TECHNICAL GUIDE

PROTECTION AND CONTROL

OF THREE-PHASE ASYNCHRONOUS MOTORS

GLOBAL SPECIALIST IN ELECTRICAL
AND DIGITAL BUILDING INFRASTRUCTURES

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Industrial applications require unstinting reliability. This is achieved by technical and operational compatibility of the various components, among other things.
Motors and their protection devices constitute a remarkable example of the need for these complementary features.
Legrand already provided a complete solution to needs for **protection**, **control**, **connection** and **provision of energy** for the majority of applications in all sectors. This field has now been extended with the new ranges of **MPX³ motor MCBs** and **CTX³ contactors**.
Electric motors are found everywhere nowadays. It is impossible to give an exhaustive list of their applications: civil engineering, port activities, material handling, conveying, air and water treatment, drying, agriculture and a whole variety of different machinery.
Although there are generic rules, covered in this guide, for motor protection, special precautions are also required depending on their operating mode; the numerous technologies available for these motors also constitute a determining factor in terms of familiarity.
After issuing a few reminders on the basics, this guide aims to be the go-to tool for people wishing to **select motor protection devices** from the ranges Legrand now offers.
Our aim is to provide an accurate, immediate response to the majority of needs, backed up by the necessary technical information for selecting and sizing installations, and advice concerning their implementation.
Whether for a cabinet for lift pumps, an air handling unit, a boiler room or an automation process, Legrand is your new partner when it comes to **motor protection and control**.

To meet these needs,
Legrand offers a whole range of products

LEGRAND ENERGY EFFICIENCY

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MOTOR APPLICATIONS

Broad outlines

Almost all machines incorporate electric motors. Their reliability is therefore a determining factor in continuity of operation of these machines and their durability. It is therefore essential to select the right protection devices for them.

Depending on the complexity of installations and reliability required, different strategies can be applied. Protection based on standard thermal-magnetic MCBs, possibly combined with switches, is an option for simple cases of little-used low-power motors which are not subject to repeated stop-start cycles.

Almost all motors used in industrial processes or integrated in machines need to be controlled and protected with special devices, such as motor MCBs and contactors.

There are numerous causes of motor faults, which have varying effects but in the end the consequences are fairly similar: dielectric breakdown or electrodynamic stresses due to both short-circuits and overheating which can lead to destruction of the windings and the motor being put out of service (see table below).

FAULTS OF ELECTRICAL ORIGIN	EFFECTS AND CONSEQUENCES
Short-circuit on the windings	Destruction of windings due to current surge or electrodynamic stress
Voltage surges associated with lightning	Dielectric breakdown and destruction of the windings
Voltage unbalance	Reduction in useful torque, additional losses and overheating
Voltage dips	Reduction in useful torque, additional losses and overheating
FAULTS OF MECHANICAL ORIGIN	**EFFECTS AND CONSEQUENCES**
Jammed transmission shaft	Moderate current surge resulting in overheating of the windings
Overload	Moderate but prolonged current surge resulting in overheating of the windings
Long starting time	Repeated current surges which can in the long term lead to premature ageing due to overheating

Protection devices should be designed and selected with special rules for motors in mind. Short-circuit protection devices must have a short-circuit breaking capacity and also a short-circuit making capacity; the fault may already have been present when the contactor closed.

An overload constitutes the most common risk for motors. It involves an increase in current consumption and thermal effects which reduce service life due to premature ageing of the insulation. Over time, deterioration of the insulation can cause short-circuits between the turns and, little by little, total destruction of the winding.

It is **essential** to select and set a thermal relay in order to provide protection against overloads which is reliable (to prevent false tripping) and effective (to provide long-term protection). Before returning to the subject of motor protection and the devices to be installed, the first part of this guide aims to remind the reader of general information about motors, their diversity, their particular characteristics and their components.

MOTOR APPLICATIONS

General

Electric motors are part of our everyday environment and are fitted in our household appliances as well as the buildings in which we live. They are used for their motive power (driving force) in a wide variety of applications.

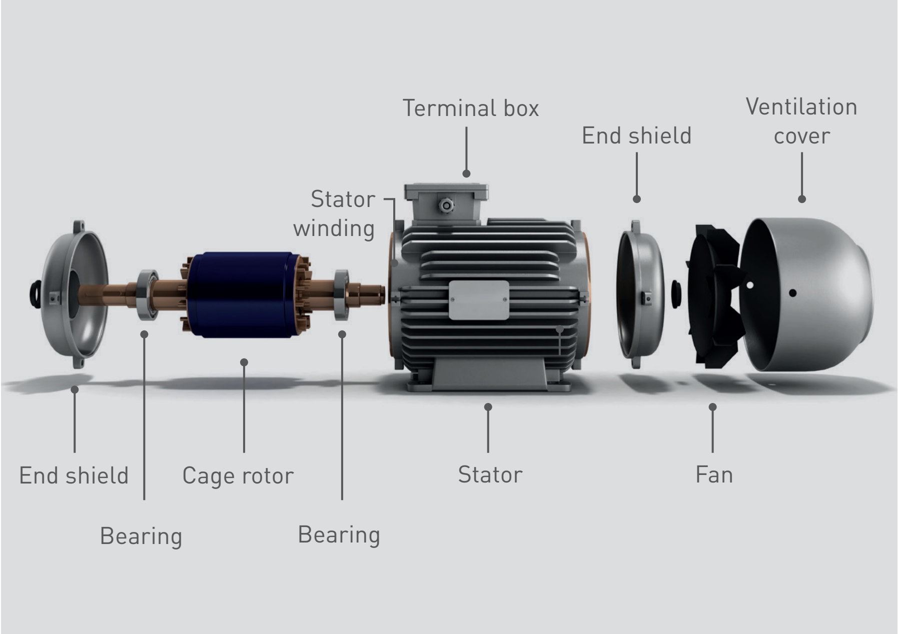
A distinction is made between several types of electric motor: asynchronous motors are regularly used in commercial and industrial applications. Single-phase asynchronous motors are more commonly used in domestic applications and building services, whereas other motors, such as synchronous motors and DC motors, are used in more specific applications.

Although most motors in our environment are single-phase, some applications call for the use of motors operating on all three phases, in order to boost the power. This is notably the case for applications in commercial environments (ventilation, air conditioning, etc), in industrial environments (pumps, compressed air, assembly lines) and for industries such as water (pumping), extracting materials (conveying, crushing) and even construction (lifting). Three-phase motors have very high power ratings (more than 400 kW) but the majority of them are low-power: more than 3/4 of three-phase asynchronous motors sold commercially have a power rating of less than 2.2 kW 400 V.

COMPOSITION

Motors are made up of several components:

- **Frame** or **casing**: this supports all the fixed parts of the motor and the end shields.
- **Stator**: this consists of copper windings and generates the magnetic field needed to turn the rotor. It is fixed to the internal walls of the frame. The ends of its windings are brought into the terminal box. Although generally reserved for DC motors, the term field winding is also used.
- **Rotor**: this consists of windings or permanent magnets and converts the magnetic field into motive power. It delivers torque to the shaft. It may be called an "armature" in DC motors.
- **Terminal box**: this is used to link the coils together and connect the power supply.



Example of an asynchronous motor with short-circuited rotor

OPERATING PRINCIPLE

Motors operate according to a common principle - induction. There is a relationship between the stator, which generates the magnetic field and the rotor, which transmits the motive power, with galvanic isolation between the two components.

The stator winding power supply generates magnetic induction which is associated with a magnetic field from which the motive power is created.

To produce a rotating motion, the rotor must be subjected to two alternating flows which are not synchronised in time and which are applied in two different places, staggered according to the desired direction of movement.

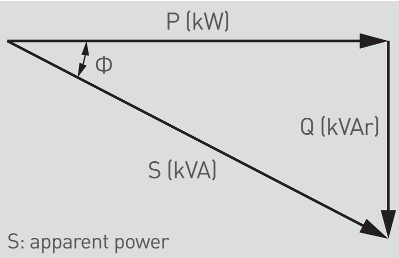
The difference between the speed of the revolving field created by the stator and the rotor rotating speed is called “slip”.

Depending on the type of current used (single-phase, polyphase AC, or DC), the design of the stator, rotor and techniques used will differ but the basic principle remains the same.

ACTIVE AND REACTIVE POWER

A motor consumes part of the active power, which it converts into mechanical force, and part of the reactive power used to magnetise its windings, but which does not participate in the motive power. The magnetisation current can represent 20% of the total current for two-pole motors and up to 60% for small 8-pole motors. It is independent of the load but depends on the stator design and the voltage applied. It is highest at the time of starting. A motor's power factor on starting is around 0.1 to 0.25, then increases to its maximum during the acceleration phase and goes back down as it approaches its maximum speed.

The active power and reactive power, illustrated by P and Q respectively in the following diagram, give the apparent power S. The ratio between the active power, measured in kW, and the apparent power, measured in kVA, is called the power factor, or Cos φ. Using Cos φ to express the power ratio is possible because motors constitute linear loads per se. If they are being used with electronic power converters, it is better to refer to the power factor (Tan φ), which takes account of the distorting power (harmonics). See Power Guide Book 2 page 16, available on our website.



S: apparent power
P: active power
Q: reactive power
Φ: phase shift between the apparent power and the active power (same as the phase shift between the current and the voltage)

Cos φ represents the angle between P and S, and generally has a value between 0.7 and 0.9 for asynchronous motors. In installations where there are a huge number of motors, a significant amount of reactive power factor is consumed and the power factor is degraded. This results in higher electricity costs and an increase in current consumption. It is therefore advisable to correct the installation power factor by using capacitor banks.

The reactive power can be compensated centrally at the point of delivery or right next to the receivers. In this second instance, the capacitors are sized to their specific motor. They are connected in parallel with the motor, or set of motors, by means of contactors which can then be optimised (low current).

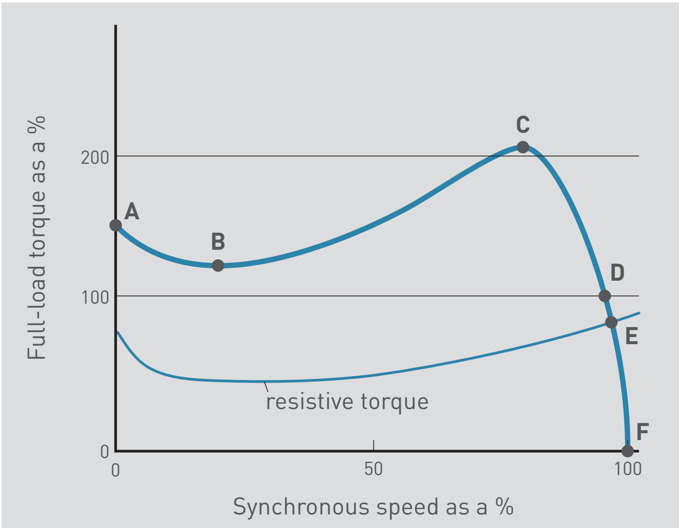
Refer to the technical guide: Automatic capacitor bank enclosure for panel builders, available for download from our website.

■ **Inrush current:**

A characteristic common to all electrical windings subjected to voltage, energisation of the stator creates a current peak, around 5 to 8 times the motor nominal current or even more for high-efficiency motors. This inrush current is one of the fundamental characteristics to be taken into account when selecting the protection device and type of starting (no-load, full load, reduced voltage, with frequency variation, etc).

OPERATING PRINCIPLE (CONTINUED)

■ **Characteristic features of a motor torque-speed curve:**



A: Starting torque or breakaway torque: This is the value of the torque delivered by the motor when it is powered up, at the point when the rotor starts to move. It can only be applied for a few fractions of a second and it is directly proportional to the power supply voltage. It is the same as nominal torque for synchronous motors. It is therefore important to check the motor operating voltage range in these starting conditions and particularly to take account of the voltage drop.

B: Acceleration torque: This is the lowest point on the curve corresponding to the period preceding motor acceleration towards its maximum speed. It should be higher than the resistive torque in order to allow the motor to accelerate. Some motors are not affected by this torque drop and the minimum value remains that of the starting torque.

C: Breakdown torque: This is the maximum point on the curve corresponding to the amount of torque available on the shaft when the motor is supplied at its nominal voltage. Increased stress on the motor creates a dip in the motor speed of rotation (increased slip), up to this breakdown torque value, beyond which the motor can become unstable (stalling). The breakdown torque should be at least 1.6 times the operating torque requested, in compliance with the standards, with the option of overloading the motor to this value for 15 seconds, at nominal frequency and voltage.

D: Nominal torque (Nm): This is the torque available on the shaft at nominal frequency and voltage without overheating. Torques stated by manufacturers of asynchronous motors are given for a maximum ambient temperature of 30°C. These motors should guarantee nominal torque in continuous operation without exceeding their maximum temperature value. There are some operating modes (S2, S3, S6), in which the nominal torque can be exceeded provided that the temperature rise limit value is respected.

E: Working point: This is the value at which the torque available on the shaft meets the resistive torque.

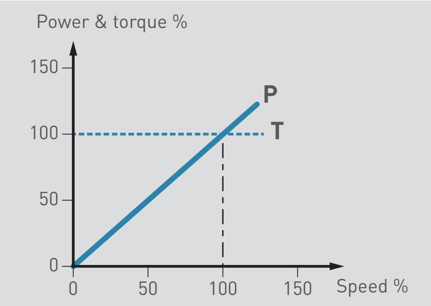
F: Synchronous speed: This is the maximum theoretical speed of the motor supplied at its nominal voltage, at which it should develop torque equal to zero. In practice, it corresponds to the speed of rotation of the revolving field, and is therefore proportional to the power supply frequency and the number of stator poles.

DIFFERENT LOAD TYPES

There are numerous load types and therefore numerous different torque-speed curves. The most common are constant torque, torque with speed variation, variable torque and hybrid forms, with for example starting using high torque then constant torque. Depending on the type of load, it is advisable to define the starting mode. The motor load is deemed to be stable when the torque developed by the motor is equivalent to the requested load torque.

■ Operation at constant torque

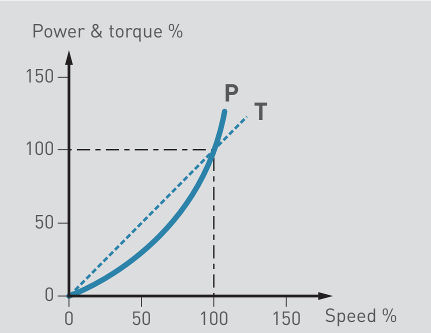
In steady state, the requested torque is the same irrespective of the speed of rotation. Applications are elevators or conveyors, for example. The torque supplied on starting (Ts) should be enough to counter the mechanical resistance and accelerate the machine. Ts ⩾ 1.5 x Nominal torque (Tn).

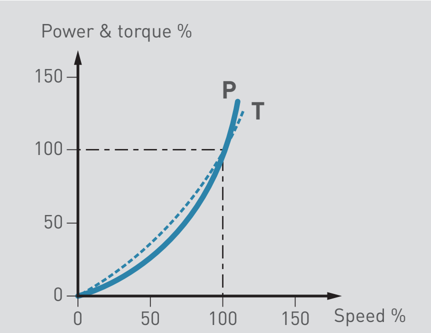


Operation at constant torque

■ Operation with torque which increases with the speed

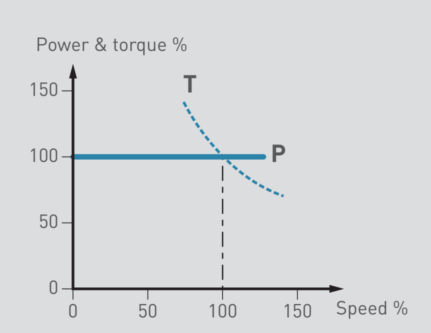
The requested torque increases with the speed of rotation. Depending on the application, the torque can increase in a linear way (volumetric pumps, extruders) or according to the square of the speed (fans). The torque requested for starting is lower. Ts ⩾ 1.2 x Tn.





■ Operation with torque which decreases with the speed

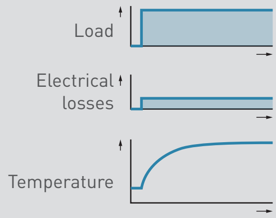
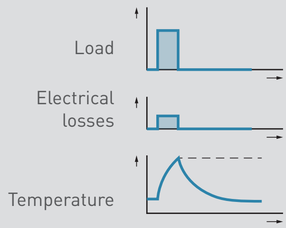
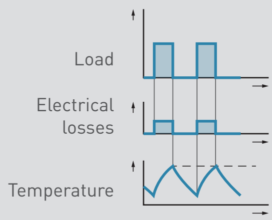
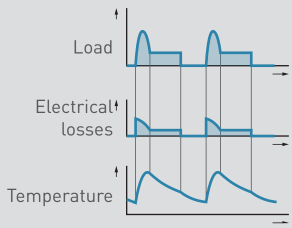
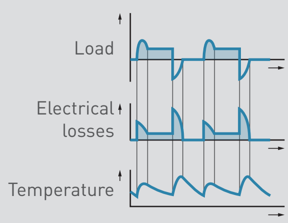
The requested torque decreases with the speed of rotation. The power remains constant. Applications are more limited (coil winders).

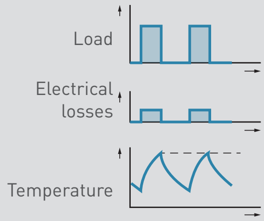
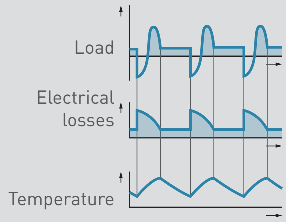
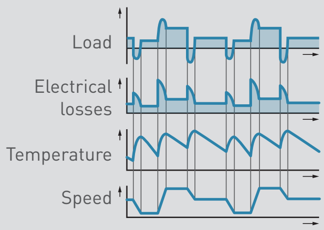
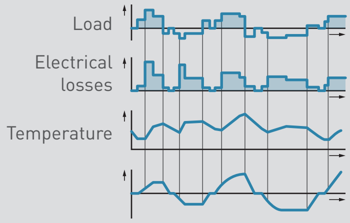
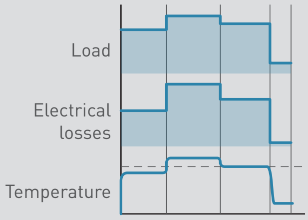


DUTY CYCLES

Duty cycles are used to select motors according to the number of starting and braking operations per unit of time, in order to take account of the temperature rise generated in the windings. These duty cycles are defined by standard IEC 34-1.

There are several classes as indicated below:

S1	**Continuous duty**	Operation at constant load of sufficient duration for thermal equilibrium to be reached.	
S2	**Short-time duty**	Operation at constant load for a set time less than the thermal equilibrium time followed by sufficient off time for equal temperatures between the motor and the ambient air to be re-established. This duty cycle can allow useful power which is higher than the nominal power.	
S3	**Intermittent duty**	Repetition of identical duty cycles, each consisting of a period of operation at constant load and an off period. The starting current does not significantly affect the motor temperature rise. This duty cycle can allow useful power which is higher than the nominal power.	
S4	**Intermittent periodic duty**	Identical to S3 duty but with a long starting period which affects the motor temperature rise. The cycle includes a period of running constantly and an off period. The cycles are too short for thermal equilibrium to be reached.	
S5	**Intermittent periodic duty with electrical starting**	Repetition of identical duty cycles, each consisting of a starting period, a period of operation at constant load, a period of rapid electrical braking and an off period. The cycles are too short for thermal equilibrium to be reached.	

S6	**Periodic continuous duty with intermittent load**	Repetition of identical duty cycles, each consisting of a period of operation at constant load and a period at no load without an off period.	
S7	**Periodic continuous duty with electrical starting and braking**	Repetition of identical duty cycles, each consisting of a starting period, a period of operation at constant load, a period of electrical braking and no off period. The cycles are too short for thermal equilibrium to be reached.	
S8	**Periodic continuous duty with speed variations**	Repetition of periodic cycles, each consisting of a starting period, a period of operation at constant load followed by periods of operation at other constant loads and other speeds of rotation. There is no off period. The cycles are too short for thermal equilibrium to be reached.	
S9	**Duty with non-periodic speed variations**	Duty in which load and speed vary according to the application. This duty can take account of significant overloads.	
S10	**Duty with discrete constant loads**	This duty consists of a maximum of 4 discrete load values (or equivalent loads), each value being applied for sufficient time for the machine to reach thermal equilibrium. The minimum load during a load cycle may be zero (no-load operation or off period).	

