Medium Voltage
Application Guide

AuCom

Contents

1 Introduction

This reference guide is designed to help engineers in the field of medium voltage select and specify the right MV equipment for their application.

This guide provides an overview of all the main components in a motor control system, in a format that is readily understood by people with limited or no experience with motor control in general and soft starters in particular.

We hope this document will help:

- consulting engineers wanting to specify motor control equipment
- technical departments using motor control equipment
- maintenance engineers at locations with soft starters installed

We would welcome your feedback so we can continue to improve this guide.

The examples and diagrams in this manual are included solely for illustrative purposes. The information contained in this manual is subject to change at any time and without prior notice. In no event will responsibility or liability be accepted for direct, indirect or consequential damages resulting from the use or application of this equipment.

2 Motors

2.1 Common types of industrial motors

Induction motors

An induction motor performs two primary functions:

- start - convert electrical energy into mechanical energy in order to overcome the inertia of the load and accelerate to full operating speed.
- run - convert electrical energy into productive work output to a driven load.

Full voltage starting (also referred to as direct on-line or across-the-line starting) results in a high starting current, equal to locked rotor current. The locked rotor current (LRC) of a motor depends on the motor design, and is typically between five and ten times motor full load current (FLC). A value of six times FLC is common. Shaft loading only affects start time, not LRC.

High motor starting currents can cause voltage fluctuations on the electrical supply system, and electrical supply authorities often require reduction in motor starting current. Reduced voltage starting of an induction motor reduces the available starting torque, and loads with demanding start torque requirements may not be compatible with reduced voltage starting.

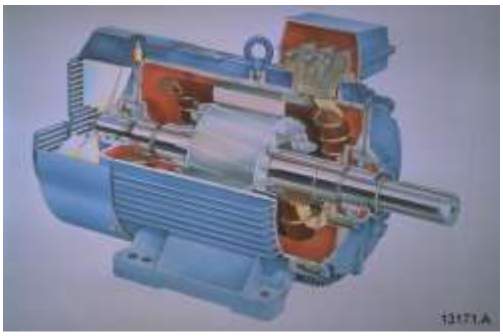
When selecting a motor for a specific application, both the start and run characteristics are very important.

Motors consist of two major components:

- The stator consists of magnetic poles created from stator windings located in slots within the frame of the motor. The full load running characteristics of the motor are determined by the winding configuration and the contour of the stator slots and laminations. Motor speed is determined by the number of pole pairs and the supply frequency applied to the stator windings.
- The rotor consists of a cylindrical short circuited winding, embedded within iron laminations. The rotor winding is often referred to as a squirrel cage. This cage is constructed from a number of bars running parallel to the motor shaft near the surface of the rotor. The rotor bars are short circuited at each end of the rotor using shorting rings. The material, position and shape of the rotor bars determines the starting characteristics of the motor.

The rotor design determines the starting characteristics of the motor. The stator design determines the running characteristics of the motor.

AC induction motor



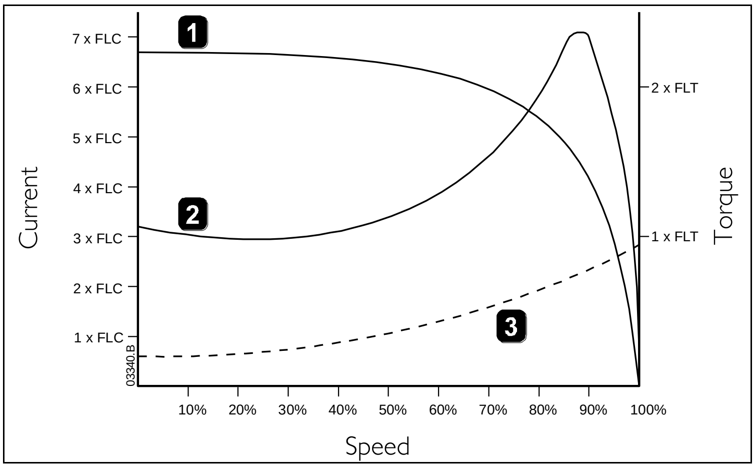
When 3-phase supply voltage is applied to the stator winding of an induction motor, a rotating magnetic field is produced which cuts through the rotor bars. The rotating speed of this magnetic field is referred to as "synchronous speed".

Interaction between the rotating magnetic field and the rotor bars induces a voltage which causes current to flow in the rotor bars. This rotor current produces a magnetic field in each rotor bar. Interaction between the stator's rotating magnetic field and the rotor bar magnetic fields produces a torque which causes the rotor to be driven in the same rotational direction as the stator magnetic field.

Torque produced by the rotor varies from stationary to full running speed. This torque is primarily a function of the rotor resistance and leakage reactance. The latter is determined by the difference in rotational speed between stator magnetic field and the rotor, otherwise known as slip. Slip is commonly expressed as a percentage of the motor's synchronous speed.

Motor start performance characteristics can vary greatly depending on rotor design and construction, but in general, a motor with high locked rotor current will produce low locked rotor torque and vice versa. A high resistance rotor produces relatively high starting torque but runs at high slip which causes inefficiency. To produce superior starting and running characteristics, specially shaped rotor bars or double cage rotors are used.

Typical start performance characteristics of an induction motor.



1	Full voltage motor current
2	Full voltage motor torque
3	Load torque (quadratic load, eg pump)

Useful formulae

Motor synchronous speed

$N_s = \frac{f \times 60}{p}$	Where: N_s = synchronous speed (rpm) f = mains supply frequency (Hz) p = number of stator pole pairs

Motor slip speed (%)

$N_{slip} = \frac{(N_s - N_r)}{N_s} \times 100$	Where: N_{slip} = percentage slip speed (%) N_s = synchronous speed (rpm) N_r = rotor speed (rpm)

Motor shaft output power

$P_o = \frac{N_r \times T_r}{9550}$	Where: P_o = output power (kW) N_r = rotor shaft speed (rpm) T_r = rotor torque (Nm)

Motor electrical input power

$P_i = \sqrt{3} \times V \times I \times \cos\Phi$	Where: P_i = input power (kW) V = motor line voltage (kV) I = motor line current (A) cos∅ = motor power factor

Motor efficiency

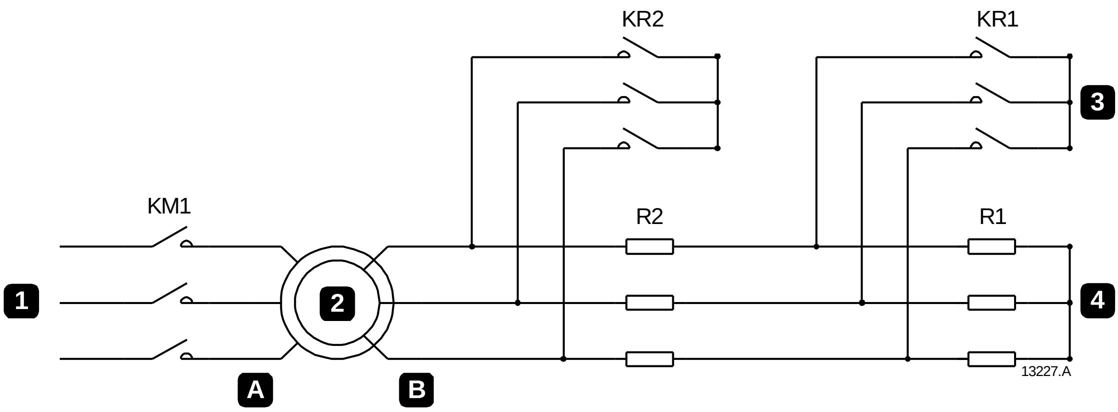
$eff = \frac{P_o}{P_i} \times 100$	Where: eff = motor efficiency (%) P_o = motor output power (kW) P_i = motor input power (kW)

Slip-ring motors

A slip-ring induction motor is also referred to as a wound rotor motor. In principle, the stator construction is the same as that of a squirrel cage induction motor. The rotor is made up of a set of windings embedded in rotor slots and brought out to a set of slip-rings. External rotor resistance is then connected to the slip-rings via a brush gear arrangement. The external rotor resistance is variable and is used for starting the motor.

Slip-ring rotor arrangement

Slip-ring motor installation



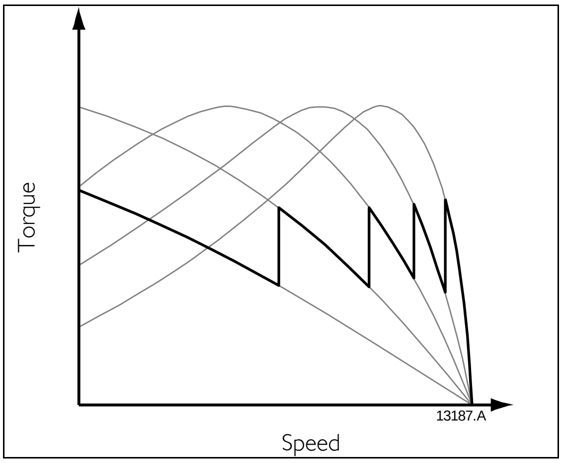
1	Three-phase supply
KM1	Main contactor
2	Slip-ring motor
A	Stator
B	Rotor

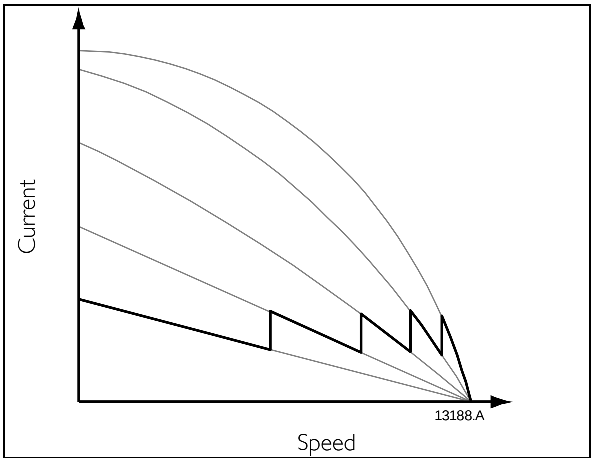
3	Bridging contactors
KR1	First stage contactor
KR2	Second stage contactor
4	External rotor resistance
R1	First stage resistor bank
R2	Second stage resistor bank

A high level of starting torque is produced by matching the rotor resistance with the rotor leakage reactance as the motor speed increases. At standstill, all the available external rotor resistance is in the circuit. As the motor speed increases, the external rotor resistance is reduced by using shorting contactors, until all the external resistance is shorted out. At this stage, the motor has reached full running speed. Motor start current is limited by the relatively high impedance of the motor due to the external rotor resistance.

> The major advantage of a slip-ring motor is that it produces very high starting torque (150-250% of full load torque) from standstill to full running speed, while consuming a relatively low level of start current (200-350% of full load current).

Typical start performance characteristics of a slip-ring motor.





Slip-ring speed control

In some cases, the variable resistance is used for speed control of the load. This method of speed control can cause erratic fluctuations in speed (if the load demand changes), and heat loss from the resistors causes major inefficiencies.

Compared with using a slip-ring motor for speed control, a better result can be achieved by using a variable frequency drive (VFD) to operate a standard squirrel cage motor. A VFD typically provides more precise speed control, as well as being more efficient, less expensive, and easier to install and maintain.

Provided sufficient start torque is developed with a single stage of rotor resistance, soft starters can be successfully applied to slip-ring motors.

Refer to *Slip ring motor control* on page 66 for further details.

Synchronous motors

The construction of a synchronous motor stator is the same as a standard induction motor, although the stator configuration is such that relatively low operating speeds are common (eg 300-600 rpm).

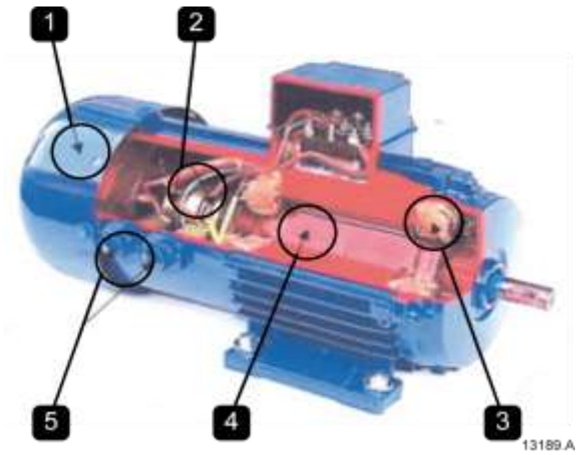
When 3-phase voltage is applied to the stator windings, a magnetic field is generated which rotates at a synchronous speed around the stator and rotor. The synchronous speed is determined by the stator construction and frequency of the supply voltage.

Motor synchronous speed

$N_s = \frac{f \times 60}{p}$	Where: N_s = synchronous speed (rpm) f = mains supply frequency (Hz) p = number of stator pole pairs

The rotor design incorporates a squirrel cage winding combined with a DC excitation winding. This allows the motor to start as a standard squirrel cage induction motor, reaching a running speed of approximately 95% synchronous speed. At this point, a DC voltage is applied to the excitation winding via a slip-ring and brush arrangement. A fixed magnetic field is created in the rotor which locks in with the rotating magnetic field of the stator. The motor shaft now runs at synchronous speed.

Synchronous motor



1	Fan inside
2	Excitation rings (x2)
3	Three phase stator windings
4	Rotor with poles and excitation windings
5	Excitation brushes (x2)

As motor shaft load is increased, the operating power factor of the motor is reduced. This power factor can be improved by increasing the DC excitation level of the rotor. This behaviour allows the AC synchronous motor to operate very efficiently at a fixed speed, independent of loading.

Soft starters are suitable for this type of application, but an external DC excitation package is required for synchronous speed control and operation.

2.2 Motor starting methods

When an induction motor is connected to a full voltage supply, it draws several times its rated current. As the load accelerates, the available torque usually drops a little and then rises to a peak while the current remains very high until the motor approaches full speed.

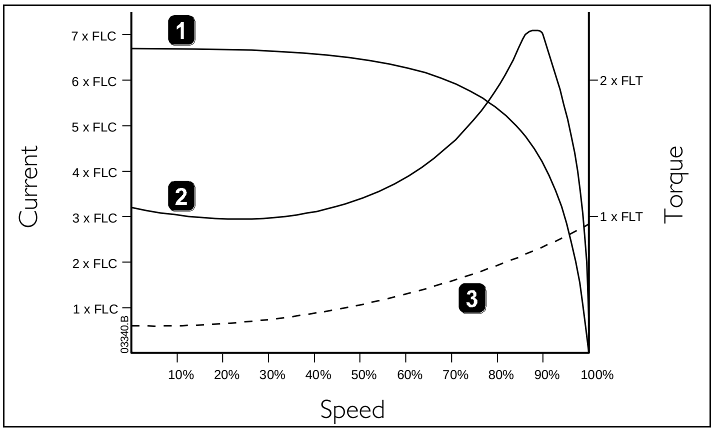
Direct on-line starting

The simplest form of starter is the direct on-line (DOL) starter, consisting of an isolation contactor and motor overload protection device. DOL starters are extensively used in some industries, but in many cases full voltage starting is not permitted by the power authority.

