7 Special-purpose motors and induction generators

Contents

Loads and installations that cannot use a standard motor due to their constructional needs, operational demands, special functions, unfavourable location of installation, hazardous items of process, etc. require a special motor, either in mechanical construction or in performance characteristics or both. During performance, such loads may require a prolonged starting time, a high starting torque, smoother acceleration, frequent cold or hot starts, stops and reversals etc. For all such applications, meticulous selection of the motor is essential, which should meet all the load requirements without excessive cost and yet achieve a higher efficiency and conserve energy in addition to fulfilling environmental needs. Special features of a few such applications are discussed below.

7.1 Textile motors

7.1.1 Loom motors (IS 2972 Part I)

Electrical features

Looms for weaving require high torque. Motors for such applications in a 6-pole design must possess a minimum starting torque, T_{st}, of 230% and a pull-out torque, T_{po}, of 270% of the rated torque T_r. For an 8-pole design these values must be T_{st} – 200% and T_{po} – 230% of T_r. The recommended poles for such motors are 6 and 8. For light fabrics such as cotton, silk, rayon and nylon etc., the kW requirement of looms may vary from 0.37 to 1.5, while for heavy fabrics (canvas, woollens, jute etc.) from 2.2 to 3.7 kW. The looms may be driven directly, requiring a high torque as above, or through a clutch, which may engage after the motor has run to speed, when a normal torque motor may also be suitable. Unless, the motor is coupled through a clutch it should be suitable for frequent starts and stops.

Constructional features

A textile mill is normally humidified up to a predetermined level with a view to smooth the process and diminish breakage of threads. Fluff and cotton dust is wet and adheres to the motor's surface. It may accumulate on the fan and inside the cooling ribs (fins) and obstruct natural cooling. These motors are therefore un-ventilated and surface cooled (without cooling ribs) or have radial cooling ribs (Figures 7.1(a) and (b)). For easy mounting on the loom frame and also to make them adjustable, they are made either flat based (Figures 7.1(a) and (b)) or cradle mounted (Figures 7.2(a) and (b)).

7.1.2 Card motors (IS 2972 Part II)

These are similar to loom motors but must possess a still higher torque, i.e. a starting torque of the order of 350% and 275% of T_r and a pull-out torque 375% and 300% of T_r for a 6-pole and an 8-pole motor respectively. The card drum is a heavy rotating mass and has a high moment of inertia. The motor, therefore, undergoes a prolonged starting time and must be capable of withstanding 2.5 times the rated current for a minimum of two minutes.

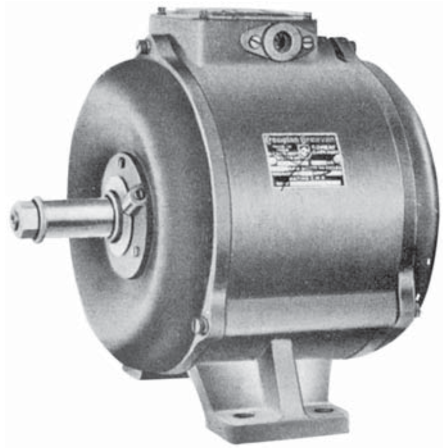


Figure 7.1(a) Surface cooled loom motor, without fins

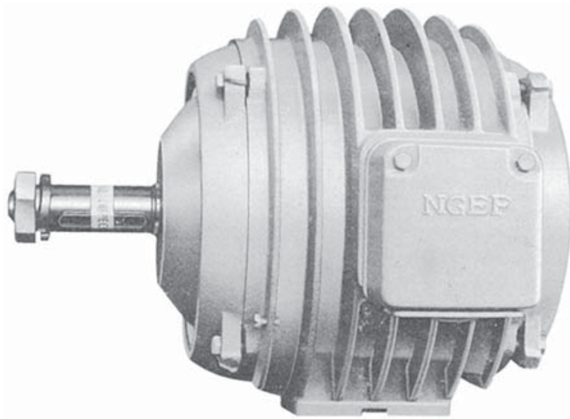


Figure 7.1(b) Loom motor with circular ribs (flat base mounted)

But unlike a loom motor, which requires too many starts and stops, the operation of carding is continuous. Such motors are also required to have circular fins and a flat base or lug mounting as for loom motors.

7.1.3 Ring frame or spinning frame motors (IS 2972 Part III)

These are required to make threads, i.e. the final drawing, twisting and winding of cotton. Such motors must possess very smooth acceleration to eliminate breakage of threads. They are recommended to have a starting torque of 150–200% of T_r and a pull-out torque of 200–275% of T_r with a mean acceleration torque of 150–175%. A normal acceleration time of 5–10 seconds is recommended. Faster acceleration may cause more breakages, while a slower acceleration may result in snarls and knots in the yarn as a result of insufficient tension.

Since card and ring frame motors are normally mounted inside the machine frame, there is an obvious obstruction in the cooling. With this in mind and to meet the torque requirements, the common practice is to choose the next

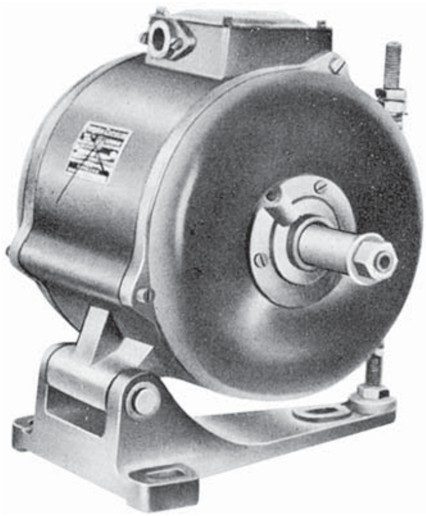


Figure 7.2(a) Surface-cooled loom motor without fins (cradle mounted)

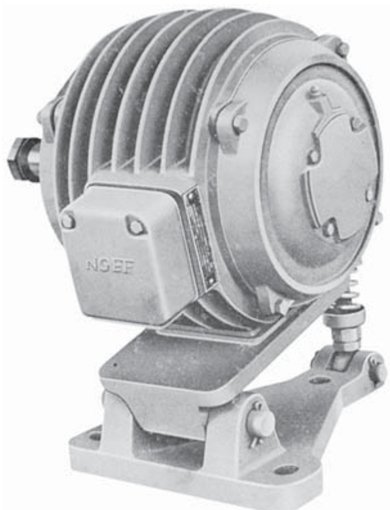


Figure 7.2(b) Loom motor with circular ribs (cradle mounted)

higher frames for such motors, compared to a standard motor. The latest practice is to employ a variable-speed drive. As for 'Cop Bottom Build' and 'Nose formation', the frame must operate at a slower speed to minimize the end breakage, while for the remaining yarn it may operate at the higher speed.

7.2 Crane motors

Crane and hoist motors

Such duties require a high starting torque, of the order of 225–275% of T_r and a low starting current, up to a maximum of five times the rated at the rated voltage as well as frequent starts, stops and reversals. They are normally short-time rated. To make these motors suitable for frequent starts and stops, the rotor is designed so that acceleration is quick and the heat generated during a start is low. This now limits the temperature rise of the rotor even after frequent starts, without sacrificing the frame size. It is possible to achieve this by keeping the GD^2 of the rotor low. In such motors also, fan cooling may be obstructed when a brake is mounted on the extended shaft at the non-driving end (NDE). For such installations also, sometimes a surface-cooled motor may be preferred. Alternatively, to increase the cooling surface, the housing may be designed with circular ribs, as shown in Figure 7.1(b) and 7.2(b).

Lift motors

Generally same as the crane motors, but comparatively silent in running and have a very low vibration level.

For general requirements of other types of lifting and hoisting applications see Table 7.1.

7.3 Determining the size of motor

For lifting/hoisting

The mechanical output of the motor for cranes and hoists in lifting the hook load is the useful work done by it. The losses produced in the crane or hoist mechanism are taken into account by the mechanical efficiency of the hoisting mechanism.

The output P_h of such motors is expressed by

$$P_h = \frac{F \cdot V}{102 \cdot \eta} \text{ kW} \tag{7.1}$$

where

F = useful load in kgf

V = lifting speed in m/s

η = efficiency of the mechanism

This output corresponds to a continuous duty of drive. It must be suitably corrected for the duty cycle the motor has to perform (see Equation (3.11)), i.e.

$$P_{heq} = \sqrt{\frac{\rho_1^2 \,.\, t_1 + \rho_2^2 \,.\, t_2 + \rho_3^2 \,.\, t_3 + \ldots}{t_1 + t_2 + t_3 + \ldots}}$$

For traverse

$$Pt = \frac{1.027 \cdot T_{max} \cdot N_r}{1000 \cdot \eta} \cdot \text{kW} \tag{7.2}$$

where

T_{max} = maximum torque, consisting of torque, resulting from weight load, friction and acceleration in kgf.m

η = efficiency of the whole mechanism for traversing.

Correct this output also depending upon the duty cycle as noted in Equation (3.12), i.e.

Table 7.1 Electrical requirements for lift and crane motors

Type of duty	*Starting torque* (T_{st})	*Pull-out torque* (T_{po})	*Over-speeding*	*If frequent acceleration, braking and reversals are required*
1 Portal and semi-portal wharf cranes	Standard as in manufacturer's design	≥ 2.25 of T_r	Up to 2.5 Nr or 2000 r.p.m. whichever is less	Yes
2 Overhead travelling cranes	> 2.25 of T_r	Up to 2.75 of T_r	As above	Yes
3 Lifts	(a) For squirrel cage motors ≥ 2.25 ≤ 2.75 of T_r (at any speed)	–	As above	–
	(b) For slip-ring motors, ≥ 2.25 of T_r (with suitable resistances)	–	As above	–
4 Power-driven winches for lifting and hauling	≥ 2.0 of T_r	≥ 2.25 of T_r for squirrel cage and ≥ 2.75 of T_r for slip-ring motors	As above	Yes

$$T_{eq}\,(\text{r.m.s.}) = \sqrt{\frac{T_1^2 \cdot t_1 + T_2^2 \cdot t_2 + T_3^2 \cdot t_3 + \ldots}{t_1 + t_2 + t_3 + \ldots}}$$

Duty cycle

Duty types S_3, S_4 and S_5 as discussed in Chapter 3 are normally applicable to crane and hoist motors. For duty types S_4 and S_5, the duty cycle per unit time is greater than S_3. The most important factor is the number of switching operations per hour. A temperature rise in the motor occurs during acceleration, braking and reversing.

Many crane manufacturers specify that the motor should be suitable for half an hour or one hour duration according to the British practice still followed in some countries. In fact, it is not possible to correlate precisely these ratings with any of the duty factors. Hence the motors are designed for any of the duty factors of 15%, 25%, 40% and 60%. In fact the duty factors for different types of cranes have been standardized, depending upon their operation, after several years of experience. For example, the cranes operated in steel industries have different types of duty factors as follows:

Hoisting	60%
Traversing	40%
Travelling	60%
Slewing	40%

For steel mill auxiliary drives or for material handling equipment, the duty factor normally chosen for slip-ring motors is either 40% or 60%.

Standardization

The fixing dimensions of the motors are standardized at national and international levels. However, the output–frame relationship is not yet established for duty type rated motors. The Indian Electrical and Electronics Manufacturers Association (IEEMA) has issued a standard on crane duty motors in which an attempt is made to list the outputs against the IEC frames for S_3–6, S_4–150 and S_5–300 starts/hour duty types.

Static drives

With the availability of *V/f* drives and other advanced technologies through static controls, as discussed in Sections 6.2 to 6.4, the use of standard squirrel cage motors for such applications is a preferred choice.

7.4 Sugar centrifuge motors

In sugar mills a rapid separation of sugar crystals from molasses is achieved through the use of massecuite* and centrifugal force. The motor drives a basket full of molasses which undergoes repeated cycles of operation, i.e.

- Charging of massecuite: at a low speed, to prevent spillage, normally by a 24–28 pole motor.
- Intermediate spinning: at half the maximum speed of spinning, i.e. at 8 or 12 pole.
- Spinning: at a very high speed compared to the above, generally at 4 or 6 pole.
- Regenerative braking: When the process is complete and the residue molasses are purged, an over-synchronous braking is applied by changing the motor from spinning (4 or 6 poles) to ploughing (48 or 56 poles). This brake energy is then fed back to the mains (see Section 2.9.1(B)).
- Ploughing of sugar crystals: at very low speeds of 50 r.p.m. or so. This is achieved by a 48- or a 56-pole motor. A further reduction in speed is obtained by conventional electrodynamic or d.c. electric braking.

*Massecuite is used to form and then remove sugar crystals from molasses by a centrifugal technique.

The centrifugal basket is a dead weight to be accelerated to the maximum spinning speed. The motor operates for short durations at different speeds and varying loads. It is required to accelerate heavy inertia loads at each speed, and is normally designed for multi-speeds such as, 4/8/24/48 poles, 6/12/28/56 poles or 6/12/24/48 poles etc., depending upon the type of centrifuge. The rotor is given special consideration at the design stage to take account of the excessive heating due to rapid speed changes, braking and acceleration of heavy masses of massecuite and basket etc. (e.g. by better bracing, high-resistance rotor bar material, better heat dissipation etc.). During one complete cycle of massecuite there is a wide fluctuation in load and the motor speed and the motor operates at different h.p. A normal over-current release (OCR) therefore cannot protect the motor. Use of RTDs and thermistors as discussed in Section 12.7, can provide total protection against such variable load drives.

The method discussed above is a conventional one to achieve required speed variations. With the application of newer technologies, speed variations may be achieved more accurately and promptly with a single-speed standard motor, by the use of the following:

1 **Variable drive fluid couplings** (see Section 8.4.1(2)) These may not prove to be as effective as the static drives from the point of view of energy conservation, as the motor will always be running at its rated speed and engagement of the coupling alone will vary the output speed.
2 **Static drives using solid-state technology** (see Section 6.2) This is the best method for achieving the required speed variations, not from the point of view of quicker and smoother speed variations, but of total energy conservation even at low outputs.

Note

Use of energy efficient (EE) motors and application of solid state technology

For all the applications discussed above, which may require special starting and/or pull-out torques, starting current or speed variations, starts, stops or reversals, the use of static drives is more appropriate today. With the use of solid state technology, soft starters and variable speed drives, a standard motor can be made to perform any required duty, except the constructional features and the applicable deratings as discussed in Chapter 1. See also Example 7.1.

The use of special motors was more relevant until the 1980s, when solid-state technology was still in its infancy and was not so widely applied. With the advent of static drives, as discussed in Sections 6.2–6.4, the use of standard motors is gradually becoming more common for all these applications. The drive itself can alter the supply parameters to the required level to make a standard motor operate and perform within desired parameters, besides conserving energy. The purpose of describing a few of these applications is only to indicate their non-standard features, where a standard motor with normal controls may not be able to perform the required duties.

For new installations, modernizations and retrofitting of the old ones, it is advisable to employ only energy efficient (EE) motors and static drives as a measure to conserve scarce energy (Section 1.19).

7.5 Motors for deep-well pumps

These pumps are used to lift deep groundwater or any other liquid from hard or rocky soil. Moreover, the liquid level may be so deep that it may prevent the use of a centrifugal pump. Theoretically, the maximum depth from which water can be lifted against atmospheric pressure is 9.8 m (32 feet). To lift water or any other liquid from greater depths than this, one has no option but to lower the pump into the well, in other words, to lower the entire pump house below ground level, which is neither economical or practical nor advisable. Moreover, as the groundwater table may be receding one cannot be certain of an ideal depth for such pump houses. A depth considered ideal today may not be so a few years hence as the water table may recede further. Better alternatives are found in a deep well turbine and a submersible pump, described briefly below.

7.5.1 Deep-well turbine or a vertical wet pit pump

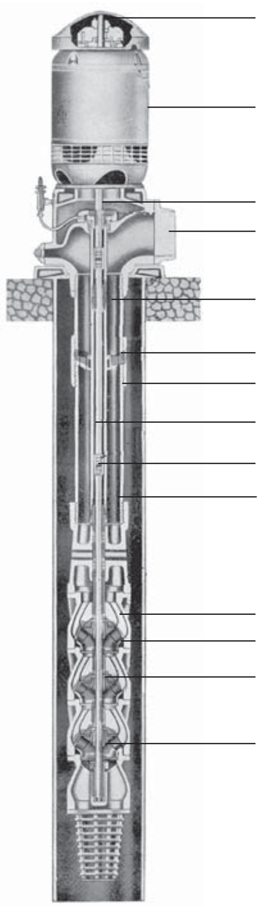
Use of vertical hollow shaft motors

With the use of such pump sets, the pump alone is lowered into the pit and the prime mover is mounted above ground level. These pumps can lift water or any other liquid from a depth of more than 10 m. They are used extensively for irrigation, domestic use, sewage disposal, etc., and are easy to instal and maintain. They have an extra-long drive shaft and an extra number of bearing assemblies to hold the long drive shaft in position and to eliminate the risk of excessive shaft vibration and hunting around its own axis. They are built to maintain permanent shaft alignment, have high thrust capacity and are compact in size.

The shaft of the pump goes through the motor shaft to the top of the motor and is bolted there. The pump shaft can be adjusted at the top to set the impeller by tightening or loosening the nut holding it. This also eliminates the use of a flexible coupling between the motor and the pump. These motors are always constructed in a vertical flange design and are provided with heavy thrust bearings to take the additional load of the pump impeller, its shaft and the fluid in the shaft. These motors are produced in squirrel cage design for simplicity and also because they have to drive only a light-duty load and operate at a fixed speed. They are also provided with an anti-reverse ratchet arrangement to prevent the rotor from rotating in the reverse direction caused by back-flow of liquid in the event of an abrupt shutdown and during an accidental phase reversal. A reverse rotation may cause the pump shaft to unscrew. Since the motor is vertical flange mounted and the pump shaft passes through the motor's hollow shaft, it is called a vertical hollow shaft motor (see Figures 7.3 and 7.4).

7.5.2 Submersible pumps using submersible motors

A more economical alternative is found in a submersible pump where the pump, directly coupled with the prime mover, is slid into the tubewell through narrow pipes. Narrow pipes are easy to sink into rocky terrain or very deep water levels. They are less expensive and are easy to instal due to the elimination of the need for a pump house. Once the unit is slid into the well it requires little



Deepwell turbine pump fitted with a hollow shaft motor

Figure 7.3(a)

maintenance. (See Figures 7.5–7.7.) Such pumps have a standard centrifugal multistage arrangement, and the motors are required to work under water or any other liquid. These motors have an exclusive application for submersible pumps.