MOTOR TYPES

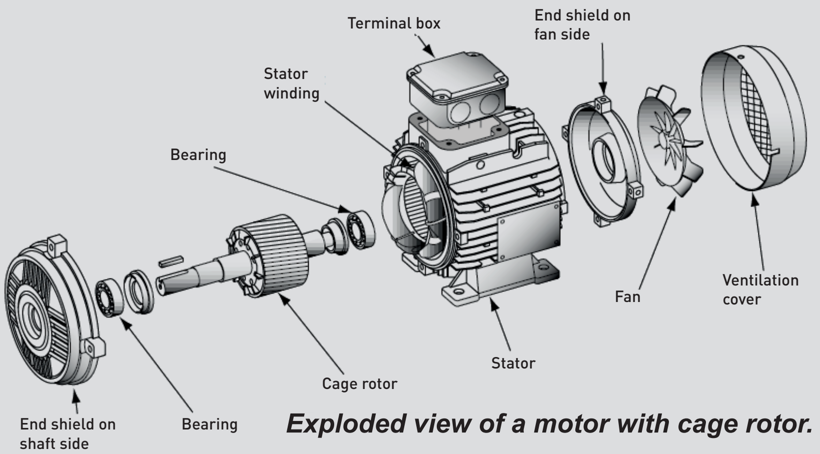
Three-phase asynchronous motors

COMPOSITION

An asynchronous motor is made up of several components such as the frame, rotor, stator, etc (see description on page 4).

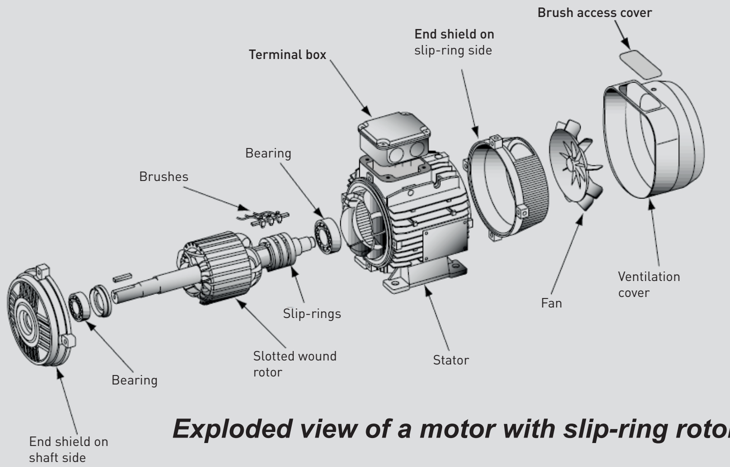
There are two different categories of asynchronous motor depending on their rotor type:

• Asynchronous motors with short-circuited rotor, called **cage motors**. These motors are the most commonly used, due to their versatility, and their simple economical design.



Exploded view of a motor with cage rotor.

• Asynchronous motors with wound rotor, called **slip-ring motors**, in which the rotor winding is extended by slip-rings to which stepped resistors are connected. They are connected to these slip-rings with brushes. They are less commonly used because they are more complicated to install and more expensive.



Exploded view of a motor with slip-ring rotor.

Both these types of motor are relatively similar in terms of construction and their operating principles obey the same physical laws.

OPERATING PRINCIPLE

■ Stator

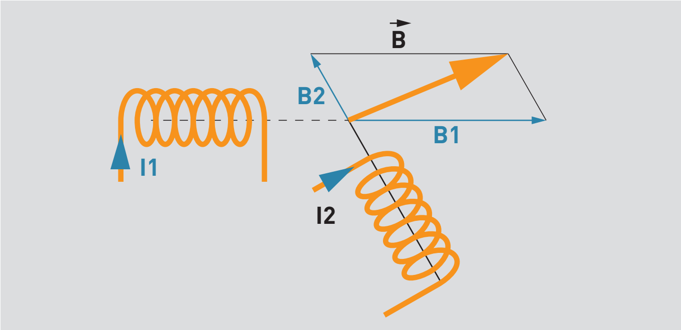
The stator is attached to the motor body and consists of a stack of very thin laminations and three windings. On a three-phase supply, each winding is wound around a stator core and forms an electromagnet (a pair of poles) when connected to a supply phase.

The AC three-phase asynchronous motor is the only one which works due to alternation of the phases of the electricity supply.

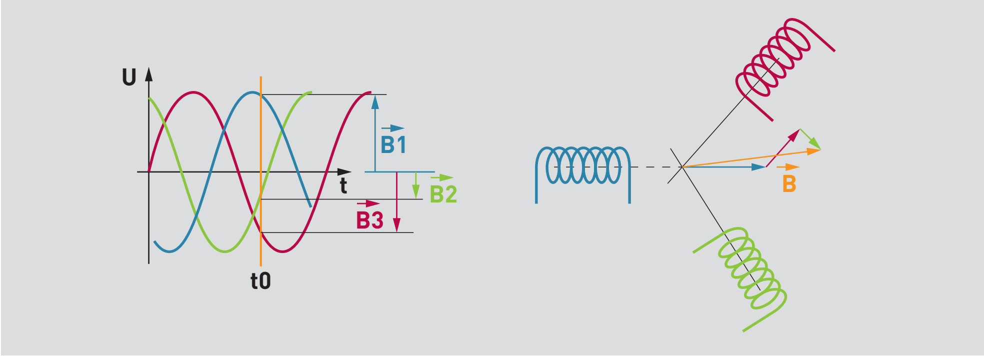
The physical explanation is as follows:

The flow of current in a coil creates a **magnetic field H**. This field is in line with the coil, its direction and its intensity are a function of the **current I**. If the current is AC, the magnetic field varies in direction at the same frequency as the current.

If two coils are placed close to one another, the resulting magnetic field is the vectorial sum of the other two.



In the case of the three-phase motor, the three coils are positioned in the stator at 120° from one another, which creates three magnetic fields. Given the nature of the current on the three-phase supply, the three fields are phase-shifted.



When supplied in this way, the stator generates a magnetic field, called a **stator field,** rotating at a speed called **synchronous** (Ns). The rotation frequency of this field is linked to the frequency of the mains supply and the number of pairs of poles in the winding.
Ns = 60xF/P (F frequency, P no. of poles), in number of revolutions per minute (RPM).

OPERATING PRINCIPLE (CONTINUED)

■ **Rotor**

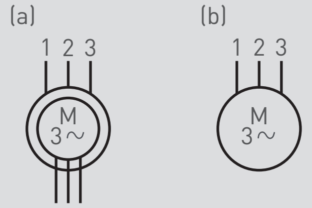
The second component is the rotor, which is a moving part. It consists of a stack of thin metal laminations which are isolated from one another (in order to prevent circulation of eddy currents), windings and short-circuited conductors. Its specific job is to react to the magnetic field generated by the stator (the stator field). According to **Lenz's law**, the current induced in the rotor opposes the effects of the induction field, because of its magnetic field. The variations in flow between the stator and rotor windings result in the appearance of a force: torque. The rotor thus starts rotating at a nominal speed (N) which is close to the synchronous speed (Ns) which is the maximum speed of rotation linked to the frequency of the mains supply.

The difference in speed between Ns and N is called the slip speed, hence the name **"asynchronous motor"** which represents this difference in speed. Slip is expressed as a % of the synchronous speed and is calculated using the following equation: (Ns-N)/Ns.

When the motor is in the starting phase, the rotor speed is zero and the difference between the speed of rotation of the magnetic field and that of the rotor is at its maximum, which generates induction of strong rotor currents due to the absence of back electromotive force (which is the reason for the strong inrush current). When the rotor accelerates, there is less difference in speed and the rotor currents diminish. The rotor speed stabilises at its speed N.

■ **Air gap**

The air gap is the gap between the rotor and stator. The smaller it is, the better the magnetic induction. The width of the air gap contributes directly to the motor efficiency.



Electrical symbols for wound rotor (a) and squirrel cage (b) asynchronous motors

■ **Quadrants**

Asynchronous motors can operate in four different ways, represented graphically as quadrants:

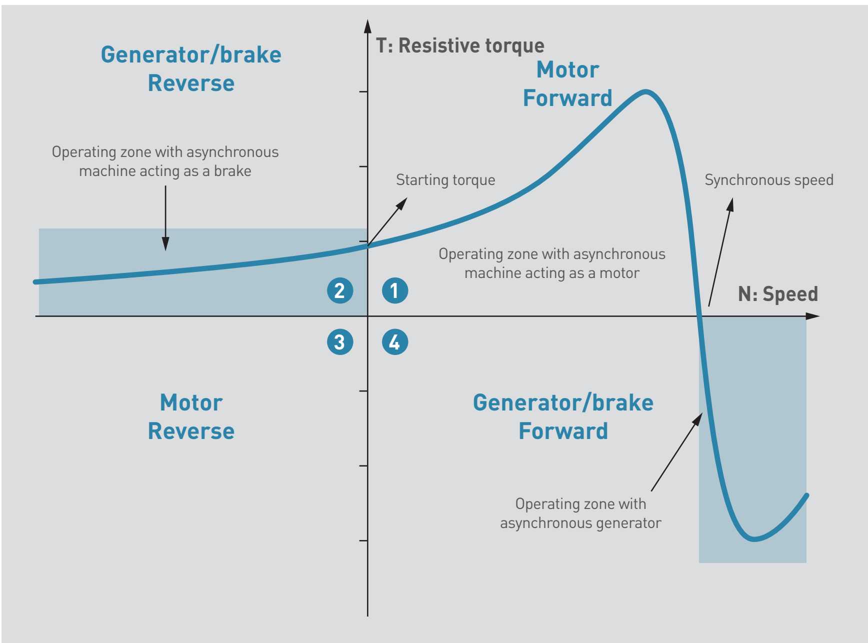
Quadrant 1: In **"motor running forward"**. The motor turns in forward direction, the same as the frequency of the mains supply. The torque is positive, in other words the motor is supplying torque to the rotor.

Quadrant 2: In **"brake or generator running in reverse"**. The motor turns in reverse direction, but the torque is reversed and the motor brakes (it consumes mechanical power). To do this, two phases should be swapped to reverse the revolving field. The speed drops below the synchronous speed, so this is called subsynchronous braking.

Quadrant 3: In **"motor running in reverse"**. The motor turns in reverse direction, the opposite of the frequency of the mains supply. The torque is positive.

Quadrant 4: In **"brake or generator running forward"**. The motor turns in forward direction, the torque is reversed (it consumes mechanical power). To do this, two phases should be swapped to reverse the revolving field. In the hypersynchronous phase (NB: greyed-out zone in the bottom right corner), the motor is driven by its load at more than its synchronous speed. It then behaves like an asynchronous generator, reinjecting energy onto the mains supply.

The three operating zones for asynchronous machines



MOTOR TYPES

Single-phase asynchronous motors

COMPOSITION

Single-phase motors are built in the same way as three-phase asynchronous motors. They are low-power and offer excellent longevity.

They are found in numerous technical devices which need to rotate at a fixed speed (for example: machine tools, lift pumps, fans).

OPERATING PRINCIPLE

They operate according to the induction principle, the same as three-phase motors. But in single-phase operation, there is no angular displacement of the three phases which creates the revolving field. Structural measures must therefore be taken to create the revolving field conditions, especially for starting.

This can be done by means of two windings physically offset by 90°, with phase-shifted currents flowing over them. In single-phase operation, only one phase is distributed, and it is therefore necessary to create this "second phase" by supplying it via a capacitor which will phase-shift the current by 90°.

The capacitor can be connected permanently for the most powerful motors or connected temporarily for less powerful motors (with auxiliary phase).

THE DIFFERENT TYPES

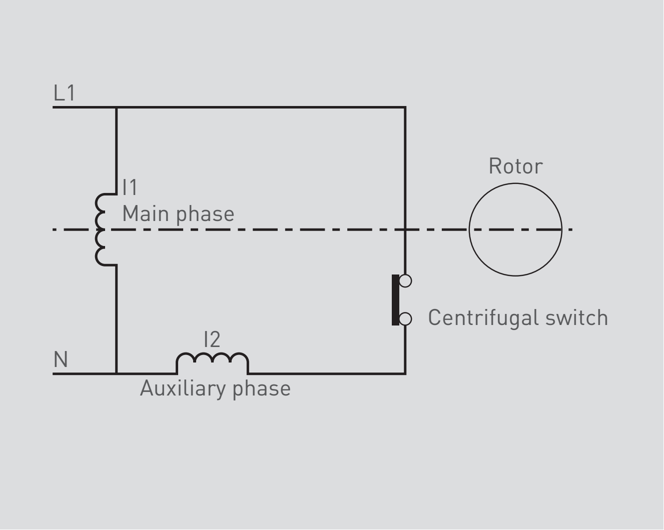
■ **Motor with resistive auxiliary phase**

In the case of a motor with resistive auxiliary phase, since the auxiliary winding has a smaller cross-section (and hence greater resistance) it will heat up. It should therefore be disconnected once the motor has started. This is done using a centrifugal switch.

This type of motor is suitable for applications which require occasional starting and moderate starting torque. Its low starting torque is explained by the minimal phase shift between the currents.

It is inexpensive and is used in applications such as small fans and centrifugal pumps. The Frager turn motor is a version of this type of motor, where the auxiliary phase (winding) is replaced by a conductor phase-shifted by 90°, placed on the stator magnetic circuit. This short-circuited conductor is used to cancel a half-wave of the magnetic flux so that the motor can start.

Its application remains limited to very low power ratings (small fans, pumps, household appliances).

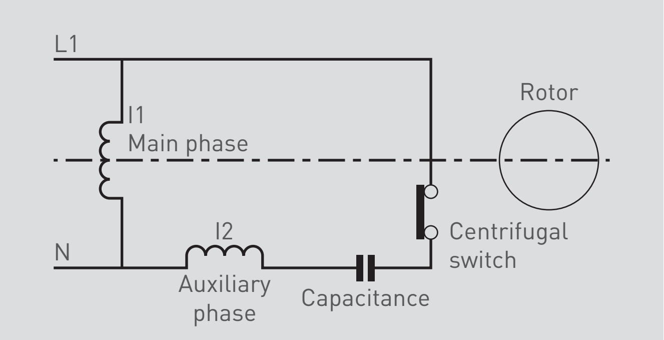


THE DIFFERENT TYPES (CONTINUED)

■ Motor with auxiliary phase with disconnectable capacitor

This motor has the same technical characteristics as the motor with auxiliary phase (auxiliary winding, centrifugal switch) but the capacitor mounted in series with the auxiliary winding creates a phase shift of 90° between the currents flowing over the main winding and the auxiliary winding.

It allows a higher starting torque. It is used for applications such as large fans, conveyors.

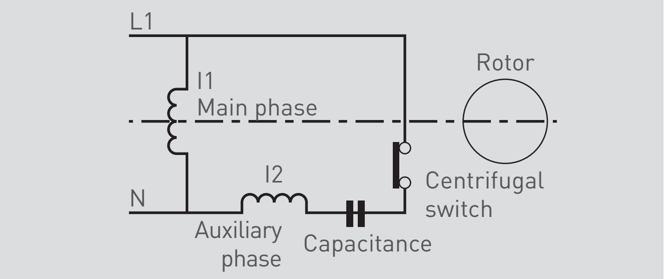


■ Motor with auxiliary phase with permanent capacitor

Unlike the motor with auxiliary phase disconnected once the motor has started, that of the motor with permanent capacitor remains powered-up after starting (via a low-capacity capacitor).

This motor does not therefore have a centrifugal switch, which simplifies its design. The auxiliary winding is used for starting and adds to the role of the main winding by creating a permanent regular revolving field.

The power and torque are significantly increased. This type of motor is used for power ratings ranging from a few dozen watts to several kilowatts in a wide variety of equipment such as compressors.

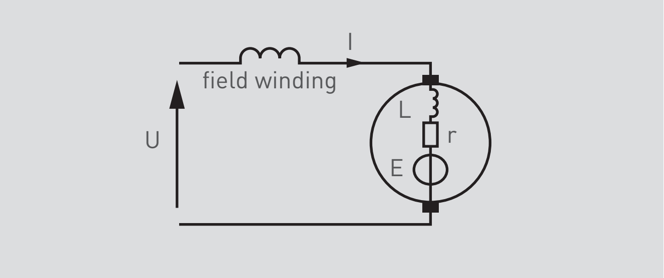


■ Universal motor in series

This motor is not an asynchronous motor in the strict sense of the term since it involves a DC series motor supplied with AC. The rotor and stator windings are connected in series, so the current flowing over them is the same. Since the flux half-wave is produced in both the rotor and the stator, there is no relative inversion of the two flows; the motor turns in one direction only.

This type of motor combines a high starting torque with the ability to reach very high speeds (up to 20,000 rpm) and is ideal for traction applications.

At low power ratings, this type of motor is also found in domestic applications such as hand-held power tools. For this type of use, it has fairly mediocre efficiency and a limited service life.



MOTOR TYPES

Synchronous motors

This motor is called synchronous because its speed of rotation is the same as its synchronous speed. The speed is independent of the load and the supply voltage.

In comparison with the asynchronous motor, the synchronous motor is much more efficient and has a higher power factor, close to 1. It has smaller dimensions, especially for those with a low speed of rotation (300 rpm). Simply supplying it with power at nominal voltage is not enough to make it start (unlike the asynchronous motor). It therefore needs to be combined with other equipment so it can reach (catch up with) the synchronous speed.

COMPOSITION

Like the asynchronous motor, the synchronous motor consists of a stator and a rotor separated by an air gap. The difference lies in the rotor design.

The stator in a three-phase motor (most common in medium and high-power applications), as its name indicates, is the static part of the synchronous motor and shares most of the same characteristics as the stator in asynchronous motors.

It consists of the frame, bearings, end shields, motor cooling fan, protective fan cover and for the electrical part a laminated iron core which channels the magnetic flux and the windings of the three phases lodged in the slots in the core, phase-shifted by 120° from one another.

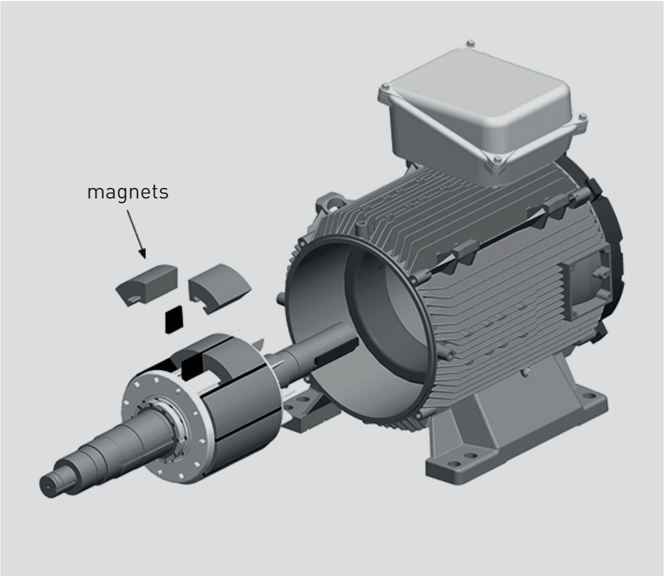
Like in the motor stator, the windings are lodged in slots made in the rotor and electrically connected to the shaft extension slip-rings.

The rotor can have salient poles consisting of permanent magnets or electromagnets supplied with DC.

Motors with permanent magnet rotor: These are motors which can take high overload currents in order to start quickly. They usually have a power rating of a few kilowatts.

Motors with wound rotor: The rotor is supplied with DC via the slip ring-brush assembly. For medium and high-power applications, synchronous motors with wound rotor, combined with a variable speed drive, procure an excellent level of performance.

These machines are reversible, and can operate as both a motor and an alternator.

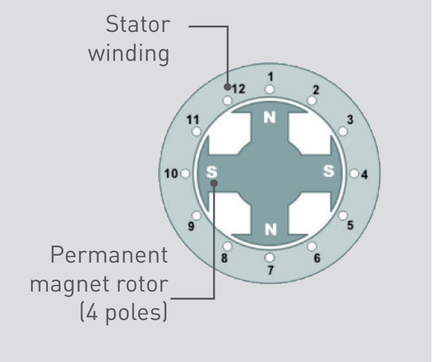


OPERATING PRINCIPLE

The stator windings are supplied by all three supply phases so as to produce the revolving field at synchronous speed (Ns). They are constructed so as to form alternating North and South poles.

Whether with permanent magnets or wound, the rotor also consists of alternating North and South poles. Its magnetic flux is constant.

Thanks to the attraction between opposite poles in the stator and rotor, the stator revolving field causes the rotor to rotate.



The rotor speed of rotation is characterised by the following equation: N = Ns = 120 x (f)/No. of poles per phase.

STARTING

When the motor is supplied with power, the rotor North pole is attracted by the South pole of the revolving field. If its speed is zero, the rotor North pole starts to move towards the South pole of the revolving field. But due to rotor inertia, in the meantime the South pole of the revolving field is replaced by the North pole and therefore causes a repulsive force, which then drives the rotor in the opposite direction. In these conditions the motor cannot start.