Full voltage starting causes a current transition from zero to locked rotor current (LRC) at the instant of contactor closure. LRC is typically between five and ten times motor FLC. The fast rising current transient induces a voltage transient in the supply, and causes a voltage deflection of six to nine times that expected under full load conditions.

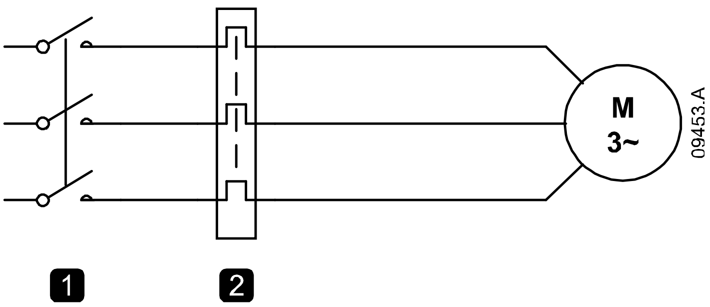
Full voltage starting also causes a torque transient from zero to locked rotor torque at the instant of contactor closure. The instantaneous torque application causes a severe mechanical shock to the motor, drive system and the machine. The damage resulting from the torque transient is more severe than that due to the maximum torque amplitude.

Current and torque profile for DOL starting



1	Full voltage motor current
2	Full voltage motor torque
3	Load torque (quadratic load, eg pump)

DOL starter installation

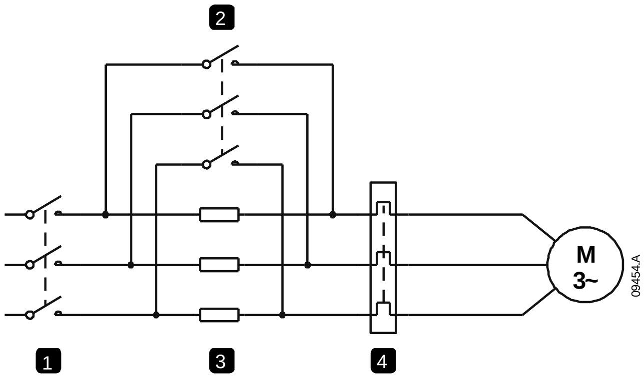


1	Main contactor
2	Overload relay

Primary resistance starting

Primary resistance starters use resistors connected in series with each phase, between the isolation contactor and the motor, which limit the start current and torque. The resistors may be wound, cast or liquid resistors.

Primary resistance starter



1	Main contactor
2	Run contactor
3	Start resistors
4	Overload relay

The motor current is equal to the line current and the starting torque is reduced by the square of the current reduction ratio. The current reduction depends on the ratio of the motor impedance to the sum of the added primary resistance and motor impedance.

As the motor accelerates, the stator impedance increases, resulting in increasing stator voltage with speed. Once the motor reaches full speed, the resistors are bridged by a second contactor to supply full voltage to the motor.

The initial start voltage is determined by the value of the resistors used. If the resistors are too high in value, there will be insufficient torque to accelerate the motor to full speed, so the step to full voltage will result in a high current and torque step.

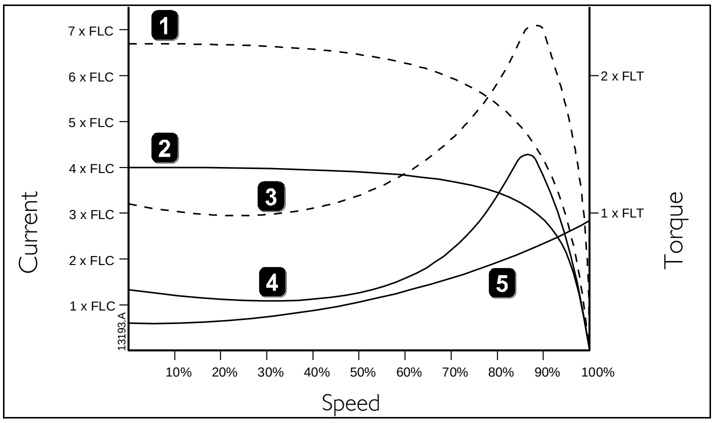
The reduced voltage start time is controlled by a preset timer which must be correctly set for the application. If the time is too short, the motor will not reach full speed before the resistors are bridged. Excessive start time results in unnecessary motor and resistor heating.

Several stages of resistance can be used and bridged in steps to control the current and torque more accurately. This minimises the magnitude of the current and torque steps.

Primary resistance starters dissipate a lot of energy during start due to the high current through, and the high voltage across the resistors. For extended times or frequent starts, the resistors are physically large and must be well ventilated.

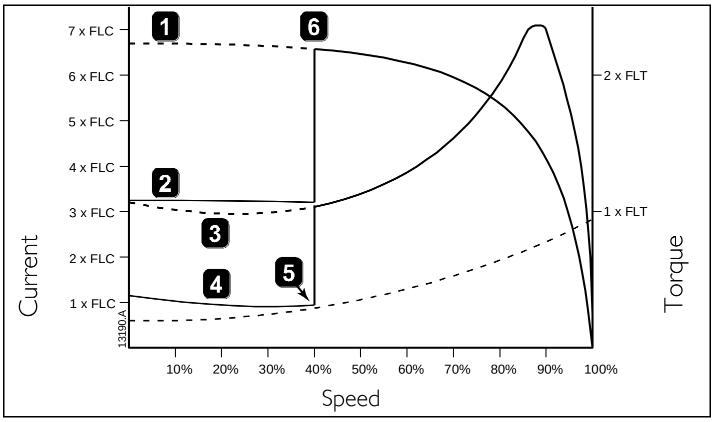
Primary resistance starters are closed transition starters, so they are not subject to 'reclose' transients.

Start performance characteristics of a correctly selected primary resistance starter



1	Full voltage start current
2	Primary resistance start current
3	Full voltage torque
4	Primary resistance torque
5	Load torque

Start performance characteristics of an incorrectly selected primary resistance starter



1	Full voltage start current
2	Primary resistance start current
3	Full voltage torque
4	Primary resistance torque
5	Stall point
6	Current and torque transient

How does soft start compare to primary resistance starting?

Compared with primary resistance starters, soft starters are more flexible and reliable.

Primary resistance starters offer limited performance because:

- Start torque cannot be fine-tuned to match motor and load characteristics.
- Current and torque transients occur at each voltage step.
- They are large and expensive.
- Liquid resistance versions require frequent maintenance.
- Start performance changes as the resistance heats up, so multiple or restart situation are not well controlled.
- They cannot accommodate changing load conditions (eg loaded or unloaded starts).
- They cannot provide soft stop.

Auto-transformer starting

Auto-transformer starters use an auto-transformer to reduce the voltage during the start period. The transformer has a range of output voltage taps which can be used to set the start voltage, and the start time is controlled by a timer.

The motor current is reduced by the start voltage reduction, and further reduced by the transformer action resulting in a line current less than the actual motor current.

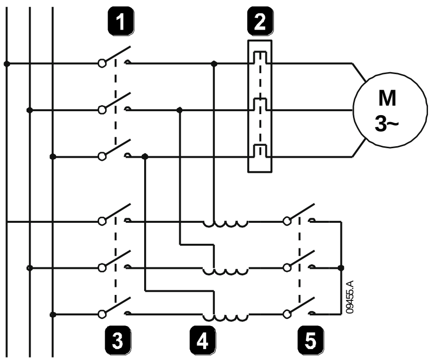
The initial line current is equal to the LRC reduced by the square of the voltage reduction. A motor started on the fifty percent tap of an auto-transformer will have a line start current of one quarter of LRC and a start torque of one quarter of LRT. If the start voltage is too low, or the start time is too short, the transition to full voltage will occur with the motor at less than full speed, resulting in a high current and torque step.

The simplest auto-transformer starters are single step and often control two phases only. More sophisticated starters may step through two or more voltage steps while accelerating from the initial start tap to full voltage.

Auto-transformer starters are usually rated for infrequent starting duties. Frequent or extended start rated auto-transformers are large and expensive due to the heating in the transformer.

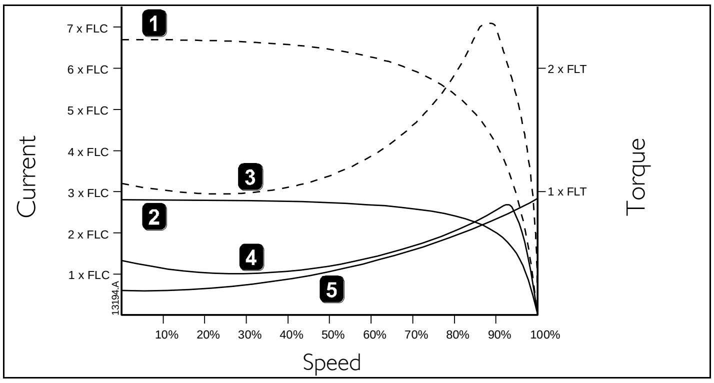
Auto-transformer starters can be constructed as open transition starters but most commonly the Korndorfer closed transition configuration is employed to eliminate the 'reclose' transients.

Auto-transformer connection



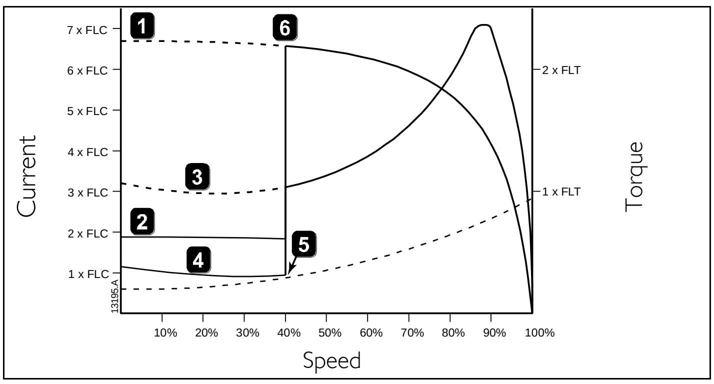
1	Run contactor
2	Thermal overload
3	Start contactor (A)
4	Auto-transformer
5	Start contactor (B)

Start performance characteristics of a correctly selected auto-transformer starter



1	Full voltage start current
2	Auto-transformer start current
3	Full voltage torque
4	Auto-transformer torque
5	Load torque

Start performance characteristics of an incorrectly selected auto-transformer starter



1	Full voltage start current
2	Auto-transformer start current
3	Full voltage torque
4	Auto-transformer torque
5	Stall point
6	Current and torque transient

How does soft start compare to auto-transformer starting?

Compared with auto-transformer starters, soft starters are much more flexible and provide a much smoother start.

Auto-transformer starters offer limited performance because:

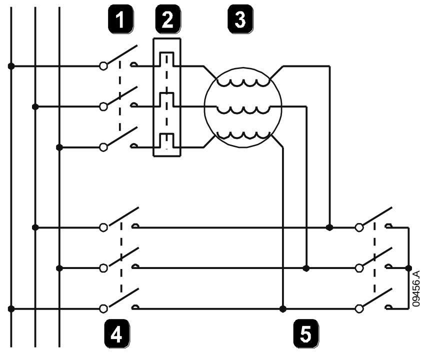
- They offer only limited ability to adjust start torque to accommodate motor and load characteristics.
- There are still current and torque transients associated with steps between voltages.
- They are large and expensive.
- They are especially expensive if high start frequency is required.
- They cannot accommodate changing load conditions (eg loaded or unloaded starts).
- They cannot provide soft stop.

Star-Delta starting

Star-delta starters are the most common reduced voltage starter used in industry because of their low cost.

The motor is initially connected in star configuration, then after a preset time the motor is disconnected from the supply and reconnected in delta configuration. The current and torque in the star configuration are one third of the full voltage current and torque when the motor is connected in delta.

Star/delta starter installation



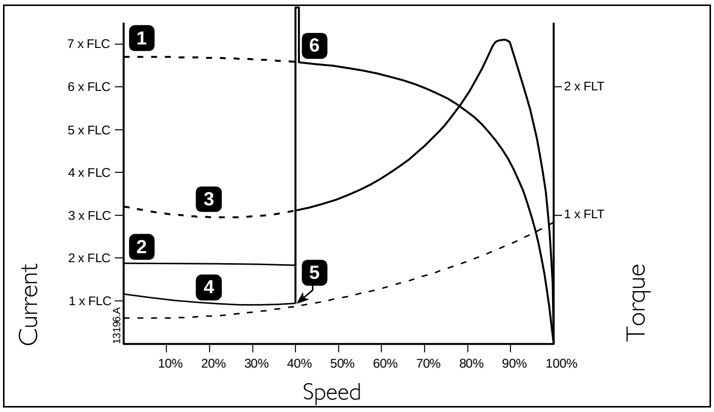
1	Main contactor
2	Thermal overload
3	Motor (three-phase)
4	Delta contactor
5	Star contactor

The star and delta configurations provide fixed levels of current and torque, and cannot be adjusted to suit the application.

- If the star configuration does not provide enough torque to accelerate the load to full speed, a high starting torque motor such as a double cage motor should be employed.
- If the motor does not reach full speed in star, the transition to delta configuration will result in a high current and torque step, defeating the purpose of reduced voltage starting.

Most star-delta starters are open transition starters so the transition from star to delta results in very high current and torque transients in addition to the high step magnitudes. Closed transition star-delta starters are rarely used due to the increased complexity and cost. The closed transition starter reduces the 'reclose' effect but does not improve the controllability of the start parameters.

Start performance characteristics of a star/delta starter



1	Full voltage start current
2	Star-delta start current
3	Full voltage torque
4	Star-delta torque
5	Stall point
6	Current and torque transient

How does soft start compare with star/delta starting?

Compared with star/delta starters, soft starters are much more flexible and provide a smooth start with no risk of transients.

Star/delta starters offer limited performance because:

- Start torque cannot be adjusted to accommodate motor and load characteristics.
- There is an open transition between star and delta connection that results in damaging torque and current transients.
- They cannot accommodate varying load conditions (eg loaded or unloaded starts).
- They cannot provide soft stop.