The application and use of deep-well turbine and submersible pumps, is extensive and a choice will depend upon the depth of liquid and the rate of discharge. In rocky areas, where the digging of larger well cavity is a difficult task, submersible pumps provide an easy alternative. Similarly, for higher heads and where only a small quantity of liquid is to be pumped, these pumps are preferred. We discuss below the characteristics of these motors and the application of these pumps.

Construction

The pump is placed above the motor and the water inlet is provided between the pump and the motor (Figures 7.5–7.7). The discharge cover or case contains the top journal bearing and small thrust pad to cope with the upward axial thrust during start-up. The pump shaft is supported in the journal bearings. The weight of the pump shaft and the hydraulic axial thrust is borne by the motor shaft and thrust bearing through a rigid mesh coupling.

Non-return valve arrangement

This is provided to prevent reverse rotation of the pump in the event of a power failure or a deliberate shutdown due to back-flow of liquid from the rising mains (pipelines). This is located immediately after the last pump stage casing/discharge outlet to prevent the shaft from rotating in the reverse direction. The provision of a non-return valve also ensures that the pump always starts in a shut-off condition, when the power requirement is at a minimum.

Special features of a submersible motor

These motors are comparatively long and slender requiring a smaller bore diameter to slide easily into the bore hole/ bore well with the pump.

Stator winding and insulation

The conductors are waterproof PVC (polyvinyl chloride)-insulated winding wires. These are sprayed with polyamide and conform to IEC 60851 and IEC 60317. For stator windings, both open and closed type (tunnel type) laminations with a PVC lining are used. Closed type laminates provide a smooth bore and reduce frictional losses. The windings are in the shape of ready-made coils or pull-through wires. For LV submersible motors, the winding cable must be suitable for 1000 V, whereas the windings are wound for 415 V ±6% or any other designed voltage.

Note

For new voltage systems as per IEC 60038 see Introduction.

Rotor

The rotor is squirrel cage with short-circuited copper rings at the ends. Here also, to vary the starting characteristics of the motor, the skin effect is used by providing deep bars, flat bars, tapered bars or other types of slots (discussed in Section 2.3).

Torque

The minimum value of pull-out torque (T_{po}) at the rated voltage should be 150% of the rated torque according to IS 9283.

Characteristics

The normal characteristics of these motors are generally the same as those of a standard squirrel cage motor.

Efficiency

These motors have a lower efficiency as a result of running in liquid, causing more liquid drag and also axial thrust bearing loss, which is also a part of the motor. However, this lower efficiency of the motor is compensated by fewer mechanical and hydraulic losses in a submersible

Vertical hollow shaft squirrel cage motor

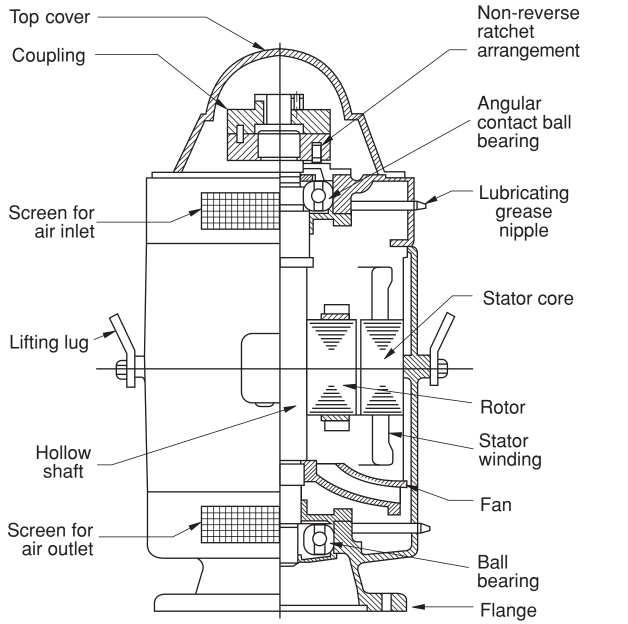
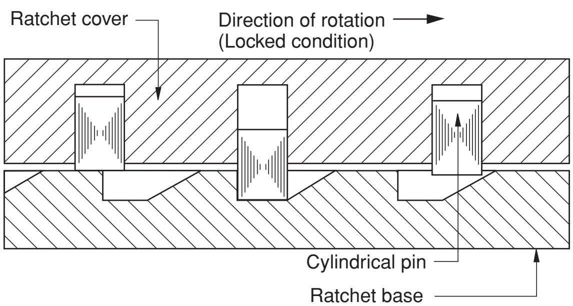
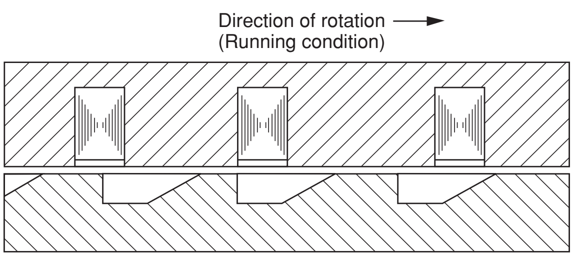


Figure 7.3(b) Vertical hollow shaft squirrel cage motor and its inside view



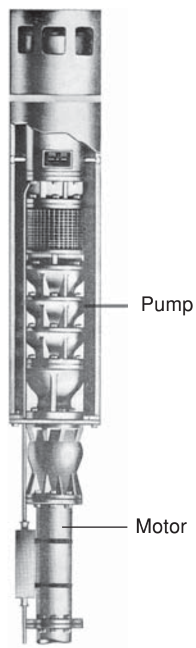
(1) When the motor is switched off, the pins drop down due to gravity and lock the rotor for any movement in opposite direction



(2) When the motor is started, the pins are lifted up by the ratchet base and are held in the ratchet cover due to centrifugal force thus releasing the ratchet for rotation

Figure 7.4 Ratchet arrangement

A small rating submersible motor and pump in disassembled condition



Submersible pump fitted with a submersible motor

Figure 7.5(a)

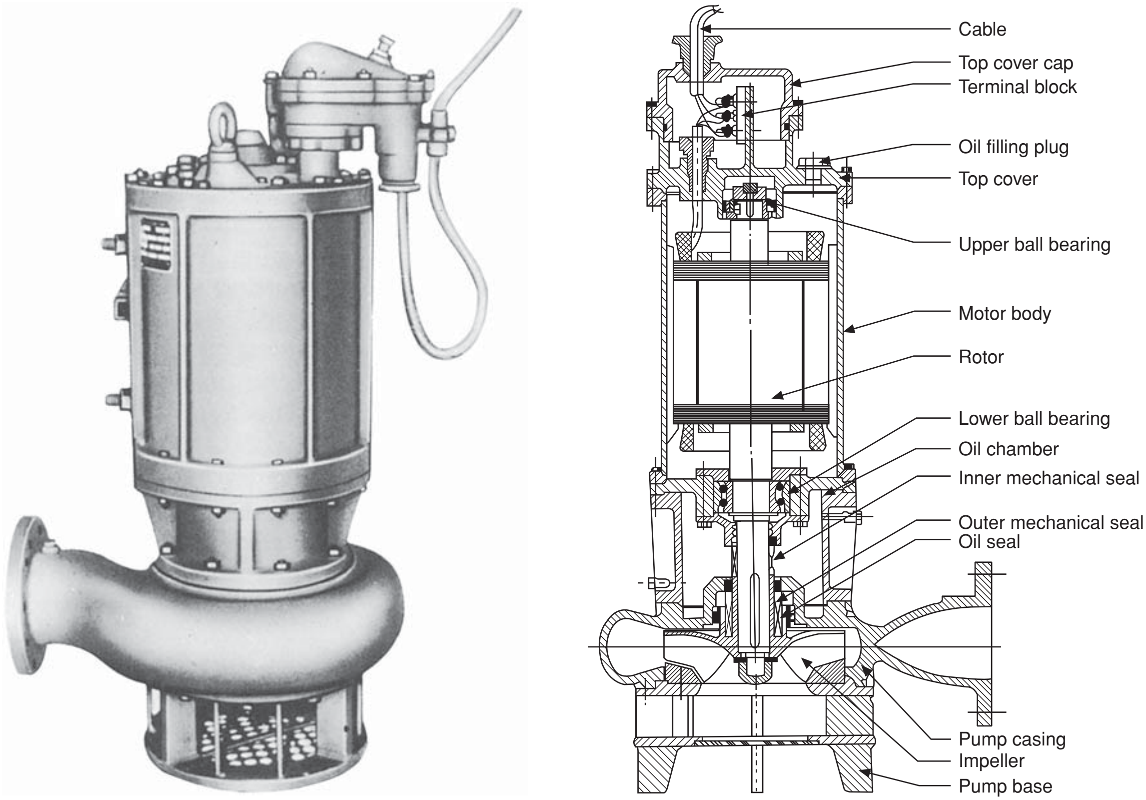


Figure 7.5(b) Sewage submersible pump and its cross-sectional view (Courtesy: SU Pumps)

motor-pump installation, compared to a vertical turbine pump installation.

Performance

The effect of frequency, voltage variation and ambient temperature etc. on the performance of such motors is as for standard motors, discussed in Chapter 1. The general routine tests and methods of conducting them are also similar to those for standard motors discussed in Chapter 11.

Protection

The protection for such motors is also as for standard squirrel cage motors. See Chapter 12.

Rewinding of stator

The maintenance of such motors at site is easy, because the stator can be wound with readymade PVC insulated winding coils, and does not need a varnish impregnation and subsequent baking etc., unlike a standard motor. It is thus easy to rewind them at site.

Bearings

The bearings are water lubricated. The typical materials of construction are carbon, copper alloys, bakelite and ceramics. The mechanical seals, like a double oil seal protected with a cap called a Sand Guard, are robust and perfect in sealing the motor to prevent the entry of pumped liquid into the bearing housing and vice versa to prevent any possible contamination.

Cooling

The motor stator windings and bearings are cooled through the pumped liquid passing externally around the motor body through heat conduction. The interior of the motor body (housing) is normally filled with a fluid to facilitate rapid dissipation of heat. The general practices are:

1 Water-filled motors: These are initially filled with clean water. Distilled water was originally used as an initial filler, but with the passage of time, clean water was found to be a better substitute and now only clean water is used as an initial filler.
2 Oil-filled motors: Instead of water oil is now used with oil and mechanical seals at the bearings to prevent leakage of oil through them.
3 Air-filled: The latest practice is to keep the housing empty. This arrangement is found to be economical and the motor operates at higher efficiency.

Motor shaft

The motor with a short shaft length has a shaft of stainless

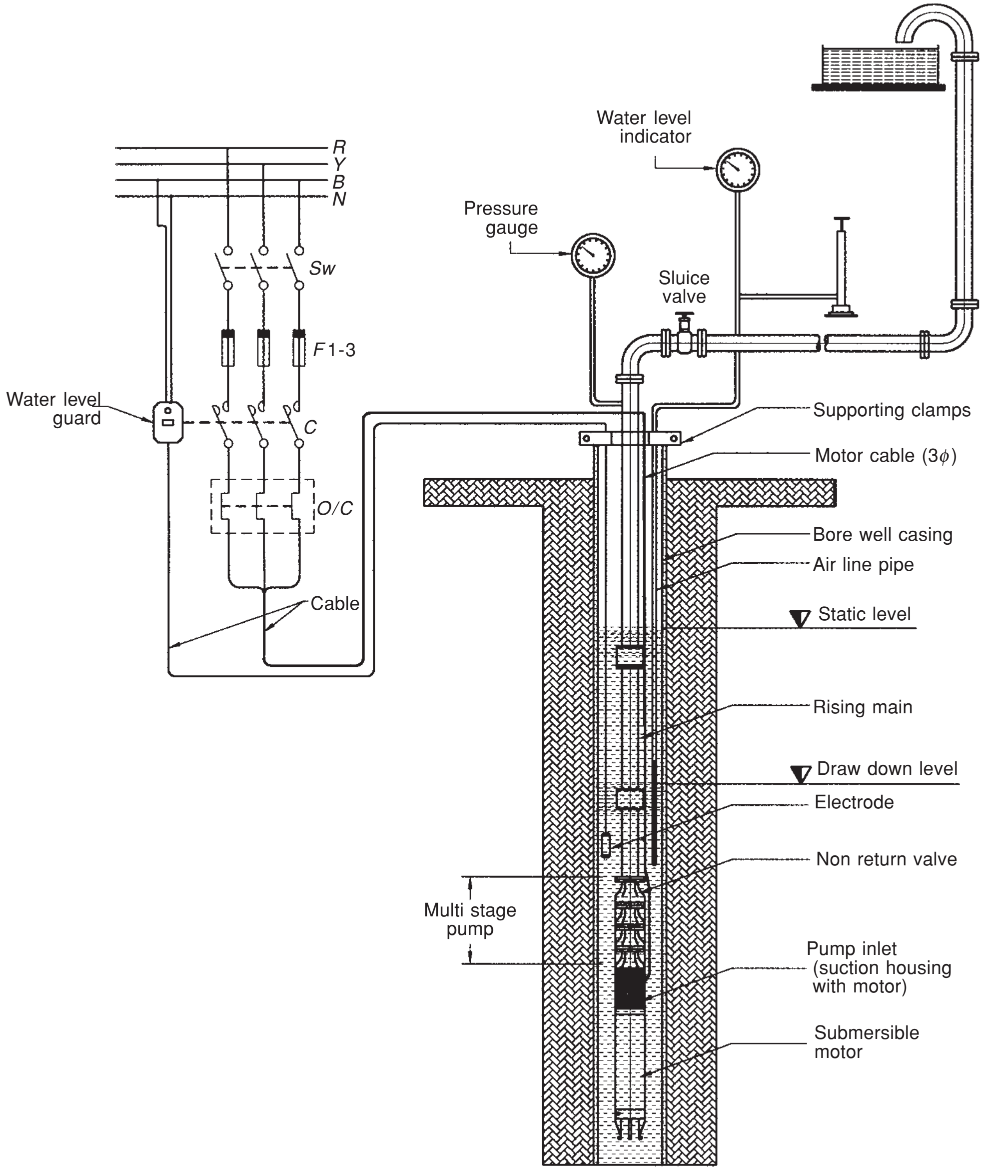


Figure 7.6 Typical arrangement of a submersible pump

steel generally while those with longer shafts have shafts made of carbon steel with stainless steel protective sleeves in the bearing portion.

Sizes of submersible motors

Submersible motors up to 350 h.p. and suitable for voltages up to 3.3 kV are being produced in India and as large as 5000 kW, 11 kV by KSB in Germany (Figure 7.8).

Applications

- Water extraction from bore holes and river beds for water supply and irrigation
- Flood water controls
- De-watering of coal, tin, copper or gold mines, coal washing and sludge pumping
- Pumping industrial effluents
- Sewage duties, industrial slurries and ash handling
- De-watering of dirty water when building roads, dams, harbours, tunnels, etc.
- Seawater services on onshore platforms, for drinking, washing and fire-fighting services on off-shore platforms
- Seawater lift pumps for cooling gas compressors on oil platforms
- Seabed trenching from remote-operated vehicles (Figure 7.9)

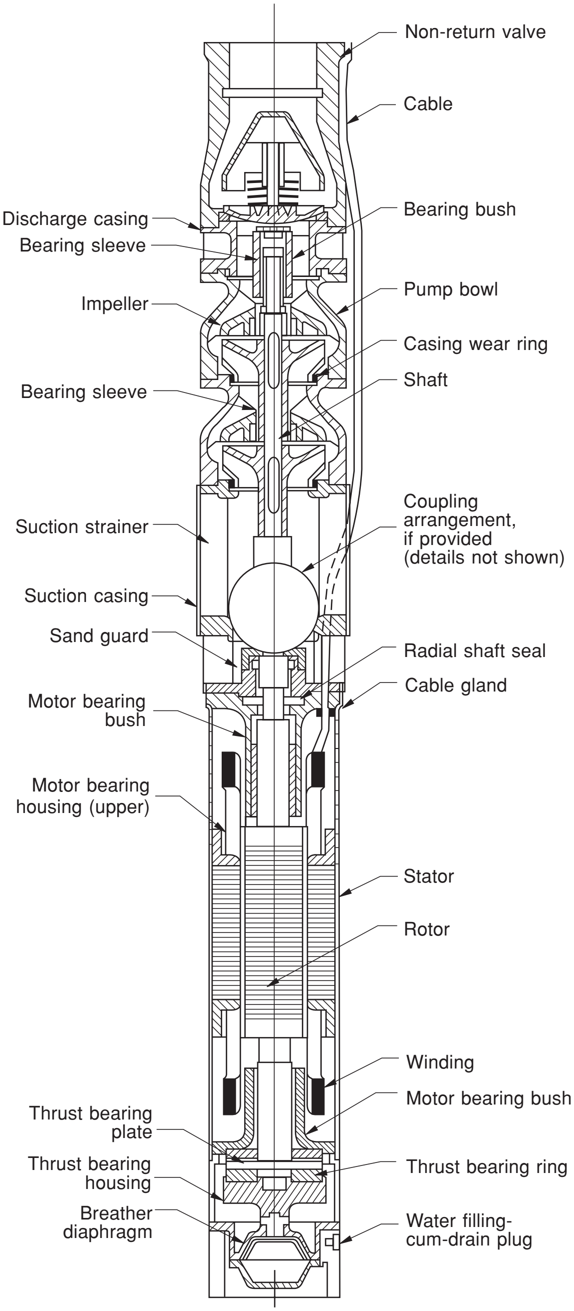


Figure 7.7 Nomenclature of a submersible pump set according to IS 9283

- Oil extraction
- Deep-sea mining for manganese nodules etc. (Figure 7.9). Many riches lie on the seabed. To explore this hidden wealth, submersible pumps have proved to be a boon. Figure 7.9 shows the arrangement of a general seabed exploration. Here three submersible pumps have been used in series, encased in a shrouding to extract and lift manganese nodules from a depth of over 5000 m to the sea surface

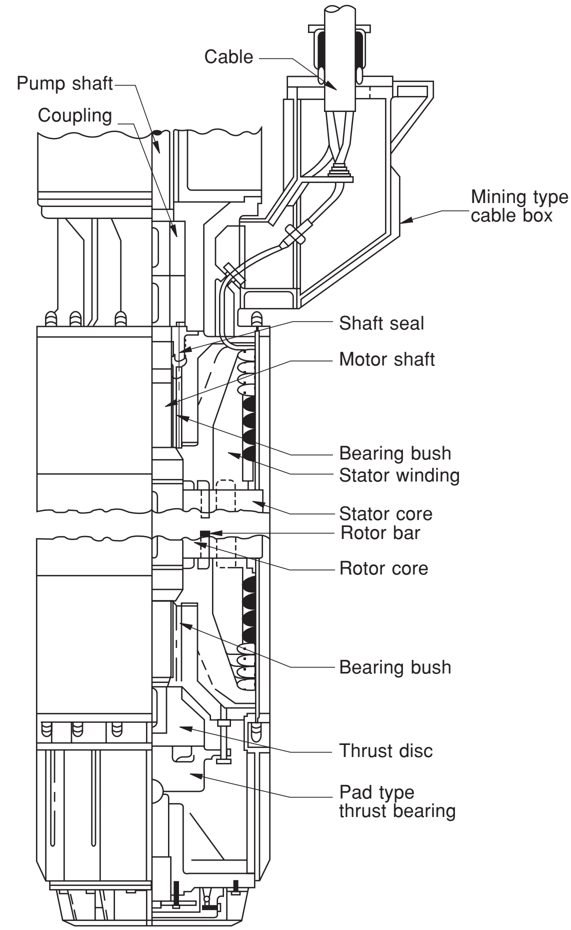


Figure 7.8 Sectional arrangement of a submersible squirrel cage motor of 860 kW, 3∅, 50 Hz, 3.3 kV, 1470 r.p.m. (Weir pumps)

- Refineries
- Chemical and process plant duties

7.6 Motors for agricultural application

In developing countries particularly, rural power distribution networks normally suffer from wide voltage fluctuations. This is generally because of LV loads which cause a high voltage dip. Consequently, in some countries the motors are designed for voltages as low as 415 V – 20% to +5% and generally 415 V–12%, i.e. 360 V*. For such high voltage fluctuations, the general practice is to select a motor larger than normal. These motors may be designed for a low starting torque, in view of their applications for pumps, winnowers, threshers etc., all requiring low starting torques. The rotor can also be designed for a low starting current, and thus protect the network from a high starting voltage dip.