For the motor to be able to start, the rotor must be set in motion so it can "catch" the revolving field. This can be done by combining an asynchronous motor for starting or having a built-in squirrel cage so the motor can be started in asynchronous mode. When the rotor speed is close to the synchronous speed, it is supplied with DC. This catch-up or synchronisation phase is only possible when the stator and the rotor have opposite poles. This kind of motor can be started without external mechanical assistance by supplying it with a starter which gradually increases the stator power supply frequency and the rotor supply voltage until they are in sync.

MOTOR TYPES

DC motors

COMPOSITION

Just like the asynchronous motor and synchronous motor, DC motors are made up of several components.

- **Frame**: this supports all the fixed parts and the end shields. It is usually made of cast steel or cast iron.
- **Stator**:

- Field poles: these consist of a stack of silicon steel laminations approximately 0.5 to 1.5 mm thick, isolated from one another by natural oxidation. Sometimes solid poles are encountered.
- Coils: these are connected in series and made of insulated copper wire wound around the pole body in order to create an electromagnet. There are an even number of poles; they alternate between North and South. The stator may sometimes have permanent magnets.
- Auxiliary poles: these are in series with the main poles and are designed to reduce sparks in the brushes.

- **Rotor**:

- This is the armature. It is laminated and is shaped like a cylinder with slots in it. The laminations are made of silicon steel approximately 0.2 mm thick and are isolated from one another by oxidation or varnish. They are mounted on the machine shaft. Active conductors are placed in the slots.
- The coils on the rotor are supplied with DC by means of carbon brushes via the commutator located at the end of the shaft. The brush holders are attached to the field winding and use springs to hold the brushes rubbing against the commutator. They are placed in line with the main poles.

- The empty space between the field winding and the armature is called the **air gap**. The smaller this space, the lower the magnetic losses.
- **Connection box**: this is used for connection to the electricity supply.

OPERATING PRINCIPLE

Unlike the revolving field generated in the stator of an asynchronous motor, the magnetic field in the DC motor stator is fixed. The field winding creates a constant magnetic flux F if the field current crossing it remains constant. The armature is supplied by a DC voltage across the commutator/brush assembly. The armature conductors are crossed by a current I, in a magnetic field created by the field winding.

These conductors are subjected to electromagnetic forces; according to Laplace's law, a conductor crossed by a current and placed in a magnetic field is subjected to a force whose direction is determined by the right-hand rule:

To determine the direction of force, place three fingers (thumb, index finger, middle finger) at right-angles. Point the thumb in the direction of the field (the direction of a field is always from N to S outside a magnet and S to N inside). Point the middle finger in the direction of the current (conventional direction always from + to -). The index finger then determines the direction of the force.

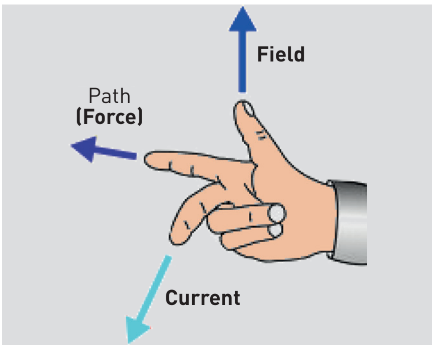
F = B * I * L

F: Force in Newtons

B: Magnetic induction in teslas

I: Current in the conductor in amps

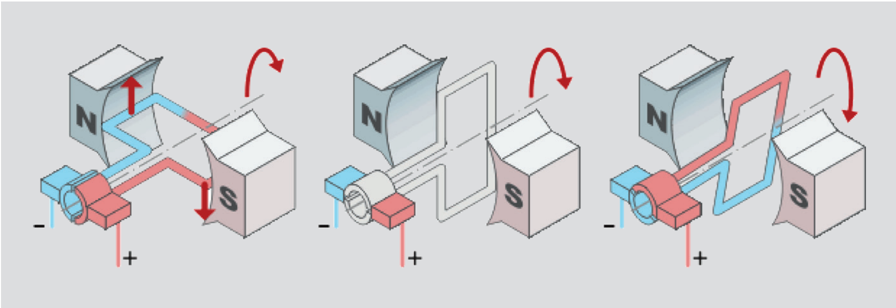
L: Length of the conductor in metres



OPERATING PRINCIPLE (CONTINUED)

The opposite forces create torque which makes the turn deviate 90 degrees from the vertical, with the direction of the current remaining unchanged in the turn.

During this movement, the torque gradually reduces until it is cancelled out after the coil rotates by around 90 degrees, in the neutral zone, the turn being in a horizontal position at right-angles to the natural magnets.



To obtain smooth rotation, the armature winding must be made up of a large number of turns. These are distributed evenly around the rotor so as to obtain torque which is independent of the angle of rotation. After the neutral zone has passed, the direction of the current is reversed simultaneously in each of the turns. According to the Lorentz law, after a half-turn, the current is reversed in the armature circuit, which reverses the forces and allows the rotor to rotate continuously. This reversal of the current is performed by the commutator in tandem with the brushes.

Reversal of the direction of rotation is obtained by inverting the armature or field winding polarities. To increase the motor speed, there are two options: increase the armature voltage or reduce the excitation flux.

If the field winding is supplied with a fixed voltage, the flux is constant and the motor speed can be set by altering the armature supply voltage. The speed is almost proportional to the armature voltage. The motor torque increases as a function of the current in the armature.

If the field current is reduced (by reducing the voltage applied to the field winding) while the armature remains supplied with a fixed voltage, the motor will go into overspeed. If the field is completely disconnected, the motor is then likely to race. In practice, this risk only affects motors with separate field excitation.

The DC motor can usually withstand overloads of short duration. It is used mainly for electrical traction applications and for industrial applications such as robotics.

STARTING, REVERSIBILITY AND CONSTRAINTS

Previously, motor starting was achieved by a starting rheostat in series with the armature which limited the current, but this solution was rather wasteful (Joule effect losses).

Nowadays, starting more usually involves electronic circuits which reduce the armature voltage and allow gradual acceleration while managing the overcurrent on starting. The properties of the DC motor are suitable for control by variable speed drives or soft starters.

The DC motor is usually reversible with certain build conditions. Series motors can operate in generator mode. Parallel motors should have appropriately-designed windings. In this case, the rotor becomes the field winding and the stator becomes the armature.

The main problem with DC motors concerns the carbon brushes which make connection with the rotating commutator. The higher the speed of rotation, the greater the mechanical stresses applied to the brushes (contact pressure, friction), thus reducing their life and the quality of the electrical contacts. A flawed electrical contact generates interference in the power supply circuit and electrical arcs which damage the commutator.

MOTOR TYPES

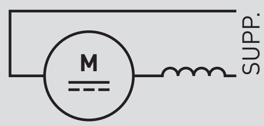
THE DIFFERENT TYPES

■ **Series motor**

The field winding circuit is connected in series with the armature circuit and the same current circulates in both circuits. The starting torque is high because the current flowing across them creates significant magnetic flux.

The load applied to the motor defines the armature current. If the resistive torque increases, the armature current increases, but the speed decreases. Conversely, with a low load, the current is lower. The lower the magnetic flux, the more the speed of rotation increases. When operating at no-load, this type of motor is likely to race and be damaged.

Its current varies less with resistive torque surges than a parallel motor (definition below). It is frequently used for traction applications.

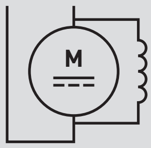


Series motor

■ **Parallel motor (also called a shunt motor)**

The field winding and armature circuits are supplied with the same voltage source. The field coil is wired in parallel with the armature. The voltage at the rotor terminals is therefore the same as that at the stator terminals. The speed obtained is very stable depending on the value of the resistive torque. It is unlikely to race, irrespective of the torque opposing it.

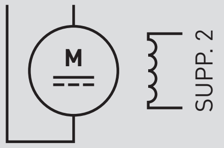
If the resistive torque is subject to sudden variations, the current varies in the same proportions, which needs to be considered when designing the power supply circuit (line cross-sections, choice of protection devices).



Shunt motor

■ **Motor with separate field excitation**

This requires two voltage sources, which makes it complicated to use. It behaves in a similar way to the parallel motor. It is used for high-power machines. The speed of rotation is proportional to the armature supply voltage, so the speed setting is independent of the load. The load applied to the motor defines the armature current. The absence of field flux leads to the motor racing.



Motor with separate field excitation

THE DIFFERENT TYPES (CONTINUED)

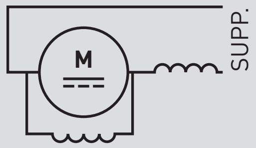
■ **Compound excited motor**

This contains two field coils, one of which is placed in series with the armature and the other in parallel.

It combines the advantages of the series motor (high torque at low speed) and those of the shunt motor (no risk of racing). It has additive flux if both windings add their magnetising effects.

It has subtractive flux if both windings subtract their magnetising effects (this type is used if it is working primarily with heavy loads).

It is normally used when the resistive torque varies significantly.



Compound excited motor

■ **Brushless motor**

This type of motor does not have a rotating commutator in the rotor, hence why it is called a brushless motor.

In comparison with a “brush” type DC motor, it resolves switching problems in the commutator and risks of unclamping. In addition, it offers better cooling since the Joule effect losses in the stator are easier to dissipate. It is also more efficient, due to lower inertia and lack of friction caused by the brushes.

It can operate at up to very high speeds (50,000 rpm).

It operates by means of an electronic control system which switches the current in the stator windings. It is equipped with an electronic position sensor which indicates when to reverse the polarities.

This sensor is integrated in the electronic system on low-power motors, which means they can operate independently, with variation of the speed linked to that of the power supply voltage.

For higher power ratings, an electronic power converter such as a UPS is used to vary the speed and regulate the torque.

These motors are widely used in industry, mainly in applications involving robotics. They are also used for traction (electric vehicles). The smallest of them are used in computers (hard disks) or even in model airplanes.

STARTING ASYNCHRONOUS MOTORS

Different starting types

These days, eight out of ten motors are used at fixed speed. This is explained by the fact that the majority of motors sold are low-power and are used for applications with no need for variation of the torque, speed or acceleration. In addition, their starting does not affect the equipment they are driving.

D.O.L. STARTING AT FULL VOLTAGE

D.O.L. starting applications at fixed speed have numerous advantages, including better efficiency than that achieved by a variable speed drive. Irrespective of the motor load, there is a negligible level of energy losses.

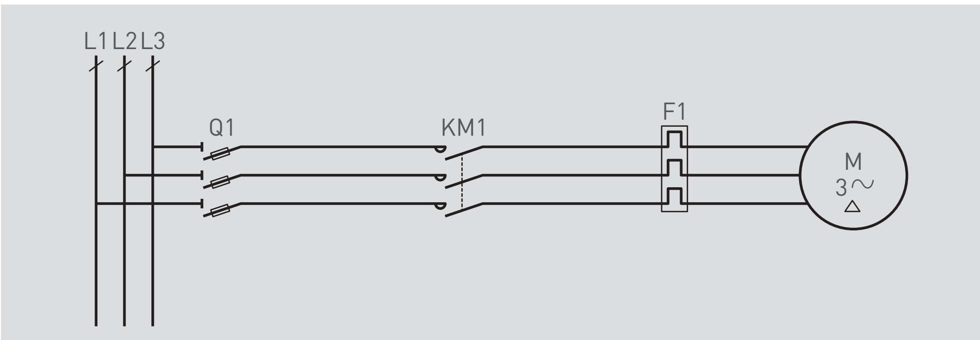
This is the simplest starting mode. The motor starts with its "natural" characteristics. It is connected to the mains supply via the KM1 contactor. On starting, the motor behaves like a transformer whose secondary (the rotor) is in a short-circuit situation, hence the current peak on starting.

This type of starting is reserved for motors with limited power as regards the power delivered by the mains, which do not require gradual acceleration. The torque is at maximum but the current inrush is high (5 to 8 times the nominal current). In the case of fixed-speed use, the motor power should be chosen to withstand any variations in the load.

Despite the advantages it has, D.O.L. starting is not suitable for certain cases when:

- the motor power is high in relation to the availability of the mains supply; the disturbance associated with the current inrush then needs to be limited
- the driven machine needs soft starting
- the starting torque can be reduced without affecting operation of the machine or the driven load
- the mains supply cannot withstand the voltage drop associated with D.O.L. starting

Nonetheless, there are solutions that are simple to implement in order to meet the need for soft starting, especially at reduced voltage.



D.O.L. STARTING AT REDUCED VOLTAGE

Starting with a star/delta connection is the most common solution due to its low cost and ease of implementation. This starting mode is normally applied to motors with power rating below 7.5 kW or starting without a load. However, certain constraints need to be taken into consideration, such as the significant reduction in starting torque and the transient current peak when switching from star connection to delta connection.

In addition, a motor should be selected whose individual winding ends are brought into the terminal box (there are thus 6 terminals in the box), whose delta connection corresponds to the mains voltage. For example, in a three-phase 400 V supply, a motor should be selected whose nominal voltage is 690 V in star connection, hence 400 V (or 690 V/√3) in delta connection.

D.O.L. STARTING AT REDUCED VOLTAGE (CONTINUED)

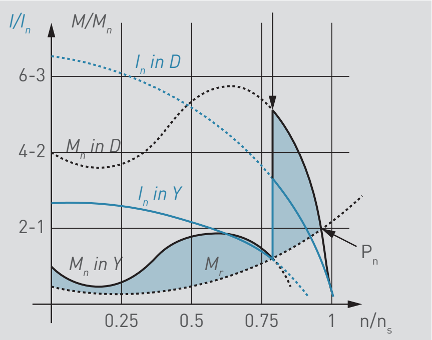
Explanation: the current is divided first by √3 (linked to the connection changeover) and secondly by √3 (linked to the relative reduction in the supply voltage from 690 V to 400 V), in other words √3 multiplied by √3.

The starting current peak (Is) is divided by 3, so:

- Is = 2.3 In if we assume an inrush current of 7 In.

The starting torque (Ts), which is proportional to the square of the supply voltage, is also divided by 3:

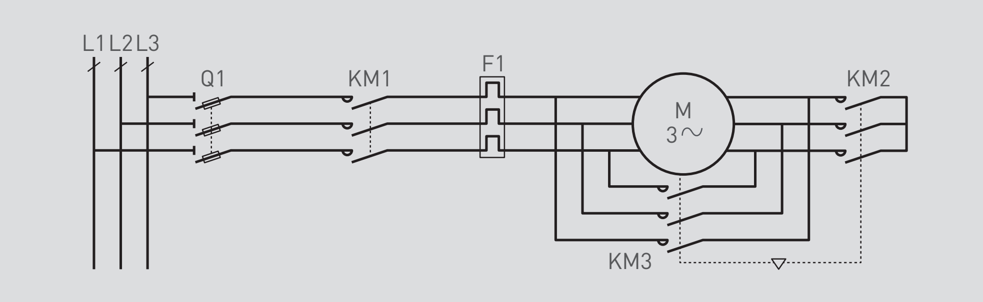
- Ts = 0.33 in this example (usually 0.2 to 0.5 Tn)



Sequence: when the speed of motor rotation stabilises (equilibrium between motor torque and resistive torque), at a speed of approximately 85% of nominal speed, the windings are then connected in a delta configuration and the motor regains its natural operating characteristics.

1. It is connected to the mains supply via KM1. Its windings are connected in a star configuration via KM2.
2. At the end of the starting period, KM2 opens.
3. KM3 closes with a slight offset.

This switching sequence is controlled by a time delay set on the star starting time. In order to prevent the delta contactor closing when the star contactor is still closed (and prevent a short-circuit between phases), it is advisable to electrically interlock the control circuits via the contactor mirror contacts (NC) in addition to using a mechanical interlock device. During the changeover from star to delta configuration, the current is interrupted briefly and a transient peak is generated when the delta contactor closes.



There is a method consisting of inserting a resistor before opening the star contactor to prevent the occurrence of transient phenomena associated with the sudden power cut. However, this process is rather more complicated and expensive to implement.

D.O.L. STARTING AT REDUCED VOLTAGE (CONTINUED)

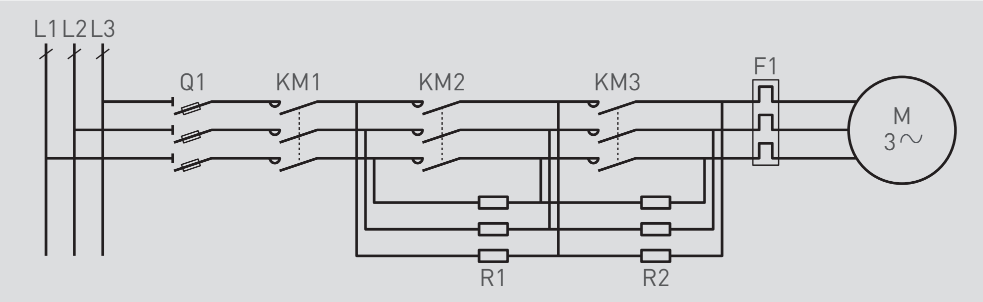
■ Stator resistance elimination starting

This starting mode applies to squirrel cage three-phase asynchronous motors for applications such as inertia machines which do not start with their maximum load (centrifugal fans, pumps, saws, etc). Its main role is to limit the starting current.

It takes place in at least two stages. The stator windings are first supplied at reduced voltage by means of resistors; they are then supplied at their nominal voltage by eliminating the resistors, which can be short-circuited in one or more stages. Depending on the number of stages, it is possible to adjust the current and the starting torque. Eliminating the resistors can help maintain an uninterrupted power supply to the motor during the starting phase.

This mode is characterised by an adjustable starting torque (0.5 to 0.8 times the nominal torque) and a current which can also be adjusted depending on the number of stages.

The starting time is relatively long (up to 10 seconds). The sequences are mainly controlled semi-automatically (using push-buttons and time delays), or automatically (by means of sensors and a PLC).



■ Starting with an autotransformer

This starting mode is normally used for motors rated above 100 kW in applications which do not need a particularly high starting torque. It is however rather expensive due to the autotransformer's technical characteristics, but on the other hand, it does mean that the advantages of squirrel cage motors can be enjoyed.

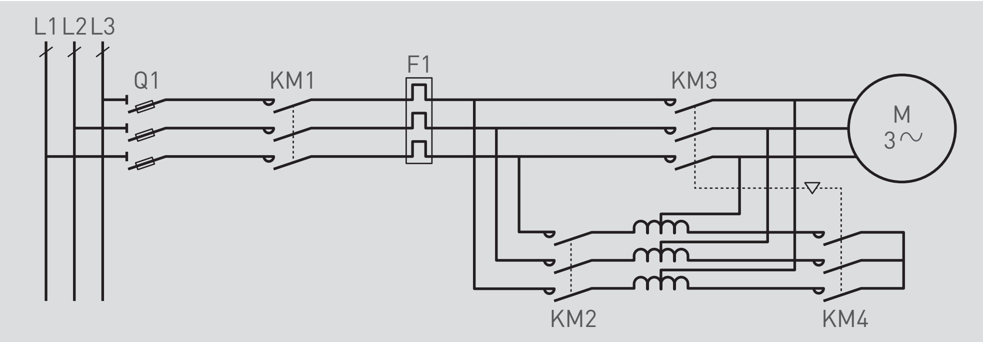
Starting with an autotransformer means that the inrush current can be reduced. The motor is supplied at reduced voltage via an autotransformer which is bypassed when starting has finished.

For this starting mode, only the three power supply conductors need to be accessible. Starting consists of three stages:

1 - Firstly the autotransformer is connected to the mains supply via the KM2 contactor. To supply the motor with reduced voltage, its secondary is first connected in a star configuration, via the KM4 contactor. In order to adapt the motor starting characteristic to the required torque, autotransformers can have several outputs (for example 80%, 65% and 50%).
2 - Once the motor reaches a speed close to its nominal speed, the "reduced voltage" connection contactor KM4 opens.
3 - The motor is then supplied at full voltage, and KM2 can open in order to disconnect the transformer from the mains supply.
4 - When the KM2 connector opens, the KM3 contactor closes, the motor still being supplied with full voltage by the mains supply.

D.O.L. STARTING AT REDUCED VOLTAGE (CONTINUED)

■ **Starting with an autotransformer (continued)**



Depending on each starting current connection and ratio, the switching current varies from 1 to 5 x In. The torque delivered varies in proportion with the starting current.

ROTOR RESISTANCE ELIMINATION STARTING

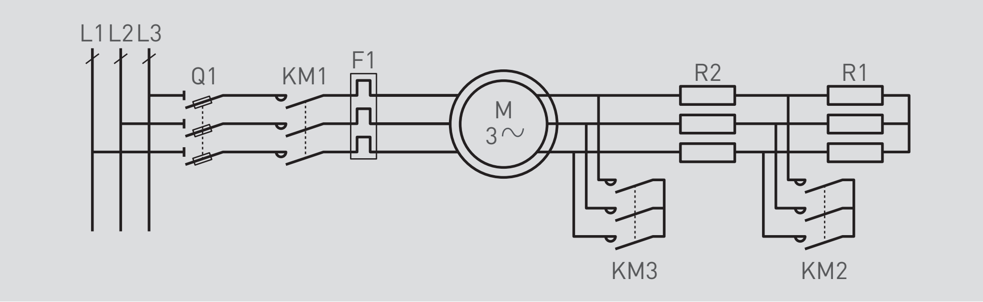
This starting mode means that the advantages of wound-rotor three-phase asynchronous motors can be enjoyed. It is currently used for applications such as machines with high inertia or which start on-load and require significant torque on starting (for example, handling equipment, pumps under pressure, conveyor).