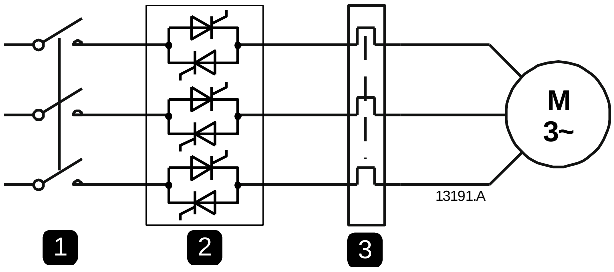
The main advantages of star/delta starters are:

- They may be cheaper than a soft starter.
- When used to start an extremely light load, they may limit the start current to a lower level than a soft starter. However, severe current and torque transients may still occur.

Soft starters

Electronic soft starters control the voltage applied to the motor by means of an impedance in series with each phase connected to the motor. The impedance is provided by AC switches – reverse parallel connected SCR-diode or SCR-SCR circuits. The voltage is controlled by varying the conduction angle of the SCRs.

Soft starter control



1	Main contactor
2	Electronic soft starter
3	Overload relay

The SCR-SCR switch is a symmetric controller, which results in odd order harmonic generation.

The SCR-diode switch is an asymmetric controller, which causes even order harmonic currents to flow in the motor and supply. Even order harmonics are undesirable for motor control because of the increased losses and heating induced in the motor and supply transformers.

Electronic soft starters come in two control formats.

- Open loop controllers, which follow a timed sequence. The most common open loop system is timed voltage ramp, where the voltage begins at a preset start voltage and increases to line voltage at a preset ramp rate.
- Closed loop controllers, which monitor one or more parameters during the start period and modify the motor voltage in a manner to control the starting characteristics. Common closed loop approaches are constant current and current ramp.

Variable frequency drives (VFD)

A variable frequency drive (VFD) converts AC (50 or 60 Hz) to DC, then converts the DC back to AC, with a variable output frequency of 0-250 Hz. The running speed of a motor depends on the supply frequency, so controlling the frequency makes it possible to control the speed of the motor. A VFD can control the speed of the motor during starting, running and stopping.

VFDs generate significant emissions and harmonics, and a filter is generally required.

VFDs are also called variable speed drives (VSD) or frequency converters.

VFD motor starting

When a VFD starts a motor, it initially applies a low frequency and voltage to the motor. The starting frequency is typically 2 Hz or less. This avoids the high inrush current that occurs when a motor is started DOL. The VFD increases the frequency and voltage at a controlled rate to accelerate the load without drawing excessive current.

- the current on the motor side is in direct proportion to the torque that is generated
- the voltage on the motor is in direct proportion to the actual speed
- the voltage on the network side is constant
- the current on the network side is in direct proportion to the power drawn by the motor

VFDs are ideal for applications with an extremely limited supply because the starting current is never more than the motor FLC.

VFD motor stopping

The stopping sequence is the opposite of the starting sequence. The frequency and voltage applied to the motor are ramped down at a controlled rate. When the frequency approaches zero, the motor is shut off. A small amount of braking torque is available to help slow the load, and additional braking torque can be obtained by adding a braking circuit. With 4-quadrants rectifiers (active-front-end), the VFD is able to brake the load by applying a reverse torque and returning the energy to the network.

The precise speed control available from a VFD is useful for avoiding water hammering in pipe systems, or for gently starting and stopping conveyor belts carrying fragile material.

VFD motor running

The ability to control motor speed is a big advantage if there is a need for speed regulation during continuous running. If the application only requires an extended starting and/or stopping time, a VFD may be more expensive than necessary.

Running at low speeds for long periods (even with rated torque) risks overheating the motor. If extended low speed/high torque operation is required, an external fan is usually needed. The manufacturer of the motor and/or the VFD should specify the cooling requirements for this mode of operation.

VFD bypassed

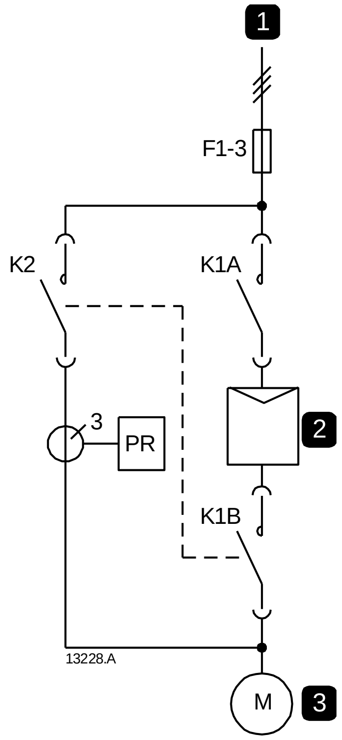
In some medium voltage motor applications, a VFD is used to start the motor but is bypassed by a contactor or circuit breaker when running at mains supply frequency.

This means:

- motor start current never exceeds the motor full load current. This is very useful on sites where the mains supply capacity is limited
- the overall motor control system is more reliable because the VFD is only required during starting and stopping
- if the VFD malfunctions, the motor can still be started and run DOL, via the bypass switch. In this case, the mains supply must have the capacity to start the motor.

Control of the bypass switch can be automatic or manual.

Bypassed VFD installation



1	Three-phase supply
2	VFD
3	Motor
K1A	VFD input contactor
K1B	VFD output contactor
K2	Bypass contactor
F1-3	Fuses
PR	Motor protection relay

Operation:

- Contactors K1A and K1B close and the motor is run up to full speed. Once the output of the VFD reaches main supply frequency, contactors K1A and K1B open. After a short delay, bypass contactor K2 closes.
- Contactors K1B and K2 are electrically and mechanically interlocked. The VFD can be isolated from operation by racking out contactors K1A and K1B.
- Motor protection relay PR protects the motor when K2 is closed.

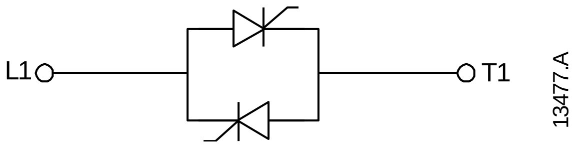
3 Soft Starters

3.1 What is a Soft Starter

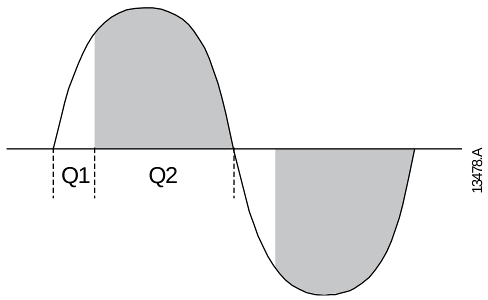
A soft starter is an electronic motor controller used on three phase squirrel cage induction motors. During motor starting, the soft starter controls the voltage or current supplied to the motor. Motor start performance is optimised by reducing the total start current while optimising the torque produced by the motor. Motor stopping can also be controlled by ramping down the output voltage over a predetermined time period. This is particularly useful for eliminating water hammer in pumping applications.

Soft starters use SCRs (silicon controlled rectifiers, also called thyristors), arranged back-to-back for each controlled phase of the soft starter. This provides phase angle control of the voltage waveform in both directions. Controlling the voltage controls the current supplied to the motor. The stepless control of motor terminal voltage eliminates the current and torque transients associated with electromechanical forms of reduced voltage starting, such as star-delta or autotransformer starters.

SCR configuration (per phase)



Voltage waveform



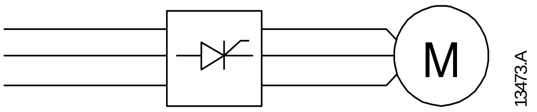
Q1	Firing angle
Q2	Conduction angle

A soft starter designed to control motor voltage is referred to as an open loop controller. A soft starter designed to control motor current is referred to as a closed loop controller.

Open loop soft start control

Open loop soft start controllers have no feedback of the starting performance to the controller and follow preset voltage transitions controlled by timers.

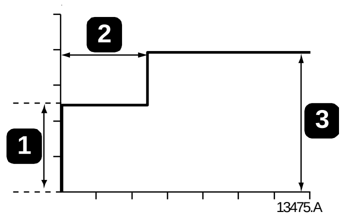
Open loop controller



Open loop soft start controllers can use a voltage step or timed voltage ramp approach.

Voltage step controllers (also called pedestal controllers) apply a preset level of voltage at start, then step to full voltage after a user-defined period. Voltage step starters have little advantage over closed transition electromechanical starters and are rarely used.

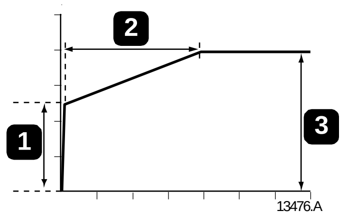
Voltage step soft start control



1	Initial start voltage
2	Start time
3	Full voltage

Timed voltage ramp controllers ramp the voltage from a user-defined start voltage to full voltage, at a controlled rate. Timed voltage ramp is used extensively in low cost soft starters.

Timed voltage ramp control



1	Initial start voltage
2	Start time
3	Full voltage

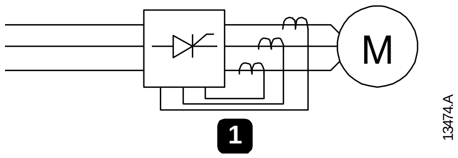
The start voltage and ramp rate are often referred to as torque and acceleration adjustments, but soft start can only influence torque and acceleration, not provide precise control.

The acceleration rate is determined by the motor and machine inertia. A high inertia load requires a slow ramp time if the current is to be minimised. If the start voltage rises to quickly, current may approach locked rotor current. A low inertia load requires a short ramp time. Excessive starting time can result in insufficient voltage for stable operation once the motor has reached full speed.

Closed loop soft start control

Closed loop soft starters have one or more feedback loops, which monitor characteristics at the motor. The starter adjusts the voltage to the motor, in order to control the monitored parameters.

Closed loop controller



1	Current transformer feedback

Common closed loop systems are:

- Constant Current or Current Limit
- Timed Current Ramp
- Constant Acceleration

Constant current soft start

Constant current starters monitor the starting current. Increasing or decreasing the output voltage increases or decreases the current supplied to the motor. As the motor accelerates, the stator impedance rises and in order to maintain a constant current the voltage also rises. The exact relationship between voltage and speed depends on the motor design.

With a constant current starter, full torque is available as the motor reaches full speed. It is important that the starting current is high enough to accelerate the motor to full speed under all conditions. If the torque is insufficient for acceleration at any time during the start, the motor will continue to run at the reduced speed. This will overheat the motor unless there is excess start time protection.

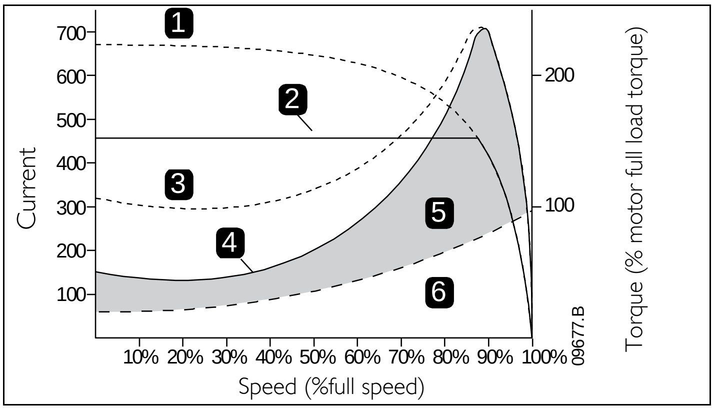
Timed current ramp soft start

Timed current ramp soft starters increase the current from a selected start level to the maximum start current, at a controlled rate. This caters for variation in starting torque requirements, or can deliver reduced starting torque without limiting the maximum starting torque. Typical applications are conveyors which start under varying load conditions, and pumps which require very low torque at low speed.

This method also suits motors running on generator supplies, as the starting load is gradually applied to the generator set. This provides stable voltage and frequency control of the generator set during motor starting.

Constant acceleration soft start

Constant acceleration or linear acceleration starters monitor the motor speed, by means of a tacho generator attached to the motor shaft. The voltage applied to the motor is controlled to deliver a constant rate of acceleration, over a selected acceleration time. A current limiting circuit can also be used to limit the maximum starting current, particularly in applications where a potential exists for jammed loads.



1	Full voltage start current
2	Current limit
3	Full voltage start torque
4	Torque output at current limit
5	Acceleration torque
6	Load torque curve

3.2 Benefits

Electrical Benefits

- Minimise start current levels to match application requirements. This reduces overall demand on the electrical supply.
- Eliminate current transients during motor starting and stopping. This avoids supply voltage dips which can affect the performance of other equipment and in severe situations, cause equipment failure.
- Reduce the size of electrical transformers, switchgear and cable.
- Reduce maximum demand charges from the electricity supplier.

Mechanical Benefits

- Minimise start torque levels to match application requirements. This eliminates mechanically damaging torque transients associated with electromechanical starting methods.
- Smooth, stepless torque is applied to the load from the motor shaft. This can:
  - reduce pipeline pressure surges and water hammer in pump applications
  - eliminate belt slippage associated with belt driven loads
  - eliminate belt slap associated with large belt conveyor applications.
- Reduce maintenance and production down-time.

Application Benefits

- Optimise performance for any motor and load combination.
- Soft stop reduces or eliminates water hammer in pump applications.
- Simplicity. The soft starter provides a complete motor control solution in one package. This includes advanced motor protection, input/output signals for remote control/monitoring and a wide range of communication options.

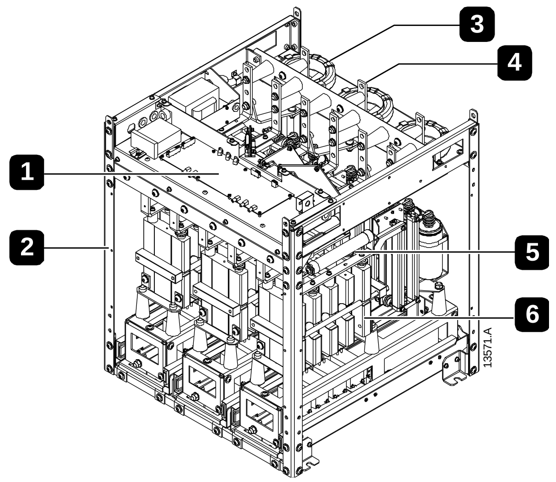
3.3 Anatomy

Key components

Most soft starters have the following main components:

- SCRs (also called thyristors)
- Snubber circuits
- Heatsink
- Fans (optional for increased thermal ratings)
- Busbars
- Current sensors
- Printed Circuit Boards (PCBs)
- Housing

Example: MVS IP00



1	Printed circuit board (PCB)
2	Housing (IP00 chassis)
3	Current sensors (CTs)
4	Busbars
5	Snubber circuits (RC network)
6	SCRs and heatsinks

SCRs

SCRs (silicon controlled rectifiers, also called thyristors) are the primary component of any soft starter. The SCR is a controlled diode that only allows current to flow in one direction.