*Since changed with the change in voltage systems as per IEC 60038. For details see Introduction.

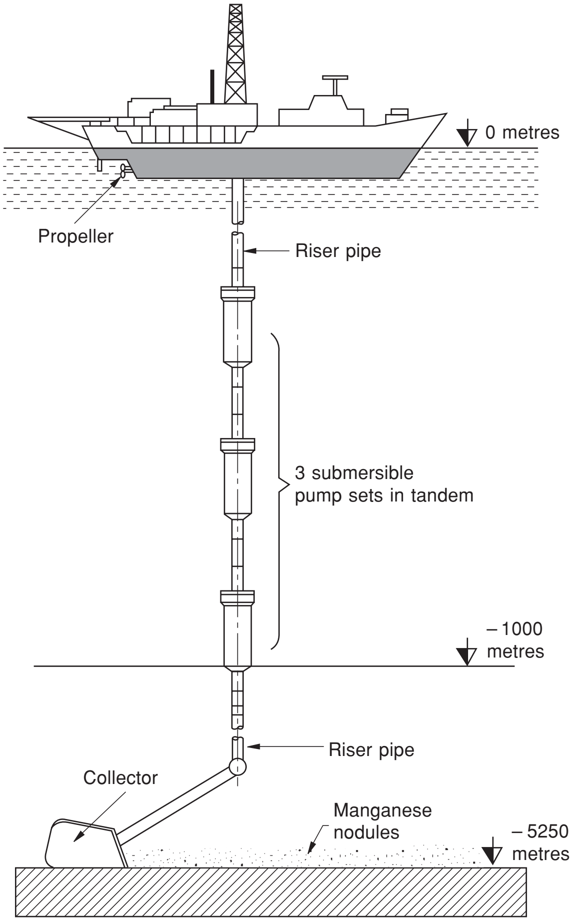


Figure 7.9 Deep-sea mining through submersible pumps (typical)

Note
IS 7538 recommends a voltage variation of –15% to +5%. But in view of the excessive voltage fluctuations in rural areas, the practice is to design a motor even for –20% to +5% of 415 V. A voltage of 415 V is considered for the sake of illustration only, for series I voltage systems (Table 13.1). It will depend upon the voltage of the LV system being used.

7.7 Surface-cooled motors

These motors are without the cooling fan and may be with or without the cooling fins shown in Figures 7.1(a) and 7.2(a). Where cooling by the external fan is likely to be obstructed, for reasons discussed in Sections 7.1 and 7.2, the application of such motors is recommended. A normal motor without a fan will become over-heated and will require a larger frame to provide extra copper and a larger surface area for heat dissipation. The higher the speed of the motor, the higher will be the cooling effect of the fan, and the higher will be the derating of the motor frame to compensate for the reduced cooling. As a rough guide, the outputs shown in Table 7.2 may be adopted for a surface-cooled motor over a fan-cooled motor (see also Figure 7.10). For exact derating contact the manufacturer.

Table 7.2 Approximate output of surface cooled motors

Serial no.	*Number of poles*	*% output*
1	2	28
2	4	60
3	6	70
4	8	75
5	10	80
6	12	82

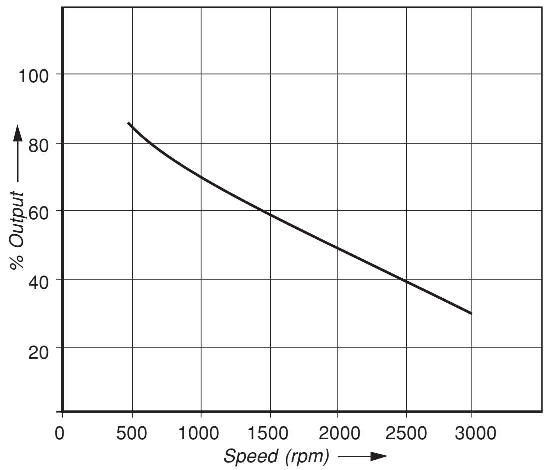


Figure 7.10 Approximate output of a surface-cooled motor

7.8 Torque motors or actuator motors

These motors are designated by their 'stall-torque' rather than kW ratings. They are fitted with a brake with an adjustable torque and are normally surface cooled. Their application is for auxiliary loads, which sometimes require a very small movement of the motor, even less than a whole revolution such as to actuate a motorized flow valve to control the flow of liquid or gas. They thus have a high slip characteristic (high rotor resistance) and are capable of providing the maximum T_{st} with the minimum power input. The design of such motors is thus different from that of a normal motor and may possess some of the following features:

- They may be short-time rated.
- Their moment of inertia is kept low to restrict their times of acceleration and deceleration (Equation (2.5)) to facilitate frequent starts and stops.
- The rating is designated by torque rather than kW.
- Maximum torque occurs at the locked rotor condition, i.e. when $S = 1$ (Figure 7.11).
- I_{st} is kept much lower than a standard motor, as it may be required to operate frequently and a high I_{st} would be a deterrent.
- The speed–torque characteristics are almost linear, with torque falling with speed (Figure 7.11).
- There is no T_{po} region, thus no unstable region. The

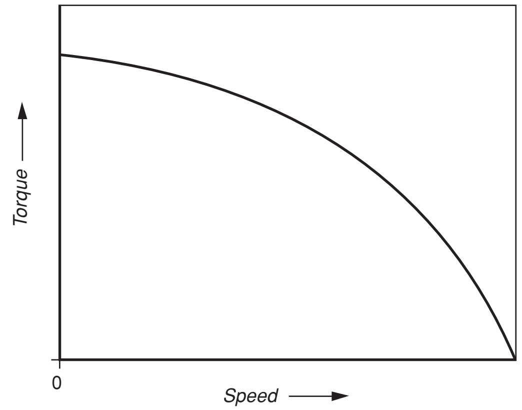


Figure 7.11 Characteristic of a torque motor

motor can operate at any speed up to the rated one without any stalling region.
- The locked rotor thermal withstand time is much higher than for a standard motor.

Likely applications

- Wire-winding machines
- Roller tables
- Frequent starts and reverses
- Material handling
- Valve actuator
- Vane control
- Bagging machines
- Fast tapping machines
- Clamping and positioning devices

7.9 Vibration and noise level

Excessive vibrations according to international codes can cause mechanical failure in the insulation by loosening of wedges, overhangs, blocks and other supports that hold the stator and the rotor windings or rotor bars in their slots. Vibrations also tend to harden and embrittle copper windings and may eventually break them when they become loose (see also Sections 11.4.6 and 11.4.7).

There are some essential features that a good motor should possess, and among these are vibrations and noise level. The noise may be magnetic or aerodynamic, assuming that there are no frictional or other noises emanating from the motor. Magnetic noise is due to resonant excitation of the stator core by slot harmonics, caused by the electro-magnetic circuit of the machine (Section 23.6(a)) and loose clamping of the stator's steel stampings and the motor's rotor core. Or loose rotor bars and magnetic unbalance, when the magnetic and geometrical axes of the motor are not concentric, as well as tooth ripples and magneto-striction. Aerodynamic noise is caused by the flow of cooling air at a higher peripheral speed over the cooling fins and the rotor bars as well as unbalanced rotating masses, aerodynamic loads and some secondary effects such as noise from the bearings, instability of the shaft in the bearings, passive resistance and aerodynamic expansion.

In an electric motor, although such parameters are inherent, they can be tolerated only to a certain extent. IEC 60034-14 gives these levels as indicated in Table 11.3. For applications such as household appliances, escalators in residential buildings, offices and hospitals, and for machine tools, the vibration levels must be even lower to eliminate the transmission of these as far as possible through the driven structure to the building or to the cutting tool in the case of a machine tool. Unless the vibrations are reduced to a reasonably low level, they may cause a noise nuisance to the occupants of a building or affect the accuracy of the cutting tool and the machine. Research on the effect of noise on a human body has revealed that noise level (sound pressure level) must be limited to 80 dB for a human body to work safely without fatigue, for eight hours a day and without causing a health hazard on a continuous basis. In the OSHA (Occupational Safety and Health Administration, USA) regulations the maximum industrial noise level is 90 dB. Table 7.9 shows the likely noise levels and their sources of origin. Vibrations, when transmitted from the source to the connected appliance or structure or a machine tool, become magnified, depending upon the contact surface area and create noise. In fact, vibrations are the primary source of noise. In machine tools, the vibrations are transmitted from the motor body to the cutting tool and affect its accuracy. For precision work and for sophisticated machine tools, a vibration level as low as 2 microns is sometimes preferred.

Vibrations and noise levels are mainly associated with the mechanical construction and electrical design of the motor. Sound mechanical construction and a balanced rotor, a tightly fastened core and smooth bearings can eliminate vibrations and mechanical noise to a large extent. Also a better electrical design can eliminate electrical vibrations in the stampings, due to magnetic forces and higher harmonics. A better electrical and mechanical design will thus mean:

1 Rigid fastening of the stator core to the housing
2 Smooth and frictionless bearings with proper greasing
3 Precision dynamically balanced rotating parts. The leading Indian manufacturers recommend and maintain a vibration level, peak to peak as shown in Table 7.3. See also Table 11.3, according to IEC 60034-14

Table 7.3 Maximum vibration levels, as practised by Indian manufacturers

	Speed Ns r.p.m. at 50 Hz	*Vibration level, peak to peak (double amplitude)*	
		LV motors (microns)	*MV motors (microns)*
1.	3000	15	15
2.	1500	40	25
3.	Up to 1000	40	25

Note
In higher speed ranges and for MV motors, these levels of shaft vibration are generally of the same order or slightly better than prescribed in IEC 60034-14, corresponding to Table 11.3.

4 A uniform air gap between the stator and the rotor
5 Judicious selection of stator and rotor slots, with angle of skew and glue density
6 Magnetic loading, i.e. flux density
7 Windage noise (noise at the suction and the exhaust of the cooling air). This makes a large contribution to the total noise emanating from a motor. To suppress this, some manufacturers provide the following additional features or noise-suppression devices in the fan and fan cover. The basic purpose of all these is to reduce to a minimum the windage (air friction) noise at the suction and exhaust points:

- By providing a uni-directional axial flow fan
- By providing a sound-absorbing fan cover at the non-driving end, as shown in Figure 7.12
- By transforming the intake axial air flow to a radial air flow, as illustrated in Figure 7.13, thus significantly reducing frictional and hence suction noise
- By changing the geometry of the fan cover, i.e. by providing muffling cones (noise-hood) at the driving end (Figure 7.14) and providing felt wool on the driving end fan cover to absorb the friction and intensity of exhaust air.

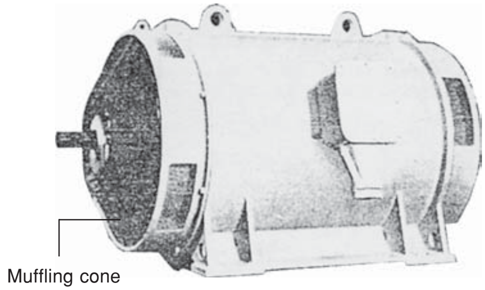


Figure 7.14 Motor with muffling cone and lining of round felt wool to absorb the exhaust noise of air

7.10 Service factor

When a motor is expected to operate in unfavourable conditions such as:

- Intermittent over-loading
- Higher ambient temperatures
- A restricted temperature rise as for a spinning mill, a refinery or a hazardous area
- Frequent starts, stops and reverses
- or any such conditions during operation

and when it is not possible to accurately define their likely occurrences or magnitudes, it becomes desirable for the motor to have some in-built reserve capacity. To account for this, a factor, known as the 'service factor', is considered when selecting the size of the motor. A 'service factor' in the range of 10–15% is considered adequate by practising engineers. With this service factor, no more derating would normally be necessary. See also Example 7.1 at the end of the chapter.

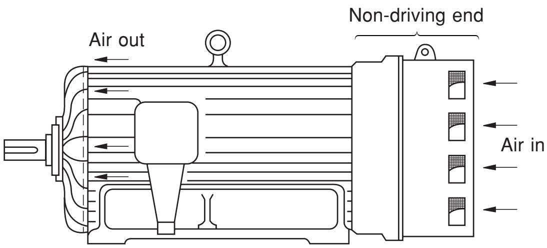


Figure 7.12 Sound-absorbing fan cover at the non-driving end

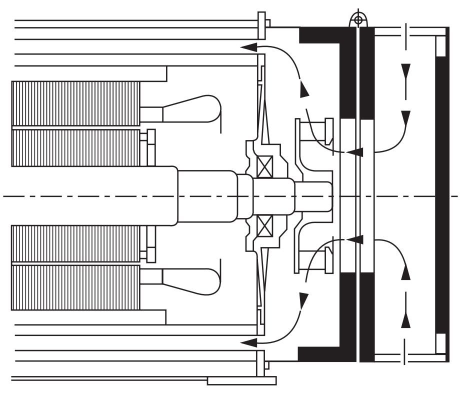


Figure 7.13 Radial flow of air to reduce suction noise

7.11 Motors for hazardous locations

Areas prone to or contaminated with explosive gases, vapours or volatile liquids are at risk from fire or explosions. A hazardous area is a location where there is a risk of fire or explosion due to the formation of an explosive mixture of air and gas or inflammable vapour and presence of source of ignition having a temperature above the ignition temperature of mixture. Squirrel cage motors can become source of ignition under abnormal conditions of operation either due to increase of surface temperature or emission of sparks. Special features are therefore incorporated in motors to be installed at such locations to reduce the possibility of such occurrences. These features may be as follows:

1 Flameproof (FLP) or explosionproof type (Ex. 'd')
2 Increased safety type (Ex. 'e')
3 Pressurized type (Ex. 'p')
4 Non-sparking type (Ex. 'n')

IEC 60079-14 provides general guidelines for the selection of electrical equipment for hazardous areas.

7.11.1 Classification of hazardous locations

It is important to identify areas in accordance with the expected degree of fire hazard to facilitate an appropriate and economical selection of electric motors. These areas, according to IEC 60079-10, are classified into three categories as follows.

Zone 0

Motors: This is a location where there is continuous presence of explosive gases, chemical vapours or volatile liquids and thus is highly susceptible to fire hazards. Installation of electrical machines in such areas should be avoided as far as possible, to reduce cost, facilitate maintenance and take other precautions. We show in Section 7.12 that an electric motor is not suitable for such locations.

Apparatus and devices: IEC 60079-14 recommends the use of only intrinsically safe apparatus and devices in such locations. Intrinsically safe apparatus and their electrical circuits are basically low energy devices and release only small amounts of energy, insufficient to ignite the surrounding atmosphere. The devices may be to record, sense or monitor the operating parameters of equipment operating in such locations or the condition of the surroundings. They may be mounted on the surface rather than the interior of an enclosure. Circuits connecting such devices and instruments are also made intrinsically safe for use in such areas. For intrinsically safe circuits see Section 7.16.

Zone 1

This is a location which is not permanently contaminated but is likely to be prone to fire hazards during processing, storage or handling of explosive gases, chemical vapour or volatile liquids, although under careful and controlled conditions. For such locations in addition to a flame- or explosion-proof enclosure, type Ex. 'd', an increased safety motor, type Ex. 'e' or a pressurized motor, type Ex. 'p' may also be considered to be safe.

Zone 2

This is a location safer than Zone 1 with a likelihood of concentration of explosive gases, chemical vapour or volatile liquids during processing, storage or handling. This would become a fire hazard only under abnormal conditions, such as a leakage or a burst of joints or pipelines etc. Such a condition may exist only for a short period. A standard motor with additional features, as discussed below, may also be safe for such locations. A non-sparking type, Ex. 'n', or an increased safety motor, type Ex. 'e', may also be chosen for such locations.

Note
Some applications creating hazardous conditions are petrochemical or fertilizer plants, refineries, coal mines etc., where inflammable gases and volatile liquids are handled, processed and stored.

Mines, collieries and quarries

In view of the magnitude and intensity of explosion and fire damp hazards at such locations, a motor with superior electrical and construction design is recommended. IEC 60079-0 categorizes such areas as Group I and recommends only flame-proof motors, type Ex. 'd', depending upon the nature and the ignition temperature of the gases, chemical vapour or volatile liquids at such locations. The maximum permissible temperature at the external surface of the machine must also be limited so that it does not ignite the inflammable substances at the installation.

7.11.2 Classification of gases, chemical vapour and volatile liquids

Based on the ignition temperature of these inflammable substances, Table 7.4 shows the groups of substances requiring specially constructed motors.