It consists of gradually eliminating the resistors inserted in the rotor circuit, which is connected in a star configuration. The stator circuit windings are directly supplied by the mains supply with their nominal voltage, depending on whether they are connected in a star or delta configuration.

Starting involves several stages: firstly, series resistors are inserted in the rotor circuit, which has the effect of limiting the current consumed by the stator. The rotor circuit resistance is then reduced until the rotor short-circuits, without interrupting the power supply.

This mode is characterised by a lower starting current (limited to approximately twice the nominal current) and a starting torque which nevertheless remains high (1.5 to 2 times the nominal torque).

The starting time is relatively long (up to 10 seconds). The sequences are mainly controlled semi-automatically (using push-buttons and time delays), or automatically (by means of a PLC).



DAHLANDER MOTORS

Multi-speed motors are mainly used in ventilation applications, to change the fan power (blowing or extraction). This is the most important field of application. It also allows two-stage starting (low speed then high speed), which limits the inrush current, just like star/delta starting.

The Dahlander motor has two speeds of rotation per pair of windings (or even pair of poles). It has two separate windings on each phase which can be connected in parallel (two poles) or in series (four poles). The ratio between low speed and high speed is 1 to 2 (usually 1500 rpm/ 3000 rpm).

The synchronous speed therefore varies in a ratio of 2 and high speed corresponds to parallel connection.

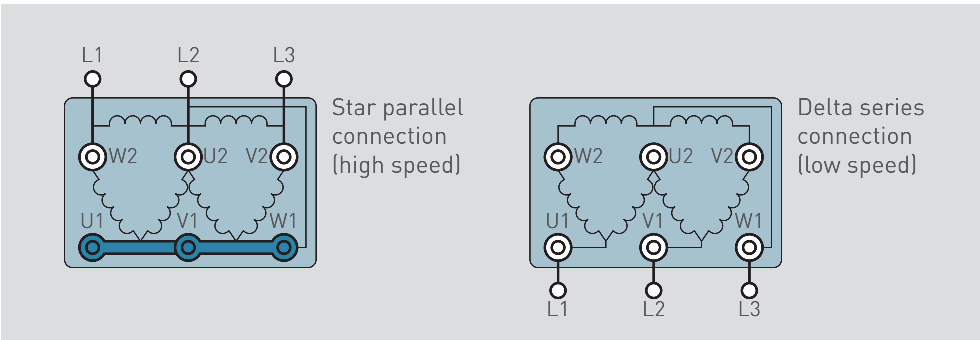
Note that:

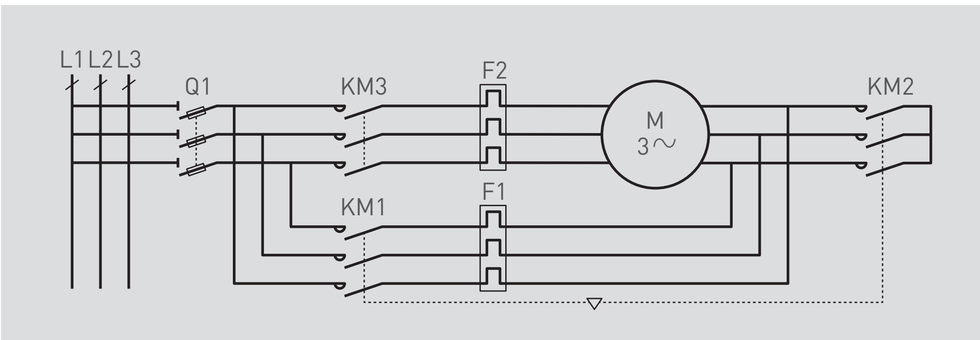
By combining both windings in parallel, their actions are superimposed and they behave like a single winding. The windings are supplied at U/(√3) and the motor turns at its maximum speed.

Terminal box connection – High speed: The "low speed" terminals are short-circuited and the "high speed" terminals are each connected to one phase. This connection is also called "parallel-star" because the windings are connected in parallel in pairs.

By combining two windings in series, the windings are supplied at U/2 instead of U/(√3), and are therefore underpowered. The number of poles is doubled and the motor speed is halved.

Terminal box connection – Low speed: The "high speed" terminals are not connected and the "low speed" terminals are each connected to one phase. This connection is also called "series-delta": in fact, the windings are connected in series.



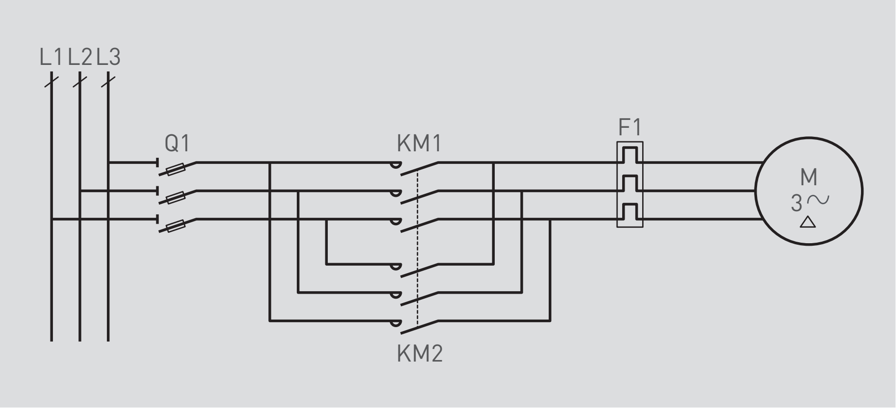


Reversing direction

To reverse the motor direction of rotation, two phases of the power circuit are swapped over, with the third left unchanged.

This has the effect of changing the revolving field direction of rotation and hence the rotor direction of rotation. This changeover is normally performed at zero speed.

A mechanical interlock is needed to prevent a short-circuit between two phases in cases where KM1 and KM2 would be in the closed position simultaneously, even for a very brief time.



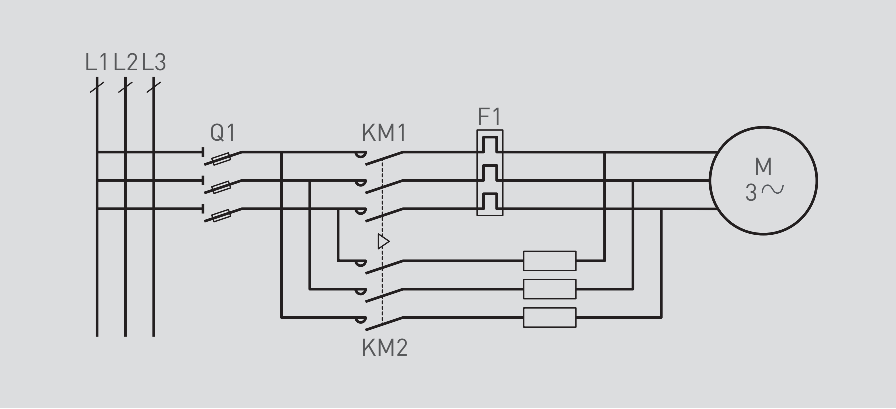
Stopping motors

In the majority of applications, the motor is stopped by natural deceleration, with the time depending on the inertia of the driven machine. Electrical braking can be used to manage this time, which is simple and inexpensive to implement, unlike mechanical braking, which is more expensive. Electrical braking also allows smoother motor deceleration.

REVERSE-CURRENT BRAKING

This braking method is obtained by reversing two of the phases. The motor develops a braking torque in quadrants Q2 and Q4 (see P. 13). At the time of inversion, the value of the slip can practically double and it then decreases due to the effect of the reverse torque compared to the direction of rotation. This results in an increase in the current consumed by the motor of around 7 x In. To minimise this current, one solution consists of putting resistors in series with the stator.

To prevent the motor starting off in the other direction, a tacho sensor disconnects the motor from the mains supply at the point when it passes through zero speed (slip = 1).



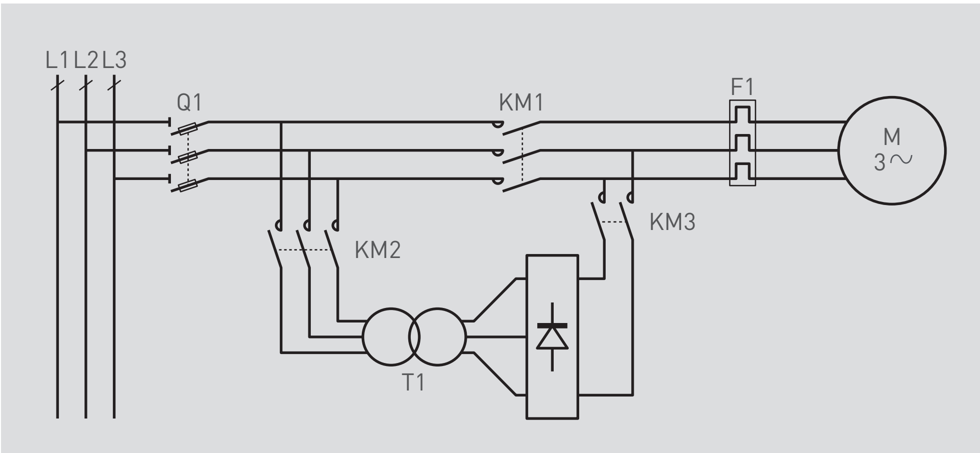
DC INJECTION BRAKING

This braking method, mainly used for motors with wound rotor, is obtained by injecting DC (usually below 20 V) over a predetermined period into one or more of the stator windings after interrupting the three-phase supply.

This can generate a fixed magnetic field which will brake the rotor. The fact that the rotor continues its rotation creates rotor currents and the kinetic energy is gradually converted to Joule effect losses, until the motor stops. The braking current is approximately 1.3 x In.

This braking method does not require the use of a tacho sensor since after the rotor stops, the magnetic field holds it in a fixed position.

The motor is not therefore in danger of starting off in the other direction. Subsequently, the DC power supply will be interrupted in order to protect the motor from a prolonged temperature rise.



MOTOR PROTECTION DEVICES

Advantages of MPX³ – RTX³

Despite its rugged construction, an asynchronous motor can suffer electrical faults, usually linked to wear and tear or poor maintenance, but the most common causes are of electrical origin. They may be external (voltage surges, phase unbalance, etc) or internal: the most vulnerable components in the motor are its rotor and stator windings. These are made up of copper wire windings covered with insulating varnish and they must be protected against overheating, as this poses a risk of short-circuits leading to destruction of the motor. For this reason, the motors usually have a fan fixed on the shaft, which cools them during normal operation.

The causes of temperature rise in the motor are mainly:

Overload: at fixed speed in standard operation, additional stress on the motor results in increased current consumption and heat dissipation in its windings. Even if the motor has been designed to withstand high overloads, these should not be prolonged. It is generally accepted that a permanent 10% motor overload halves its service life.

Too long a starting time or lasting jammed transmission shaft: when the motor is in a long starting phase or stalled, the rotor is subjected to much greater thermal stresses associated with the increased input current, with a serious risk that the windings will be damaged.

The loss of a supply phase: usually of accidental origin (or caused by a fuse blowing), results in an increase in current, of around 150 to 170%, in both windings which continue to be supplied with power. Its consequences are particularly harmful when the motor is operating at full load and will destroy it in the starting phase. The same phenomenon occurs when there is significant unbalance between the phases. It is advisable to select a device which can protect against this risk, usually qualified "sensitive to phase losses". See the section concerning thermal overload relays and that on motor MCBs (see P. 36).

The advantage of the motor thermal protection device lies in its ability to react very quickly. Standard IEC 60947-4-1 concerning contactors and motor starters therefore defines several categories of tripping class. The most common is class 10.

TRIPPING CLASS	TRIPPING TIME (Tp) FROM COLD STATE				MOTOR
	1.05 Ir	1.2 Ir	1.5 Ir	7.2 Ir	
10A	Tp > 2 hrs	Tp < 2 hrs	Tp < 2 min	2 s < Tp < 10 s	Quick start
10	Tp > 2 hrs	Tp < 2 hrs	Tp < 4 min	4 s < Tp < 10 s	Quick start
20	Tp > 2 hrs	Tp < 2 hrs	Tp < 8 min	6 s < Tp < 10 s	Slow start (high inertia)
30	Tp > 2 hrs	Tp < 2 hrs	Tp < 12 min	9 s < Tp < 10 s	Slow start (high inertia)

RTX³ thermal relay = class 10A, differential type (increased sensitivity to unbalances or phase losses)

MPX³ motor MCB = class 10, differential type (increased sensitivity to unbalances or phase losses)

MPX³ motor MCBs and RTX³ thermal relays both offer motor protection, but the choice of one solution over another depends on several operating criteria summarised in the table below:

	RTX³ THERMAL RELAY	MPX³ MOTOR MCB
Motor thermal protection	Yes	Yes
Line protection	No	Yes
Isolation	No	Yes
Current making or breaking	No	Yes
Automatic reset	Mode selector: auto	Yes, on thermal trip
Manual reset	Mode selector: manual	Yes, on magnetic trip
Status indication	Yes, via built-in auxiliary contacts	Yes, via additional auxiliary contacts
Mounting	Downstream of the contactor Directly connected to the contactor Separate mounting possible with fixing base	Upstream of the contactor Connected to the contactor with the dedicated connector Separate mounting with wired connection

MPX³ motor MCBs have an advantage in terms of compactness, with similar functions. Opting for RTX³ thermal relays involves the use of upstream line protection devices (circuit breakers or fuses) and an isolating device to fully comply with the definition of a motor starter.

■ **Criteria to be taken into account when defining equipment and motor protection devices**

	OPERATING OR ENVIRONMENTAL CHARACTERISTICS	CRITERIA	MOTOR MCB CHARACTERISTICS
0	**Mains supply characteristics**		
0.1	Voltage	220 V, 230 V, 240 V, 380 V, 400 V, 415 V, 690 V, etc.	Rated operating voltage Ue > mains supply voltage
0.2	Frequency	50 Hz, 60 Hz, 400 Hz, etc.	Rated frequency
1	**Load type**		
1.1	Motor type	Three-phase asynchronous motor Three-phase synchronous motor Single-phase motor DC motor Etc.	Utilisation category Inrush current Nominal power (kW) (see P. 30-31)
1.2	Motor characteristics	Number of conductors Nominal voltage and frequency Nominal power Cos φ Etc.	Number of poles Operating current

■ **Table G.1 – Motor rated operating power and rated operating currents**

RATED OPERATING POWER		GUIDE VALUES FOR RATED OPERATING CURRENTS AT										
kW [a]	hp [b]	110-120 V A	200 V A	208 V A	230 V A	220-240 V A	380-415 V A	400 V A	440-480 V A	500 V A	550-600 V A	690 V A
0.06	-	-	-	-	0.35	-	-	0.20	-	0.16	-	0.12
0.09	-	-	-	-	0.52	-	-	0.30	-	0.24	-	0.17
0.12	-	-	-	-	0.70	-	-	0.44	-	0.32	-	0.23
0.18	-	-	-	-	1.0	-	-	0.60	-	0.48	-	0.35
0.25	-	-	-	-	1.5	-	-	0.85	-	0.68	-	0.49
0.37	-	-	-	-	1.9	-	-	1.10	-	0.88	-	0.64
-	1/2	4.4	2.5	2.4	-	2.2	1.3	-	1.1	-	0.9	-
0.55	-	-	-	-	2.6	-	-	1.5	-	1.2	-	0.87
-	3/4	6.4	3.7	3.5	-	3.2	1.8	-	1.6	-	1.3	-
-	1	8.4	4.8	4.6	-	4.2	2.3	-	2.1	-	1.7	-
0.75	-	-	-	-	3.3	-	-	1.9	-	1.5	-	1.1
1.1	-	-	-	-	4.7	-	-	2.7	-	2.2	-	1.6
-	1-1/2	12.0	6.9	6.6	-	6.0	3.3	-	3.0	-	2.4	-
-	2	13.6	7.8	7.5	-	6.8	4.3	-	3.4	-	2.7	-
1.5	-	-	-	-	6.3	-	-	3.6	-	2.9	-	2.1
2.2	-	-	-	-	8.5	-	-	4.9	-	3.9	-	2.8
-	3	19.2	11.0	10.6	-	9.6	6.1	-	4.8	-	3.9	-
3.0	-	-	-	-	11.3	-	-	6.5	-	5.2	-	3.8
4	-	-	-	-	15	-	-	8.5	-	6.8	-	4.9
-	5	30.4	17.5	16.7	-	15.2	9.7	-	7.6	-	6.1	-
5.5	-	-	-	-	20	-	-	11.5	-	9.2	-	6.7
-	7-1/2	44.0	25.3	24.2	-	22.0	14.0	-	11.0	-	9.0	-
-	10	56.0	32.2	30.8	-	28.0	18.0	-	14.0	-	11.0	-
7.5	-	-	-	-	27	-	-	15.5	-	12.4	-	8.9
11	-	-	-	-	38.0	-	-	22.0	-	17.6	-	12.8
-	15	84	48.3	46.2	-	42.0	27.0	-	21.0	-	17.0	-
-	20	108	62.1	59.4	-	54.0	34.0	-	27.0	-	22.0	-
15	-	-	-	-	54	-	-	29	-	23	-	17
18.5	-	-	-	-	61	-	-	35	-	28	-	21
-	25	136	78.2	74.8	-	68	44	-	34	-	27	-
22	-	-	-	-	72	-	-	41	-	33	-	24
-	30	160	92	88	-	80	51	-	40	-	32	-
-	40	208	120	114	-	104	66	-	52	-	41	-
30	-	-	-	-	96	-	-	55	-	44	-	32
37	-	-	-	-	115	-	-	66	-	53	-	39
-	50	260	150	143	-	130	83	-	65	-	52	-
-	60	-	177	169	-	154	103	-	77	-	62	-
45	-	-	-	-	140	-	-	80	-	64	-	47
55	-	-	-	-	169	-	-	97	-	78	-	57
-	75	-	221	211	-	192	128	-	96	-	77	-
-	100	-	285	273	-	248	165	-	124	-	99	-
75	-	-	-	-	230	-	-	132	-	106	-	77

■ **Table G.1 (continued)**

RATED OPERATING POWER		GUIDE VALUES FOR RATED OPERATING CURRENTS AT										
kW [a]	hp [b]	110-120 V A	200 V A	208 V A	230 V A	220-240 V A	380-415 V A	400 V A	440-480 V A	500 V A	550-600 V A	690 V A
90 - 110	- 125 -	- - -	- 359 -	- 343 -	278 - 340	- 312 -	- 208 -	160 - 195	- 156 -	128 - 156	- 125 -	93 - 113
- 132 -	150 - 200	- - -	414 - 552	396 - 528	- 400 -	360 - 480	240 - 320	- 230 -	180 - 240	- 184 -	144 - 192	- 134 -
150 160 185	- - -	- - -	- - -	- - -	- 487 -	- - -	- - -	- 280 -	- - -	- 224 -	- - -	- 162 -
- 200 220	250 - -	- - -	- - -	- - -	- 609 -	604 - -	403 - -	- 350 -	302 - -	- 280 -	242 - -	- 203 -
- 250 280	300 - -	- - -	- - -	- - -	- 748 -	722 - -	482 - -	- 430 -	361 - -	- 344 -	289 - -	- 250 -
- - 300	350 400 -	- - -	- - -	- - -	- - -	828 954 -	560 636 -	- - -	414 477 -	- - -	336 382 -	- - -
315 - 335	- 450 -	- - -	- - -	- - -	940 - -	- 1030 -	- - -	540 - -	- 515 -	432 - -	- 412 -	313 - -
355 - 375	- 500 -	- - -	- - -	- - -	1061 - -	- 1180 -	- 786 -	610 - -	- 590 -	488 - -	- 472 -	354 - -
400 425 450	- - -	- - -	- - -	- - -	1200 - -	- - -	- - -	690 - -	- - -	552 - -	- - -	400 - -
475 500 530	- - -	- - -	- - -	- - -	- 1478 -	- - -	- - -	- 850 -	- - -	- 680 -	- - -	- 493 -
560 600 630	- - -	- - -	- - -	- - -	1652 - 1844	- - -	- - -	950 - 1060	- - -	760 - 848	- - -	551 - 615
670 710 750	- - -	- - -	- - -	- - -	- 2070 -	- - -	- - -	- 1190 -	- - -	- 952 -	- - -	- 690 -
800 850 900	- - -	- - -	- - -	- - -	2340 - 2640	- - -	- - -	1346 - 1518	- - -	1076 - 1214	- - -	780 - 880
950 1000	- -	- -	- -	- -	- 2910	- -	- -	- 1673	- -	- 1339	- -	- 970

[a] Preferred rated values according to IEC 60072-1 (primary series).
[b] Horsepower and current values according to UL 508 (at 60 Hz).