An SRC has three terminals. When the gate terminal is triggered with a low voltage signal, the SCR is turned on. This allows current to pass through from the anode to cathode terminals. An SCR is self commutating and current stops flowing when it reaches the zero point crossing.

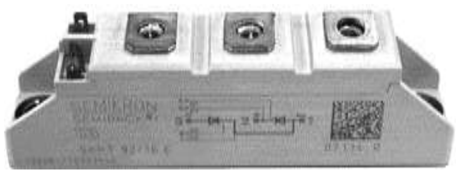
A soft starter has at least two SCRs per phase, connected in reverse-parallel configuration so that current can be controlled in both directions. The soft starter can control one, two or all three phases.

There are two physical styles of SCR:

- modular pack SCRs are a self contained reverse-parallel device. These are often found in low voltage soft starters with a voltage range of 200 VAC to 690 VAC and a current rating less than 300 A.
- disk or hockey puck style devices are a single SCR which needs to be electromechanically configured in reverse-parallel configuration for soft starter use. This style of SCR is used on higher current rated, low voltage soft starters with current ratings greater than 300A.

Medium voltage soft starters with an operating voltage range of 2.3kV to13.8kV always use disk style SCRs connected in series for each half of a phase to obtain the necessary voltage rating.

Modular SCR



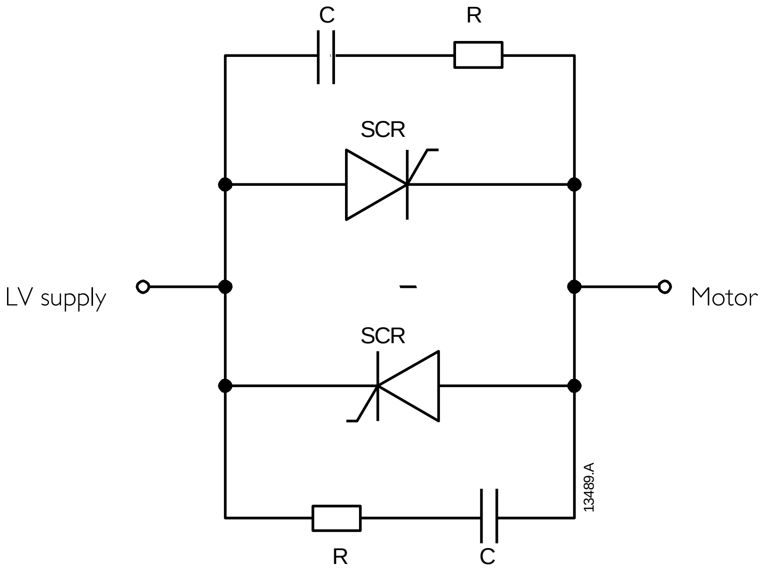
Disk style ("hockey puck") SCR

Snubber circuits

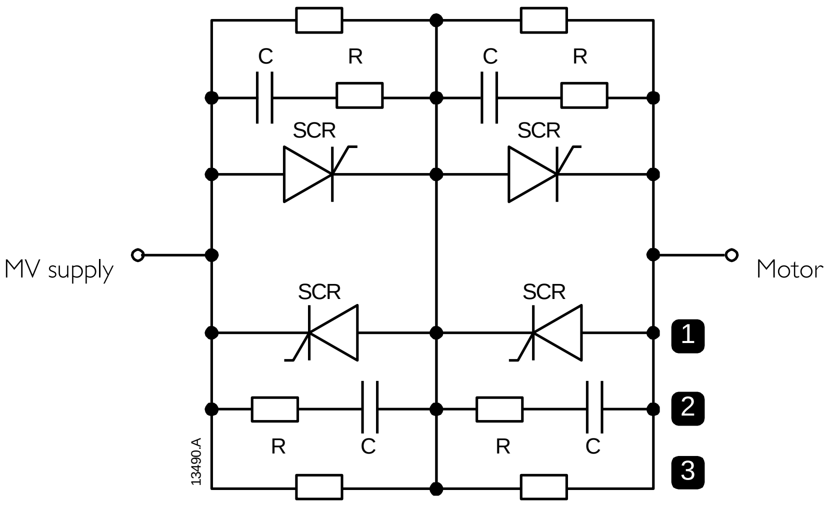
Snubber circuits are used to suppress a phenomenon called notching which occurs at the zero voltage crossing point. Snubber circuits provide SCR control stability and a level of overvoltage protection.

In the simplest form, a snubber is a resistor-capacitor network connected in parallel across each SCR. Resistors used for this purpose are typically wire wound, for the necessary power rating. In medium voltage soft starters, grading resistors are connected in a series-parallel configuration across all SCRs. This divides the voltage across SCR in each phase evenly.

Basic LV snubber arrangement



Basic MV snubber arrangement



1	SCRs
2	RC snubber network
3	Grading resistors

Heatsinks

Heatsinks are designed to efficiently dissipate the heat generated by SCR switching during motor starting and stopping. Optimum heatsink design maximises the rating of the soft starter by keeping the SCR internal junction temperature below 130°C.

SCRs are always bonded to a heatsink, using an appropriate thermal paste.

- modular SCRs are bonded to an isolated heatsink arrangement.
- for disk SCRs, the conducting faces of each SCR are compressed against a conducting heatsink face.

Many soft starters reduce the heatsink size by turning the SCRs off at the end of a start and bypassing the SCR arrangement during motor running.

Fans

Fans are often used in conjunction with SCR/heatsink assemblies to increase the thermal rating of soft starters in arduous conditions, eg:

- applications requiring high start current and/or times (eg 450%FLC start current for 30 seconds)
- applications with excessive starts per hour (eg >10 starts per hour)
- installations with excessive operating ambient temperatures (eg 45-60°C)

Busbars

Busbars are used to connect the motor and the mains supply to the SCR power assembly. Busbars are sized according to the soft starter's maximum current rating. For lower current rated soft starters, aluminium busbars are common. Higher current applications use tinned copper busbars to minimise the cross sectional area.

There are various methods for connecting conductors to busbars. Low current terminations may use small cage clamps. High current terminations may use large spreader plates.

To ensure a good electrical connection when clamping together two conducting faces:

- clean all conducting surfaces so they are free from oil, grease and other contaminants. Use an appropriate industrial solvent for best results.
- lightly buff the mating surfaces of busbars, spreader plates, cable lugs, etc, then remove any leftover residue
- apply an approved electrical jointing compound to all mating surfaces
- use the correct type and size of fasteners and tighten to the specified torque
- insulate bare exposed electrical joints according to local electrical regulations

Current sensors

Soft starters which control motor start current or provide a motor protection function will have some form of current sensing on the controlled phases. If only two phases are monitored, the current in the third phase is normally surmised using vector calculation.

Current transformers are widely used, but other forms of current sensing are becoming mode widely used.

PCBs

Compact printed circuit boards are used to mount all the necessary electronic firmware, such as:

- digital microprocessors for I/O function, SCR firing control, motor protection function, communications, etc
- SCR firing circuits
- current sensing input circuits (necessary for certain soft starter types)
- metering circuits
- user interface
- digital and analog input and output circuits
- terminals for customer interfacing
- communication port options

Some soft starter manufacturers have protective conformal coating as an option. Conformal coating protects PCBs from moisture and general dust and grime. In aggressive gaseous and chemical environments, the soft starter should be installed in a suitable, totally sealed enclosure.

> Conformal coating is standard on all AuCom soft starters.

Housing

Industrial products are constructed to provide a certain level of electrical and mechanical protection against foreign solid objects and the ingress of moisture. IEC 60529 and NEMA 250 are the main international standards which rate the level of protection that a product provides.

Open chassis soft starters

Open chassis (gear tray style, IP00) starters have very little protection from the outside world and must be mounted in a suitable electrical enclosure. This style is common with medium voltage soft starters, which need to be integrated into an adequately rated switchgear cabinet along with other associated switchgear.

Enclosed soft starters

Enclosed soft starters have varying levels of electrical and mechanical protection from the outside world. Housings are made from a combination of metals, alloys and plastics with many different finishes. This style is more common amongst low voltage soft starter products. In some cases, the housing provides enough protection that the soft starter can be wall mounted and does not have to be fitted inside an electrical enclosure.

Common functionality and features

Soft starters vary widely in functionality and choosing the correct product depends mainly on the performance and features required. Serviceability and product support are also important factors. In fewer cases, the main consideration is product cost.

The most common features of industrial soft starters can be grouped into functional categories:

SCR control

A soft starter can control one, two or three phases:

- Single phase controllers - These devices reduce torque shock at start but do not reduce start current. Also known as torque controllers, these devices must be used in conjunction with a direct on-line starter.
- Two phase controllers - These devices eliminate torque transients and reduce motor start current. The uncontrolled phase has slightly higher current than the two controlled phases during motor starting. They are suitable for all but severe loads.
- Three phase controllers - These devices control all three phases, providing the optimum in soft start control. Three phase control should be used for severe starting situations.

Common control methods include:

- Open loop, voltage ramp control
- Closed loop, current control
- Soft stopping
- Special control formats

Adaptive control

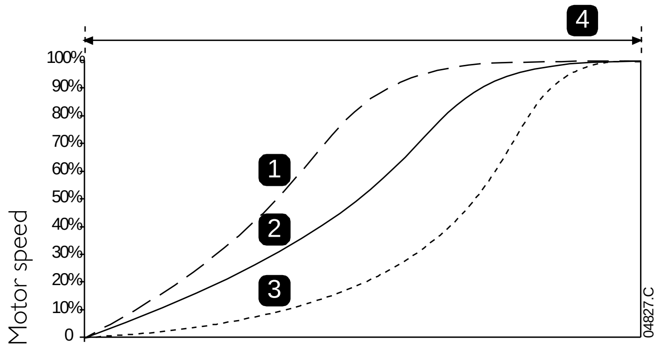
AuCom has developed a special control format known as Adaptive Control.

Adaptive Control is a new intelligent motor control technique that controls current to the motor in order to start or stop the motor within a specified time and using a selected profile.

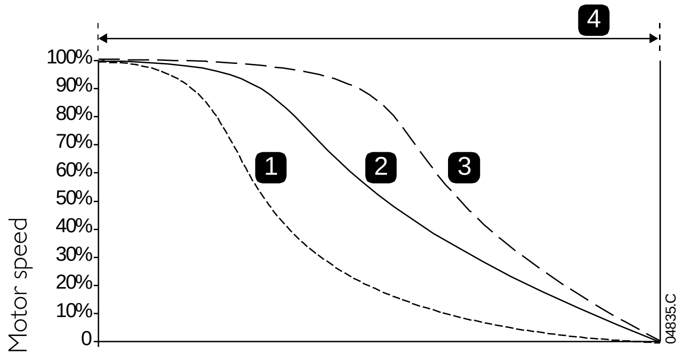
For soft starting, selecting an adaptive profile that matches the inherent profile of the application can help smooth out acceleration across the full start time. Selecting a dramatically different profile can somewhat neutralise the inherent profile.

For soft stopping, adaptive control can be useful in extending the stopping time of low inertia loads.

The soft starter monitors the motor's performance during each start, to improve control for future soft starts. The best profile will depend on the exact details of each application. If you have particular operational requirements, discuss details of your application with your local supplier.



	Adaptive start profile:
1	Early acceleration
2	Constant acceleration
3	Late acceleration
4	Start time



	Adaptive stop profile:
1	Early deceleration
2	Constant deceleration
3	Late deceleration
4	Stop ramp time

Inputs/Outputs

- Digital and analog inputs with fixed or programmable functions
- Relay or analog outputs with fixed or programmable functions
- PT100 or thermistor inputs with adjustable set points
- Communication ports for remote control and status monitoring

Protections

Protection	ANSI protection code
Under/ Overvoltage	27 / 59
Mains frequency	81
Phase sequence	46
Phase loss	46
Motor overload (electronic thermal model)	49 / 51
Time-overcurrent (I^2t)	51
Instantaneous overcurrent (shearpin or locked rotor)	50
Ground fault	50G
Undercurrent	37
Current imbalance	46 / 60
SCR temperature	26
SCR shorted	3
Motor thermistor	26 / 49
PT100	26 / 49
Excess start time (stall at start)	48
Excess starts per hour	66
Power loss	32
Auxiliary input trips	86 / 97
Battery/clock failure	3

For additional information, refer to ANSI protection codes.

Local control and feedback

- local keypad
- emergency stop actuator
- alphanumeric or graphical display
- multi-language interfacing
- status LEDs
- motor and starter monitoring data
- metering data
- event counters
- data logging

Communication options

- signal level protocols (eg ASi, InterBus-S)
- serial protocols (eg DeviceNet, Modbus RTU, Profibus DP)
- Ethernet protocols (eg EtherNet/IP, Modbus TCP, ProfiNet)
- fibre optic linking (provides superior EMC and LV/MV isolation)

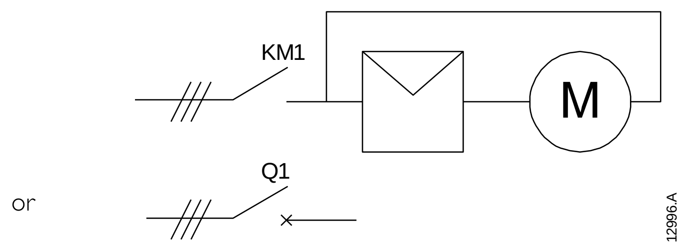
Special Functions

- Internally bypassed (when starter is in run state)
- Dynamic braking
- Slow speed forward and reverse operation (ie: jogging)
- Auto reset and restart (on selected trip types)
- Auto start and stop (timer or clock)
- Slip-ring (wound rotor) motor control
- Synchronous motor control
- In-line (3 wire) or inside delta (6 wire) motor connection

What is an inside delta connection?

Inside delta connection (also called six-wire connection) places the soft starter SCRs in series with each motor winding. This means that the soft starter carries only phase current, not line current. This allows the soft starter to control a motor of larger than normal full load current.

When using an inside delta connection, a main contactor or shunt trip MCCB must also be used to disconnect the motor and soft starter from the supply in the event of a trip.



Inside delta connection:

- Simplifies replacement of star/delta starters because the existing cabling can be used.
- May reduce installation cost. Soft starter cost will be reduced but there are additional cabling and main contactor costs. The cost equation must be considered on an individual basis.

Only motors that allow each end of all three motor windings to be connected separately can be controlled using the inside delta connection method.

Not all soft starters can be connected in inside delta.

3.4 AuCom Medium Voltage Soft Starters

MVS Soft Starter

Overview

The MVS provides compact and robust soft start solutions for control of medium voltage motors. MVS soft starters provide a complete range of motor and system protection features and have been designed for reliable performance in the most demanding installation situations.