7.12 Specification of motors for Zone 0 locations

For Zone 0 locations only intrinsically safe, low-energy apparatus is recommended. Induction motors, being large

Table 7.4 Grouping of gases, chemical vapour and volatile liquids, their ignition temperature and limits of permissible temperature at the external surface of the motor based on IEC 60079–20

Ignition group	*T1*	*T2*	*T3*	*T4*	*T5*	*T6*
1 Ignition temp. (°C)	Above 450	300/450	200/300	135/200	100/135	85/100
2 Grouping	Acetone Ethane Ethyl-acetate	Acetylene Ethyl amine Ethylene	Acetaldehyde Ethyl glycol Crude oil	Ethyl-ether		Carbon disulphide Ethyl Nitrite
	Ammonia Benzene Acetic acid Carbon monoxide Methane (fire damp)	Iso-amyl acetate Butane n-Butyl alcohol n-Propyl alcohol Butanol Methanol	n-Hexane Turpentine Mineral oils Cyclo hexene			
	Naphthalene Propane Coal gas (town gas) Petroleum Toluene Water gas Hydrogen					

energy sources, release high energy, particularly during switching or a fault condition, as discussed in Section 6.13.2, are not suitable for such locations. See Section 7.16 for more details.

7.13 Specification of motors for Zone 1 locations

For Zone 1 locations, the following types of enclosures are recommended

7.13.1 Flame- or explosion-proof motors, type Ex. 'd'

IEC 60079-1 defines the basic requirements for such motors which, besides limiting the maximum temperature of any part of the motor, accessible to the contaminated area, as shown in Table 7.4, also maintain definite lengths of paths, air gaps, widths, and diametrical clearances between various rotating and stationary parts to prevent propagation of flame outside enclosure. The following design considerations may also be noted.

Design considerations

These motors should be able to withstand an internal explosion of inflammable gases, chemical vapour or volatile liquids without suffering damage or allowing the internal inflammation to escape to external inflammable substances through joints or other structural openings in the enclosure. (The explosion may have been caused by the gases, vapour or volatile liquids that might have entered or originated inside the enclosure.)

Apart from withstanding the internal explosion, the construction must be such, that the flame escaping from the interior is cooled down to such an extent that it is rendered incapable of igniting the surrounding hazardous atmosphere. This is achieved by providing joints with extra long surfaces (flame paths) and special clearances (gaps). The flame path is the breadth or the distance across the face of the flange, and the gap is the distance between the two faces of the flange, as shown in Figure 7.15. The requirements of minimum lengths of flame paths and maximum gaps for various gas groups are specified in IEC 60079-11. Some of the important constructional features of such enclosures are as follows:

- All components such as stator housing, end shields, terminal box and covers etc. are pressure tested before use.
- No light metal such as aluminium is used as an external surface to avoid frictional arcing.
- The maximum surface temperature must remain below the temperature class specified in Table 7.4 for a specific application.

7.13.2 Increased safety motors, type Ex. 'e'

These motors will also suit areas defined for Zone 1. Use of MV Ex. 'e' motors, however, should be avoided in this zone. Such enclosures do not produce arcs internally and also restrict the temperature rise of any part accessible to such an environment to a limiting value, during start-up or run, in accordance with the applicable class of insulation shown in Table 7.5. The limiting temperature must be less than or equal to the ignition temperature of the prevalent atmosphere shown in Table 7.4, otherwise the limiting temperature will become the same as the ignition temperature, according to Table 7.4. The rotor temperature is also restricted to 300°C during start-up, unless Table 7.4 shows a lower limiting temperature.

Design considerations

IEC 60079-7 outlines the basic requirements for increased safety, type Ex. 'e' motors as follows:

- The enclosure must have a high degree of protection to prevent entry of dust, water or moisture. The minimum protection specified is IP:54 (IP:55 is preferred) according to IEC 60034-5.
- All terminals must be the anti-loosening and anti-rotating types.
- The minimum clearance and creepage distances must be maintained for conductors as specified.
- The temperature rise of windings must be 10°C lower than that specified for normal machines.

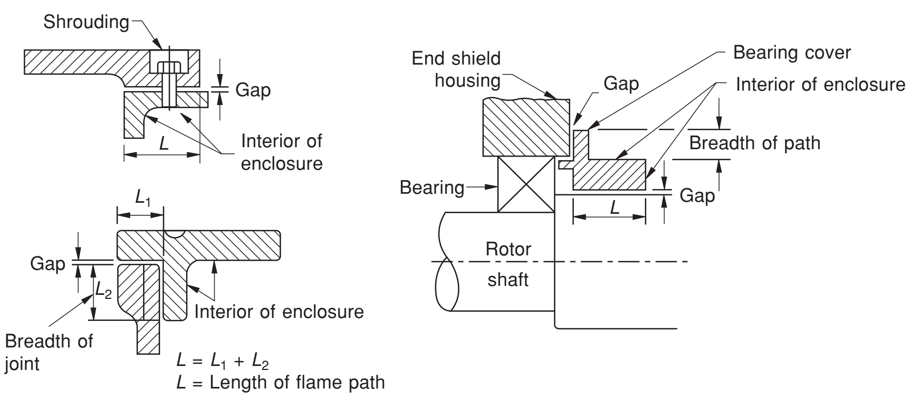


Figure 7.15 Flame paths and gaps in a flame-proof or explosion-proof motor

Table 7.5 Limiting temperature and limiting temperature rise for type Ex. 'e' motors

		Measuring method	*Class of insulation*				
			A	*E*	*B*	*F*	*H*
Limiting temperature under rated service conditions	(°C)	R T	90[a] 80	105[a] 95	110[a] 100	130[a] 115	155[a] 135
Limiting temperature rise under rated service condition (referred to an ambient temperature of 40°C)	(°C)	R T	50 40	65 55	70 60	90 75	115 95
Limiting temperature at the end of time t_E^b	(°C)	R	160	175	185	210	235
Limiting temperature rise at the end of time t_E^b (referred to an ambient temperature of 40°C)	(°C)	R	120	135	145	170	195

As in IEC 60079–7
R – by resistance method.
T – by thermometer method (only permissible if the resistance method is not practicable).
[a] These values are restricted by 10°C, compared to the working temperature prescribed for standard motors, as in Table 9.1.
[b] These values are composed of the temperature (or the temperature rise) of the windings in rated service and the increase of temperature during time t_E.

- The mechanical clearance between rotating parts, e.g., fan and fan cover or the radial air gap between the stator and the rotor, should not be less than specified to prevent sparking.
- The temperature of the windings and other parts must not exceed the limiting temperature specified in Table 7.5, even if the motor, after a prolonged operating period, remains energized in a stalled condition, for a specified time of t_E seconds while t_E will not be less than 5 seconds.

All gases are classified according to their ignition temperatures as in Table 7.4. Table 7.6 recommends the limiting surface temperatures of motors for these ignition categories in terms of temperature classes T_1 to T_6. The motor's surface temperature must not exceed the limiting temperature specified in Table 7.6 under the same condition and time t_E. The protective switch will thus be set to operate within the heating-up time t_E for the relevant temperature class. Embedded temperature detectors or thermistors are recommended to give the required signal to the tripping circuit during an emergency. Figure 7.16 illustrates the general requirements for an increased safety motor.

Table 7.6 Temperature class and limiting surface temperature with regard to gas ignition

Temperature class	*Ignition temperature (°C)*		*Limiting surface temperature (°C)*
	Above	*Up to and including*	
T6	85	100	85
T5	100	135	100
T4	135	200	135
T3	200	300	200
T2	300	450	300
T1	450	—	450

As in IEC 60079-14

Time t_E

This is the time taken by the stator or the rotor, whichever is less, to reach the limiting temperature rise, as specified

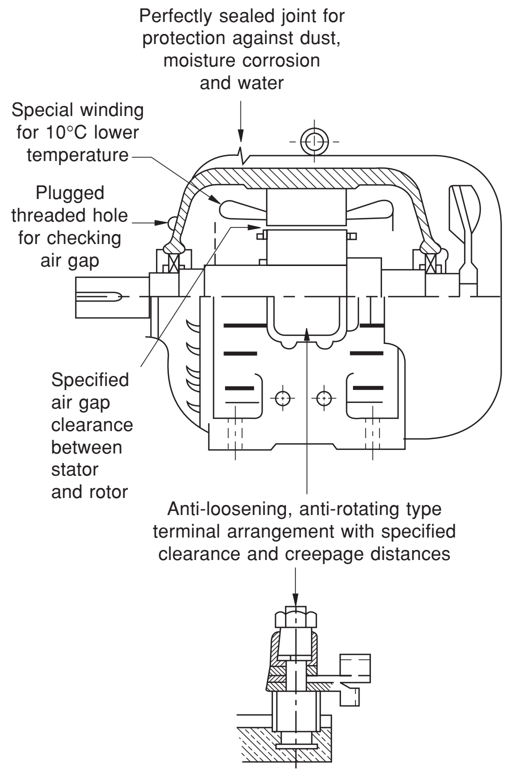


Figure 7.16 General requirements for an increased safety motor

in Table 7.5, when the starting current I_{st} is passed through the stator windings after the motor has reached thermal equilibrium, under rated conditions. For increased safety motors, this time should not be less than 5 seconds (preferably 10 seconds or more). For details see IEC 60079-7.

7.13.3 Pressurized enclosures, type Ex. 'p'

These may be standard TEFC motors suitable for operating under an internal pressure of 0.05 kP_a or a pressure slightly above atmospheric. The minimum specified is 5 mm water-gauge above atmosphere. During operation this pressure is maintained with inert gas or air through an external closed circuit, preventing inflammable gases from reaching the motor's inner components. Before re-switching such a motor after a shutdown, inflammable gases which may have entered the enclosure must first be expelled. For pressurizing, two holes are normally drilled on the motor's end shields, one for entry and the other for exit of the air or gas. For large motors, a totally enclosed single or dual-circuit type enclosure is normally used so that the motor's interior is pressurized with air or nitrogen to minimum 5 mm water-column. The enclosure is sealed and the leakage rate controlled to as low as possible. Such enclosures are recommended only when there are a number of these machines installed at the same location so that a common pressurizing and piping system may be employed to reduce costs on piping network and pressurizing equipment and its accessories, in addition to its regular maintenance. Some of the basic safety features and devices are noted below.

Safety features

- The equipment is usually fitted with interlocks to ensure that if the internal pressure or flow rate of air or inert gas falls below a certain minimum level, the supply to the motor is cut off.
- Pressure-measuring device: This is provided for the operation of alarm or trip devices in the event the pressure within the casing falls below the permitted minimum.
- Safe-starting device: This is provided to ensure that no apparatus within the enclosure is energized until the initial atmosphere within the casing has been completely displaced.

7.14 Motors for Zone 2 locations

Locations falling within this category can employ motors that are more economical than the other types discussed above. IEC 60079-14 has defined the basic requirements for such enclosures which are obviously less stringent than the others. In addition to maintaining specified creepages and clearances between the rotating and the stationary parts, the following are the two main requirements specified for such enclosures:

1 They should produce no arcing during a start-up or run.
2 Surface temperature should not exceed the ignition temperature noted in Table 7.6 for a particular temperature class under any condition of operation. There is no limit to the temperature rise to the permissible limits for a particular class of insulation of windings or other parts of the machine, except the limiting surface temperature as in Table 7.6. For such an application, a normal IP:55 enclosure may also be employed.

7.14.1 Non-sparking motors, type Ex. 'n'

A subsequent study of construction features of motors for Zone 2 locations, resulted in the development of non-sparking, type 'n' motors. The basic design consideration for such motors is similar to that of type 'e' motors but now there is no restriction in the limiting temperature, by 10°C, as in type 'e' motors. Frame sizes for these motors are generally the same as for general-purpose motors. Thus they tend to be smaller and less expensive than type 'e' motors for the same output.

7.15 Motors for mines, collieries and quarries

Special provisions are laid down in IEC 60079-0 and IEC 60079-1 for motors required for such locations in view of fluctuating degrees of humidity and temperature. Such locations are defined with a surface temperature limit of 150°C where coal dust can form a layer, or 450°C where it is not expected to form a layer. Otherwise, other details are generally the same as for flameproof motors type Ex 'd', according to IEC 60079-1. For variations in length of paths, gaps, widths, creepage and clearance distances, the reader should consult these Standards.

7.16 Intrinsically safe circuits, type Ex 'i'

IEC 60079-14 specifies two categories of intrinsically safe circuits for low energy apparatus and devices, i.e.

- Intrinsically safe category 'ia' as in IEC 60079-11 for installations in Zone 0, and
- Intrinsically safe category 'ib' for installations in Zones 1 and 2. The apparatus for this category must be of groups ΠA, ΠB, and ΠC (IEC 60079-0).

The main stipulation for such systems is that they will not emit sparks in normal or fault conditions. This therefore restricts the use of only low-energy auxiliary and control circuits connecting instruments and devices at these locations. Such instruments and devices may record, sense or monitor certain operating parameters of machines or apparatus installed at these locations or the surrounding atmosphere itself, through temperature detectors (RTDs), instruments to measure humidity and pressure, and vibration detectors.

To comply with the requirement of intrinsic safety, all electrical circuits installed at such locations should be safe and must produce no spark or heat under normal or fault conditions, sufficient to cause ignition of the surrounding medium. The parameters of the circuit such as V, I, R, L, and C, which can release heat energies by I^2R, $\frac{1}{2}\ I^2L$ and $\frac{1}{2}CV^2$ have a cognisable bearing on the ignitability of an explosive atmosphere. For an inductive circuit, for instance, with a magnetic or solenoid coil, V and L would be the most potential parameters. During a fault condition the circuit may release high stored energy by heating the wires or any other part of the device to which it is connected. This energy may be sufficient to cause ignition of the surrounding atmosphere (for more clarity see Section 6.13.2).

For the safety of these circuits, therefore, the main consideration is defined by the level of this energy, which should always be less than that required to ignite explosive gases, chemical vapour or volatile liquids in the surrounding atmosphere. Accordingly, minimum safe ignition currents (MICs) have been established by laboratory tests for different control voltages and R, L, and C of the circuit, and are the basis of testing the circuits of these devices and instruments at such locations to determine their compliance for safe installation. For details refer to the said Standards. Since such circuits would be required for other zones and groups of gases also with different limiting temperatures, IEC 60079-11 would also apply to all such zones and groups of gases. The test requirements, however, would vary for different locations, as stipulated.

To contain the temperature of the electrical circuits within safe limits for a particular temperature class of the surroundings, the maximum current rating for a minimum size of a conductor is also stipulated in IEC 60079-11. The constructional requirements also stipulate the minimum clearances and creepage distances in air between the conducting parts of all the intrinsically safe electrical circuits.

7.17 Testing and certifying authorities

Installations categorized as hazardous locations, requiring these types of motors, would be regarded as critical applications, where stringent safety measures would be mandatory. Normally, the government of a country would authorize some agencies to independently grant approval for the use of this equipment at such locations. This is mandatory for the installation and operation of any electrical equipment in hazardous areas. These authorities may also specify construction requirements for equipment and issue regulations for its installation and operation.

In India, the Central Mining Research Institute, Dhanbad carries out this testing and provides the necessary certification for motors used in explosive atmospheres. But for approval of the equipment, whether it is worthy of use in a particular hazardous area, there are accredited agencies. Some of these are Directorate General Mines Safety, Dhanbad, Chief Controller of Explosives, Nagpur and Directorate General of Factory Advice Service and Labour Institute, Bombay. Some such accrediting agencies worldwide are mentioned in Table 11.10 (Section 11.7).

7.17.1 Co-ordination of motors and drives

Special precautions are necessary when drives are employed for hazardous locations because of inverter PWM switching surges and high harmonics that may endanger safe operation of motors in terms of electrostatic discharges and high windings temperatures, both being highly detrimental for hazardous locations. Certifying agencies have promulgated special directives to take account of it. It is mandatory to co-ordinate the motor and the drive and testing them together as one unit along with actual length of inter-connecting cables for the purpose of certification to ensure,

- that the PWM switching surges are safe for the motor windings for the required cable length.
- that motor temperature does not rise beyond the safe limits for a particular hazardous location because of heating caused by harmonics.
- that there is no sparking inside the motor as a consequence of,
  - – Electrostatic discharges in the motor windings due to PWM high frequency switching surges
  - – Electrostatic discharge through the stator-rotor air gap due to capacitive coupling. Also see Section 6.14.
- that precautions are taken to avoid any kind of surface sparking also that may occur due to motor body field and loosening of hardwares outside or inside the terminal box/boxes
- that radiated radio frequency (RF) waves (an EMI effect) are within permissible limits. (It is taken care of by the drive manufacturer as per EMC/EMI requirements).
- that bearing insulation is provided to avoid parasitic bearing currents.

Co-ordination of the drive and the motor and testing them as one unit with the inter-connecting cables can safeguard the above.

All this may be possible for new installations when co-ordination between different agencies can be planned in advance. But it may be cumbersome and time consuming when undertaking retrofitting activity, due to co-ordination between different manufacturing and certifying agencies at short notices and other practical hold-ups. Users may sometimes resort to the following short-cut also as a permissible alternative,

– In case of flameproof type Ex.'d' motors, choose an inverter duty Ex.'d' motor fitted with thermistors to ensure temperature rise within permissible limits during operation, and procure the drive separately. Now only the motor needs to be certified as the drive is installed in a separate room away from the motor. Same procedure can be adopted for motors for mines, collieries and quarries. This procedure however, is not permissible in case of increased safety motors type Ex.'e' and non-sparking motors type Ex.'n' as both these prohibit sparking inside the enclosure unless the motors too are replaced with flameproof motors type Ex.'d' during retrofitting.

There is no such restriction in case of pressurised enclosures type Ex.'p' because of maintaining positive pressure inside the enclosure not permitting the arc to come out. Now an inverter duty motor subject to temperature limitations and a safe cable length (or with due protection for longer cables) can be chosen and certified separately.

7.18 Additional requirements for critical installations

A process industry, a refinery, a petrochemical, a fertilizer plant or a power station are installations that can be classified as critical. They cannot afford a breakdown during normal operation and would prefer to incorporate more safety features into the drive motors, even if these are expensive. These features can be one or more of the following.

7.18.1 Powerhouse treatment of insulation

Special insulation and coating of stator windings and overhangs are sometimes essential to ensure protection against tropical weather, fungus growth, moisture, oil abrasives, and acid and alkali fumes. Powerhouse treatment is one insulating process that can meet all these requirements (see Section 9.3).

7.18.2 Terminal boxes

It is recommended that the motor should have separate terminal boxes for the main supply and for the accessories such as space heaters, embedded temperature detectors, bearing temperature indicators and moisture detector terminals, etc. In LV motors, however, if it is not possible to provide a separate terminal box for these accessories, the main terminal box may be adequately spaced to segregate these terminals from the main terminals within the box.