■ **Criteria to be taken into account when defining equipment and motor protection devices (continued)**

	OPERATING OR ENVIRONMENTAL CHARACTERISTICS	CRITERIA	MOTOR MCB CHARACTERISTICS
2	**Starting method**		
2.1	D.O.L. starting (at full voltage), or at reduced voltage	On-load or no-load starting Inrush current	Setting current (Ir)
2.2	Starting duration	Quick start, long start	Tripping class
3	**Operating mode**		
3.1	Permanent, Occasional	Use: permanent (VMC), intermittent (extrusion, lifting, pumping), occasional (smoke control) Switching frequency Number of switching operations	Electrical endurance Mechanical endurance Number of cycles per hour
3.2	Overload fault	Thermal fault tripping Thermal or magnetic fault tripping Magnetic fault tripping only	Overload protection Overload and short-circuit protection Short-circuit protection only
4	**Installation**		
4.1	Environment	Ambient temperature, Altitude, Vibration and impacts, presence of corrosive and polluting substances	Pollution level Altitude-dependent derating Temperature-dependent derating Heat dissipation
4.2	Short-circuit fault	Short-circuit current	Ultimate breaking capacity (Icu) Standard breaking capacity (Ics) Breaking capacity with 1 pole (SEA = IT)
4.3	Associated protection device	Modular circuit breakers, MCCB, Isolating switch	Type 1, type 2 coordination Permissible rated short-time withstand current (Icw), and all electrical characteristics compatible with associated products (voltage, current, etc)
4.4	Associated control equipment	Undervoltage release, shunt trip coil	Compatibility with control auxiliaries (MPX³)
4.5	Associated contactor	Size, rating	Size compatibility
4.6	Reset mode	Automatic or manual Manual	Thermal relay Thermal relay or circuit breaker
5	**Auxiliary circuits**		
	Auxiliary contacts	Status feedback	Utilisation category AC14 AC15 DC13
6	**Installation**		
	Connection	Terminal type Cable cross-sections	Terminal connection capacities
	Mounting	Rail Plate	Fixing centres, rail fixing centres

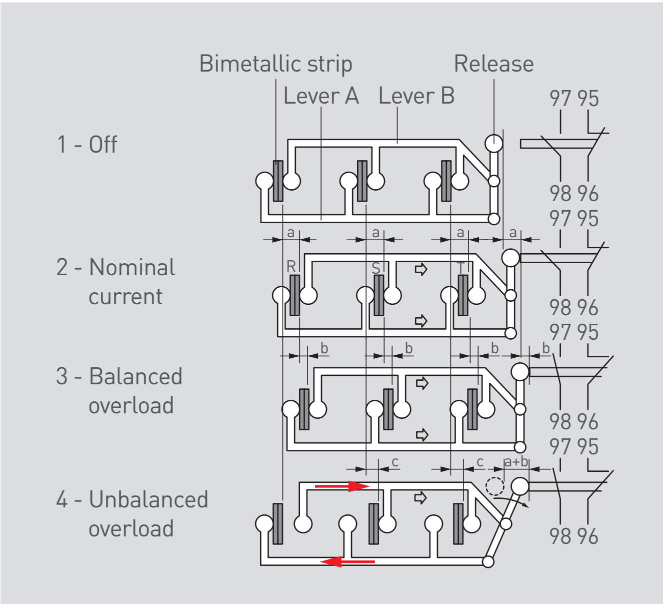
Find these characteristics in our technical data sheets.

RTX³ thermal relays

Thermal relays are available in a "standard" version for protecting motors against overheating and a "differential" version with increased sensitivity to phase unbalances which are the main cause of damage to motors. Caution, the concept of a differential thermal overload relay should not be confused with the term residual current protection device, used to protect people and property (RCCBs or RCBOs for example).

If one of the phases breaks or there is significant unbalance, the current increases on the remaining phases; this causes the windings to overheat. We recommend using the differential version of a thermal overload relay since it can quickly detect unbalance between the phases.

The differential function mechanical device consists of a set of three bimetallic strips and two independent levers which affect the release. Illustration below:



1) If there is no current, the bimetallic strips and levers are deemed to be at rest.
2) When they start to support a current flow up to their nominal current, the bimetallic strips bend (side "a"). As the current is deemed to be equivalent on each of the three phases, levers A and B change in the same direction.
3) Above the nominal current threshold value, the bimetallic strips bend beyond side "a" and trip the relay. In this case it is a balanced overload because the bimetallic strips all change in the same proportions.
4) If one of the phases breaks, the bimetallic strip not subjected to any current stays in the off position whereas both the others see their current multiplied by a coefficient ranging between 150% and 170%. The two levers then change in opposite directions. The action of the bimetallic strips is amplified, thus allowing the relay response time to be significantly reduced.

RTX³ thermal relays and MPX³ motor MCBs are temperature-compensated in order to prevent false tripping due to variations in the ambient temperature. Between -5°C and +40°C, thermal relays and motor MCBs are calibrated automatically.
Outside this range, the setting will need to be altered (see manual).

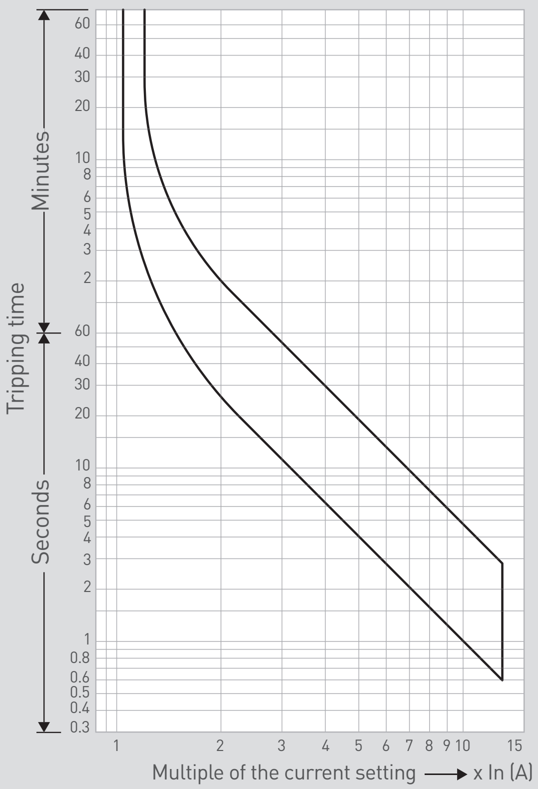
■ Understanding cold starting and warm starting curves

The thermal tripping curve (in Amps) follows a trend which is inversely proportional to the duration, expressed in seconds and minutes. The tripping zone is defined by an interval limited by the maximum and minimum values in standard IEC 60947-4-1. In order to prevent false tripping, it is advisable to select a thermal protection device whose curve is not superimposed with the motor starting characteristics.

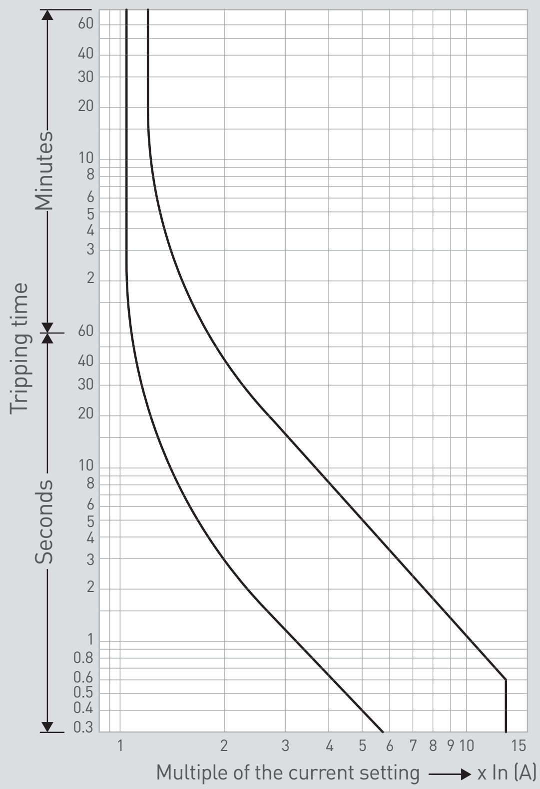
Cold state characterises the bimetallic strips when no current is applied to them. They are in their initial position. After a certain operating time, the bimetallic strips are affected by thermal stress, and bend more or less depending on the current value.

This is referred to as "warm state". In practice, it means that the trip thresholds are lowered (memory effect). In other words, the relay is more sensitive to an increase in current after an overload, stalling or loss of phase. This allows the protection to be strengthened for the motor whose windings are at a higher temperature and which is therefore more sensitive to another overload.

Cold starting



Warm starting



MPX³ motor MCBs

The motor MCB is a thermal-magnetic MCB specially designed to protect motors. It provides protection against short-circuits (magnetic function) and overloads (thermal function). It complies with the IEC 60947-2 and IEC 60947-4-1 product standards.

Just like the RTX³ thermal overload relay, the motor MCB's thermal sensitivity should be set as close as possible to the motor nominal current. It operates in exactly the same way; its protection components also consist of bimetallic strips which expand according to the intensity of the current flowing through them. It is temperature-compensated, which guarantees optimum operation in a wide temperature range.

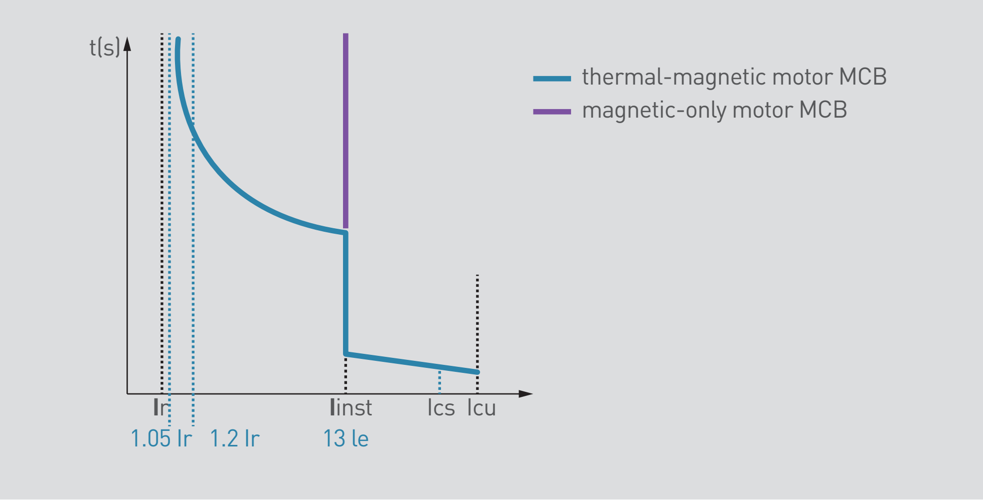
The magnetic trip threshold is fixed; it is 13 times the motor MCB rated operating current.

The motor MCB can be "magnetic only" type, in other words without a thermal protection component. In this case, it only offers protection in the event of a short-circuit. It is often used for smoke control applications, in which the motor should continue to run, including when there is a fault associated with an overload. For certain starting modes using contactors, with thermal protection provided by a thermal relay, a "magnetic only" type circuit breaker is sufficient.

The motor MCB is designed to satisfy type 2 coordination requirements (according to standard IEC 60947-4-1), which are the most stringent of the tests conducted. It is characterised by an ultimate breaking capacity (Icu) and by a standard breaking capacity (Ics) which guarantee continuity of operation after a short-circuit.

The motor MCB also satisfies the definition of a "motor starter", by performing the dual function of interruption and isolation; the latter is particularly associated with sufficient clearance between the fixed and moving contacts.

The motor MCB tripping type curve is illustrated as shown in the diagram below:



The circuit breaker should not trip for I ⩽ or = 1.05 Ir (setting current), in compliance with the requirements of standard IEC 60947-4-1. Above Ir, in the event of a thermal overload, the circuit breaker trips in a time inversely proportional to the current flowing across it.

For example, it should open in less than 2 hrs when I = 1.2 Ir, in less than 4 min when I = 1.5 Ir and in less than 10 s when I = 7.2 Ir. In the event of overcurrent associated with a short-circuit, it is the magnetic device which acts, in the space of a few milliseconds, called instantaneous tripping.

In the case of the "magnetic only" motor MCB, there is no thermal tripping zone, only the instantaneous tripping vertical curve.

The motor MCB status feedback is provided by using side- or front-mounting auxiliary contacts. There are several types depending on the type of data to be fed back (open or closed state, tripped on magnetic fault).

The motor MCB can also be fitted with remote control auxiliaries (shunt or voltage release, available from 24 V~ to 400 V~).

Definition of Type 2 coordination according to IEC 60947-4-1.
The contactor or motor starter must not endanger people and property in the event of a short-circuit.
The contactor or motor starter must remain functional.
No damage must occur to the thermal relay or other components, except for welding of the contacts but these must be easily separable without significant warping.

MOTOR CONTROL

Advantages of CTX³

Motors are usually subjected to more intensive stress than other electrical loads (lighting, heating), mainly because of the shorter, closer operating cycles and the high inrush current.

Switching their power supply circuit requires a special control device which can cope with all these stresses: this is the power contactor (also called a motor-contactor).

The power contactor is made up of fixed contacts and moving contacts moved by a coil which, when supplied with power, closes its contacts and ensures electrical continuity between the upstream and downstream terminals, thus supplying the motor with power. Other demanding loads can also be supplied by this type of contactor.

It is characterised by:

- excellent electrical and mechanical endurance
- a high number of operating cycles (output rate) per hour suitable for the motor operating frequency
- a reinforced, partitioned structure so as to limit and confine the electric arc

It is selected on the basis of several criteria, summarised in the table below.

■ **Criteria to be taken into account when defining motor control equipment**

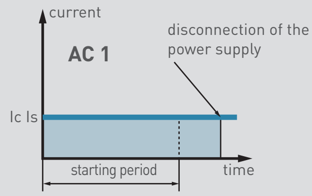
	OPERATING OR ENVIRONMENTAL CHARACTERISTICS	CRITERIA	CONTACTOR CHARACTERISTICS
0	**Mains supply characteristics**		
0.1	Voltage	12 V, 24 V, 230 V, 400 V, 690 V, 1000 V	Rated operating voltage Ue > mains supply voltage Rated insulation voltage (Ui) Overvoltage category (class) Permissible surge voltage (Uimp)
0.2	Frequency	50 Hz, 60 Hz, 400 Hz	Rated frequency
1	**Load type**		
1.1	Receiver type	Three-phase asynchronous motor, Single-phase motor, DC motor Resistive heating, Transformer, etc	Utilisation category
1.2	Receiver characteristics	Number of conductors Mains supply voltage and frequency Nominal power Cos φ	Number of poles Operating current
2	**Starting method**		
2.1	Starting at full voltage	Ignition (lighting, heating, etc), D.O.L. starting (motors), switching capacitors and chokes for power factor correction	Making and breaking current (Ic) Rated operating current (Ie) Conventional free-air thermal current (Ith)
2.2	D.O.L. starting at reduced voltage	Soft starting (motors)	Making and breaking current (Ic) Rated operating current (Ie)

	OPERATING OR ENVIRONMENTAL CHARACTERISTICS	CRITERIA	CONTACTOR CHARACTERISTICS
3	**Operating mode**		
3.1	Operating frequency	Use: DC (VMC), intermittent (extrusion, lifting, pumping), occasional (smoke control) Switching frequency (number per hour) Number of switching operations (over the life of the product)	Electrical endurance Mechanical endurance Operating factor (current flow duration/operating cycle duration)
4	**Contactor coil power supply**		
4.1	Type of current	AC, DC Voltage drop and variation	Control circuit rated voltage (Uc) Control power supply rated voltage (Us)
	Switching time	Change of contact status	Opening or closing duration
4.2	Power	Inrush power Holding power	Coil consumption (VA), (W)
5	**Auxiliary circuits**		
	Auxiliary contacts	Status feedback Electrical interlocking Control of external circuits	Utilisation category AC14 AC15 DC13 Conformity of auxiliary contacts with the standard definition of "mirror contacts"
6	**Installation**		
6.1	Environment	Ambient temperature outside the cabinet Temperature around the device Altitude, Dust, Gas, Vibrations, Oil	Pollution level Spacing between contactors Heat dissipation (coil and contacts) Operating temperature range (upper and lower) Derating according to altitude if > 2000 m Mechanical impact and vibration resistance values
6.2	Connection	Terminal type with or without conductor preparation (end caps, lugs, etc) Cable cross-sections	Terminal connection capacities
6.3	Associated equipment	Motor thermal protection Line protection	Operational compatibility with the motor MCB or thermal relay Type 2 coordination
6.4	Mounting	Rail, Plate	Rail fixing centres, dimensions and type Rail mounting position

Utilisation categories

AC UTILISATION CATEGORIES

AC-1: This category applies to all receivers operating on **alternating current,** whose **power factor is 0.95 or more.** Included in this category are the usual resistive loads (heating, ovens), compensated loads (lighting). The contactor operating current AC-1 is also taken into account in load-shedding and switching operations in distribution systems (busbars); these operations should remain within the framework of all the usual contactor characteristics for the loads being considered.

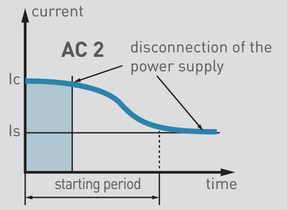


The contactor disconnects the motor nominal current

AC-2: This category applies to **slip-ring motors**, during starting, reverse-current braking and inching.

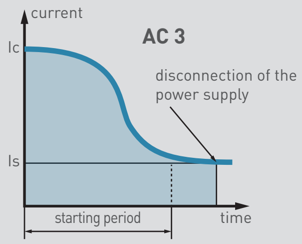
The current inrush on closing can reach several times the motor nominal current.

This current surge makes contact opening or reopening more problematic and difficult; the voltage/current phase shift is still significant.

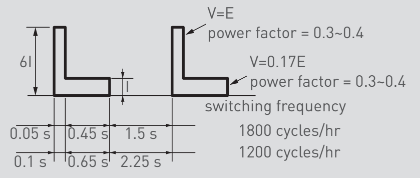


The contactor must be able to disconnect the starting current

AC-3: This category applies to **cage motors** for which breaking occurs with the motor started. The current inrush on closing reaches 5 to 8 times the motor nominal current. On opening, the current is interrupted according to the motor nominal characteristics with limited voltage/current phase shift. Breaking is easily achieved.

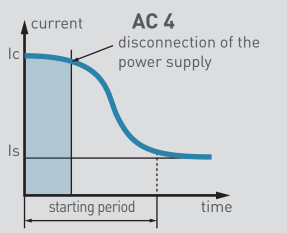


The contactor disconnects the motor nominal current

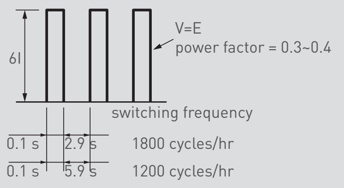


Test sequence in category AC-3
I: Nominal current E: Nominal voltage

AC-4: This category applies to **cage motors** used intensively, for inching, reversing direction, reverse-current braking (lifting and handling machines for example). The current inrush on closing reaches 5 to 8 times the motor nominal current. On opening, it interrupts this current at a voltage which increases as the motor speed decreases. Breaking is more difficult than in category AC-3.
In general, this operating mode involves oversizing control devices for this category.



The contactor must be able to disconnect the starting current



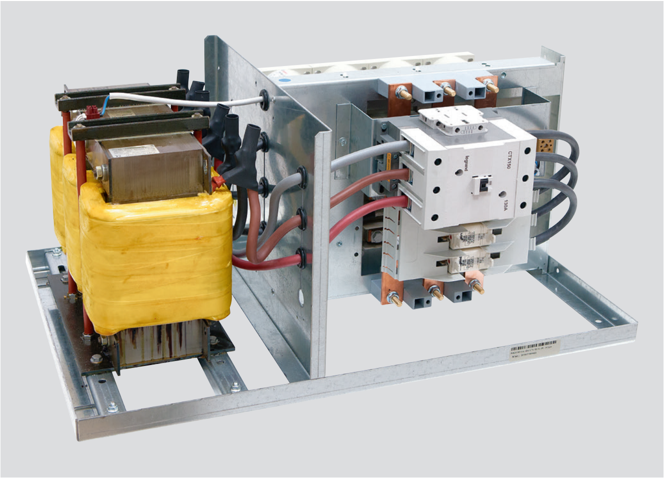
Test sequence in category AC-4
I: Nominal current E: Nominal voltage

AC UTILISATION CATEGORIES (CONTINUED)

AC-6a: This category applies to LV ferromagnetic transformers. When switching occurs in the primary windings, on transformer energisation, the peak value of the inrush current can reach 5 to 25 times the nominal current. (This value is dependent on the transformer power and the power supply upstream impedance).