Each IP00 MVS soft starter comprises two elements:

- a power assembly
- a controller module

The power assembly and controller module are supplied as a pair and share the same serial number. Care should be taken during installation to ensure the correct controller and power assembly are used together.

Each MVS is also supplied with two fibre-optic cables, to connect the controller module to the power assembly, and three non-conduction lead assemblies, allowing the soft starter to be tested with a low-voltage motor (< 500 VAC).

Feature List

Starting
- Constant current
- Current ramp

Stopping
- Coast to stop
- Soft stop

Protection
- Under/ Overvoltage
- Mains frequency
- Phase sequence
- Shorted SCR
- Motor overload (thermal model)
- Instantaneous overcurrent (two stages)
- Time-overcurrent
- Ground fault
- Undercurrent
- Current imbalance
- Motor thermistor
- Excess start time
- Power circuit
- Auxiliary trip

Extensive input and output options
- Remote control inputs (3 x fixed, 2 x programmable)
- Relay outputs (3 x fixed, 3 x programmable)
- Analog output (1 x programmable)
- Serial port (with module)

Comprehensive feedback
- Starter status LEDs
- Date and time stamped event logging
- Operational counters (starts, hours-run, kWh)
- Performance monitoring (current, voltage, power factor, kWh)
- User-programmable monitoring screen
- Multi-level password protection
- Emergency stop push button

Power Connection
- 50 A to 600 A, nominal
- 2300 VAC to 7200 VAC

Accessories (optional)
- DeviceNet, Modbus or Profibus communication interfaces
- Synchronous motor control
- PC Software
- Overvoltage protection
- Control supply transformer
- MV/LV Control transformer

Key Features

MVS soft starters offer several special functions to ensure ease of use and to provide optimal motor control in all environments and applications.

Customisable Protection

The MVS offers comprehensive protection to ensure safe operation of the motor and soft starter. The protection characteristics can be customised extensively to match the exact requirements of the installation.

Advanced Thermal Modelling

Intelligent thermal modelling allows the soft starter to predict whether the motor can successfully complete a start. The MVS uses information from previous starts to calculate the motor's available thermal capacity, and will only permit a start which is predicted to succeed.

Comprehensive Event and Trip Logging

The MVS has a 99-place event log to record information on soft starter operation. A separate trip log stores detailed information about the last eight trips.

Informative Feedback Screens

A digital display screen allows the MVS to display important information clearly. Comprehensive metering information, details of starter status and last start performance allow easy monitoring of the starter's performance at all times.

Dual Parameter Set

The MVS can be programmed with two separate sets of operating parameters. This allows the soft starter to control the motor in two different starting and stopping configurations.

The secondary motor settings are ideal for conventional (squirrel-cage) motors which may start in two different conditions (such as loaded and unloaded conveyors).

NOTE
MVS soft starters are not suitable for controlling two separate motors. The secondary parameter set should only be used for a secondary configuration of the primary motor.

The MVS will use the secondary motor settings to control a start when instructed via a programmable input.

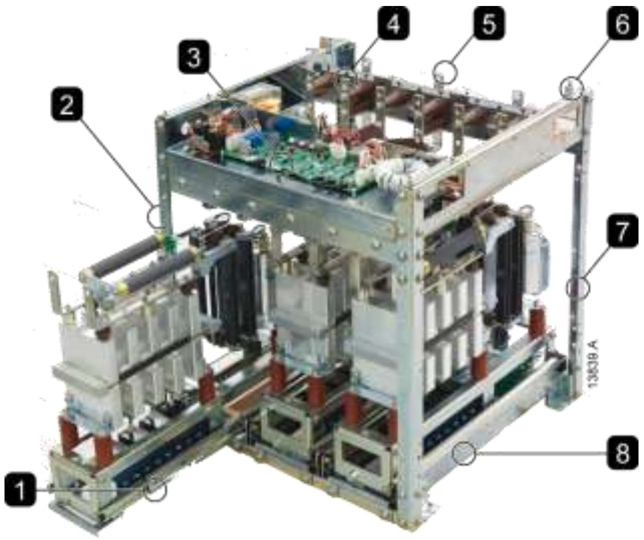
Fibre Optics

The MVS uses two-line fibre optic connections between the low voltage control module and the high voltage power assembly for electrical isolation. This fibre optic link simplifies installation of chassis mount MVS starters into custom panels.

MVS Power Assembly

The MVS power assembly is a very robust and compact design, minimising panel space requirements. The unique draw-out design simplifies general maintenance and servicing.

MVS power assembly



1	Phase arms extend via built-in runner, including balance resistors, snubbers and gate drive.
2	Small footprint and depth saves space.
3	Conformal coating on all PCBs for protection in environments up to Pollution Degree 3.
4	Current measured on all three phases.
5	Bypass terminals retain motor protection.
6	Convenient earth points.
7	Mounted inside frame to ensure sufficient clearance.
8	Compact modular design as a single unit.

General Technical Data

Supply

Mains Voltage

- MVSxxxx-V02 ... 2.3 kV Phase-phase
- MVSxxxx-V03 ... 3.3 kV Phase-phase
- MVSxxxx-V04 ... 4.2 kV Phase-phase
- MVSxxxx-V06 ... 6.6 kV Phase-phase
- MVSxxxx-V07 ... 7.2 kV Phase-phase

Rated Frequency (fr) ... 50/60 Hz

Rated lightning impulse withstand voltage (U_p)

- MVSxxxx-V02 ~ 04 ... 45 kV
- MVSxxxx-V06 ~ V07 ... 45 kV

Rated power frequency withstand voltage (U_d)

- MVSxxxx-V02 ~ V04 ... 11.5 kV
- MVSxxxx-V06 ~ V07 ... 20 kV

Rated normal current (I_r)

- MVS0080-Vxx ... 80 A
- MVS0159-Vxx ... 159 A
- MVS0230-Vxx ... 230 A
- MVS0321-Vxx ... 321 A
- MVS0500-Vxx ... 500 A
- MVS0600-Vxx ... 600 A

Rated short-time withstand current (symmetrical RMS, I_k) ... 48 kA [1]

Form Designation ... Bypassed semiconductor motor starter form 1

Control Inputs

Start (Terminals C23, C24) ... 24 VDC, 8 mA approx

Stop (Terminals C31, C32) ... 24 VDC, 8 mA approx

Reset (Terminals C41, C42) ... 24 VDC, 8 mA approx

Input A (Terminals C53, C54) ... 24 VDC, 8 mA approx

Input B (Terminals C63, C64) ... 24 VDC, 8 mA approx

Motor Thermistor (Terminals B4, B5) ... Trip point > 2.4 kΩ

NOTE

All control inputs are potential free. Do not apply external voltage to these inputs.

Low Voltage Supply

Rated Voltage ... 110 ~130 or 220 ~ 240 V

Rated Frequency ... 50/60 Hz

Typical power consumption ... 70 W continuous [2]

Outputs

Relay Outputs ... 10 A @ 250 VAC resistive

... 6 A @ 250 VAC 15 p.f. 0.3

10 A @ 30 VDC resistive

Outputs on interface PCB

- Main Contactor (13, 14) ... Normally Open
- Bypass Contactor (23, 24) ... Normally Open
- Run Output/ PFC (33, 34) ... Normally Open

Outputs on Controller

- Output Relay A (43, 44) ... Normally Open
- Output Relay B (51, 52, 54) ... Changeover
- Output Relay C (61, 62, 64) ... Changeover

Analog Output (B10, B11) ... 0-20 mA or 4-20 mA

Environmental

Degree of Protection

- Power Assembly ... IP00
- Controller ... IP54/ NEMA 12

Operating Temperature ... - 10 °C to + 60 °C, above 40°C with derating

Storage Temperature ... - 25 °C to + 80 °C

Humidity ... 5% to 95% Relative Humidity

Pollution Degree ... Pollution Degree 3

Vibration .... Designed to IEC 60068

EMC Emission

Equipment Class (EMC) .... Class A
Conducted Radio Frequency Emission .... 10 kHz to 150 kHz: < 120 - 69 dB µV
0.15 MHz to 0.5 MHz: < 79 dB µV
0.5 MHz to 30 MHz: < 73 dB µV
Radiated Radio Frequency Emission .... 0.15 MHz to 30 MHz: < 80-50 dB µV/m
30 MHz to 100 MHz: < 60-54 dB µV/m
100 MHz to 2000 MHz: < 54 dB µV/m

This product has been designed as Class A equipment. Use of this product in domestic environments may cause radio interference, in which case the user may be required to employ additional mitigation methods.

EMC Immunity

Electrostatic Discharge .... 6 kV contact discharge, 8 kV air discharge
Radio Frequency Electromagnetic Field .... 80 MHz to 1000 MHz: 10 V/m
Fast Transients 5/50 ns (main and control circuits) .... 2 kV line to earth, 1 kV line to line
Surges 1.2/50 µs (main and control circuits) .... 2 kV line to earth, 1 kV line to line
Voltage dip and short time interruption (safe shutdown) .... 5000 ms (at 0% nominal voltage)

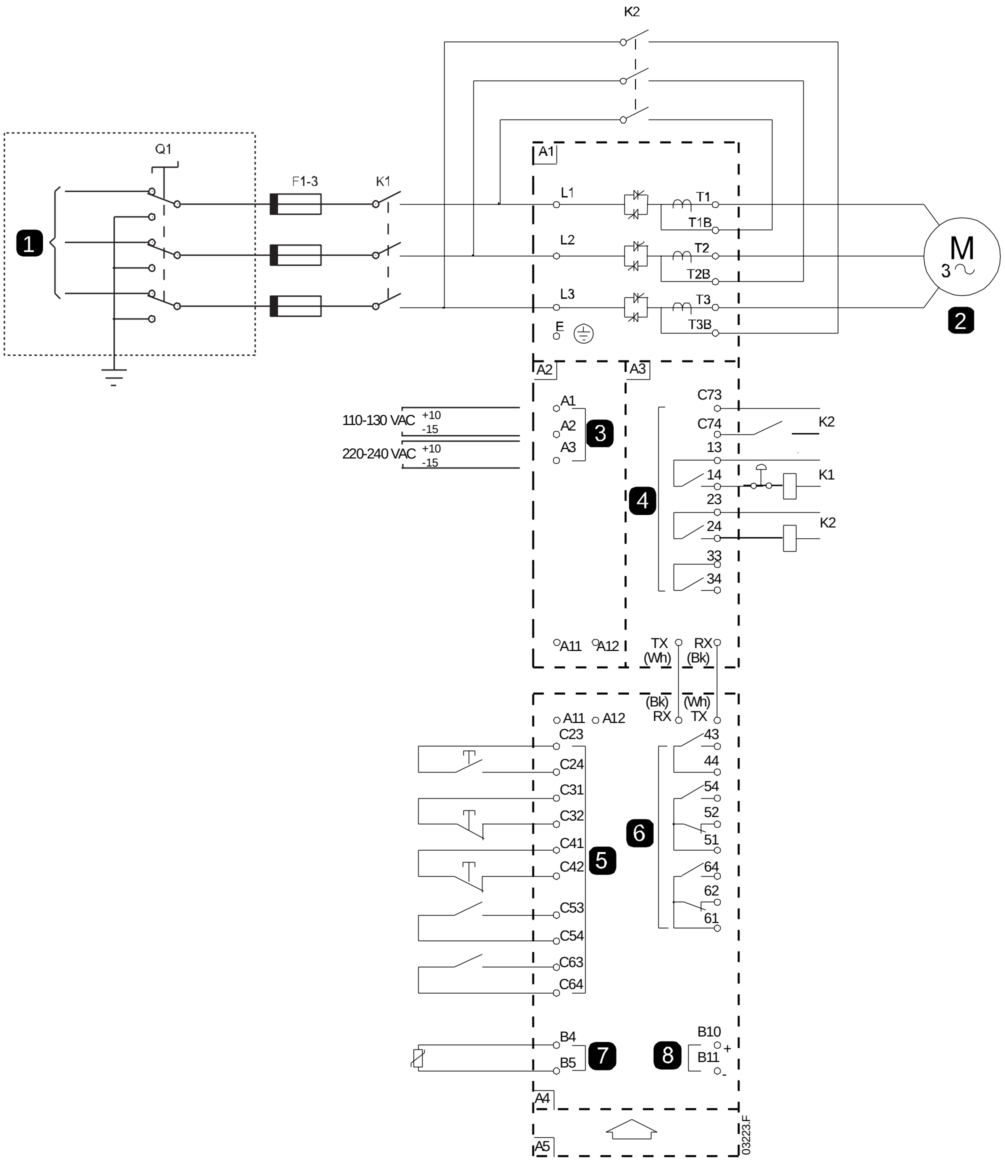
Standards Approvals

C✓ .... EMC requirements
CE .... EMC EU Directive

[1] Short circuit current, with appropriate R rated fuses fitted.
[2] Excludes contactors and/or circuit breakers.

Power Circuit Configuration

MVS power circuit with main contactor, bypass contactor, main isolator/ earth switch, R Rated fuses and control supply.



A1	Power assembly
1	3 Phase 50/60 Hz Supply
Q1	Main isolator/Earth switch
F1-3	R-Rated protection fuses
K1	Main contactor
K2	Bypass contactor
2	To motor
A2	Control voltage terminals
3	Control supply
A3	Power interface PCB
4	Relay outputs
C73~C74	Bypass contactor feedback signal
13~14	Main contactor K1
23~24	Bypass contactor K2
33~34	Run output (PFC)

A4	Controller
5	Remote control inputs
C23~C24	Start
C31~C32	Stop
C41~C42	Reset
C53~C54	Programmable input A
C63~C64	Programmable input B
6	Programmable outputs
43, 44	Programmable Relay output A
51, 52, 54	Programmable Relay output B
61, 62, 64	Programmable Relay output C
7	Motor thermistor input
8	Analog output
A5	Communications module (optional)

MVX Soft Starter

Overview

The MVX provides compact and robust soft start solutions for control of medium voltage motors. MVX soft starters provide a complete range of motor and system protection features and have been designed for reliable performance in the most demanding installation situations.

Each MVX soft starter comprises:

- a Phase Cassette
- a Controller module

The Phase Cassette and Controller module are supplied as a pair and share the same serial number. Care should be taken during installation to ensure the correct Controller and Phase Cassette are used together.

NOTE
Fibre-optic cables are only supplied in IP00 variants of the MVX soft starter. In all other MVX soft starters, this is part of the main assembly.