In MV motors, however, these terminal boxes are always separate because of two or more voltages (main and auxiliary). For main terminals there are normally two terminal boxes – one on one side of the stator to house the main three-phase stator terminals and the second on the other side to form the star point. These boxes are generally interchangeable to facilitate cable routing.

7.18.3 Phase segregation

It may be necessary to separate the live phases within the terminal box to eliminate any occurrence of a flashover or a short-circuit and a subsequent explosion. Such explosions may be very severe, depending upon the short-circuit level of the system and the surrounding atmosphere and may cause a damage to life and property. Such a provision is normally desirable for MV motors, where such incidents are more likely due to a higher short-circuit level. For a terminal box with a less stringent design and adequate air and creepage distances between phases, and phase and ground, capable of withstanding system faults, phase segregation may not be necessary. An explosion diaphragm will, however, be essential at a suitable location on the terminal box to allow the high-pressure gases to escape in the event of a fault inside the terminal box.

An elaborate phase segregation arrangement is shown in Figure 7.17. Each individual phase lead of incoming cable separates within a compound-filled separating chamber and terminates in the main terminal box with a separate enclosure for each phase, thus eliminating the possibility of flashover inside the terminal box. For more details see Section 28.2.2. A few designs of different types of terminal boxes are illustrated in Figure 7.18(a)–(c). The usual practice, however, is to provide air segregation that is adequate.

7.18.4 Applied voltage up to 200%

When a motor is energized there is an induced e.m.f. in the stator windings which takes time to decay to zero after it is switched OFF ($\tau = L/R$, an analogue to capacitive discharge, Section 25.7). In ordinary switching operations, the sequential delay may be sufficiently long for the induced e.m.f. to persist and affect the motor's performance. But, a system that has an emergency source of supply, through an automatic changeover scheme, may have a changeover time of just a few seconds on failure of the main supply. This period sometimes can be too short for the motor-induced e.m.f. to decay to a safe level. As a consequence, the impressed voltage of the other system, at the instant of closing, may fall phase apart with the motor's own induced e.m.f., and the motor windings may be subject to a momentary over-voltage. The effect of such changeovers is felt up to 200% of the rated voltage of the motor windings, and may occur when the applied bus voltage and the residual motor voltage fall phase apart by 180°. This voltage may cause a flashover inside the terminal box if the motor terminals are not adequately spaced, and damage the inter-turn

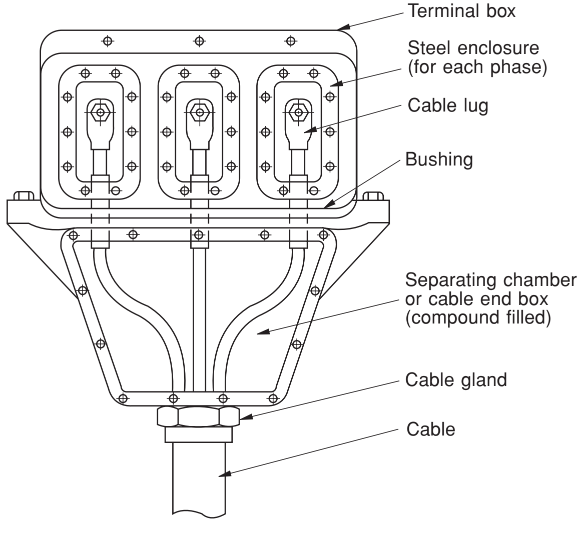
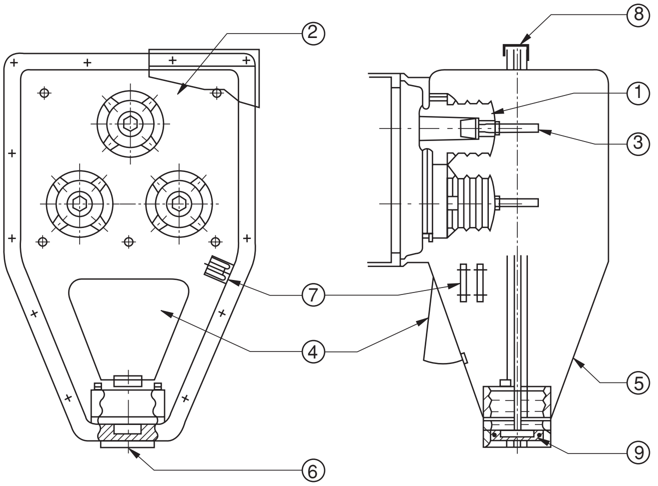
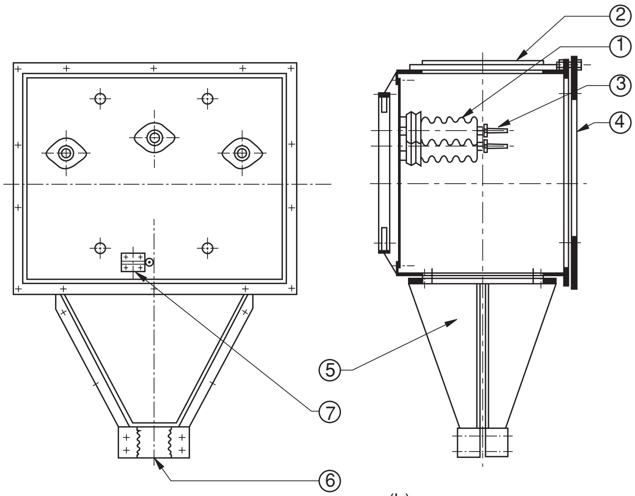


Figure 7.17 Phase-segregated terminal box



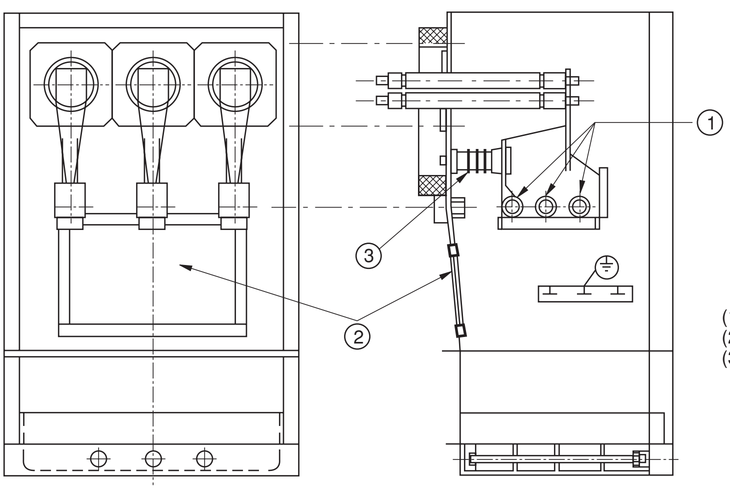
(1) Bushing insulator (cast resin)
(2) Bottom view of terminal box
(3) Terminal stud
(4) Pressure relief flap
(5) Top view of the box
(6) Cable entry
(7) Grounding terminal
(8) Weather guard for upper joint and fitting aid
(9) Sealing ring

(a)



(1) Bushing insulator
(2) Pressure relief plate
(3) Terminal stud
(4) Cover
(5) Cable box for compound filling
(6) Cable entry
(7) Grounding terminal

(b)



(1) Terminals for cable connections
(2) Pressure relief diaphragm
(3) Post insulator (cast resin)

(c)

Note
The terminal boxes up to a fault level of 350 MVA for 5 cycles at 6.6 kV are generally non-segregated and beyond 350 MVA segregated type.

Figure 7.18 Typical designs of a few MV terminal boxes insulation and the overhangs of the motor windings etc. To withstand such over-voltages that may result in higher dielectric and electrodynamic stresses the overhangs can be treated by an additional coat of varnish, and held together with a tight binding. A similar treatment is desirable for the slot coils, as well as liberal spacings and creepage distances between the phases and the ground inside the terminal box. In addition to this the motor and the driven equipment shafts may also be braced to withstand transient torques. This is the case when the interrupter remains closed during the changeover period. If it is not closed the changeover may also cause switching surges in MV motors (Section 17.7.2(ii)).

7.18.5 Re-acceleration of motors

It may be essential for certain critical process drives to have an auto-starting feature, to reaccelerate them after a momentary main power failure. This is required to save the process and the downtime, and prevent re-switching of these drives on a rapid restoration of power. This scheme can also be useful for critical processes where a restart of a drive may take a long time due to its torque characteristics or process requirements and result in a long downtime. Such a scheme can achieve faster stabilization of the process by retaining the drive in motion, and picking it up quickly on a rapid restoration of power, as in polypropylene plants and gas crackers. A paper mill, for instance, would require the whole length of paper to be removed from its drying cylinders if the mill is to be re-started after a shutdown. This is a waste of paper, in addition to a longer downtime. A power generating station has many such drives that are critical by nature and must remain operative during momentary power failures as far as possible, to save the station. Boiler feed pump is one such drive. See also Section 17.4 on fast bus transfer.

Re-acceleration can be achieved by introducing an OFF-delay timer T_1 (Figure 7.19) into the control circuits of all these drives with a time setting of, say, 0–60 seconds, so that the contactors of the critical drives restart automatically after restoration of power within the set period. The time setting, however, has to be such that the drives are still in motion at speeds so that the process can be restored. Figure 7.19 illustrates a typical scheme. This can also be achieved by placing a capacitor across the operating coil of the main contactor which can provide a time delay up to 1–4 seconds by holding the contactor. Contactors with built-in capacitors are available, and are called OFF-delay release contactors. Such a short-duration hold-on feature may be adequate when the system is required to hold without a trip against momentary heavy voltage dips, arising from system disturbances or simultaneous switching of large motors or during an auto-manual bus transfer.

Re-acceleration may be restricted to only critical drives to avoid a high switching inrush current on resumption of power. This can be achieved by grouping all these drives in two groups, one with a delay of T_1 and the other through an ON-delay timer T_2. Thus extending a progressive time delay so that each subsequent group of drives accelerates only after the previous group is switched,

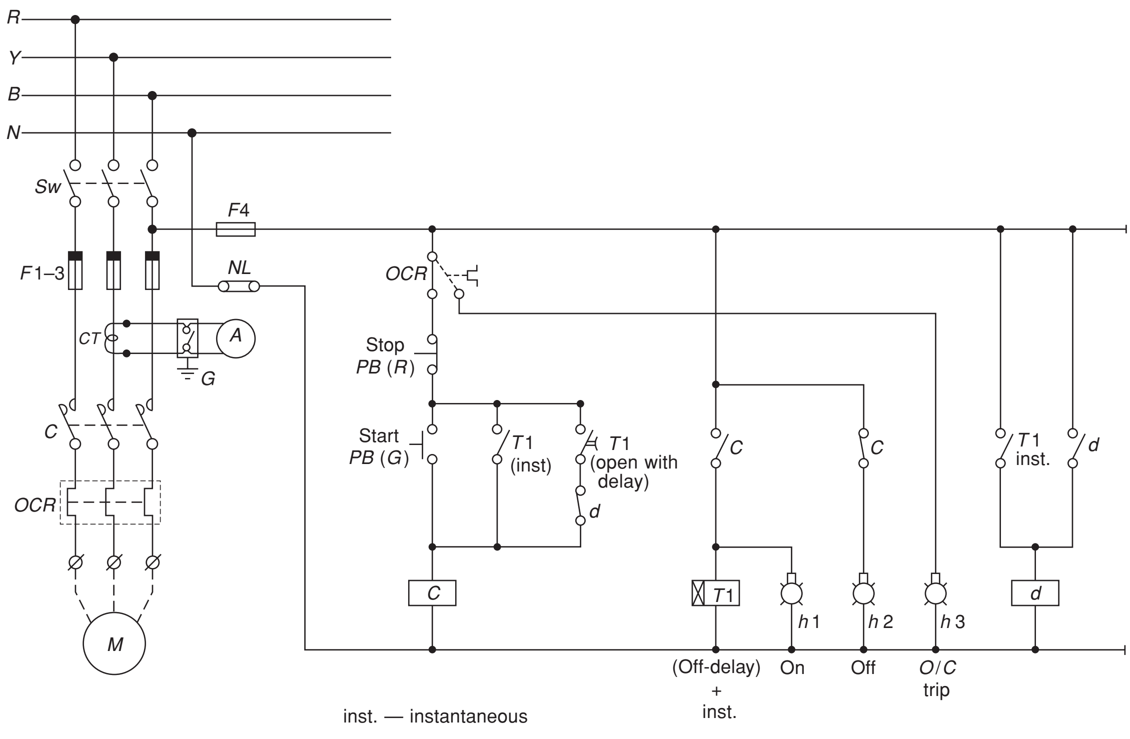


Figure 7.19 A typical scheme illustrating re-acceleration of a critical motor

to avoid simultaneous switching of all motors. Figure 7.20 illustrates a typical scheme.

7.19 Motors for thermal power station auxiliaries

These applications have considerably more stringent performance requirements than any other application. Circulating water pumps, boiler feed pumps, forced-draught (FD) and induced-draught (ID) fans, pulverizers (ball mills) and condensate pumps are components in a thermal power station that may require extra safety in a standard motor to make it able to fulfil these requirements and withstand abnormal service conditions and system disturbances. Abnormal operating conditions may be one or more of the following:

- High ambient temperature
- High humidity
- Dust-laden environment (coal dust and fly ash)
- Long continuous operation
- High fault levels
- Over-voltages, caused by a fast bus transfer
- Re-acceleration in some drives
- Voltage surges, caused by system disturbances or switching operations (for MV motors).

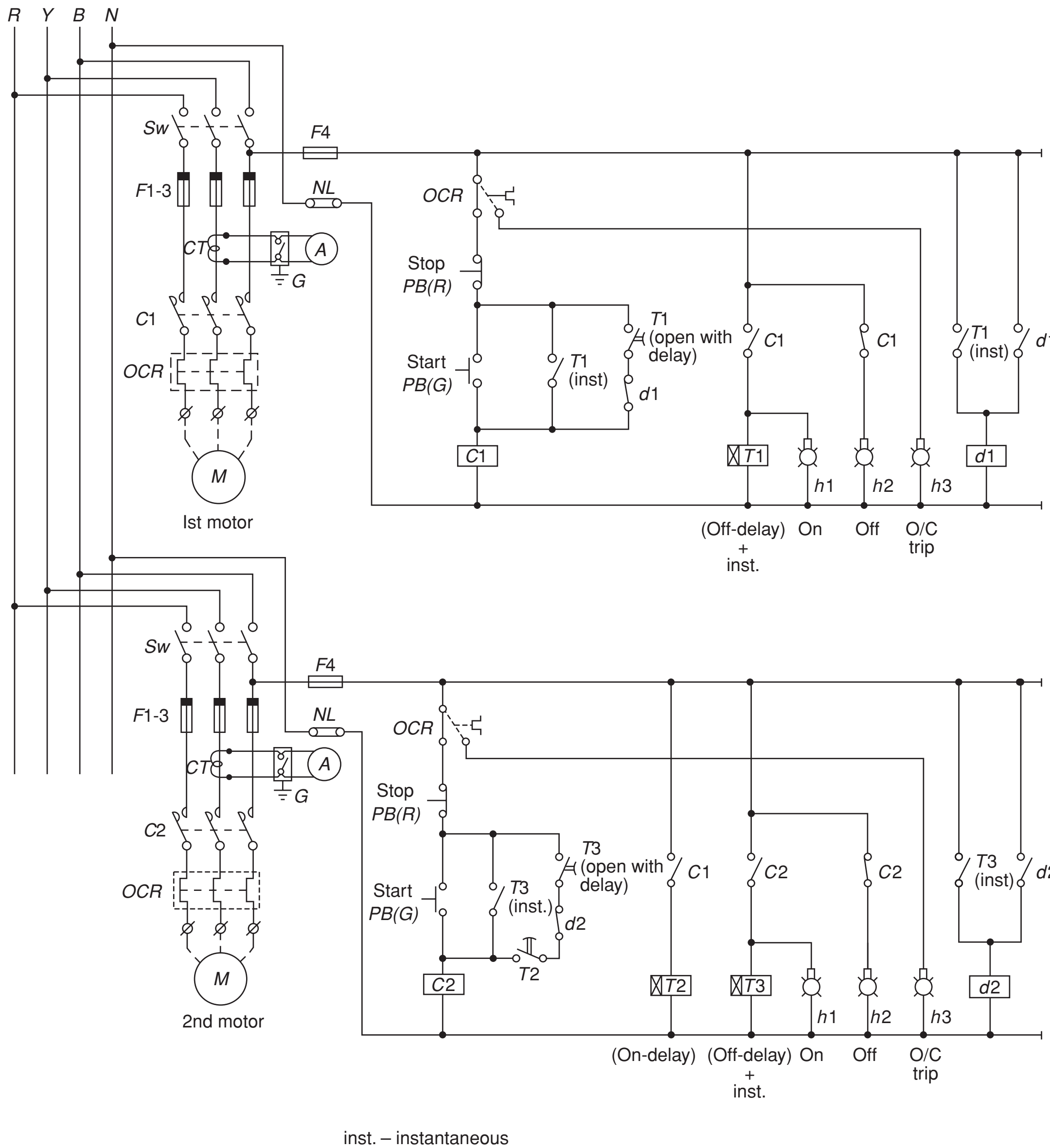


Figure 7.20 A typical scheme illustrating re-acceleration of two motors (or two groups of motors) with a time gap

In a large power station, connected to a transmission network through a power grid, system disturbances are a common feature. For details see Section 17.5.