AC-6b: This category applies to capacitors, used for power factor correction. When several capacitor banks or steps are connected in parallel, the transient voltage surges need to be limited by using inductances in series with the capacitors or by energising the capacitors via a resistor.

In the absence of such devices, the contactor rated current must be selected with an increased value.



Alpimatic racks with detuned reactor

DC UTILISATION CATEGORIES

DC-1: This category applies to receivers operating on direct current whose time constant (L/R) is 1 ms or less. The current inrush on closing can reach 1.5 times the load nominal current.

Examples: Non-inductive or barely inductive loads, resistance furnaces.

DC-3: This category applies to parallel motors whose time constant (L/R) is 2.5 ms or less. The current inrush on closing can reach 4 times the motor nominal current during starting, reversing direction, inching phases. On opening, the contactor should interrupt a current which can reach 4 times the motor nominal current at mains voltage. During breaking, the voltage increases as the motor speed decreases.

DC-5: This category applies to series motors whose time constant (L/R) is 15 ms or less. The current inrush on closing can reach 4 times the motor nominal current during starting, reversing direction, inching phases. The current inrush on closing can reach 2.5 times the motor nominal current.On opening, it should interrupt this current at a voltage which is mains voltage or less.

Current making and breaking conditions

Breaking is harder to do in DC than in AC, especially when the time constant is high. For this reason, it can be a good idea to connect the poles in series to increase the breaking capacity of the DC contactor. In AC, it is possible to connect the poles in parallel if certain rules are followed.

Standard IEC 60947-4-1 defines the following conditions for the test sequences of each utilisation category in normal use. Legrand contactors conforming to this standard are also tested in occasional-use conditions. Making and breaking conditions according to the utilisation categories in use (see table 10).

CATEGORY		MAKING			OPENING		
		I/I	U/U	Cosφ or L/R (ms)	I/I	U/U	Cosφ or L/R (ms)
CONTACTORS FOR AC BREAKING							
AC-1		1	1	0.95	1	1	0.95
AC-2		2.5	1	0.65	2.5	1	0.65
AC-3	I≤ 17 A	6	1	0.65	1	0.17	0.65
	17<I≤100 A	6	1	0.35	1	0.17	0.35
	I>100 A	6	1	0.35	1	0.17	0.35
AC-4	I≤ 17 A	6	1	0.65	6	1	0.65
	17<I≤100 A	6	1	0.35	6	1	0.35
	I>100 A	6	1	0.35	6	1	0.35
CONTACTORS FOR DC BREAKING							
DC-1		1	1	1	1	1	1
DC-3		2.5	1	2	2.5	1	2
DC-5		2.5	1	7.5	2.5	1	7.5

UTILISATION CATEGORY	MAKING AND BREAKING CONDITIONS					
	I_c/I_e	U_r/U_e	Cos φ	Current flow time [b] s	Off period s	Number of operating cycles
AC-1	1.0	1.05	0.80	0.05[b]	[c]	6000[i]
AC-2	2.0	1.05	0.65	0.05[b]	[c]	6000[i]
AC-3	2.0	1.05	[a]	0.05[b]	[c]	6000[i]
AC-4	6.0	1.05	[a]	0.05[b]	[c]	6000[i]
AC-5a	2.0	1.05	0.45	0.05[b]	[c]	6000[i]
AC-5b	1.0[e]	1.05	[e]	0.05[b]	60	6000[i]
AC-6	[g]	[g]	[g]	[g]	[g]	[g]
AC-8a	1.0	1.05	0.80	0.05[b]	[c]	30000
AC-8b[hj]	6.0	1.05	[a]	1 10	9 60[d]	5900 100
			L/R ms			
DC-1	1.0	1.05	1.0	0.05[b]	[c]	6000[f]
DC-3	2.5	1.05	2.0	0.05[b]	[c]	6000[f]
DC-5	2.5	1.05	7.5	0.05[b]	[c]	6000[f]
DC-6	1.0[e]	1.05	[e]	0.05[b]	60	6000[f]

Ic = making or breaking current. Except for categories AC-5b, AC-6 or DC-6, the making current is expressed in DC or AC, like the rms value of symmetrical components, on the understanding that in AC, the actual peak value of the making operation can have a higher value than the peak value of the symmetrical component.
Ie = rated operating current
Ui = = recovery voltage at power frequency or in DC
Ue = = rated operating voltage
a = Cos φ = 0.45 for Ie ≤ 100 A; 0.35 for Ie > 100 A.
b = The time can be less than 0.05 s, provided that the contacts can be positioned suitably
c = These off periods should not be higher than the values in Table 8.
d = The manufacturer can choose any value for the off period up to 200 s.
e = Tests to be performed with a load consisting of incandescent lamps.
f = 3000 operating cycles at one polarity and 3000 operating cycles at the opposite polarity.
g = To be established.
h = The tests for category AC-8b should be supplemented by tests for category AC-8a. These tests can be performed on different samples.
i = For manually-operated connection devices, the number of operating cycles should be 1000 on load, followed by 5000 at no load.
j = It is accepted that a lower Ic/Ie ratio (blocked rotor current over full load current) can be used if this is specified by the manufacturer.

Contactor applications

APPLICATIONS IN CATEGORY AC-1

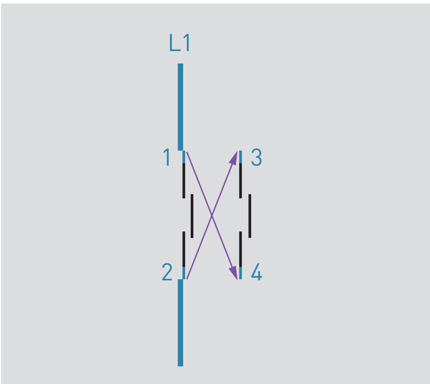
■ **Maximum operating current and maximum permissible power**

		CTX³ 22				CTX³ 40		CTX³ 65		CTX³ 100			CTX³ 150		CTX³ 225		CTX³ 400			CTX³ 800		
		9 A	12 A	18 A	22 A	32 A	40 A	50 A	65 A	75 A	85 A	100 A	130 A	150 A	185 A	225 A	265 A	330 A	400 A	500 A	630 A	800 A
Max. number of cycles per hour		600											-									
Cable	mm²	4	10	10	10	10	16	25	35	35	50	50	70	95	95	150	240	240	370	480	-	-
Max. oper. current ≤40°C	A	25	25	32	40	50	60	70	100	110	135	140	160	210	230	275	300	350	450	580	660	900
Max. oper. current ≤55°C	220/ 240 V	10	10	13	17	21	25	29	42	46	56	58	61	80	88	105	114	133	171	221	251	343
	380/ 240 V	19	19	24	30	38	46	53	76	84	103	107	105	138	151	181	197	230	296	382	434	592
	500/ 550 V	24	24	30	38	48	57	67	95	105	129	133	139	182	199	238	260	303	390	502	572	779
	690 V	30	48	48	60	72	84	90	120	131	161	167	191	251	275	329	359	418	538	693	789	1076

■ **Operating current with poles connected in parallel**

The operating current for the contactor indicated in the above table can be increased by using poles connected in parallel and applying the following coefficients:

- 2 poles in parallel K = 1.6
- 3 poles in parallel K = 2.25
- 4 poles in parallel K = 2.8



It is advisable to connect contacts in parallel by crossing over the connections, so as to divide the current equally in each pole.

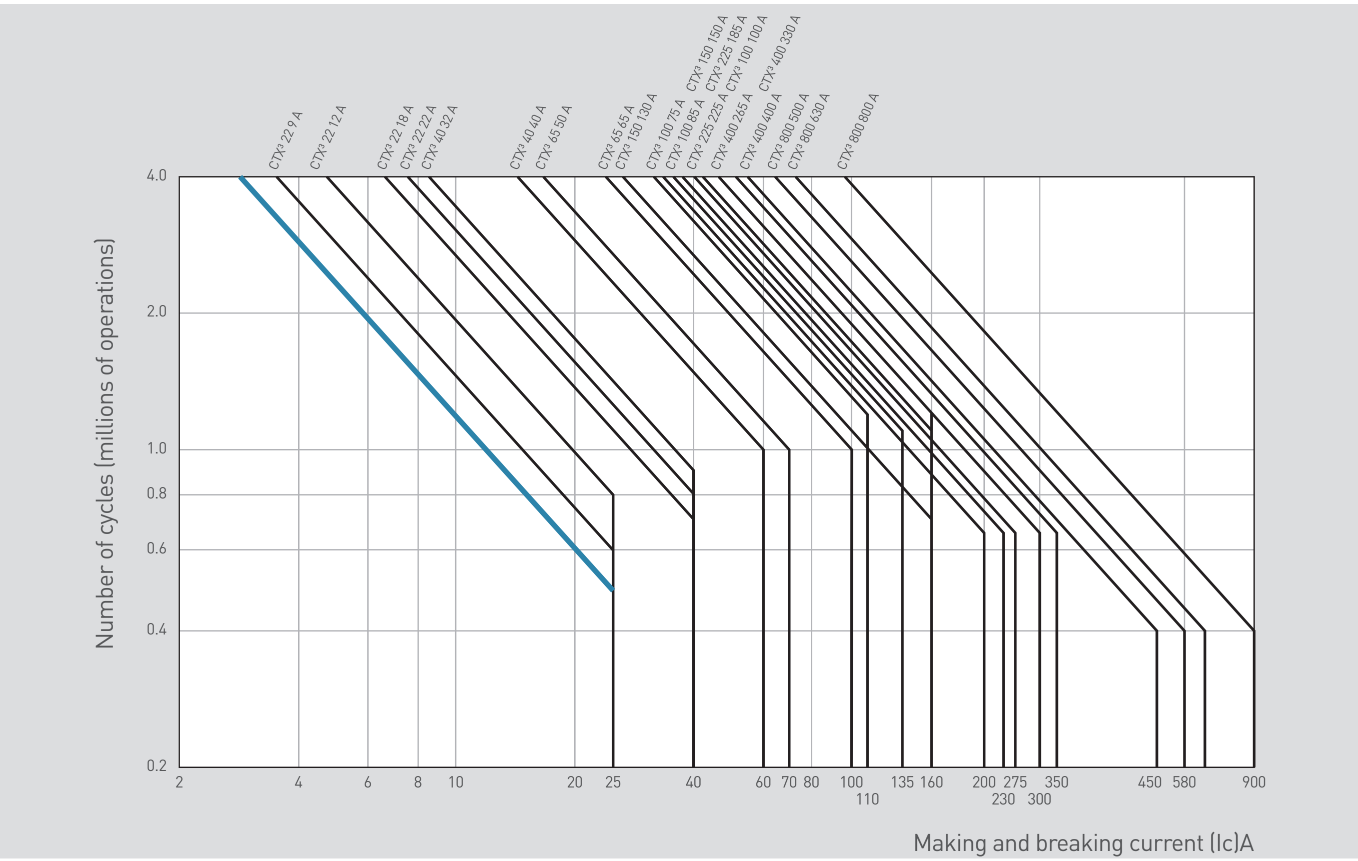
APPLICATIONS IN CATEGORY AC-1 (CONTINUED)

■ **Electrical endurance**

The following data are applicable for a maximum voltage of 440 V and a power factor higher than 0.95 for switching resistive loads.
The current making and breaking conditions are as follows:

CATEGORY	RATED BREAKING AND MAKING CAPACITY		ELECTRICAL ENDURANCE	
	MAKING	BREAKING	MAKING	BREAKING
AC-1	1.5 Ie, 1.1 Ue Cos φ 0.95	1.5 Ie, 1.1 Ue Cos φ 0.95	Ie, Ue Cos φ 0.95	Ie, Ue Cos φ 0.95

(NB) Ie: Rated operating current, Ue: rated operating voltage, Cos φ: power factor



Example: For an AC-1 operating current of 50 A and endurance of 2 million operations for an external ambient temperature below 40°C, you should select a 65 A CTX³.

APPLICATIONS IN CATEGORY AC-3

■ **Maximum operating current and maximum permissible power (t°<55°C)**

TYPE			CTX^3 22				CTX^3 40		CTX^3 65		CTX^3 100			CTX^3 150		CTX^3 225		CTX^3 400			CTX^3 800		
			9 A	12 A	18 A	22 A	32 A	40 A	50 A	65 A	75 A	85 A	100 A	130 A	150 A	185 A	225 A	265 A	330 A	400 A	500 A	630 A	800 A
Max. operating current	≤440 V	A	9	12	18	22	32	40	50	65	75	85	95	120	150	185	225	265	330	400	500	630	800
Max. oper. current ≤55°C	220/ 240 V	kW	2.5	3.5	4.5	5.5	7.5	11	15	18.5	22	25	30	37	45	55	75	80	90	125	147	190	220
	380/ 440 V		4	5.5	7.5	11	11	18.5	22	30	37	45	55	60	75	90	132	147	160	200	265	330	400
	500/ 550 V		4	7.5	7.5	15	15	22	30	33	37	45	55	60	75	110	132	147	160	225	265	330	400
	690 V		4	7.5	7.5	15	15	22	30	33	37	45	55	55	75	110	140	160	200	250	300	400	500

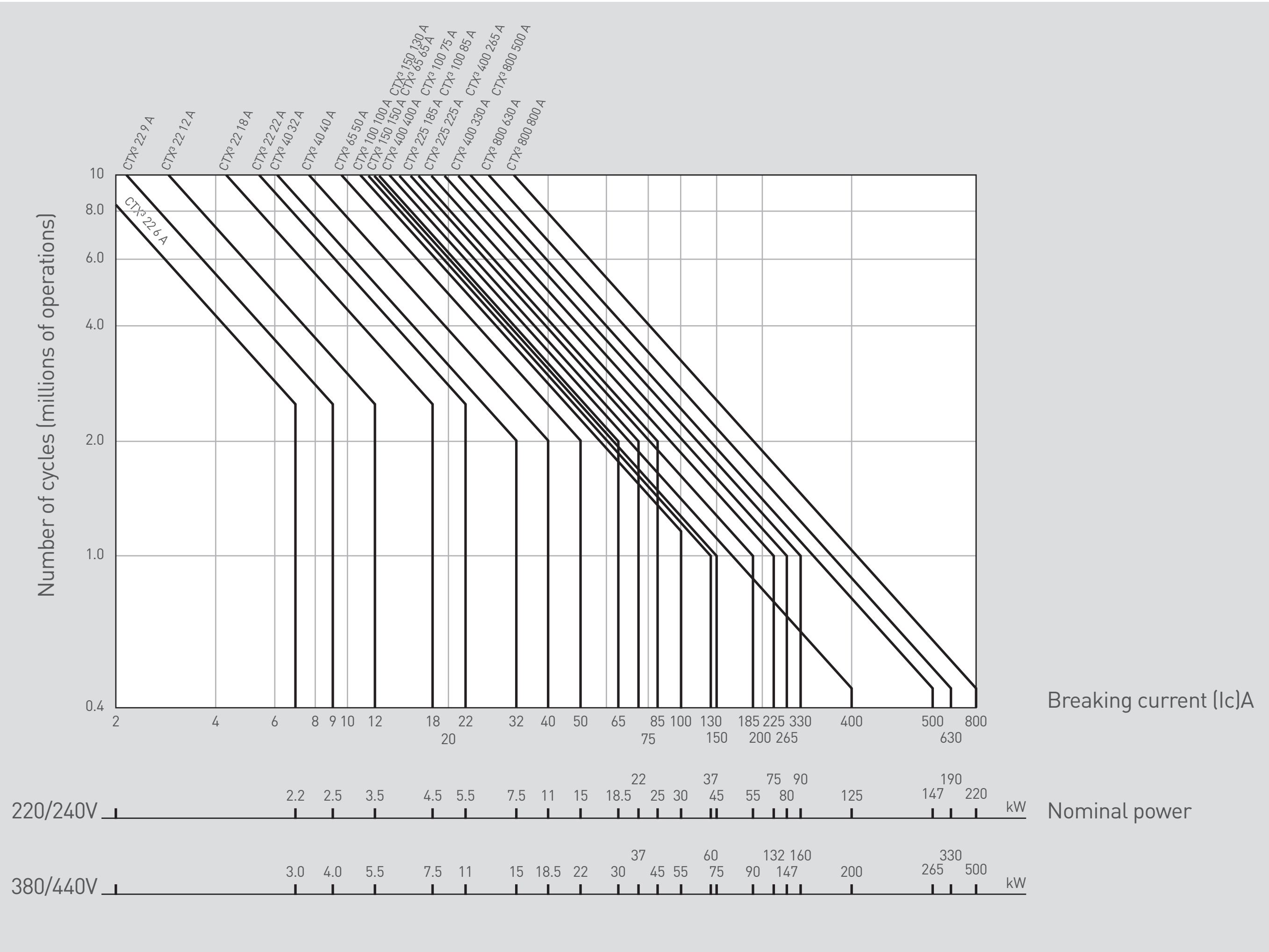
■ **Max. number of cycles per hour**

NUMBER OF CYCLES	CTX^3 22				CTX^3 40		CTX^3 65		CTX^3 100			CTX^3 150		CTX^3 225		CTX^3 400			CTX^3 800		
	9 A	12 A	18 A	22 A	32 A	40 A	50 A	65 A	75 A	85 A	100 A	130 A	150 A	185 A	225 A	265 A	330 A	400 A	500 A	630 A	800 A
1/hr	1800	1800	1800	1800	1800	1800	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200

APPLICATIONS IN CATEGORY AC-3 (CONTINUED)

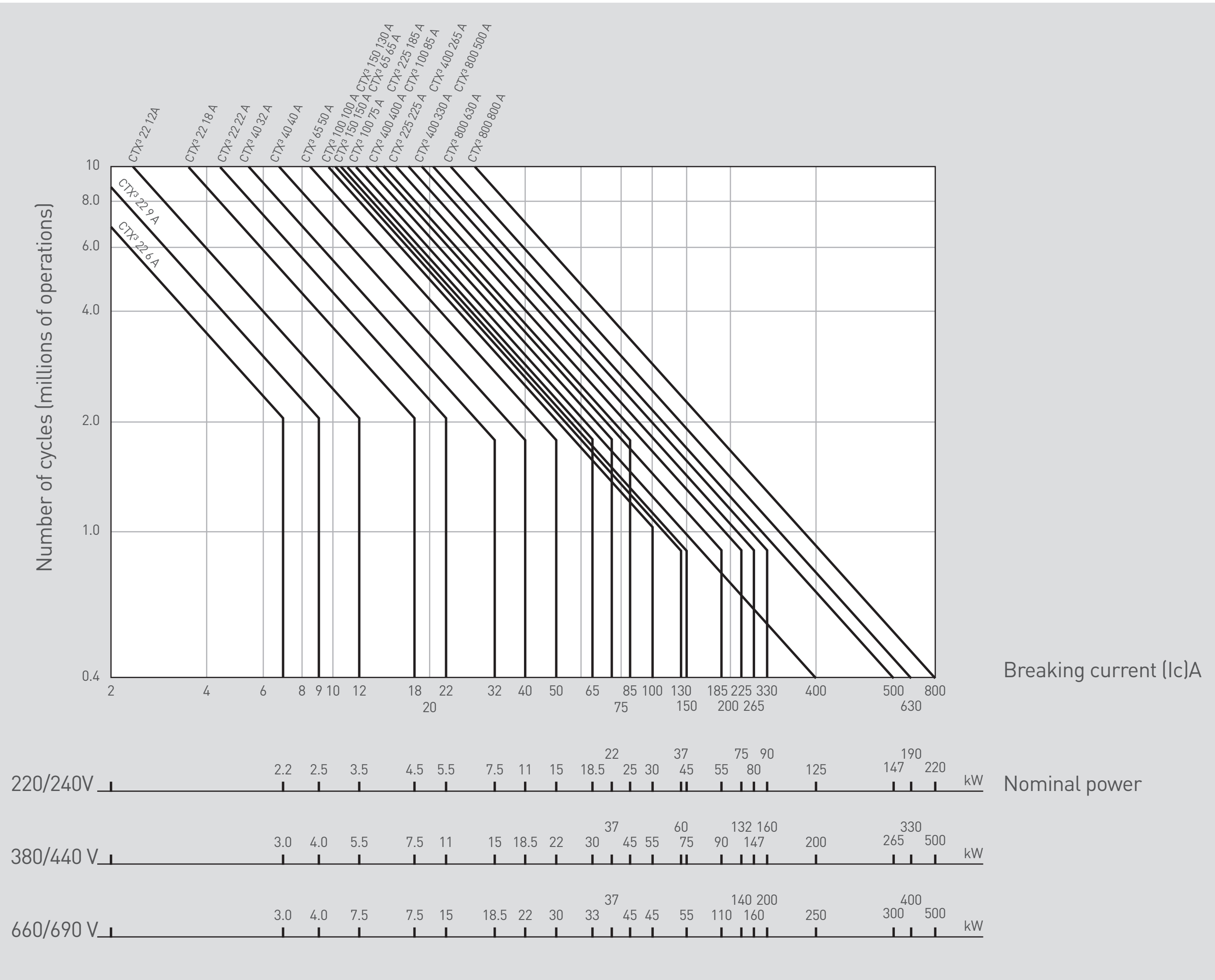
■ **Electrical endurance**

Operating voltage < 440 V



Electrical endurance (continued)