Feature List

Starting
- Constant current
- Current ramp

Stopping
- Coast to stop
- Soft stop

Protection
- Under/ Overvoltage
- Mains frequency
- Phase sequence
- Shorted SCR
- Motor overload (thermal model)
- Instantaneous overcurrent
- Time-overcurrent
- Ground fault
- Undercurrent
- Current imbalance
- Motor thermistor
- Excess start time
- Power circuit
- Auxiliary trip

Extensive input and output options
- Remote control inputs (3 x fixed, 2 x programmable)
- Relay outputs (3 x fixed, 3 x programmable)
- Analog output (1 x programmable)
- Serial port

Comprehensive feedback
- Digital display with multi-language support
- Controller buttons for quick access to common tasks
- Starter status LEDs
- Date and time stamped event logging
- Operational counters (starts, hours-run, kWh)
- Performance monitoring (current, voltage, power factor, kWh)
- User-programmable monitoring screen
- Multi-level password protection
- Emergency stop

Power Connection
- 15 A to 800 A, nominal
- 2200 VAC to 11000 VAC

Accessories (optional)
- DeviceNet, Modbus, Profibus or USB communication interfaces
- PC Software
- RTD relay
- Motor Protection Relay
- Predictive Maintenance Module (PMM)

Key features

MVX soft starters offer several special functions to ensure ease of use and to provide optimal motor control in all environments and applications.

Customisable Protection

The MVX offers comprehensive protection to ensure safe operation of the motor and soft starter. The protection characteristics can be customised extensively to match the exact requirements of the installation.

Advanced Thermal Modelling

Intelligent thermal modelling allows the soft starter to predict whether the motor can successfully complete a start. The MVX uses information from previous starts to calculate the motor's available thermal capacity, and will only permit a start which is predicted to succeed.

Comprehensive Event and Trip Logging

The MVX has a 99-place event log to record information on soft starter operation. A separate trip log stores detailed information about the last eight trips.

Informative Feedback Screens

A digital display screen allows the MVX to display important information clearly. Comprehensive metering information, details of starter status and last start performance allow easy monitoring of the starter's performance at all times.

Dual Parameter Set

The MVX can be programmed with two separate sets of operating parameters. This allows the soft starter to control the motor in two different starting and stopping configurations.

The secondary motor settings (parameter groups 9 and 10) are ideal for dual speed motors or conventional (squirrel-cage) motors which may start in two different conditions (such as loaded and unloaded conveyors).

The MVX will use the secondary motor settings to control a start when instructed via a programmable input (refer to parameters 6A and 6F *Input A or B Function*).

Fibre Optics

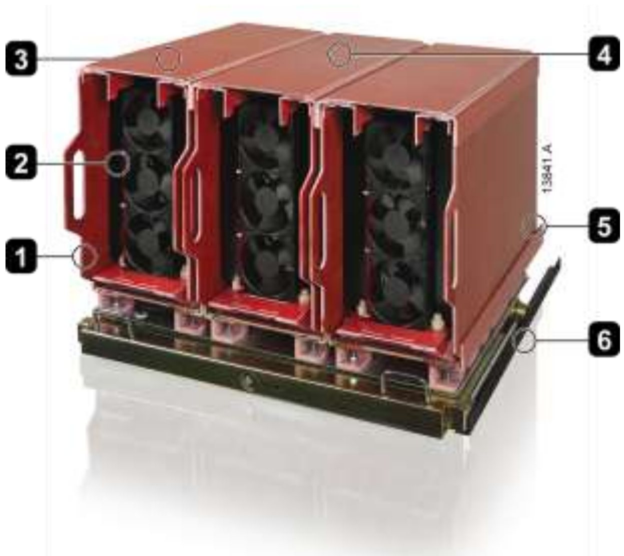
The MVX uses two-line fibre optic connections (per phase) between the low voltage control module and the high voltage phase cassette for electrical isolation. This fibre optic link simplifies installation of chassis mount MVX starters into custom panels.

MVX Phase Cassette

The MVX phase cassette is a robust and extremely compact design, for easy integration into a panel enclosure. The unique draw-out design simplifies general maintenance and servicing.

A service lifting trolley is supplied with each MVX panel or phase cassette, for easy installation and removal.

MVX phase cassette



1	GP06 and air insulation.
2	Small footprint IP00 starter.
3	Self-contained phase cassette.
4	Standard 150 mm pole centres.
5	Isolated control via fibre optic connections.
6	Rack-in/rack-out phase cassettes.

General Technical Data

Supply

Mains Voltage

MVXxxxx-V11 .... 11 kV Phase-phase

Rated Frequency (fr) .... 50/60 Hz

Rated lightning impulse withstand voltage (U_p)

MVXxxxx-V11 .... 75 kV

Rated power frequency withstand voltage (U_d)

MVXxxxx-V11 .... 42 kV

Rated short-time withstand current (symmetrical RMS) (I_k)

MVXxxxx-V11 .... 31.5 kA for 100 ms [1]

Form Designation .... Bypassed semiconductor motor starter form 1

Control Inputs

Start (Terminals C23, C24) .... 24 VDC, 8 mA approx

Stop (Terminals C31, C32) .... 24 VDC, 8 mA approx

Reset (Terminals C41, C42) .... 24 VDC, 8 mA approx

Input A (Terminals C53, C54) .... 24 VDC, 8 mA approx

Input B (Terminals C63, C64) .... 24 VDC, 8 mA approx

Motor Thermistor (Terminals B4, B5) .... Trip point > 2.8 kΩ

NOTE
All control inputs are potential free. Do not apply external voltage to these inputs.

Low Voltage Supply

Rated Voltage

MVXxxxx-V11 .... 85 ~ 275 VAC

Rated Frequency .... 50/60 Hz

Typical power consumption - MVXxxxx-V11

Start .... 300 W

Stop .... 100 W

Outputs

Relay Outputs .... 10 A @ 250 VAC resistive

.... 6 A @ 250 VAC AC15 p.f. 0.3

10 A @ 30 VDC resistive

Outputs on interface PCB

Main Contactor (13, 14) .... Normally Open

Bypass Contactor (23, 24) .... Normally Open

Run Output/ PFC (33, 34) .... Normally Open

Outputs on Controller

Output Relay A (43, 44) .... Normally Open

Output Relay B (51, 52, 54) .... Changeover

Output Relay C (61, 62, 64) .... Changeover

Analog Output (B10, B11) .... 0-20 mA or 4-20 mA

Environmental

Degree of Protection

Phase Cassette IP00

Controller (mounted on a panel) .... IP54/ NEMA 12

Operating Environment

IEC60721-3-3: IE34: Climatic 3K4 .... -5 °C to 40 °C, with derating to 55 °C

Relative Humidity .... 5% to 95%

Storage Environment

IEC60721-3-1: IE12 .... -5 °C to 55 °C

Relative Humidity .... 5% to 95%

Pollution Degree .... Pollution Degree 2

Vibration .... IEC 60068-2-6 Fc

EMC Emission

Equipment Class (EMC) .... Class A

Conducted Radio Frequency Emission .... 10 kHz to 150 kHz: < 120 - 69 dB µV

0.15 MHz to 0.5 MHz: < 79 dB µV

	0.5 MHz to 30 MHz: < 73 dB μV
Radiated Radio Frequency Emission	0.15 MHz to 30 MHz: < 80-50 dB μV/m
	30 MHz to 100 MHz: < 60-54 dB μV/m
	100 MHz to 2000 MHz: < 54 dB μV/m

EMC Immunity

Electrostatic Discharge	6 kV contact discharge, 8 kV air discharge
Radio Frequency Electromagnetic Field	80 MHz to 1000 MHz: 10 V/m
Fast Transients 5/50 ns (main and control circuits)	2 kV line to earth, 1 kV line to line
Surges 1.2/50 μs (main and control circuits)	2 kV line to earth, 1 kV line to line
Voltage dip and short time interruption	5000 ms (at 0% nominal voltage safe shutdown)

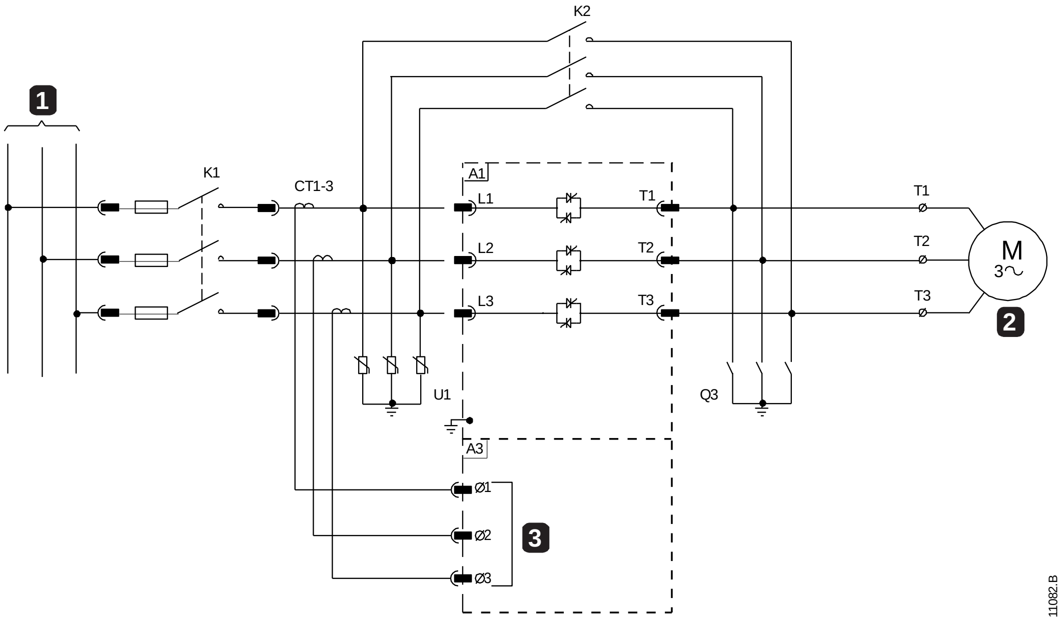
Standards Approvals

C✓	EMC requirements
CE	EMC EU Directive

[1] Short circuit current, with appropriate protection.

Power Circuit Configuration (with Contactors)

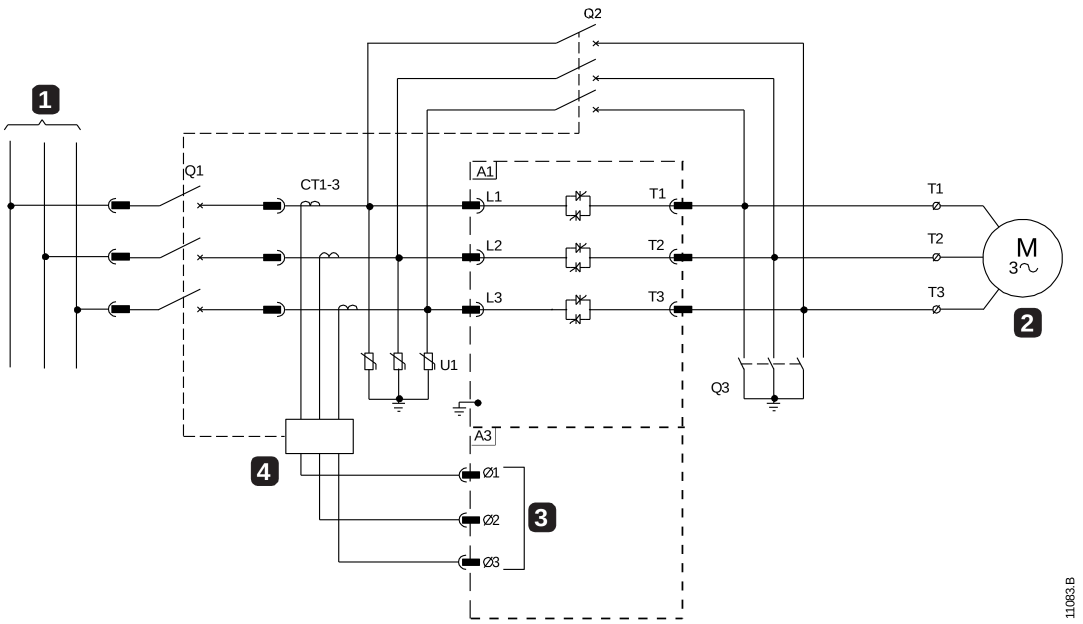
MVX power circuit with fused main contactor and bypass contactor.



A1	Phase cassette	L1-L3	Input power terminals (supply side)
1	3 Phase 50/60 Hz Supply	2	Motor
K1	Main contactor (fused/ withdrawable)	Q3	Earth switch
K2	Bypass contactor (fixed)	T1-T3	Output power terminals (motor side)
CT1-3	Current transformers (x3)	A3	Power interface PCB
U1	Metal oxide varistors (MOVs)	3	Current transformer inputs

Power Circuit Configuration (with Circuit Breakers)

MVX power circuit with main circuit breaker and bypass circuit breaker.

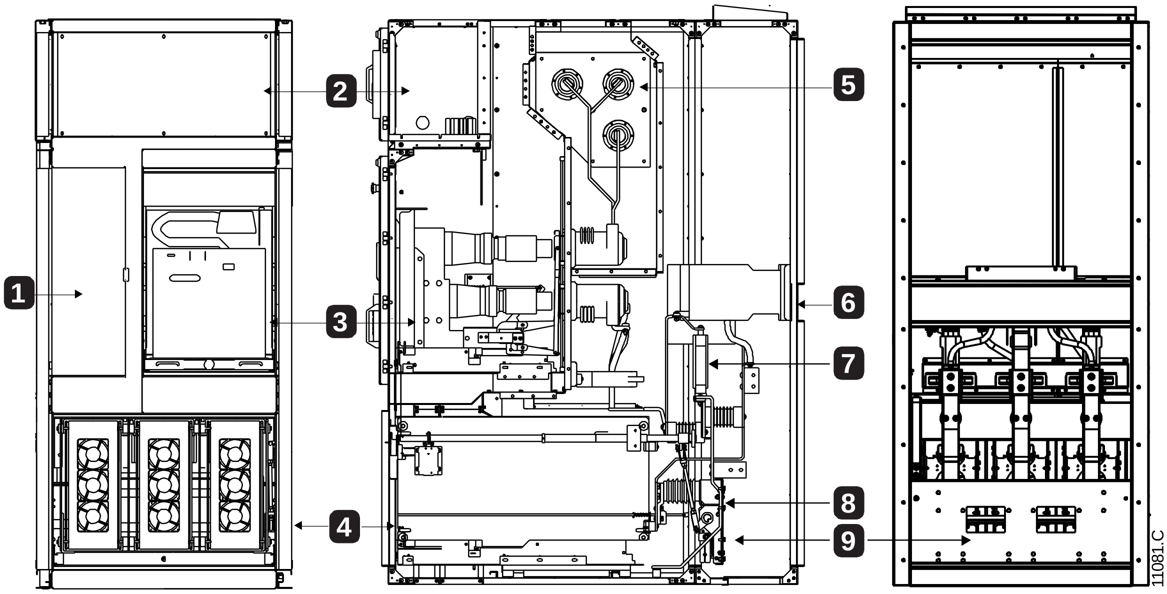


A1	Phase cassette	2	Motor
1	3 Phase 50/60 Hz Supply	Q3	Earth switch
Q1	Main circuit breaker (withdrawable)	T1-T3	Output power terminals (motor side)
Q2	Bypass circuit breaker (fixed)	A3	Power interface PCB
CT1-3	Current transformers (x3)	3	Current transformer inputs
U1	Metal oxide varistors (MOVs)	4	Motor protection relay (MPR)
L1-L3	Input power terminals (supply side)		

Enclosures

MVX soft starters can be installed easily into standard enclosures to provide a complete motor control cabinet. The compact size of the power assembly leaves room for auxiliary equipment to be installed.