With a view to standardizing the basic requirements of an electric motor for essential services, electricity authorities may sometimes stipulate norms and outline their basic minimum requirements for the benefit of users and the manufacturers. In India, for instance, the Central Electricity Authority (CEA) publishes manuals based on the actual feedback obtained from various thermal sites, electricity companies, leading consultants and the NTPC (National Thermal Power Corporation), in addition to motor manufacturers. Below are extracts from these manuals:

1 Motors must be generally squirrel cage type and not slip-ring.
2 The preferred ratings for motors above 110–4000 kW, must follow the 'Renard Series', R–20, according to ISO 3, as shown in Table 1.1(a).
3 The preferred synchronous speed is as shown in Table 7.7.
4 The enclosure and type of cooling is as shown in Table 7.8.
5 Space heaters: motors above 30 kW must be provided with anti-condensation space heaters suitable for 240 V 50 Hz (or 60 Hz), a.c. supply. The space heaters must switch ON automatically when the motor is out of service. Motors of 30 kW and below must be suitable for connection to a 240 V, 50 Hz (or 60 Hz) a.c. supply. Here also the windings must be connected automatically to the 240 V supply when the motor is out of service. (For new voltage systems as per IEC 60038 see Introduction.)
6 Terminals and terminal box.
   - MV motors must be provided with phase-segregated terminal boxes as illustrated in Figure 7.17.
   - In MV motors the terminal box for space heaters and embedded temperature detectors must be separate from the main terminal box.
   - The terminal box must be capable of withstanding the system fault current for at least 0.25 second.
   - The terminal box must be suitable for being turned through 180°, for bottom or top cable entry.
   - The terminal box must have the same degree of protection as the motor.
   - For large motors, 1000 kW and above, if they are provided with star windings the three neutral end leads must be connected to a separate terminal box to enable mounting of CTs for differential protection. The neutral terminal box need not be phase segregated.
7 Performance
   - Motors must be designed for an ambient temperature of 50°C.
   - MV motors must be generally wound with class F insulation and the temperature rise should not exceed the prescribed limits of class B insulation. LV motors up to 250 kW, however, can be wound with class B insulation.
   - The performance of the motors must conform to IEC 60034-12.
8 Voltage and frequency variations (as may occur during a momentary system disturbance (Section 17.4)
   - During start-up, the motors must be suitable for accelerating at 80% of the rated voltage.
   - Motors must run at full h.p. under the following conditions:
     Variation in frequency: ±5%
     Variation in voltage: ±10%
     Combined variation in frequency and voltage: ±10% (absolute)
   - Motors must not stall due to a momentary dip in voltage up to 70% of the rated voltage, i.e. T_{po} to be more than $T_r/(0.7)^2$, i.e. 204% for a 1500 or any other r.p.m. motor. (Table 1.5 is not applicable during run as there being no saturation effect when the voltage drops during run.)
   - Motors must run satisfactorily for 5 minutes at a supply voltage of 75% of the rated value.

     Note
     This operating condition is, however, not specific for it does not stipulate the frequency of occurrence of such a contingency. It may be assumed that this condition will not occur more than once before thermal stability is reached. See also Section 3.7. In normal practice a motor meeting the other operating conditions noted above in all likelihood will satisfy this requirement also without needing yet another derating. See also Example 7.1.
9 Starting current
   - On DOL the I_{st} must not exceed 600% of I_r but for boiler feed pumps it must be limited to 450% of I_r, subject to the tolerance stipulated in IEC 60034-1.
   - To determine the starting current, when the test is conducted at a reduced voltage ($1/\sqrt{3}\, V_r$), allowance must be made for the saturation effect while estimating the value of I_{st} at the rated voltage.

Table 7.7 Preferred speeds for thermal power station auxiliaries

Auxiliary	*Synchronous speed (r.p.m.)*
Induced-draught fan (ID fan)	500, 600, 750, 1000
Forced-draught fan (FD fan)	1000, 1500
Primary air fan (PA fan)	1500
Ball mill (coal crusher)	1000
Vapour fan	1000, 1500
Boiler feed pump (BFP)	1500, 3000
Condensate pump	1000, 1500
Circulating water pump (CW pump)	300, 375, 429, 500

Table 7.8 Recommended enclosures and type of cooling for power station auxiliaries

Enclosure	*Type of cooling as in IEC 60034-6*
1 TEFC	IC 0141
2 TETV	IC 0151
3 CACA	IC 0161
4 CACW	ICW 37A 81 or ICW 37A 91

See also Section 1.6.2(a) also (the important note on starting torque).

Note
At full voltage, the stator core will offer a lower impedance, because of the saturation effect, than at a reduced voltage. The I_{st} at full voltage therefore would be slightly higher than that calculated from the starting current, measured at a reduced voltage. Hence the allowance for this. See also Figure 27.2(b).

10 Frequency of start: The MV motors must be suitable for two starts in quick succession when the motor is hot or three equally spread starts in an hour (not to be repeated in the second successive hour).

11 Stresses during a fast bus transfer: A fast bus transfer between the unit and station supplies is an essential feature in a power station to maintain an uninterrupted power supply to the unit and station auxiliary services (Figure 13.21). The changeover may be as fast as three or four cycles which is adequate to break before make in the modern interrupting devices and hence is safe to adopt. The motors should, however, be suitable of withstanding excessive voltages on account of this up to 150% of the rated voltage for at least one second during such bus transfers.

Note
The time gap between a fast bus transfer is so small (Section 24.9.1) that it will not permit the various drives to slow down sufficiently to affect their performance or the system if they are made to reaccelerate (re-energize) on restoration of power.

In a fast bus transfer scheme, the phase angle is monitored through special relays (Section 16.11) which initiate the changeover, so that the self-induced e.m.f. of the motor does not slip too far in the phase angle, $\Delta\theta$, between the two voltages and the motor is not exposed to excessive over-voltages. At higher $\Delta\theta$ the relays will block the transfer and protect the system from excessive voltages. If the fast bus transfer fails to changeover automatically, slow changeover takes place and the motor-induced e.m.f. is allowed to decay by up to 40–20% before the bus transfer takes place. For insulating and bracing the windings, such bus transfers may occur up to 500 times in the total life span of the motor.

12 Starting time and locked rotor withstand time.
- For motors with a starting time up to 20 seconds, with the minimum permissible applied voltage (80%), the locked rotor withstand time under hot conditions at rated voltage must be at least 2.5 seconds more than the starting time.
- For motors with a starting time of more than 20 seconds but within 45 seconds, at the minimum permissible applied voltage (80%), the locked rotor withstand time, under hot conditions at rated voltage, must be at least 5 seconds more than the starting time.

13 Bearings: The bearings will preferably have an arrangement for self-lubrication.

14 Bearings must be insulated wherever necessary, to prevent them from shaft currents (Section 10.4.5).

15 Over-speed: Motors will be designed to withstand 120% of N_r for at least 2 minutes without any mechanical damage.

16 Noise level: Motors must conform to the requirements of IEC 60034-9. A safe sound pressure level for a human body to perform better, during an 8-hour working day, without undue fatigue, is considered at 80–85 dB as noted in Section 7.9. For recommended values of sound level for airborne noise, refer to the IEC publication. See also Table 7.9 for sources in day-to-day life that emit noise and their likely noise levels.

17 Temperature detectors
- MV motors must have a minimum six numbers of resistance temperature detectors (RTDs) (See Section 12.8).
- All bearings of MV motors must be provided with embedded temperature detectors (ETDs).

18 Polarization index test
- Motors rated 7500 kW and less must be considered suitable for dielectric tests or operation only when the polarization index or the value of the insulation resistance (at 40°C) is at least the minimum recommended values.
- Motors rated above 7500 kW must have both the polarization index and the insulation resistance above the minimum recommended values.
- The recommended minimum value of the polarization index for motors having class B or F insulation must be 2 when determined according to IEC 60034-18-1.

Note
The above recommendations are those of an electricity authority of one country and may vary for other countries.

7.20 Selection of a special-purpose motors

Example 7.1
Select a suitable motor for a ball mill with the following load details:

kW = 450
r.p.m. = 400 through V-belts
Starting torque = 40% rising to 100% at full load (Figure 7.21).
GD^2 of rotating masses = 10 000 kgm^2

Supply system:

Voltage = 3.3 kV ± 10%
Frequency = 50 Hz ± 3%

Combined voltage and frequency variation not to exceed ±10%. Voltage may fall to 80% during running for about 20

Table 7.9 Sources emitting sound and their likely loudness level

Noise level (dB)	*Sound source*
0	Threshold of hearing
20	Rustling sound, whisper, homes and offices (quiet places)
40	Motor cars
60	Normal conversation
80	Street traffic
100	Light engineering workshop
120	Thunder/lightning

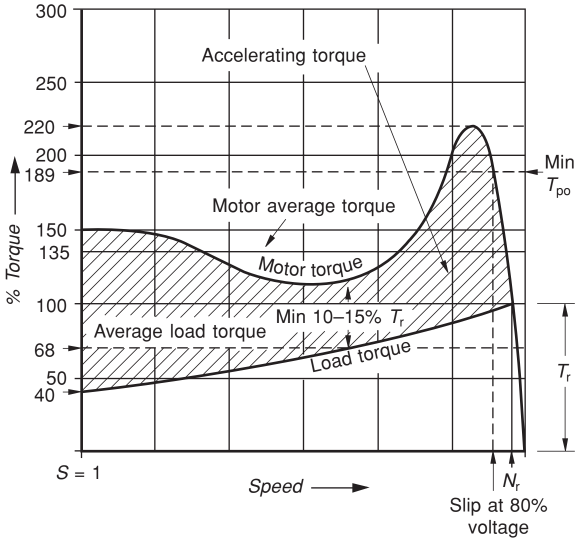


Figure 7.21 Determining the accelerating torque

minutes and can be assumed to occur once an hour. Also likely over-loading by 20% for the same period in the same duration. Only one contingency occurring at a time. The motor should also be capable of running, without stalling if the voltage drops to 70% momentarily, say, for 25 cycles.

Ambient temperature	= 50°C
Permissible starting	= DOL in a squirrel cage or rheostat in a slip-ring motor
Desired starts	= six equally spread starts per hour and three consecutive hot starts not to be repeated for one hour
Service factor	= 1.1, alternatively 1.15

Solution

Deratings

(a) For ±10% voltage and frequency variation: 90% (Section 1.6.2).

(b) For 50°C ambient temperature: 92% (Section 1.6.2(c)).

(c) At 80% voltage, the starting torque of the motor will drop to 0.73^2, i.e. 0.53 times the rated torque, as shown in Table 1.5 while the running and pull-out torques will drop to 0.8^2 or 0.64 times the rated torque. Also the motor will tend to stall unless adequate torque is available on the motor torque curve, i.e. T_{PO} must not be less than 1/0.64 or 156%. The motor will thus start dropping its speed until it reaches a point where a motor torque of 156% of 450 kW is available. The motor will now operate at a higher slip, causing higher slip losses. Assuming the mill torque at the reduced speed to be the same as at 100% speed, then the kW requirement of the mill

$$\text{kW} \propto N \cdot T$$

This will also decrease in the same proportion as the increase in slip. For a rough estimate, we may also ignore the higher slip losses for an equal reduction in the required kW. However, due to the lower voltage the motor current will increase proportionately and will be $I_r/0.8$ or 1.25 I_r. The motor will thus run over-loaded by 25% for 20 minutes which is likely, and not more than once an hour. The frequency of occurrence must be known. A higher derating may be necessary if such a condition is frequent.

(d) Over-loading of 20% for 20 minutes per hour need not be considered in view of condition (c) which is more severe. Therefore, average loading of motor in one-hour cycle

$$= \sqrt{\frac{(1.25\, I_r)^2 \times 20 + I_r^2 \times 40}{60}}$$

$$= I_r \sqrt{1.187}$$

$$\simeq 1.09 I_r$$

i.e. the rating of the motor should be higher by 9% to account for this stipulation.

Note
Normally, the heating-up time constant τ for an MV motor varies between 0.9 to 1.5 hours, i.e. heating-up time under normal running condition from 2.5 to 4.0 hours approximately. In one hour, therefore, the motor will not reach its thermal equilibrium and the equivalent rating as determined above is in order. One should not consider a cycle longer than heating time, which may give incongruous results:

∴ kW to be chosen, considering all deratings

$$= \frac{450 \times 1.09}{0.92 \times 0.90}$$

$$\simeq 600 \text{ kW}$$

A 1000 r.p.m. 600 kW motor should be an economical choice.

(e) To meet the condition at 70% voltage, the motor should have a T_{po} of more than 156% and should be minimum $1/(0.7)^2$ or 204% of 450 kW or 153% of 600 kW, so that the motor does not stall.

(f) To consider the service factor (SF): the motor should have a continuous reserve capacity as may be desired, for example for a SF of 1.15, a motor of at least 1.15 × 450, i.e. a 517.5 kW rating must be required. We have already selected a motor of 600 kW, therefore this factor need not be considered again. Moreover, too large a motor than the load requires would make it operate under-loaded and diminish its operating efficiency and p.f., which is a drain on the usable energy and is not desirable. See also Sections 23.3 and 7.10.

Checking the suitability of a squirrel cage motor

Assume that the motor is designed for an average speed-up torque of 135% and T_{po} of 220% (Figure 7.21). Since the average load torque works out to 68% (calculated from Figure 7.21) (for procedure see Example 2.5), the average accelerating torque, T_a, will be 67% on DOL starting, i.e.

$$T_a = \frac{450 \times 974}{980} \times 0.67 \text{ mkg (considering } N_r = 980 \text{ r.p.m.)}$$

$$\simeq 300 \text{ mkg}$$

Say, the $GD_M^2 = 200 \text{ kgm}^2$

and $GD_L^2 = 10000\left(\frac{400}{980}\right)^2$ (at motor speed)

$$\simeq 1666 \text{ kgm}^2$$

$$\therefore \quad GD_T^2 = 1866 \text{ kgm}^2$$

and starting time,

$$t_s = \frac{1866 \times 980}{375 \times 300}$$

$$\simeq 16.25 \text{ seconds}$$

Considering the permissible tolerances in the declared torque values, the safer starting time should be taken as roughly 10–15% more than the calculated value. Therefore, consider the safe starting time as 16.25 × 1.15, i.e. 19.0 seconds. For a single start under hot conditions the motor should have a minimum thermal withstand time of 19.0 seconds, and for three consecutive starts, a minimum 57.0 seconds, which, for this size of motor, may not be practicable in view of design economics. For this application, therefore, a squirrel cage motor is not recommended, unless a fluid coupling is employed to transmit the power.

Corollary

The use of a squirrel cage motor is, however, inevitable as discussed earlier particularly for a process plant or a powerhouse application, where downtime for maintenance of a slip-ring motor is unwelcome, or a chemical plant or contaminated locations, where the application of a slip-ring motor is prohibited. To meet such load requirements with a squirrel cage motor, the use of fluid couplings to start the motor lightly and reduce starting time, is quite common and economical, as discussed in Chapter 8, and must be adopted in the above case.

Let us use a fluid coupling and start the motor lightly, similar to Figure 8.3. The revised accelerating torque and approximate clutching sequence of the coupling is illustrated in Figure 7.22.

1 Consider the clutching of the coupling with the load at roughly $0.8N_r$, by which time the motor would be operating near its T_{po} region

$\therefore N_{r_1} = 0.8\ N_r$

$= 800$ r.p.m.

Considering an average coupling opposing torque as roughly $0.4T_r$ and average motor torque as $1.35T_r$, between 0 to 0.8 N_r. The exact torque can be calculated by measuring the torque ordinates at various speeds and then calculating the average. See Example 2.5 for more clarity.

$$\therefore T_{a1} = 1.35T_r - 0.4T_r$$

$$= 0.95T_r$$

$$= \frac{450 \times 974}{980} \times 0.95$$

$$= 424.88 \text{ mkg}$$

GD^2 during a light start, considering the GD_c^2 of the coupling (impeller) as equal to the motor (the exact value should be obtained from the manufacturer).

$$\therefore \qquad GD_T^2 = 200 + 200$$

$$= 400 \text{ kgm}^2$$

$$\text{and} \quad t_{s1} \text{ up to } 0.8N_r = \frac{400 \times 800}{375 \times 424.88}$$

$$= 2.01 \text{ seconds}$$

2 The coupling average accelerating torque after it has engaged with load, up to N_r, $T_{r2} \cong 1.65T_r$

(by calculating average ordinates at points 1 to 6)

$$= \tfrac{1}{6}\left[80 + 135 + 185 + 215 + 215 + \tfrac{1}{2}(215 + 100)\right]$$

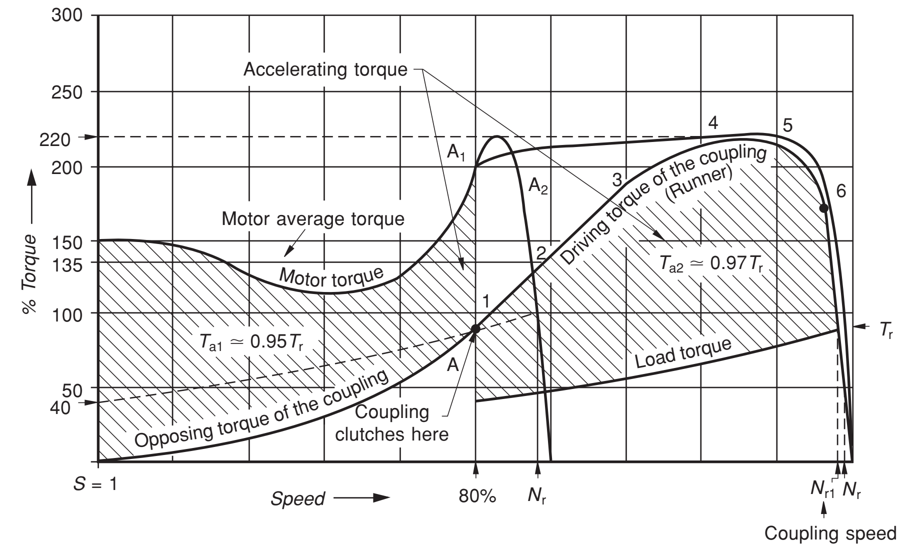
$$= 165\%$$

Load average torque $\cong 0.68T_r$ (as calculated before)

$$\therefore \qquad T_{a2} = 1.65T_r - 0.68T_r$$

$$= 0.97T_r = \frac{450 \times 974 \times 0.97}{980}$$

$$= 433.83 \text{ mkg}$$



Note To further reduce strain on the motor the clutching may be adjusted to take place after the T_{po} region, i.e. corresponding to point A_2 rather than A_1 (see Section 8.4.1(2))

Figure 7.22 Accelerating torque with the use of fluid coupling now $\quad GD_T^2 = GD_M^2 + GD_C^2 + GD_L^2$

$= 200 + 200 + 1666$

$= 2066 \text{ kgm}^2$

$N_{r2} = 980 - 800$

$= 180$ r.p.m.

$\therefore\ t_{s2}$ from $0.8N_r$ to $N_r = \dfrac{2066 \times 180}{375 \times 433.83}$

(The actual speed will be slightly less due to coupling slip)

$= 2.28$ seconds

$\therefore$ Total accelerating time $= 2.01 + 2.28$

$= 4.29$ seconds

With permissible tolerance $= 1.15 \times 4.29$

$= 4.93$ seconds

For three consecutive starts, the motor must possess a minimum thermal withstand time of about 14.8 seconds which will now be possible with a standard squirrel cage motor. The motor starting torque requirement can also be relaxed with the use of flexible couplings, if this can economize on the cost of the motor.