Operating voltage < 690 V



APPLICATIONS IN CATEGORY AC-2/AC-4

■ **Maximum operating current and maximum permissible power**

AC-2: slip-ring motors

AC-4: cage motors

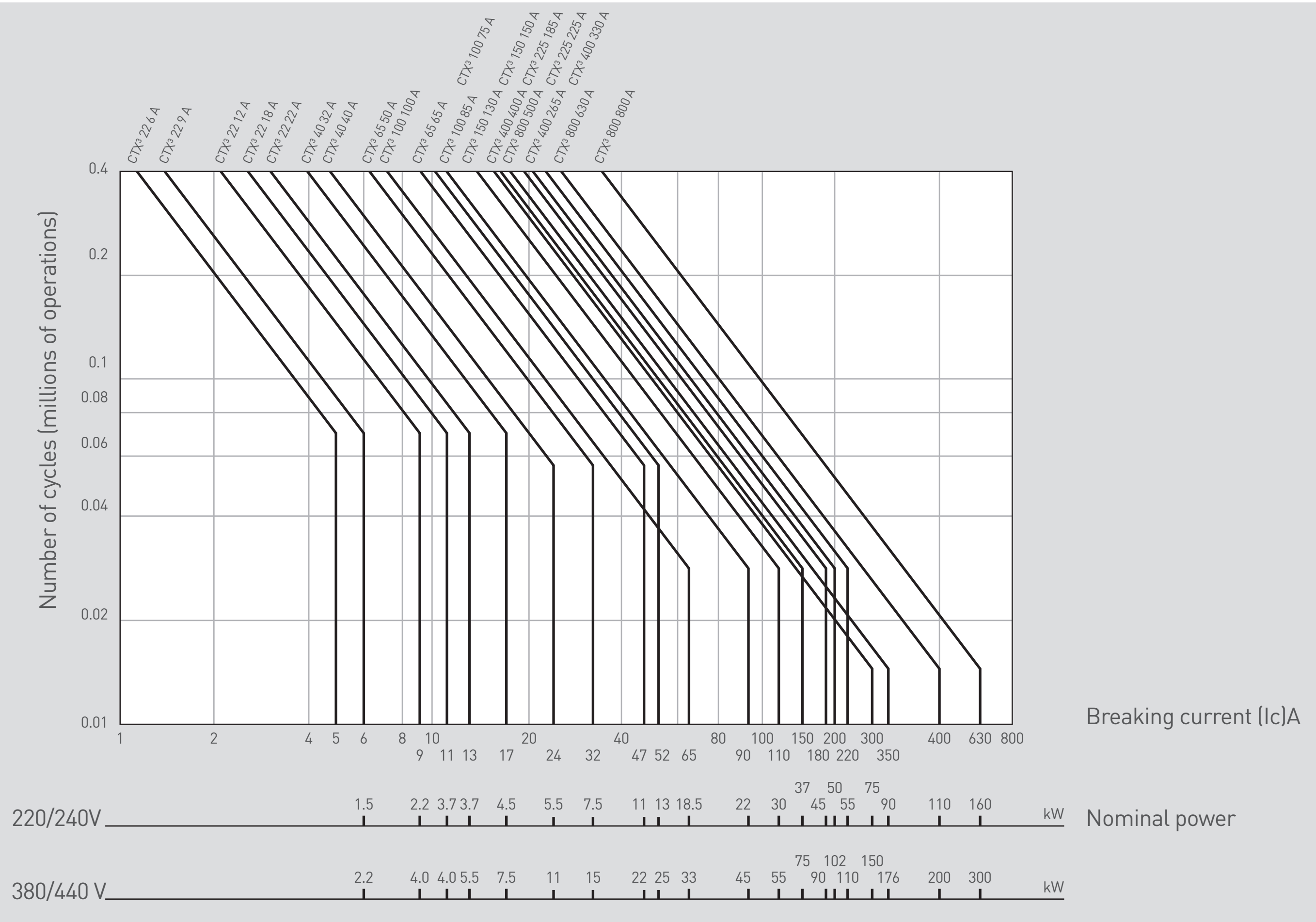
NUMBER OF CYCLES	CTX^3 22				CTX^3 40		CTX^3 65		CTX^3 100			CTX^3 150		CTX^3 225		CTX^3 400			CTX^3 800		
	9 A	12 A	18 A	22 A	32 A	40 A	50 A	65 A	75 A	85 A	100 A	130 A	150 A	185 A	225 A	265 A	330 A	400 A	500 A	630 A	800 A
Ue ≤ 440 V	54	72	108	132	192	240	300	390	450	510	570	780	900	1110	1350	1590	1980	2400	3000	3600	4800
440 V < Ue ≤ 690 V	40	50	70	80	105	150	170	210	210	250	250	540	640	708	810	1020	1410	1830	2130	2760	2910

APPLICATIONS IN CATEGORY AC-2/AC-4 (CONTINUED)

■ Maximum power in AC-4

OPERATING VOLTAGE \ NOMINAL POWER (kW)	CTX³ 22				CTX³ 40		CTX³ 65		CTX³ 100			CTX³ 150		CTX³ 225		CTX³ 400			CTX³ 800		
	9 A	12 A	18 A	22 A	32 A	40 A	50 A	65 A	75 A	85 A	100 A	130 A	150 A	185 A	225 A	265 A	330 A	400 A	500 A	630 A	800 A
220/240 V	1.5	2.2	3.7	3.7	4.5	5	5.5	7.5	7.5	7.5	9	22	30	37	45	50	55	75	90	110	160
380/240 V	2.2	4	4	5.5	7.5	9	11	11	11	15	15	45	55	75	90	102	110	150	176	200	300
415 V	2.2	4	4	5.5	7.5	9	11	11	11	15	15	45	55	75	90	102	110	150	176	200	300
440 V	2.2	4	4	5.5	7.5	9	11	15	15	15	15	45	55	75	90	102	110	150	176	200	300

■ Selection table (electrical endurance)



Example: Ic = 6 x Ie = 66 A for a 5.5 kW motor, Ue = 400 V Ie = 11 A. For endurance of 200,000 operations, you should select a 22 A contactor.

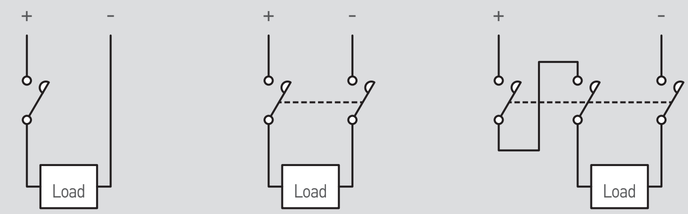
APPLICATIONS IN CATEGORY DC-1/DC-3, DC-5

■ **Connection method for poles in series**

In DC, a single contact is enough to break the receiver power supply, but by using several contacts in series, the contactor breaking capacity can be increased. This allows the arc generated by switching voltage surges to be spread across the poles and optimises the cost of the solution.

Applied to resistive loads such as DC arc furnaces, the contactors can be used for a current higher than that of loads such as motors, due to a low inrush current and a high power factor.

Thus, breaking in DC-1 is easier than in DC-3 or DC-5, resulting in the table below:



1 single pole — 2 poles in series — 3 poles in series

Motor load (category DC-3 - DC-5): time constant L/R = 15 ms.

		CTX^3 22				CTX^3 40		CTX^3 65		CTX^3 100			CTX^3 150		CTX^3 225		CTX^3 400			CTX^3 800		
		9 A	12 A	18 A	22 A	32 A	40 A	50 A	65 A	75 A	85 A	100 A	130 A	150 A	185 A	225 A	265 A	330 A	400 A	500 A	630 A	800 A
24 V	1	12	12	12	12	20	20	35	35	40	40	40	200	200	240	260	300	360	430	580	850	1300
	2	15	15	15	15	25	25	45	45	60	60	60	200	200	240	260	300	360	430	580	850	1300
	3	18	18	18	18	30	30	55	55	80	80	80	200	200	240	260	300	360	430	580	850	1300
48/75 V	1	10	10	10	10	15	15	15	15	15	15	15	200	200	240	260	300	360	430	580	850	1300
	2	12	12	12	12	20	20	40	40	50	50	50	200	200	240	260	300	360	430	580	850	1300
	3	15	15	15	15	30	30	50	50	70	70	70	200	200	240	260	300	360	430	580	850	1300
110 V	1	2	2	2	2	2.5	2.5	2.5	2.5	2.5	2.5	2.5	100	100	-	-	-	-	-	-	-	-
	2	8	8	8	8	15	15	25	25	40	40	40	140	140	160	180	250	300	350	500	700	1000
	3	12	12	12	12	20	20	35	35	60	60	60	200	200	240	240	250	310	350	550	850	1000
220 V	1	0.75	0.75	1	1	1	1	1	1	1	1	1	100	100	-	-	-	-	-	-	-	-
	2	1.5	1.5	2	2	3	3	5	5	7	7	7	120	120	140	160	220	280	310	480	680	900
	3	6	6	6	6	10	10	25	25	35	35	35	140	140	160	160	250	300	350	500	700	1000

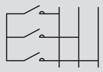
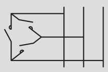
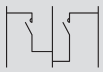
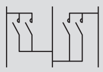
APPLICATIONS FOR SLIP-RING MOTORS

The contactor is used to short-circuit the rotor circuit resistors used when starting or stopping the slip-ring motor.

With starting, the contactor is used in a closing role (gradually short-circuiting resistors until they are totally eliminated). When the stator contactor closes, the rotor contactor must be open.

With stopping or braking, the contactor is used in an opening role, to gradually insert resistors in the rotor circuit. It opens after the stator contactor opens.

These two operating modes explain the different rotor voltage characteristics (Ir).
Depending on the connection method, the values of Ie (contactor operating current) can differ.

		Ir/Ie RATIO	MAXIMUM ROTOR VOLTAGE	MAXIMUM ROTOR VOLTAGE WITH REVERSE-CURRENT
Star		1	1500 V	750 V
Delta		1.4	1250 V	625 V
In V		1	1250 V	625 V
In W		1.6	1250 V	750 V

TYPE / DURATION / NUMBER OF CYCLES		OPERATING CURRENT (A)																				
		CTX³ 22				CTX³ 40		CTX³ 65		CTX³ 100			CTX³ 150		CTX³ 225		CTX³ 400			CTX³ 800		
		9 A	12 A	18 A	22 A	32 A	40 A	50 A	65 A	75 A	85 A	100 A	130 A	150 A	185 A	225 A	265 A	330 A	400 A	500 A	630 A	800 A
≤ 30/hr	6 s	60	60	90	90	130	210	250	300	330	360	380	390	450	550	670	800	900	1100	1500	2000	2500
	12 s	50	50	60	60	125	160	200	250	275	300	320	250	280	400	480	550	600	730	1000	1500	2000
	20 s	35	35	45	45	90	100	110	120	135	150	170	190	220	300	360	400	450	550	750	1200	1500
> 30/hr		25	25	32	32	50	60	80	80	100	125	140	170	200	270	330	350	420	500	700	1000	1600

Other power contactor applications

LIGHTING

The inrush currents generated when receivers are powered up and their power factor depend on the type of light source, the connection method and their compensation. For this type of use, standard IEC 60947-4-1 defines two utilisation categories: AC-5a for controlling discharge lamps, AC-5b for controlling incandescent lamps.

The making current is particularly high for fluorescent lamps and mercury lamps (up to 10 times their nominal current). For LEDs, it can be even higher (depending on the compensation electronics).

In order to guarantee optimum performance, the contactor can be selected by ensuring that the sum of the controlled light source nominal currents is always less than the contactor AC-3 operating current. For the power analysis, operation is assumed to be constant (devices on permanently) and the diversity coefficient equal to 1 (all devices controlled simultaneously).

A lighting line is protected by means of a short-circuit protection device (thermal-magnetic MCB or fuse) in accordance with the usual selection criteria (line length, cross-section, core, conductor type, installation method, etc) and receiver type (power, inrush current, Cos φ). As a general rule, it is assumed that the lighting does not generate current surges.

Lighting appliances are very varied in their electrical characteristics. Due to the large number of selection criteria, the selection tables are included in the CTX³ contactor technical data sheets which exhaustively document applications for this type of use.

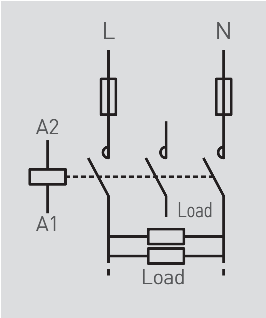
HEATING

Just like lighting appliances, radiated or infrared electrical heating appliances do not generate electrical overloads. They are so-called passive receivers, as opposed to so-called active receivers such as motors, for which there is a correlation between the mechanical load applied to them and the current they consume.

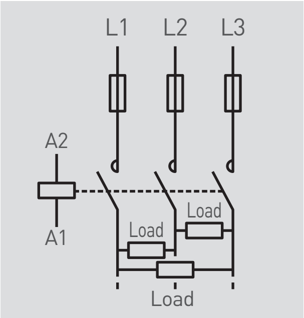
The inrush current of a heating appliance is relatively low, being linked to its resistive nature. It is on average 2 to 3 times the receiver nominal current. Once its status has stabilised, its consumption remains constant. For this reason, there is no point in using a specific thermal protection device. Conversely, the line must be protected by an SCPD, defined in accordance with the usual selection criteria (line length, cross-section, core, conductor type, installation method, etc) for the receiver being considered (power, inrush current, Cos φ).

There is no phase shift between the voltage and current and we therefore consider that this type of application has a Cos φ equivalent to 1 (classification type AC-1). Nonetheless for mixed appliances, fitted with fans (air heaters) or pumps (industrial heaters), you should refer to the Cos φ stated in the manufacturer's technical data.

- Switching in single-phase operation



- Switching in three-phase operation



HEATING (CONTINUED)

Switching on 2 poles

TYPE OF CONTACTOR		CTX³ 22				CTX³ 40		CTX³ 65		CTX³ 100			CTX³ 150		CTX³ 225		CTX³ 400			CTX³ 800		
		9 A	12 A	18 A	22 A	32 A	40 A	50 A	65 A	75 A	85 A	100 A	130 A	150 A	185 A	225 A	265 A	330 A	400 A	500 A	630 A	800 A
Max. power (kW)	240/ 240 V	4	4	5	5	9	11	14	14	20	20	20	44	44	48	52	80	75	86	116	155	225
	380/ 415 V	7	7	9	9	15	19	24	24	35	35	35	76	76	83	90	104	130	145	200	368	389
	660/ 690 V	12	12	15.5	15.5	25.5	33	41.5	41.5	61	61	61	118	118	130	145	160	200	230	310	415	602

Switching on 3 poles

TYPE OF CONTACTOR		CTX³ 22				CTX³ 40		CTX³ 65		CTX³ 100			CTX³ 150		CTX³ 225		CTX³ 400			CTX³ 800		
		9 A	12 A	18 A	22 A	32 A	40 A	50 A	65 A	75 A	85 A	100 A	130 A	150 A	185 A	225 A	265 A	330 A	400 A	500 A	630 A	800 A
Max. power (kW)	240/ 240 V	6	6	8	8	15	19	24	24	34	34	34	76	76	82	90	103	130	149	200	268	389
	380/ 415 V	11	11	15.5	15.5	26	32	41	41	59	59	59	131	131	143	155	179	225	256	346	464	672
	660/ 690 V	21	21	27	27	44	57	72	72	105	105	105	206	206	220	250	275	345	395	530	710	1030

LV/LV TRANSFORMER

Switching 3 phases on the primary of LV/LV transformers: In accordance with standard IEC 947-4-1 (Table VII b).

Powering up an LV/LV transformer is comparable to that of an asynchronous motor. It generates a strong inrush current which must be taken into account when sizing the contactors. Standard IEC 60947-4-1 defines a specific utilisation category for this type of application: AC-6a.

The peak value of the inrush current associated with magnetisation of the primary windings depends on the transformer power. It can reach between 10 and 30 times the transformer nominal current over a period of a few dozen milliseconds, after which the transformer reaches equilibrium.

■ Contactor selection

The data stated below are applicable for a temperature below +55°C and for a maximum number of 60 hourly cycles.

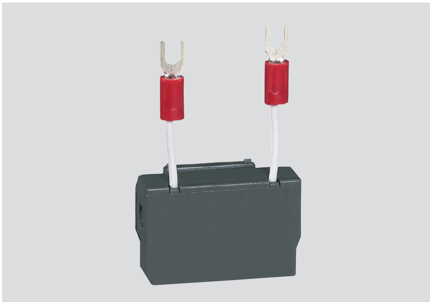
TYPE OF CONTACTOR		CTX³ 22				CTX³ 40		CTX³ 65		CTX³ 100		
		9 A	12 A	18 A	22 A	32 A	40 A	50 A	65 A	75 A	85 A	100 A
Max. switching power (kVA)	240/240 V	3	4	5	6.1	8.5	16	16	18	18.1	19.3	24.1
	380/415 V	5	6.7	8.4	10.2	15	27	27	31	30.1	32.1	40.2
	415/440 V	5.5	7.3	9.2	11.2	17	32	32	36	33.2	35.4	44.2
	500 V	6.2	8.3	10.4	12.8	20	36	36	40	37.7	40.2	50.2
	660/690 V	8.6	11.5	14.4	17.6	26.5	48	48	53	52	55.5	69.3
Max. permissible peak switching current - [A]		350	350	420	420	770	1250	1250	1400	1400	1550	1650

TYPE OF CONTACTOR		CTX³ 150		CTX³ 225		CTX³ 400			CTX³ 800		
		130 A	150 A	185 A	225 A	265 A	330 A	400 A	500 A	630 A	800 A
Max. switching power (kVA)	240/240 V	31.3	31.3	40	45.8	50.7	64.5	74.8	99.8	114.7	179.6
	380/415 V	52.2	52.2	66.6	76.4	84.5	112	130.3	166.3	191.2	288.2
	415/440 V	57.5	57.5	73.3	84	92.9	123.2	149.4	182.9	210.3	323.1
	500 V	65.3	65.3	83.3	95.5	105.6	140	169.7	207.8	249.4	367.2
	660/690 V	90.1	90.1	115	131.8	142.5	173.5	200.8	268.9	329.9	411.11
Max. permissible peak switching current - [A]		1800	2000	2900	3300	3800	5000	6300	7700	9000	12,000

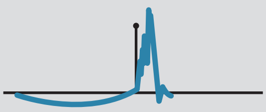
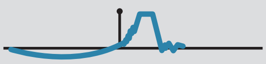
COIL POWER SUPPLY

When the contactor coil control circuit is powered up, energisation of the electromagnet generates an inrush current in the cable and a voltage drop which can interfere with contactor closing.
If the voltage drop is excessive, the contactor cannot close and its coil is destroyed by overheating (it keeps trying to draw the current it needs to close, which is several times higher than its holding current, generating destructive heat losses).

The main risk factors associated with failure to close are:
- Too long a line
- Too small a conductor cross-section
- Too low a power supply voltage



It is therefore advisable to take account of these factors when defining the characteristics of the contactor control circuit. There are a number of possible solutions: increase the conductor cross-section, increase the power supply voltage, which is not always possible, or ideally opt for a control relay from the CTX³ range.
As long as the coil is supplied with power, the electromagnet is closed ("on" position). The supply voltage must be held at a value higher than the holding voltage (stated in the technical data sheets).
Legrand contactors are designed to maintain an optimum performance level in a range from 85% to 110% of the control power supply voltage (Uc).
In order to limit the voltage surge caused by interrupting the coil power supply, a CTX³ transient voltage suppressor module (variable resistor) can be inserted in parallel with the A1 and A2 contactor power supply terminals.