The phase cassette should be mounted at the bottom of the enclosure, and the Controller can be mounted on the front panel. The diagrams below illustrate a possible configuration for installation.



Front view Side view Rear view

1	Controller compartment
2	Upper LV compartment
3	Main contactor/ circuit breaker compartment
4	Phase cassette
5	Input supply terminals

6	Bypass contactor/ circuit breaker
7	Surge arrester
8	Phase cassette power connections
9	Earth switch

Soft starter communication options

AuCom medium voltage soft starters can connect easily to Modbus, Profibus or DeviceNet communication networks, using simple add-on communication interfaces.

All communication interfaces allow you to:

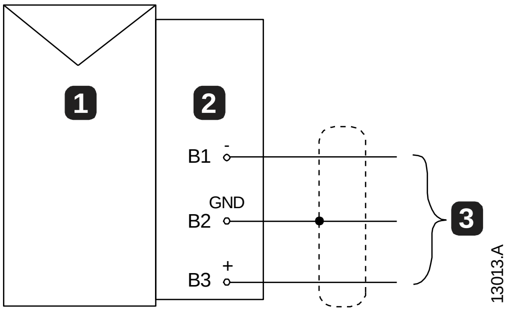
- control the soft starter
- monitor the starter's operational or trip status
- monitor the starter's current level and motor temperature (using the motor thermal model)

Some protocols also allow you to read and write soft starter parameters.

For installations with no existing network, AuCom also offers WinMaster, a PC-based software program which allows control, monitoring and parameter management via an RS485 or USB connection.

Modbus Interface

MVS and MVX soft starters can operate as slaves on a Modbus network via a Modbus Interface.

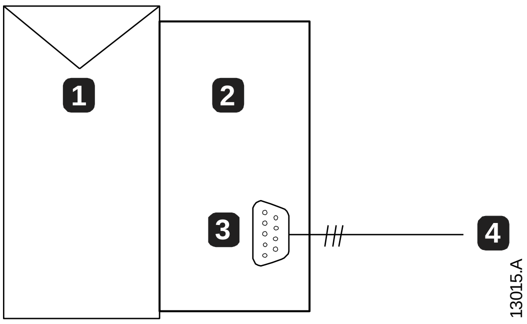


1	Soft starter
2	Modbus interface
3	RS485 connection onto a Modbus RTU network

- The Modbus Interface is powered by the soft starter.
- Each soft starter requires a separate Modbus Interface.
- A Modbus RTU network can support up to 31 Modbus Interfaces as slaves.
- The interface is configured using 8-way DIP switches. For more information on using the Modbus Interface, refer to the Modbus Interface instructions.

Profibus Interface

MVS and MVX soft starters can connect to a Profibus network using the Profibus Interface.



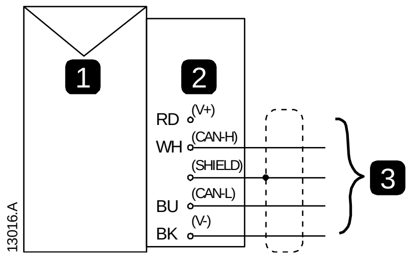
1	Soft starter
2	Profibus interface
3	Standard DB9 connection
4	Profibus DP (3-wire network cable)

- The Profibus Interface requires an external 24 VDC supply.
- Each soft starter requires a separate Profibus Interface.
- A Profibus DP network can support up to 31 Profibus Interfaces as slaves.
- The Profibus node address is selected using two rotary switches on the interface. The interface automatically detects the data rate.
- The GSD installation file is available from the AuCom website. For more information on using the Profibus Interface, refer to the Profibus Interface instructions.

PROFI BUS® Tested and certified by Profibus.

DeviceNet Interface

MVS and MVX soft starters can connect to a DeviceNet network using the DeviceNet Interface.



1	Soft starter
2	DeviceNet Interface
3	Standard 5-wire connection onto a DeviceNet network 120 Ω termination resistors are required at each end of the network cable

- The Devicenet Interface is powered from the network.
- Each soft starter requires a separate DeviceNet Interface.
- A DeviceNet network can support up to 63 DeviceNet Interfaces as slaves.
- The DeviceNet node address (MAC ID) and data rate are selected using three rotary switches on the interface.
- The EDS installation file is available from the AuCom website. For more information on using the DeviceNet Interface, refer to the DeviceNet Interface instructions.

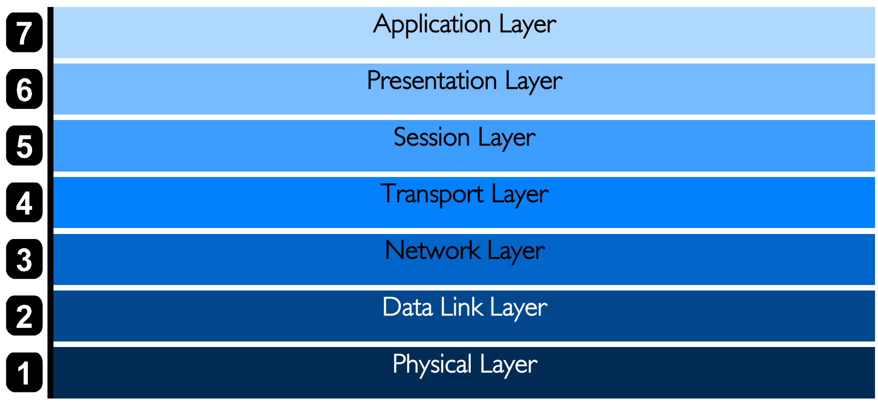
DeviceNet CONFORMANCE TESTED Tested and certified by ODVA.

Ethernet options

Industrial plant automation is rapidly moving towards Ethernet based protocols. Ethernet is a real-time, high speed technology which provides a seamless and unified system linking information from the factory and plant floors through to the corporate environment. A major advantage of Ethernet based protocols is their accessibility via the internet.

Industrial Ethernet protocols use the Open Systems Interconnection (OSI) model developed by the International Standards Organisation (ISO). The standard protocol stack consists of 7 layers, covering the protocol requirements of all industrial automation systems.

Seven-layer OSI model



In basic terms, industrial Ethernet protocols use a common industrial protocol at the application layer (eg Modbus RTU, Profibus DP or DeviceNet)). This is encapsulated within TCP/IP protocol headers (layers 4 and 3) for transport over a physical Ethernet network (via layers 2 and 1).

AuCom is developing Ethernet based communication options for use with its medium voltage soft starter products. These options will be certified to the relevant IEC, ODVA and Profibus international standards.

- Modbus TCP (Modbus RTU over Ethernet)
- ProfiNet (Profibus DP over Ethernet)
- Ethernet/IP (DeviceNet over Ethernet)

Predictive Maintenance Module (PMM)

AuCom's PMM Predictive Maintenance Module provides an easy-to-use solution for maintenance planning. Using leading-edge condition monitoring techniques, the PMM can pinpoint equipment failure 2-3 months in advance. The PMM can be used with a wide range of applications, from pumps and fans to compressors and crushers.

By directly monitoring the voltage and current waveforms at the motor, PMM can quickly and reliably detect changes in the characteristics, and reports these through a streamlined, easy to understand interface. Because the PMM uses a model-based fault detection and diagnostic system, it is largely immune to noise, making it ideally suited to erratic loads.

PMM can detect and identify a very wide range of mechanical, electrical, operational and efficiency problems, affecting both the load and the motor itself:

- Mechanical: loose foundation or components; imbalance; misalignment; mechanical looseness; deterioration of the couplings, bearings or gearbox
- Electrical: loose windings; stator fault; insulation and capacitor breakdown; supply problems; damaged rotor bars; bad connections; phase imbalance
- Operational: abnormal loads, cavitation, filter blocking
- Electrical performance: power factor; active/reactive power; Vrms/Irms (3 phase); voltage or current imbalance; frequency; total harmonic distortion

3.5 Selection Guidelines

Considerations

The following information is required to select the starter appropriately. This information is required regardless of whether you are integrating an IP00 soft starter into a custom-built enclosure or choosing a complete soft starter panel option.

Information	IP00 Soft Starter	Soft Starter Panel
Operating voltage (U)	●	●
Operating current (I)	●	●
Expected start current (I_{STR})	●	●
Expected start time (t_{STR})	●	●
Expected stop time (t_{STP})	●	●
Ambient temperature (T_A)	●	●
Altitude (Alt)	●	●
Switchgear requirements		●
Incoming and motor supply configuration		●
Customer specific requirements		●

Operating Voltage, U (kV)

Operating voltage is the voltage (kV) of the network where the equipment is installed, and is the line voltage applied across the soft starter's power terminals L1, L2, L3.

The operating voltage will dictate the rated voltage U_r (kV) for the equipment to be used.

AuCom solutions are designed to conform to the insulation requirements of IEC 62271-1, where:

- the power frequency withstand voltage U_d (kV rms, 1 minute) simulates high level voltage surges on the main supply line at standard frequency;
- the rated impulse withstand voltage U_p (kV peak) simulates a high level voltage transient induced on the main supply from a lightning strike. This is a 1.2/50 μs transient wave.

Operating Voltage U (kV)	IP00			Panel		
	Rated Voltage U_r (kV)	Power Frequency withstand U_d (kV rms, 1 min)	Impulse withstand U_p (kV peak)	Rated Voltage U_r (kV)	Power Frequency withstand U_d (kV rms, 1 min)	Impulse withstand U_p (kV peak)
2.3	2.3	11.5	45	4.2	11.5	45
3.3	3.3	11.5	45			
4.2	4.2	11.5	45			
6~6.6	6.6	20	45	7.2	20	45
7.2	7.2	20	45			
11	12	42	75	12	42	75

Operating Current, I (A)

The maximum operating current (I) of a soft starter installation is the full load current (FLC) of the motor.

The soft starter's rated current I_r (A) must be equal to or greater than the motor FLC after considering the following operating parameters:

I_{STR} expected start current (percentage of motor FLC)
t_{STR} expected start time (seconds)
t_{STP} expected stop time (seconds)
SPH starts per hour
T_A ambient temperature (degrees celsius)
Alt installation altitude (metres)

Expected start current and time can be based on typical requirements for a particular load, or can be calculated using a fully engineered solution. AuCom uses a purpose-designed selection software to select appropriate soft starter models.

Medium voltage starter selection software

13491.A

Switchgear Requirements

MVS Panel Options

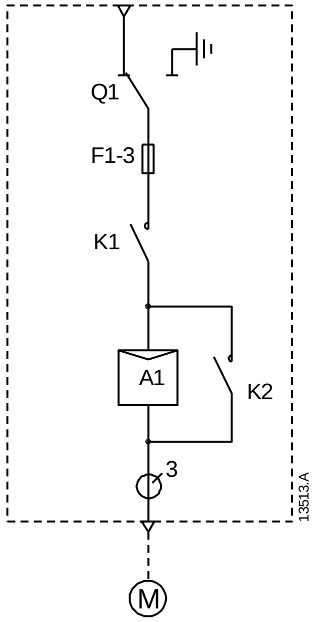
The MVS soft starter is suitable for operating voltages between 2.3 kV ~ 7.2 kV and currents ≤ 600 A, and can be supplied in switchgear panels.

In all MVS panel options, the following LV equipment is standard and is mounted on the LV compartment door:

- Controller
- emergency stop pushbutton
- soft starter reset pushbutton

E3 panel

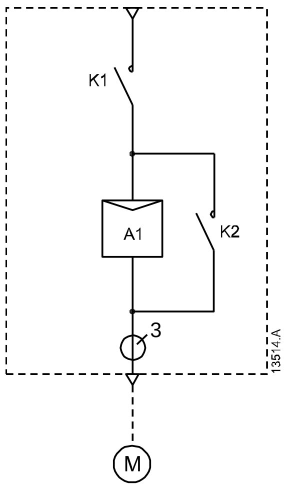
E3 panel schematic (for use with MV motor 2.3 kV~7.2 kV, 80 A ~ 600 A)



A1	Soft starter power assembly
Q1	Incoming isolator/earth switch
F1-3	R-rated line fuses
K1	Main contactor
K2	Bypass contactor

E2 panel

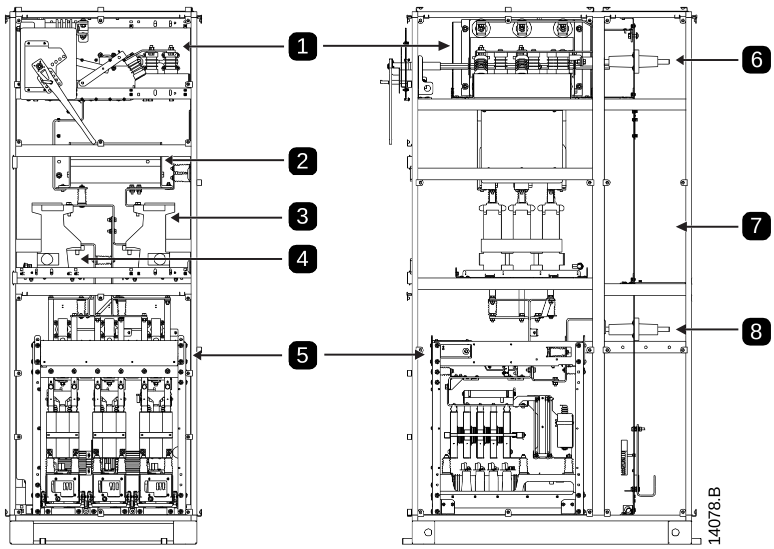
E2 panel schematic (for use with MV motor 2.3 kV~7.2 kV, 80 A ~ 600 A)



A1	Soft starter power assembly
K1	Main contactor
K2	Bypass contactor

Short-circuit line protection is provided externally using R-rated fuses or an MV circuit breaker.