Checking the suitability of a slip-ring motor

With the same pull-out torque as above, if we select a slip-ring motor and arrange the starter to develop an average pick-up torque of 200%, the available accelerating torque will be (200 – 68) = 132%

i.e. $T_a = \dfrac{450 \times 974}{980} \times 1.32$

or 590 mkg and starting time

$t_s = \dfrac{1866 \times 980}{375 \times 590}$ (considering same GD_M^2 for brevity)

or 8.26 seconds.

Assuming a safe start time of 8.26×1.15, i.e. 9.5 seconds, a motor with a safe hot stall time of 30 seconds will be adequate to withstand three consecutive hot starts. A slip-ring motor will usually be suitable for such a duty.

Note

In a slip-ring motor I_{st} is much less compared to a squirrel cage motor, say 200–300% I_r, and therefore a hot thermal withstand time of only 6 to 9 seconds should be quite safe for such a duty, e.g.

Heating, $H \propto I_{r1}^2 \cdot R \cdot t_1 \propto I_{r2}^2 \cdot R \cdot t_2$

or $\quad t_2 = \dfrac{I_{r1}^2}{I_r^2} \cdot t_1$

Since the thermal withstand time refers to locked rotor condition and normally corresponds to 600 to 700% I_r,

$\therefore$ at 300% I_{st}, the equivalent thermal withstand time, considering the hot thermal withstand time at 600% starting current as 8 seconds will be

$t_2 = \left[\dfrac{600}{300}\right]^2 \times 8$

$= 32$ seconds

To determine the number of equally spread starts and stops, heating and cooling curves of the motor should be available and the manufacturer may be consulted.

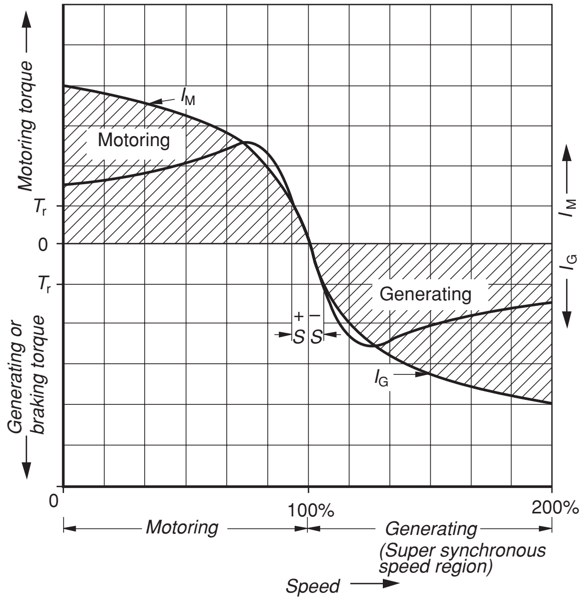
The above exercise is only for a general guidance. In such cases, the manufacturer should be consulted who may offer a better and more economical design.

7.21 Induction generators (or asynchronous generators)

During generator action, the slip, and currents of the stator and the rotor are negative. The motor draws reactive power from the source for its excitation (magnetization) since it is not a self-excited machine. However, it feeds back to the supply system an active power almost equal in magnitude to the motor rating or slightly less or more, depending upon its super synchronous speed. As an induction generator, it can feed back to the supply source roughly equivalent to its h.p. at the same negative slip, say, 3–5%, as the positive slip, at which it operates under normal conditions and delivers its rated h.p. As a result of the absence of the reactive power, which is now fed by the source and the mechanical losses that are fed by potential energy of the descending loads or the wind, the power output of an induction generator is usually more than its power consumption when working as a motor (Figure 7.23).

The power factor, however, is poor because of higher negative slip. The power output is expressed in the same way as the motor input, i.e.

$$G_1 = \sqrt{3} \cdot I_G \cdot V \cdot \cos\phi \cdot K \tag{7.3}$$



I_M – *Motoring current drawn from the source*
I_G – *Generating or braking current fed to the source*

Figure 7.23 Current, torque and speed characteristics of an induction generator where

G_1 = generator output at the same negative slip as for the motor. See also Figure 7.23 and the circle diagram of Figure 1.16, redrawn in Figure 7.24 for an induction generator

K = factor to account for the lower p.f. at higher negative slips when working as an induction generator (say, 0.97).

I_G = generator rated current in A.

$\cos\phi$ = generator rated p.f. which is quite high compared to a motor, as the reactive power is now supplied by the external source.

Example 7.2

For a 100 kW, 380 V induction motor operating at an approximate η of 92.2%, having I_r as 185 A and $\cos\phi$ as 0.89, the output as an induction generator will be

$$G = \sqrt{3} \times 380 \times 185 \times 0.89 \times 0.97 \text{ W}$$

(considering η as $\simeq$ 100%)

$$= 105 \text{ kW}$$

and the kVAr consumed by the induction generator from the source of supply,

$$\simeq \frac{\sqrt{3} \times 380 \times 185 \times \sqrt{(1^2 - 0.89^2)}}{0.97 \times 1000}$$

$$\simeq 57.24 \text{ kVAr}$$

Corollary

The power output of an induction motor, when operating as an induction generator, is usually more than its output when working as a motor. There are no mechanical or windage losses which are fed by the mechanical power that makes the motor run as a generator, such as the potential energy accumulated during downhill conveying or wind power etc. The power output is approximately equal to the effective power intake except for the lower power factor and resistive (copper) losses, that are ignored above.

The circle diagram (Figure 1.16) reverses in this case and the magnitude of braking torque and corresponding stator and rotor currents can be ascertained at any particular speed from this diagram redrawn in Figure 7.24. A study of this diagram will reveal that for a motor's normal running speed N_r to reach the synchronous speed N_s, the motor will behave as a generator without output (region D_1P_1) and will draw power from the main supply to meet its no-load core losses and friction losses etc. (D_1P_1). This will deliver active power back to the main supply as soon as it exceeds its synchronous speed. The maximum power that can be delivered is measured from the no-load line of the motor to the output line of the generator (D_1P_2) minus the no-load losses (D_1P_1), i.e. the downward hemisphere from the centre line or the generator output line (P_1P_2).

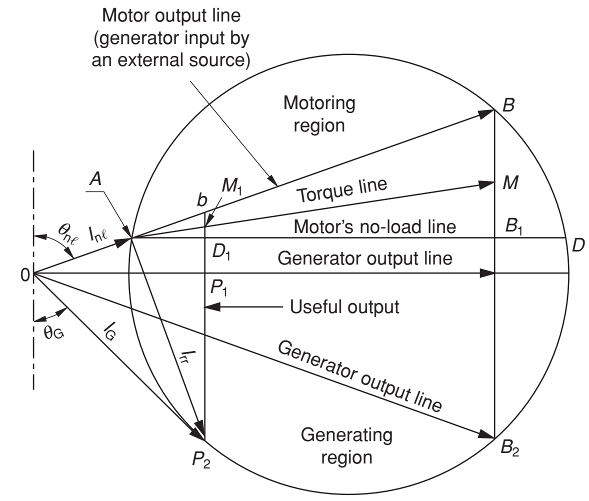
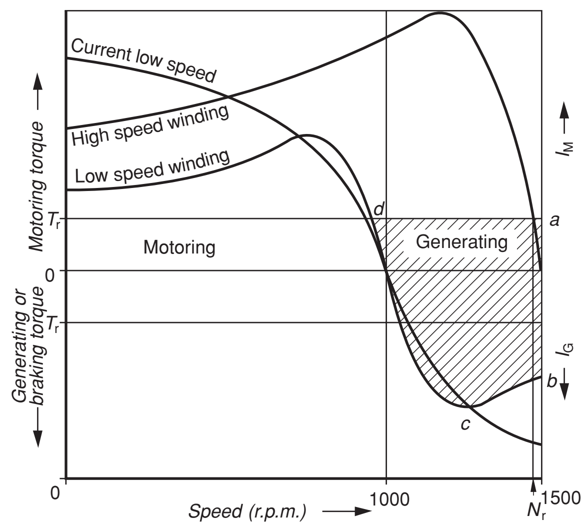


Figure 7.24 Circle diagram for an induction generator



I_M – Motoring current drawn from the source
I_G – Generating or braking, current fed to the source

Figure 7.25 Motoring and generating torque curves for a 1500/1000 r.p.m. dual-speed motor (torque and current curves for generating region are drawn for only low-speed winding)

Figure 7.25 shows the generating region and torque and current variation for a dual-speed motor when at higher speed the supply is changed over to the low-speed winding. From the torque curve it is evident that the torque reverses twice in quick succession through two reverse peaks (curve area *abcd*) and the motor must be suitable to withstand this. All the parts, subject to this phenomenon should be carefully designed and selected and rotor bars and end rings should be tightly secured and braced. When the generator action is due to external power (potential energy or wind power), precautions against heavy centrifugal forces to which the rotor conductors will be subject to, at super-synchronous speed should also be taken into account. At a higher speed beyond the synchronous (a higher rated degenerative slip) the higher will be the stator current and the generator will run over-loaded. To safeguard against over-loading, relays or similar protections must be provided in the supply lines to disconnect the motor beyond a specific speed (generally beyond the rated negative slip), after a certain time delay, if such a situation arises.

In downhill conveyors, running mostly on stored potential energy by gravity, the motor may overspeed beyond excessive limits unless prevented by a brake or a tachogenerator relay.

Critical speed

At certain speeds, rotating masses become dynamically unstable and cause deflection and vibration in the rotor which may damage the motor. The speed at which such instability occurs is known as critical speed and occurs at different multiples of the rated speed. The masses must therefore rotate within 20% below or above the critical speeds to avoid such a situation. These vibrations settle down again at higher speeds above critical and recur at the next higher critical speed.

To achieve a vibration level of 0 micron in a rotating mass is practically impossible. It will possess some run-out, however precisely and accurately it has been balanced. While rotating, therefore, the shaft on which the other masses rotate, will deflect to the side which is heavier and the opacity around the centre of the shaft will become uneven. The masses will rotate in small circles about their own geometrical axis rather than the axis of the shaft.

In a motor the first critical speed is several times higher than the operating speed and may not reach in operation. In downhill conveyors, without any mechanical speed control, such speeds may be reached when the motor over-speeds while descending. When so, the motor should be disconnected from the supply lines, otherwise there will be excessive over-loading. There may be several critical speeds in a rotating mass which tend to become infinite with the number of loads on the same shaft. But the first critical speed alone is of significance, as other critical speeds much higher than even the first critical speed are of no relevance. No rotating mass may possibly reach this during operation in an induction motor.

Induction generator as a wind powered generator

The main application of this machine is found in non-conventional energy generation, such as for wind power, gas turbines and mini- or micro-hydropower generation etc. They are used extensively to convert wind power into electrical power. The wind power is first converted into rotating kinetic energy by aerodynamically designed blades. This energy is then converted into electrical energy through these machines. They are thus known as wind electricity generators (WEG). Presently such machines are in use from 50 kW to 6 MW worldwide. In India they are in use for up to 1 MW (mostly in the range 400–600 kW). Potential locations for such machines are coastal areas, where there are high and continuous winds. In India examples of these locations are in the states of Maharashtra, Kerala, Tamil Nadu, Karnataka and Gujarat.

The electricity generated depends primarily on the speed of the wind at the site of installation. A conventional formula to determine the wind energy, based on the design of the rotor (rotating blades) and the site conditions is given by

$$P = 0.5 \cdot C_p \cdot A \cdot \rho \cdot V^{3\text{a}} \qquad (7.4)$$

where

P = power generated by the turbine (windmill) in watts
C_p = coefficient of performance which depends upon the aerodynamic efficiency of the rotor and varies with the number of blades and their profile. This factor is provided by the mill supplier and generally varies between 0.35 and 0.45
A = swept area of the rotor in m^2

$$= \frac{\pi D^2}{4}$$

where

D = diameter of the rotor (blades) in m
ρ = air density = 1.225 kg/m^3
V = velocity of wind at the site of installation, at the height of the hub in m/s

Typical specification for a KEC 400 kW machine is provided below for a general reference:

Cut-in speed = 4.5 m/s

Approximate output at the cut-in speed from the manufacturer's data (Figure 7.26) = 8 kW

Rated wind speed = 11.5 m/s

Mean wind speed = 25 kmph

$$= \frac{25 \times 1000}{60 \times 60} \text{ m/s}$$
$$= 6.94 \text{ m/s}$$

Note
Generally, the ratio of rated to mean wind speed may be quite high due to long lean periods, when the machine may stay idle, reducing the value of the mean speed.

Shutdown speed = 20 m/s
Rotor diameter including hub = 39.35 m

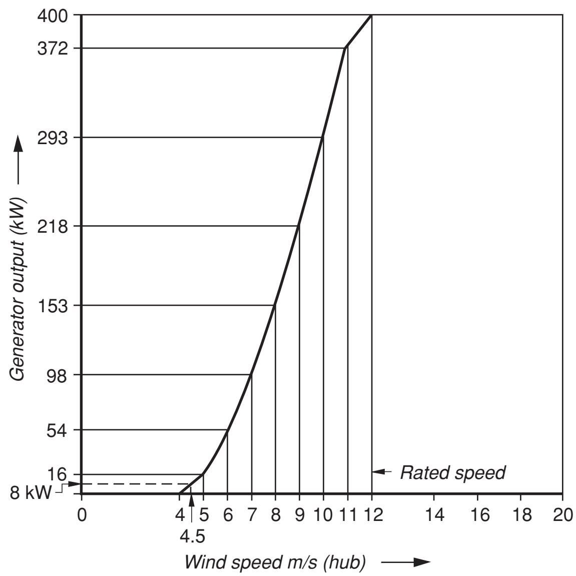


Figure 7.26 Typical power curve for an induction generator of 400 kW at 11.5 m/s wind speed

[a] The ideal condition would be when the rotor output is a cubic function of wind speed. But in practice this may not be so. It is found to be linear or a near quadratic (square) function of the wind speed, as shown in Figure 7.26.

Rotational speed of the rotor at the rated wind speed = 38 r.p.m.

Example 7.3

For the above machine the wind power considering the C_p as 0.35 will be:

$$P = 0.5 \times 0.35 \times 1.225 \times \pi \times \frac{39.35^2}{4} \times 11.5^3$$

$$= 396.3 \text{ kW}$$

Below we give a brief idea of the mechanical system of such a mill and its various controls, as a passing reference. For more details on the subject, see the Further Reading at the end of the chapter.

Mechanical system

See Figure 7.27, illustrating the general arrangement of a windmill.

1 **Tower** This may be tubular or lattice type to mount the mill's mechanism. The structural design is based on the cutout wind speed.
2 **Nacelle** This is the main housing of the mill, made of metal or FRP and contains a rotating hub on which is mounted the blades. Inside the housing is a gearbox, one end of which is coupled to the rotating blades and the other to the generator. For optimum efficiency of the mill, it is essential that the blades fall perpendicular to the direction of the wind. To accomplish this, the nacelle is made to rotate at the top of the tower. It aligns to the required direction through a yawing mechanism which adjusts the rotor assembly so that when the blades are in motion they fall perpendicular to the wind direction and, when at rest, at low and high cut-out speeds, they fall in line with the wind direction for minimum stress.
3 **Blades** These are made of wood and epoxy compound composite material or fibre glass. Their mechanical strength is also commensurate with the cut-out wind speed. These blades are connected to a rotating shaft coupled to the generator through a gear assembly. They may also be fitted with an additional feature of a pitch control mechanism through a servomotor or a hydraulic system. Such a system can rotate the blades around their own axis to adjust their angular speed with the speed of the wind. This feature assists the gear system to provide a near-constant speed to the

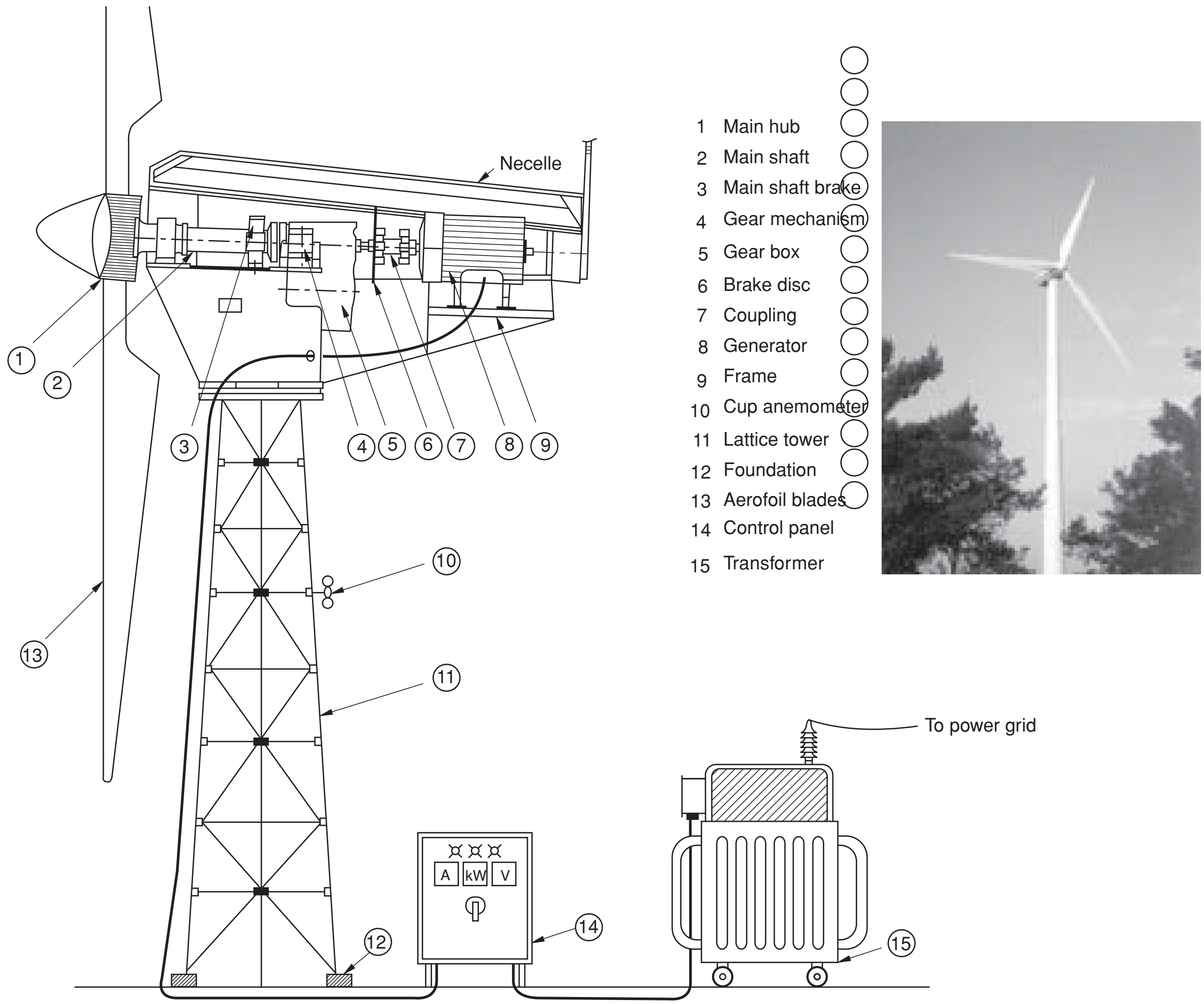


Figure 7.27 General arrangement of a windmill

rotating shaft. It also helps in 'slipping' the excess power of wind to some extent, to optimize the operation and running hours of the machine during excessive wind speeds exceeding the cut-out speed. This feature also protects the machine from excessive wind pressure (for example, during storms).