WITHOUT VARIABLE RESISTOR	WITH VARIABLE RESISTOR
Voltage surge normally seen	Peak-limited voltage surge
	

MOTOR STARTERS

In accordance with standard IEC 60364-5-53, starting devices can be combined with those providing motor protection; they then need to comply with the rules applicable to protection devices.
Motor starters consist of one or more devices which combine the following functions:

ISOLATION

It is mandatory for installations to have a master isolating switch, for example in France, according to standard NF-C 15 100. At motor starter level, it is recommended. The motor MCB is used to isolate and maintain the installation's continuity of service when working on a specific circuit. It **isolates the circuit located downstream** and allows the operator to work safely (during maintenance operations for example). The isolator cannot interrupt the on-load circuit.

INTERRUPTION

Unlike isolation, interruption is used to **cut power to an on-load receiver**. This is allowed by using a switch, which can be an isolator if the rules for this function are complied with (contact status feedback and clearance). On a motor MCB, interruption is made possible by switching the front handle to the OFF position. Remotely, this is done by using a contactor or using a trip coil associated with the circuit breaker for emergency breaking.

PROTECTION

The following should be provided:
Line protection (magnetic or thermal-magnetic protection). The wiring diagrams can show an SCPD upstream in the form of fuses. But of course, a thermal-magnetic MCB, magnetic MCB or motor MCB all perform the same function.
Receiver protection (thermal protection). The wiring diagrams often show a thermal relay, but here too a motor MCB performs the function.
MPX³ motor MCBs can isolate, interrupt and protect the motor circuits. They constitute the most integrated level of response.

SWITCHING

Switching is the action of **allowing or interrupting the flow of current to the receiver**. This is the role of the contactor. It is automatically controlled, by supplying power to the coil remotely (programmed via a PLC) or manually (human-machine interface). Contactors are not usually designed to be mechanically actuated manually, except for specific models such as CX³ modular contactors.
If manual switching is necessary, a motor MCB can be used appropriately for its characteristics.

TYPE 1 AND TYPE 2 COORDINATION

A contactor is mainly used for controlling motors but does not provide thermal protection, nor line protection. Its operating current is limited. It is not intended to interrupt the current surges generated by a short-circuit (this is the role of the circuit breaker), but must be able to withstand them.

It withstands current surges between 8 and 10 times its rated operating current, in accordance with utilisation categories AC-3 and AC-4 of standard IEC 60947-4-1. These values can sometimes reach between 10 and 15 times its rated operating current.
If there is an associated thermal relay, its permissible thermal stress (Icw or I^2t) must be higher than that limited by the circuit breaker or fuse in the prospective short-circuit conditions. Above this threshold, there is a danger that the bimetallic strips which can intervene above a certain current will melt.
To avoid this situation, standard IEC 60947-4-1 defines a minimum current threshold that the thermal relay must be able to withstand, set at 13 times its rated operating current, which is in theory higher than the contactor can withstand.

MOTOR STARTER FUNCTIONS

Disconnection and short-circuit protection:
- Circuit opening, isolation
- Magnetic protection of the line and the receiver against short-circuit overcurrents (curve D for example)

Control:
- Switching on the receiver
- Switching off the receiver

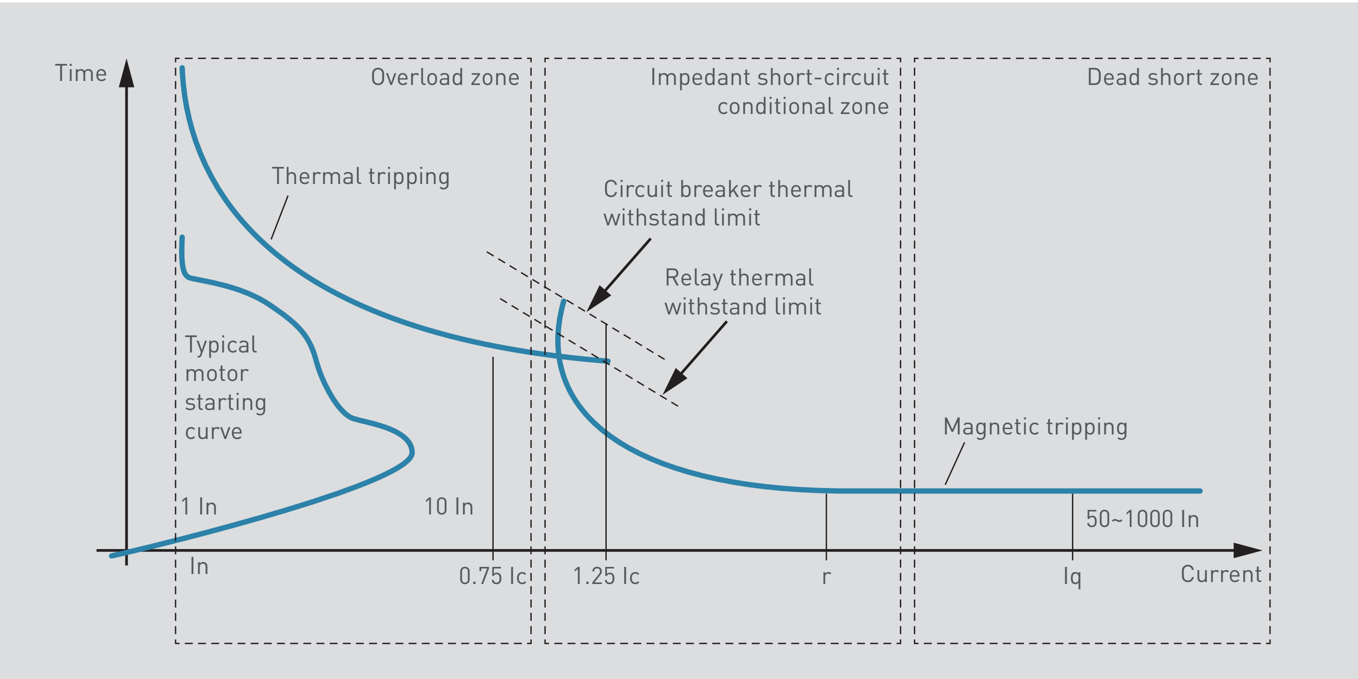
Thermal protection:
- Protection of the receiver against long-lasting overcurrents (overloads)
- Additional protection in the event of motor failure

Current surges of less than 10 In can be caused when there is significant unbalance between the phases, or loss of one of them, or even in the event of abnormally long starting times (excessive resistive torque).

Current surges of between 10 and 50 In are usually associated with a break in the motor insulation.

Current surges of more than 50 In are more often associated with a short-circuit between phases, of accidental origin (maintenance operation for example).

Standard IEC 60947-4-1 requires several fault current tests to establish type 2 coordination.



MOTOR STARTER FUNCTIONS (CONTINUED)

In the overload zone, the thermal relay should protect the magnetic MCB. Its thermal stress limiting curve should be lower than that of the circuit breaker and associated conductors.

In the dead short zone, conversely, the circuit breaker protects the thermal relay. The value of the current is established in accordance with the power supply characteristics (power, upstream impedance, conductor cross-sections, etc).

In the impedant short-circuit conditional zone, special care must be taken to ensure compatibility between protection devices. It is at the point where long-lasting overcurrents and low-value short-circuits overlap. An internal fault in the motor can go through a process ranging from overload to short-circuit, as the insulation is gradually destroyed. For the contactor to be protected, its thermal stress limit must be higher than the thermal protection limit curves.

MOTOR NOMINAL CURRENT (AC-3)	PROSPECTIVE CURRENT
Ie ≤ 16	1
16 < Ie ≤ 63	3
63 < Ie ≤ 125	5
125 < Ie ≤ 315	10
315 < Ie ≤ 630	18

Making and breaking current Ic < overload (I <10 In)
The thermal relay provides protection against overcurrent Ic. Up to 0.75 Ic, only the thermal protection should act. Above 1.25 Ic, only the magnetic protection should act.

Prospective current "r" test
The aim of this test is to simulate a break in the insulation. This test is conducted to check that the protection device plays its full part if there is a short-circuit. After this test, there should be no change in the contactor or starter technical characteristics. The SCPD should open in less than 10 ms if the current is higher than 15 x In.

Current Iq short-circuit I > 50 In
This type of fault is relatively rare. It can happen when a mistake is made while connecting the phases during a maintenance operation. Magnetic protection is provided by an SCPD, at a conditional short-circuit current level set at 50 x In by standard IEC 60947-4-1. The current Iq is used to check that there is good coordination between the protection devices and the contactor.

MOTOR STARTER FUNCTIONS (CONTINUED)

The standard defines two types of laboratory test for coordinating motor protection and control equipment.

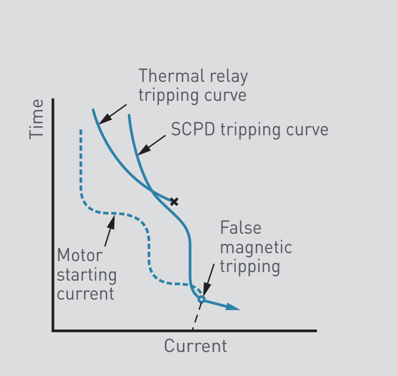
- **Type 1 coordination** accepts deterioration of the contactor and protection relay provided that their status, after testing, poses no safety risks for people and they have not damaged other equipment in the installation during the test.
- **Type 2 coordination** accepts superficial contact welding in the contactor or starter provided that it is reversible. The contactor or starter should still be in working order after completing the test and should pose no safety risks for people.

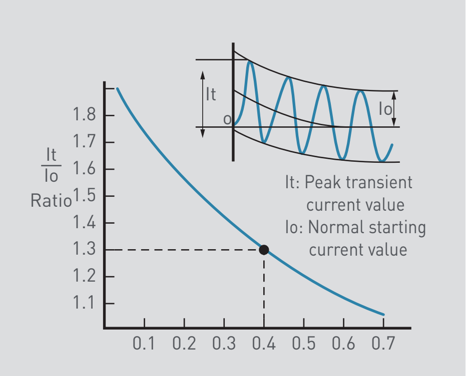
Lack of coordination is prohibited since it is likely to endanger people's life. The coordination level should be chosen on the basis of criteria such as cost, continuity of service and qualification of maintenance personnel.

FACTORS TO BE TAKEN INTO ACCOUNT

During the motor starting phase, there is a risk of tripping the SCPD.

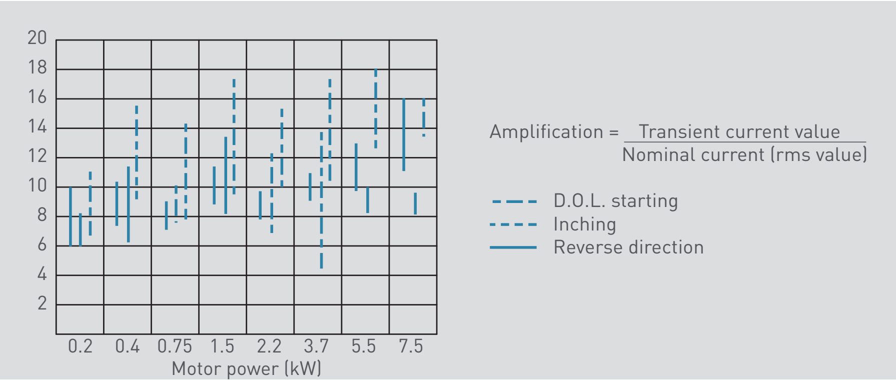
For a three-phase asynchronous cage motor, the inrush current is approximately 7 x In, but a transient current is superimposed (especially right at the start of the first half-cycle). Its amplification value varies in particular according to the power factor, the motor power and mains supply characteristics.





For a power factor on starting of 0.4, the inrush current reaches 1.3 times the normal starting peak current (7 x In x root of 2). If the motor restarts before the end of its rotation, this current surge can be twice as high. In this case, it can reach 2.6 times the nominal starting current, due to the residual current in the motor.

This example, based on actual measurements, illustrates the principle of starting current amplification.



MOTOR STARTER FUNCTIONS (CONTINUED)

In order to prevent false tripping of protection devices, it is advisable to study their behaviour carefully by superimposing their tripping curves.
When devices are selected correctly, the thermal protection and magnetic protection curves meet at an intersection point which ensures continuity of protection irrespective of the origin of the fault, overload or short-circuit (illustration on P. 57).

■ **Common low-power applications: motor MCB and contactor**

<table>
<tr><th colspan="2">STANDARD MOTOR (400 V)</th><th colspan="2">MPX^3</th><th>CTX^3</th></tr>
<tr><th>[kW]</th><th>[A]</th><th>TYPE</th><th>NOMINAL CURRENT - In [A]</th><th>TYPE</th></tr>
<tr><td>0.37</td><td>1.1</td><td>MPX^3 32S</td><td>1.6</td><td rowspan="2">CTX^3 22 - 9 [A]</td></tr>
<tr><td>0.55</td><td>1.5</td><td>MPX^3 32S</td><td>1.6</td></tr>
<tr><td>0.75</td><td>1.9</td><td>MPX^3 32S</td><td>2.5</td><td>CTX^3 22 - 12 [A]</td></tr>
<tr><td>1.1</td><td>2.7</td><td>MPX^3 32S</td><td>4</td><td rowspan="5">CTX^3 22 - 18 [A]</td></tr>
<tr><td>1.5</td><td>3.6</td><td>MPX^3 32S</td><td>4</td></tr>
<tr><td>2.2</td><td>5.2</td><td>MPX^3 32S</td><td>6</td></tr>
<tr><td>3</td><td>6.8</td><td>MPX^3 32S</td><td>8</td></tr>
<tr><td>4</td><td>9</td><td>MPX^3 32S</td><td>10</td></tr>
<tr><td>5.5</td><td>11.5</td><td>MPX^3 32H</td><td>13</td><td rowspan="2">CTX^3 22 - 22 [A]</td></tr>
<tr><td>7.5</td><td>15.5</td><td>MPX^3 32H</td><td>17</td></tr>
<tr><td>10</td><td>20</td><td>MPX^3 32H</td><td>22</td><td rowspan="3">CTX^3 40 - 32 [A]</td></tr>
<tr><td>11</td><td>22</td><td>MPX^3 32H</td><td>26</td></tr>
<tr><td>15</td><td>29</td><td>MPX^3 32H</td><td>32</td></tr>
<tr><td>18.5</td><td>35</td><td>MPX^3 63H</td><td>40</td><td>CTX^3 40 - 40 [A]</td></tr>
<tr><td>22</td><td>41</td><td>MPX^3 63H</td><td>50</td><td>CTX^3 65 - 50 [A]</td></tr>
<tr><td>30</td><td>55</td><td>MPX^3 63H</td><td>63</td><td>CTX^3 65 - 65 [A]</td></tr>
<tr><td>37</td><td>67</td><td>MPX^3 100H</td><td>75</td><td>CTX^3 100 - 75 [A]</td></tr>
<tr><td>45</td><td>80</td><td>MPX^3 100H</td><td>100</td><td>CTX^3 100 - 85 [A]</td></tr>
</table>

Type 2 coordination as per IEC 60947-4-1, Ip = 50 kA, frequency = 50/60 Hz

■ **Common high-power applications: moulded case MCCB, contactor and thermal relay**

MOTOR		CIRCUIT BREAKER				CONTACTOR	THERMAL RELAY		
NOMINAL POWER (kW)	NOMINAL CURRENT (A)	TYPE	NOMINAL CURRENT (A)	MAGNETIC THRESHOLD (A)	CAT. NO	TYPE	TYPE	SETTING RANGE (A)	CAT. NO
15	29	DPX³ 160	40	140-400	4 201 22	CTX³65 50 A	RTX³65	24-36	4 166 87 4 167 07
16	31	DPX³ 160	40	140-400	4 201 22	CTX³65 50 A	RTX³65	24-36	4 166 87 4 167 07
18.5	35	DPX³ 160	40	140-400	4 201 22	CTX³65 50 A	RTX³65	28-40	4 166 88 4 167 08
20	38	DPX³ 160	40	140-400	4 201 22	CTX³65 50 A	RTX³65	34-50	4 166 89 4 167 09
22	41	DPX³ 160	63	220-630	4 201 23	CTX³65 65 A	RTX³65	34-50	4 166 89 4 167 09
25	47	DPX³ 160	63	220-630	4 201 23	CTX³100 85 A	RTX³100	34-50	4 167 26/46
30	57	DPX³ 160	63	220-630	4 201 23	CTX³100 100 A	RTX³100	45-54	4 167 27/47
31.5	59	DPX³ 160	63	220-630	4 201 23	CTX³100 100 A	RTX³100	54-75	4 167 28/48
37	68	DPX³ 250	100	350-1000	4 206 05	CTX³100 100 A	RTX³100	63-85	4 167 29/49
40	74	DPX³ 250	100	350-1000	4 206 05	CTX³150 130 A	RTX³100	63-85	4 167 62/72
45	82	DPX³ 250	100	350-1000	4 206 05	CTX³150 130 A	RTX³150	63-85	4 167 62/72
50	92	DPX³ 250	100	350-1000	4 206 05	CTX³150 130 A	RTX³150	80-105	4 167 63/73
55	102	DPX³ 250	100	350-1000	4 206 05	CTX³150 150 A	RTX³150	95-130	4 167 64/74
63	115	DPX³ 250	160	560-1600	4 206 07	CTX³150 150 A	RTX³150	95-130	4 167 64/74

For more information, please refer to the technical data sheets

Notes

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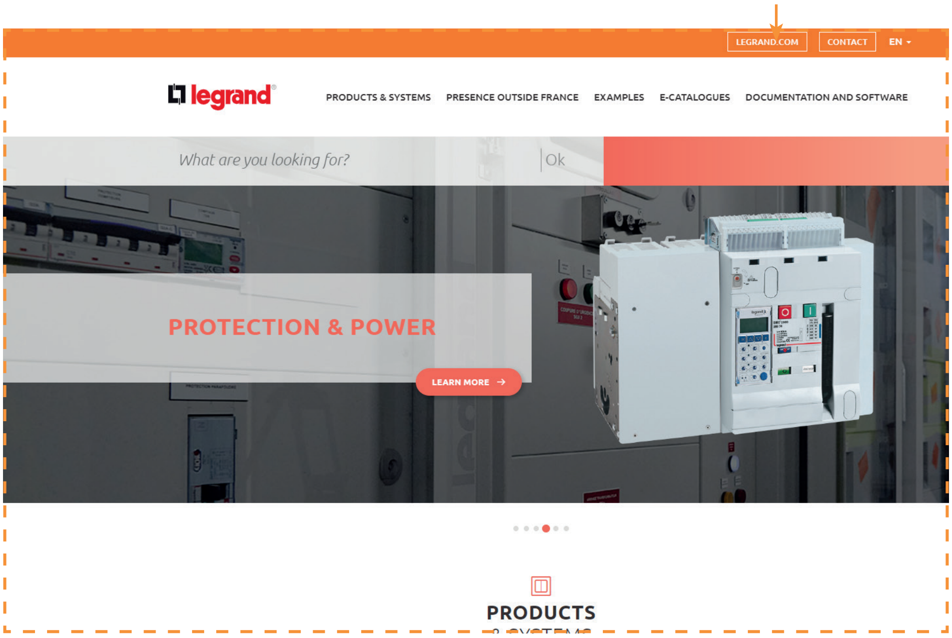
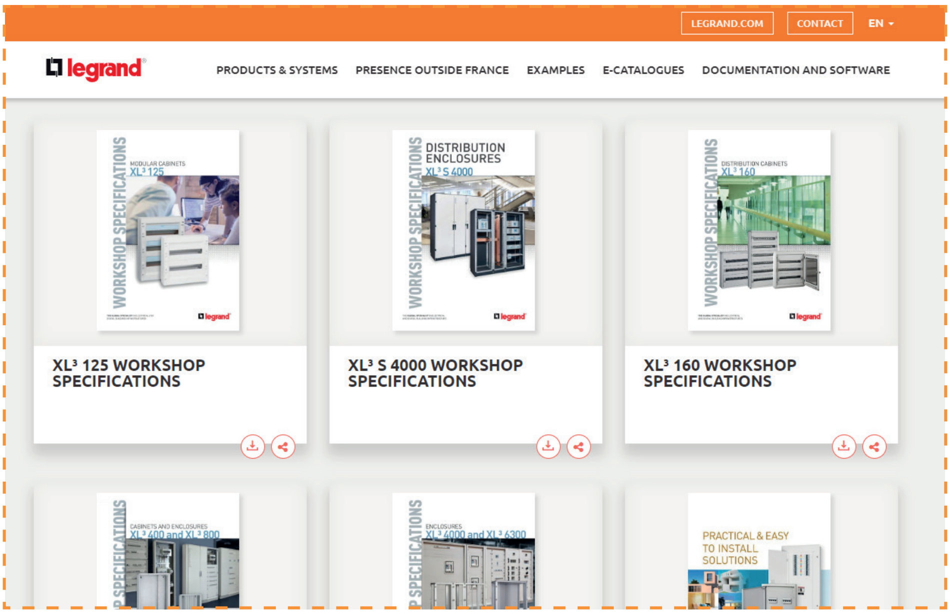


>Documentation



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