 3-phase stator winding and a rotor winding which carries a dc current (figure 8). When the 3-phase stator winding is fed by a 3-phase supply, a magnetic flux of constant magnitude but rotating at synchronous speed, is produced (as in 3-phase induction motors). This field interacts with the field produced by the dc field winding on the rotor and produces a torque which can be used to rotate a load. It runs at a constant speed (synchronous speed). However, the synchronous motor is not self-starting and hence needs additional means for starting.

Although the induction motor is cheaper for small power applications, the synchronous motor is preferred for applications above 50 kW. Typical applications include Banbury mixers (used to mix raw ingredients for rubber production), cement grinding mills, centrifugal compressors, mine ventilating fans, pumps, reciprocating compressor drives, electric ship propulsion drives, large low head pumps, rolling mills, ball mills, pulp grinders, etc. They are also used for power factor correction and voltage regulation.

Single-Phase Motors

Single phase motors are designed to operate from a single-phase supply and are manufactured in a large number of types to perform a wide variety of useful services in homes, offices, factories, workshops, vehicles, air crafts, power tools, etc.

Single-phase motors are usually classified based on their operating principle and method of starting, such as

(1) Induction motors (split-phase, capacitor, shaded-pole etc.)

(2) Repulsion motors (some times called inductive series motors)

(3) AC series motors

(4) Synchronous motors.

The single-phase induction motor is similar to a three-phase induction motor except that its stator is provided with a single phase winding and a special mechanism employed for starting purposes (It does not develop a rotating field but a pulsating field). It has a distributed stator winding and a squirrel cage rotor. Special mechanisms are employed for starting and there are different motor types based on starting method such as split-phase (fans, blowers, centrifugal pumps, washing machines, small machine tools, duplicating machines, domestic refrigerators), capacitor start (small power drives) and shaded-pole (small fans, toys, instruments, hair dryers, ventilators, circulators, electric clocks). Repulsion type motor applications include machine tools, commercial refrigerators, compressors, pumps, hoists, floor-polishing and grinding devices, garage air-pumps, petrol pumps, mixing machines, lifts and hoists. The ac series motor is a modified ordinary dc series motor that can be connected to an ac supply. A similar one is the universal motor, which is a small version of ac series motor. This can work with both ac and dc and used in applications such as vacuum cleaners, food mixers, portable drills and domestic sewing machines. Single-phase synchronous motors are typically used in signaling devices, recording instruments and in many kinds of timers and house hold electric clocks.