4 **Yaw** This is a mechanism that helps the nacelle to move in the right direction with the help of a yawing motor or a hydraulic system. In this case the hydraulic system provides a smoother movement.

5 **Hydraulic power supply** This actuates brakes and also feeds the yawing and pitch control (if they are also hydraulically operated).

6 **Brakes** These block the rotor at the cut-in and cut-out speeds and also during maintenance:

- Cut-in wind speed is the minimum wind speed at which the generator commences the generation of power. At this speed the brakes release and the prime mover (blades) starts rotating.
- Cut-out wind speed is the maximum wind speed beyond which the prime mover may overspeed above its permissible limits. As the structure and the blades are designed for a particular maximum speed, a wind speed higher than this may exceed their mechanical endurance and become unsafe. At this speed the brakes apply and the machine is disconnected from the grid. The cut-in and cut-out speeds define the wind speed limits within which the turbine will work safely through the generator.
- Rated wind speed is the speed at which the prime mover rotates at the rated negative slip and generates the rated power.

Note
To avoid unnecessary wear and tear of the machine, the blades are braked when the machine is not in operation. In fact the main protection to the machine is through the brakes only. During an over-loading or system fault condition the blades are braked and the machine ceases to generate. The control panel monitors closely all the operating parameters and sends out warning signals or stops the machine when operating conditions exceed the permissible limits.

7 **Gear system** Since the wind speed is never the same, and the rotor is never permitted to rotate at a higher speed than its designed parameters, a gear system is provided between the blades and the generator rotor to protect it from excessive wear and tear. The gear system helps the generator rotor to run at the generator's rated speed. The normal gear ratio to boost the speed of the prime mover to the generator speed is from roughly 30–40 r.p.m. to a little over the synchronous speed of the induction generator. The gear system is a two- or three-stage fixed ratio gearbox giving fixed output speeds. Fine adjustment is achieved through pitch control of the blades.

8 **Sensors**

- Anemometer – to monitor wind speed
- Temperature sensors – to monitor the operating temperature of the gearbox, generator windings and other important parts of the machinery
- Wind vane – to monitor wind direction
- Vibration sensors – to monitor correct alignment, loose or worn-out parts etc.
- Pressure sensors – for the hydraulic system that actuates the yawing mechanism, brakes and pitch of the blades

9 **Electrical system**

- Frequency inverters to regulate the voltage and frequency – Earlier they used to be thyristor controlled, but now they are usually IGBTs or other transistor-thyristor based hybrid semiconductor devices as discussed in Section 6.7, depending upon the rating of the wind generator. They are capable of handling large powers besides being economical.

  Rating for inverters – In case of wound generators the rating of frequency inverters can be commensurate with the rotor power it has to handle rather than the rating of the machine as in the case of cage generators. In wind generators the rotor power refers to the power between the cut-in and cut-out speeds which is much less than the synchronous rotor power (P_r) (Equation (1.9)). The low and high cut-off speeds can be well defined to optimize the running hours of the wind energy conversion. The inverters for wound generators, therefore, can be rated for just 30% or less of the rating of the generator. Figures 6.47 and 6.48 show a slip recovery system and its block diagram that can be applied now also. For wind power generation therefore usually wound rotor motors are preferred when controls are easy and power generation efficient and economical and a lower capacity inverter would suffice. This is more true in case of large wind farms where such controls are very costly compared to small drives.

  The inverter using PWM technique first excites the generator until the stator voltage builds up and synchronizes with the grid and then switches it to the grid. The sequence reverses when the generator is switched off. The phasor or field oriented control technique adjusts the torque of the machine and the reactive power to the preset values.
- Control and relay panel – This may be microprocessor based to record, display, monitor and control the generated power, voltage and frequency and also detect fault conditions. It can also have interfaces for remote monitoring and control of the machine such as through a 'remote drive and a telemetry software' (Section 6.7.4(5)).
- Related switchgears
- Main power panel to receive power from the generator and feed this back to the grid.
- Step-up transformer if the voltage of the generator is different from that of the grid.

Use of capacitors

To optimize the power generated, power capacitors are installed to compensate for the reactive power, particularly that which the machine draws from the grid. The capacitors must be suitable for a minimum voltage of $V_r + 13\%$.

Active power

The power the machine feeds back to the grid is expressed by Equation (7.3) discussed earlier.

Note

A normal motor is designed for a slightly lower voltage than the system voltage to account for cable drops from the source of supply up to the motor. But as an induction generator, it is designed for a slightly higher voltage than the grid voltage or the primary voltage of the transformer (when a transformer is installed to raise the voltage of the wind generator to the grid voltage) to account for the voltage drop from the generator to the grid or the transformer.

10 Wound rotor motors as induction generators

Usually it is a standard wound motor also termed as doubly fed asynchronous motor that is used as induction generator with additional treatment to weather the site conditions. The normal specifications are generally the same as for a standard motor. The permissible voltage and frequency variations are, however, wider as noted below,

Voltage ± 13%

Frequency – 3% + 3%

or as may be required to suit a particular grid system. A frequency limit of +3% signifies that the machine should not overspeed beyond 101.5% of its synchronous speed. This is to avoid over-loading of the machine as well as retaining synchronism with the grid.

As soon as the wind speed reaches the minimum required speed (cut-in speed), the brakes release and the prime mover picks-up speed. At about 95% of the rated speed of the machine, the stator of the induction generator is supplied with the necessary reactive power from the grid through the inverter, to generate the required magnetic field. At this speed, which is almost the rated speed of the motor, the machine draws just enough reactive power from the grid to meet its magnetizing requirements, also a small amount of mechanical power from the wind power to meet its friction and windage losses (line D_1P_1 of Figure 7.24). The magnetizing current is now much less than the no-load losses of the machine when it operates as a motor. The inverter provides the machine a soft start to control the starting current to almost the rated current in case of excessive machine speed. It also avoids an excessive voltage dip at the generator terminals and time to hook up to the grid. As soon as the machine exceeds its synchronous speed, it starts generating and feeding the active power back to the grid, similar to the output curve of the machine in Figure 7.26. (The curve is provided by the machine supplier.) The generator, when hooked up to the grid, will follow the grid voltage and frequency (Section 16.9.1(II)). The generator is regulated not to overspeed beyond 101% of its synchronous speed. Small speed variations are carried out through pitch control to optimise the power output and running hours of the machine. The power generated is proportional to the negative slip at which the machine operates (line P_1P_2 of Figure 7.24).

The total reactive power that it draws from the grid

$$VAr = \sqrt{3} \cdot V_r \cdot I_m \text{ watts}$$

where

V_r = rated voltage of the machine in volts, and
I_m = magnetizing current of the machine in amps. (Figure 1.15)

Squirrel cage motors as induction generators

Now the control of the motor is through the stator rather than the rotor as was in the previous case. The rating of the inverter unit now has to be commensurate with that of the machine and makes it a costly arrangement compared to the wound motors. Large wind generators as squirrel cage motors therefore are not preferred. But small mills up to 500 kW or so can use cage generators when controls may not be so costly.

Note

In small mills it is possible that the wind energy is consumed directly by the connected loads or stored through the batteries than feeding to the grid and thus save on the cost of drives. When so the machine can also be wound for a dual speed, such as 4/6 pole, so that when the wind speed falls below the minimum cut-in speed the lower speed windings take over and the generator may still operate and supply the power to the connected load at a slightly lower output (in the ratio of motor outputs at the two speeds). To achieve this, two switching circuits may be provided, one for each speed as shown in Figure 13.59 (Table 6.1). By doing this we can improve the running hours and so the efficiency of the generator.

The changeover is obtained by measuring the average power generated during a particular time period, say, one minute or so, rather than the speed of the wind. When this average power falls below a preset level the machine changes over to the lower speed windings and vice versa. Due to the unpredictable nature of the wind speeds, this may require frequent changeovers and may affect the reliability of a double-speed system.

Micro siting

To identify the correct location and size of a mill it is essential to ensure that there is adequate wind at high speeds at the site. The process of identifying the most appropriate locations is termed micro siting. Local government and private agencies conduct surveys and compile wind data for potential areas for these mills. A list of these agencies in India is provided at the end of the chapter. These mills are generally installed away from areas of habitation for maximum wind and safety for people and animals or in remote areas not connected with power lines. The power so generated may be captive to supply nearby areas or feedback to a power grid to augment its capacity. In remote areas where no power grid exists the power so generated may also be stored in batteries through a voltage source inverter and utilized when required. Such a system, however, is more convenient for small mills, say, up to 5 kW, otherwise the cost factor may act as a deterrent to such an arrangement. Normally such mills are installed in groups known as wind farms to provide a sizeable power source, except in remote areas, where power demand may be restricted to a very limited area and small mills may suffice. When mills are installed in groups, precautions are necessary to ensure that there is enough distance between any two mills so that there is no hindrance to routine maintenance, on the one hand, and obstruction of wind to other mills, on the other. For more details, refer to the literature available on the subject in the Further Reading at the end of the chapter.

Relevant Standards

IEC	*Title*	*IS*	*BS*	*ISO*
60034-1/2004	Rotating electrical machines. Single speed three phase induction motors for driving lifts.	4722/2001, 8151/2002	BS EN 60034-1/1998, BS 5000-99/1986	–
60034-3/2005	Rotating electrical machines. Specific requirements for turbine type synchronous machines.	–	BS EN 60034-3/1996	–
60034-5/2001	Rotating electrical machines. Classification of degrees of protection provided by enclosures for rotating machinery (IP code).	4691/1999	BS EN 60034-5/2001	–
60034-6/1991	Designation of methods of cooling of rotating electrical machines (IC Code).	6362/2002	BS EN 60034-6/1994	–
60034-7/2000	Rotating electrical machines. Classification of types of constructions and mounting arrangements (IM Code).	2253/2002	BS EN 60034-7/1993	–
60034-9/2003	Rotating electrical machines. Noise limits.	12065/1999	BS EN 60034-9/1998	–
60034-12/2002	Values of performance characteristics for induction motors. Three phase motors for centrifugal pumps for agricultural application.	8789/2002 7538/2002	BS EN 60034-12/2002	–
60034-14/2003	Rotating electrical machines – mechanical vibration of certain machines with shaft heights 56 mm and above. Measurement, evaluation and limits of vibration.	–	BS 4999-142/1987	–
60034-18-1/1992	Guide for testing insulation resistance of rotating electrical machines, rated for 1MW and above.	7816/2002	BS EN 60034-18-1/ 1994	–
60072-1/1991	Dimensions and output series for rotating electrical machines. Frame number 56 to 400 and Flange number 55 to 1080.	1231/1997	BS 4999-141/2004	–
60072-2/1990	Dimensions and output series for rotating electrical machines. Frame number 355 to 1000 and Flange number 1180 to 2360.	1231/1997	BS 4999-103/2004	–
60072-3/1994	Dimensions and output series for rotating electrical machines. Small built-in motors – Flange numbers BF 10 to BF 50.	996/2002	BS 5000-11/1989	–
60079-0/2004	Electrical apparatus for explosive gas atmospheres. General requirements.	2148/1998	BS 5501-1/1977	–
60079-1/2003	Construction and verification test of flameproof enclosures of electrical apparatus – Enclosure ‘d’.	2148/1998	BS 4683-2/1993, BS EN 50018/2000	–
60079-2/2001	Electrical apparatus. Type ‘p’.	7389/2001	–	–
60079-7/2004	Construction and testing of electrical apparatus with type of protection *‘e’*.	6381/2001	BS EN 50019/2000, BS 5000-15/1985	–
60079-10/2002	Electrical apparatus for explosive gas atmospheres. Classification of hazardous areas.	5571/2000	BS EN 60079-10/2003	–
60079-11/1999	Specifications for intrinsically safe electrical system ‘i’.	3682/2002	BS EN 50020/2002	–
60079-12/1978	General recommendations on the selection of the appropriate group of electrical apparatus based on safe gaps and minimum igniting currents.	–	–	–
60079-14/2002	Electrical installations in hazardous areas (other than mines).	5572/1999	BS EN 60079-14/2003	–
60079-15/2001	Electrical apparatus with type of protection ‘n’.	9628/1999, 8289/2001	BS EN 50021/999, BS 5000-16/1997	–
60079-17/2002	Inspection and maintenance of electrical installations in hazardous areas (other than mines).	–	BS EN 60079-17/2003	–

IEC	Title	IS	BS	ISO
60079-19/1993	Repair and overhaul for apparatus used in explosive atmospheres (other than mines or explosives).	–	BS IEC 60079-19/1993	–
60079-20/1996	Data for flammable gases and vapours for electrical apparatus.	–	–	–
60851/1996	Winding wires for submersible motors.	8783-1-4/2000	BS EN 60851/1998	–
61241-3/1997	Electrical apparatus for use in the presence of combustible dust. Part 3 – Classification of areas where dust are or may be present.	–	–	–
–	Textile motors : Loom motors.	2972-1/2002	–	–
–	Textile motors : Card motors.	2972-2/2002	–	–
–	Textile motors : Spinning frame motors.	2972-3/2002	–	–
–	Code of practice for safe use of cranes.	3177/1999	BS 7121-1,3	–
–	Code of practice for heavy duty power driven overhead travelling cranes, including special service machines for use in steel work.	4137/2000	BS 466/1984	4301-1/1986, 8306/1985
–	Specification for power-driven mobile cranes.	4573/2000	BS 1757/1986	–
–	Code of practice for design of portal and semi portal wharf cranes (electrical).	4594/2000	BS 2452/1954	–
–	Intrinsically safe electrical apparatus and circuits	5780/2002	–	–
–	Submersible pump sets – Specifications.	8034/2002	–	–
–	Interconnecting busbars for a.c. voltage above 1 kV up to and including 36 kV.	8084/2002	BS 159/1992	–
–	Guide for Electrical equipment for explosive atmospheres.	8240/1991	–	–
–	Method of marking for identifying electrical equipment for explosive atmospheres.	8241/1991	–	–
–	Motors for submersible pump sets.	9283/2002	–	–
–	Specification for general purpose electrical power driven winches for lifting and hauling.	9507/2000	–	–

Relevant US Standards ANSI/NEMA and IEEE

NEMA/MG-1/2003	Motors and generators ratings, construction, testing and performance.
NEMA/MG-2/2001	Safety Standards (enclosures) for construction and guide for selection, installation and use of rotating machines.
NEMA/MG-3/2000	Sound level prediction for insulated rotating electrical machines.
NEMA/MG-10/2001	Energy management guide for selection and use of three phase motors.
NEMA/C50.41/2000	Polyphase induction motors for power generating stations.

Notes

1 In the table of relevant Standards while the latest editions of the Standards are provided, it is possible that revised editions have become available or some of them are even withdrawn. With the advances in technology and/or its application, the upgrading of Standards is a continuous process by different Standards organizations. It is therefore advisable that for more authentic references, one may consult the relevant organizations for the latest version of a Standard.

2 Some of the BS or IS Standards mentioned against IEC may not be identical.

3 The year noted against each Standard may also refer to the year it was last reaffirmed and not necessarily the year of publication.

List of formulae used

Determining the size of motor

For lifting and hoisting

$$P_h = \frac{F \cdot V}{102 \cdot \eta} \text{ kW} \tag{7.1}$$

F = useful load in kgf

V = lifting speed in m/s

η = efficiency of the mechanism

For traverse

$$P_t = \frac{1.027 \cdot T_{max} \cdot N_r}{1000 \cdot \eta} \text{ kW} \tag{7.2}$$

T_{max} = maximum torque

η = efficiency of the whole mechanism for traversing

Induction generator power output

$$G_1 = \sqrt{3} \cdot I_G \cdot V \cdot \cos\phi \cdot K \quad (7.3)$$

G_1 = generator output at the same negative slip as for the motor
K = factor to account for the lower p.f. at higher negative slips, when working as an induction generator
I_G = generator rated current in A
$\cos\phi$ = generator rated p.f.

Wind energy

$$P = 0.5 \cdot C_p \cdot A \cdot \rho \cdot V^3 \quad (7.4)$$

P = power generated by the windmill in watts
C_p = coefficient of performance
A = swept area of the rotor in m^2
D = diameter of the rotor (blades) in m
ρ = air density = 1.225 kg/m^3
V = velocity of wind at the site of installation, at the height of hub in m/s

Further Reading

1 Anderson, H.H., *Submersible Pumps and their Application*, The Trade and Technical Press Ltd, Morden, Surrey.
2 Battiwala, N., 'Centrifugal motors for the sugar industry,' *Siemens Circuit*, **III**, No. 4, July (1968).
3 Brown Boveri & CIE, *Explosion Protection Manual*, Aktiengesellschaft Mannheim Verlag, W. Giradet, Essen, Germany.
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State agencies in India for micro siting of windmills

1 The Agency for Non-conventional Energy and Rural Technology (ANERT), PB No. 442, Thaycaud PO, Trivandrum 695 014, Kerala.
2 The Tamil Nadu Energy Development Agency (TEDA), Jhaver Plaza, IV Floor, 1-A, Nungambakkam High Road, Chennai 600 034, Tamil Nadu.
3 The Karnataka State Council for Science and Technology, Indian Institute of Science, Bangalore 560 012, Karnataka.
4 The Non-conventional Energy Development Corporation of Andhra Pradesh (NEDCAP), 5-8-207/2, Pisgah Complex, Nampally, Hyderabad 500 001, Andhra Pradesh.
5 The Gujarat Energy Development Agency (GEDA), Suraj Plaza II, 2nd Floor, Sayajiganj, Vadodara 390 005, Gujarat.