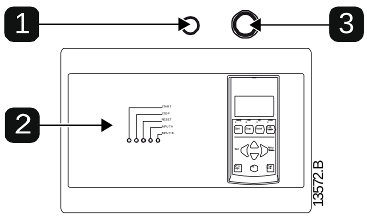
Panel physical layout



Front view Side view

1	Main isolator/earth switch (Q1)
2	R-rated protection fuses (F1-3)
3	Main contactor (K1)
4	Bypass contactor (K2)
5	Power assembly (A1)
6	Input terminals (L1, L2, L3)
7	Rear cable compartment
8	Output terminals (T11, T2, T3)

Control components mounted on the LV compartment door



1	Reset pushbutton
2	Controller
3	Emergency stop pushbutton

Front view of a typical MVS starter panel

MVX panel option

Soft starters such as the MVX are rated for a maximum operating voltage (U) of 11 kV. The MVX is available as an IP00 unit or an indoor-style metal enclosed switchgear panel with a rated voltage (U_r) of 12 kV and an arc-proof classification of 31.5 kA for 1 second.

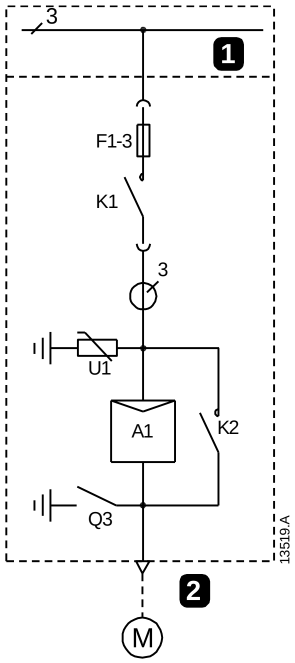
For operating currents (FLC) ≥160A, circuit breakers are required. For operating currents ≤160A, the switching device can be either contactors or vacuum circuit breakers.

- The main switching device is a rack-in/out component housed in the main switching compartment.
- The bypass switching device is a fixed component housed in the cable compartment.

In all MVX panel options, the following LV equipment is standard and is mounted on the controller compartment door:

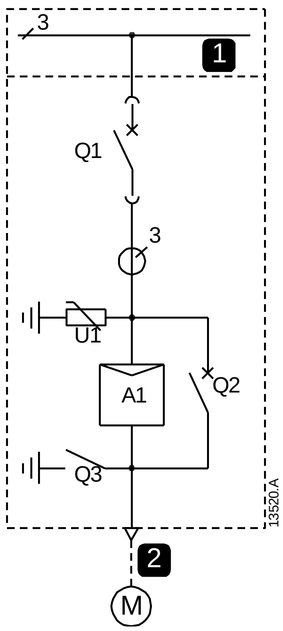
- Controller
- emergency stop pushbutton
- soft starter reset pushbutton

MVX panel with contactors



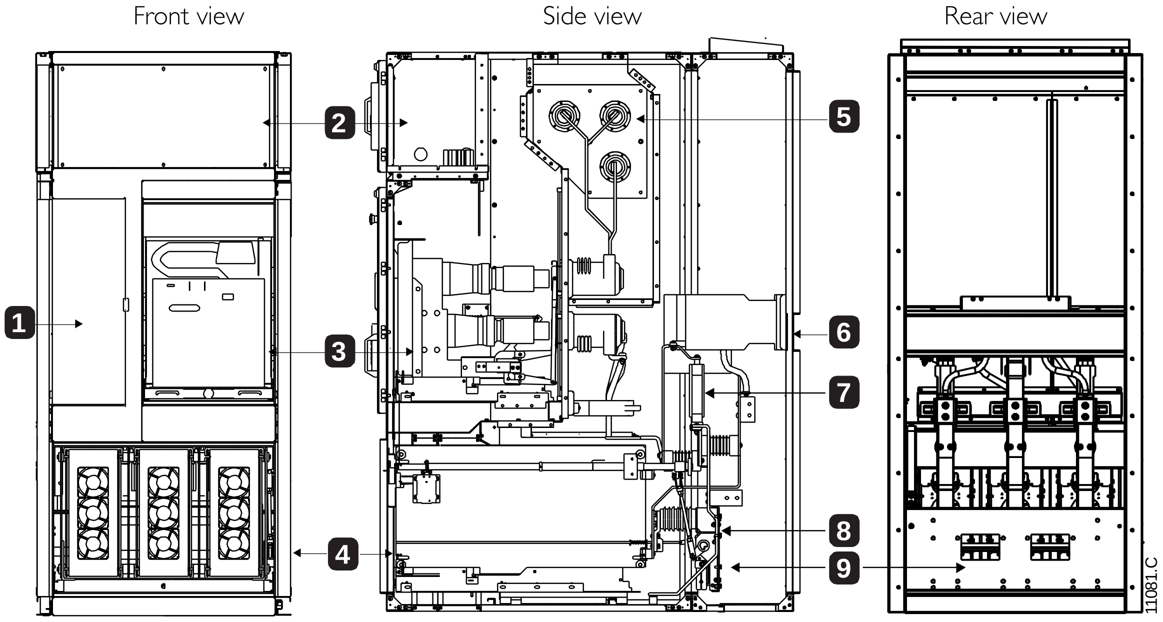
1	Operating voltage ≤11 kV
2	Operating current ≤160 A
A1	Soft starter phase cassette
F1-3	Motor rated protection fuses
K1	Main contactor (withdrawable)
K2	Bypass contactor (fixed)
Q3	Earth switch
U1	MV surge arrestors

MVX panel with circuit breakers



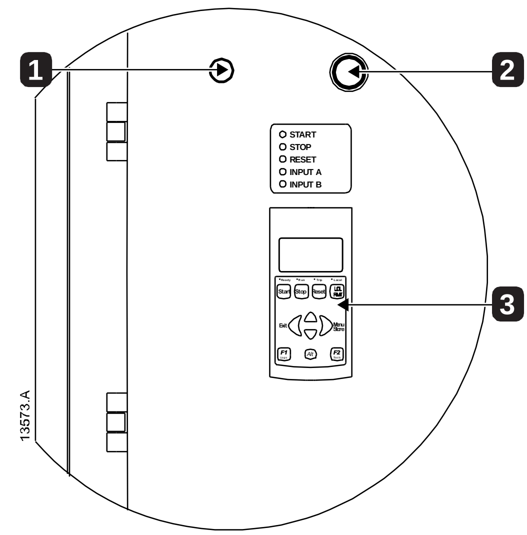
1	Operating voltage ≤11 kV
2	Operating current >160 A
A1	Soft starter phase cassette
Q1	Main circuit breaker (withdrawable)
Q2	Bypass circuit breaker (fixed)
Q3	Earth switch
U1	MV surge arrestors

MVX panel physical layout



1	Controller compartment		6	Bypass contactor/ circuit breaker (K2/Q2)
2	Upper LV compartment		7	Surge arrester (U1)
3	Main contactor/ circuit breaker compartment (K1/Q1)		8	Phase cassette power connections
4	Phase cassette (A1)		9	Earth switch (Q3)
5	Input supply terminals (L1, L2, L3)			

Control components mounted on the controller compartment door

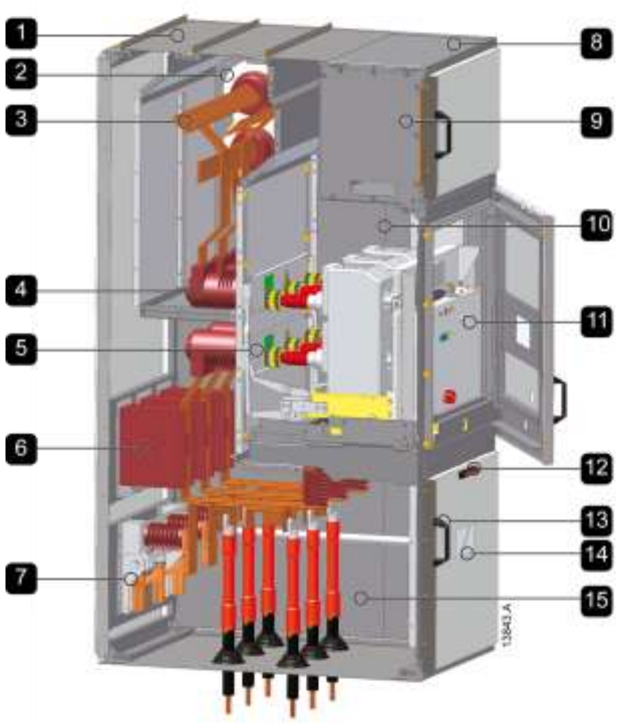


1	Reset pushbutton
2	Emergency stop pushbutton
3	Controller

Typical MVX panel line-up

1	Busbars isolated in separate compartment.
2	Internal separation compartments isolate bus work during LV service
3	Interlocking racking system for VCBs etc
4	AuCom keypad and analog/digital metering options available
5	Safe LV compartment access without need to de-energise MV section
6	Easy to manoeuvre and install via lifting eye bolts
7	Modular design allows for single panels or line-ups

8	Arc-fault resistant enclosure
9	Lockable doors as standard
10	Two-step door locking prevents accidental access
11	Hinged door panels (no more lost or damaged panels)
12	Small footprint phase cassette
13	Viewing window to inspect switchgear status without opening doors



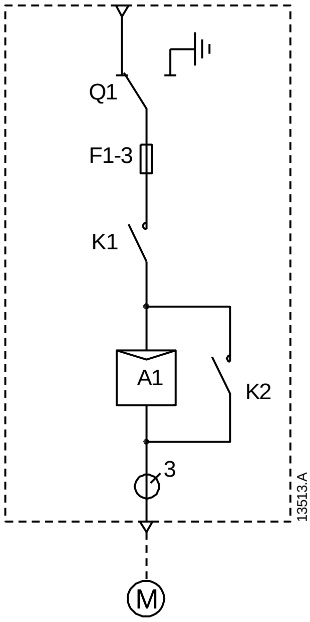
1	Overpressure flap
2	Bushing
3	Busbar system
4	Fixed contact insulator
5	Shutter
6	Current transformer
7	Earth switch
8	Enclosure
9	Low voltage compartment
10	Circuit breaker compartment
11	Vacuum circuit breaker
12	Door lock
13	Door handle
14	Inspection window
15	Cable compartment

Incoming and motor supply configuration

MV soft starter panels can be constructed for standalone use or with a horizontal busbar system for an MCC line-up. If the soft starter panel will connect to a different switchgear style busbar system, a termination or transition panel will be required. All panels can accommodate top or bottom exit for the outgoing motor cables.

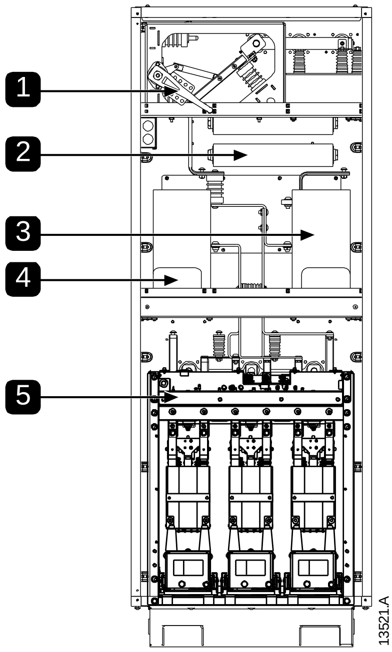
Standalone MV soft starter panel

Incoming supply
(top or bottom cable entry)



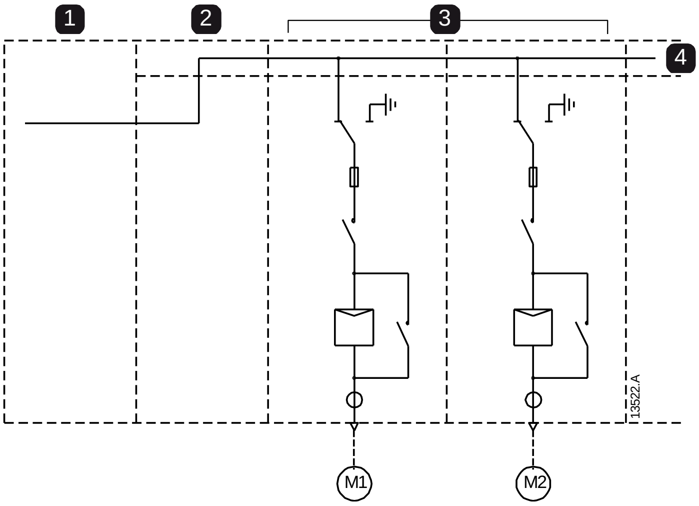
Motor cable (top or bottom exit)

Front view



1	Main isolator/earth switch
2	R-rated fuses
3	Main contactor
4	Bypass contactor
5	Power assembly

Typical MCC panel line-up



1	Existing switchgear panel
2	Transition panel
3	Soft starter MVS E3 panels
4	Mains supply busbar system

Customer-specific requirements

Additional equipment can be designed and integrated into AuCom MVS and MVX panel solutions, depending on the customer's specific needs.

In some cases, extra switchgear panels matching the soft starter panels may be required in order to house the extra equipment.

- Motor protection relay (in addition to soft starter motor protection)
- RTD (PT100) temperature protection relay
- Insulation monitoring relay
- Predictive Maintenance Module (PMM)
- Metering relay
- PLCs, auto changeover contactors, PFC controllers etc
- Inverters and switch mode power supplies
- Low voltage control equipment (eg indicators, switches, pushbuttons)
- LV section panel light
- Panel anti-condensation heaters
- Motor heater circuit
- MV/LV control supply transformer
- Voltage transformer (1 or 3 phase)
- Extra CTs for protection or metering
- LV control transformer
- Power factor correction (requires dedicated panel to install capacitor banks and associated switchgear)

AC53 Utilisation Codes

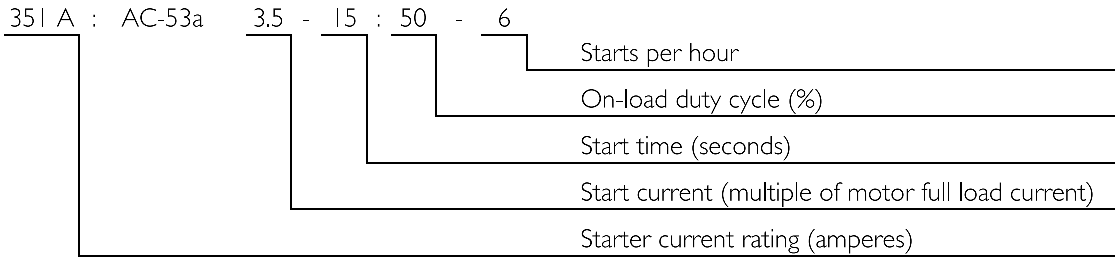
The IEC60947-4-2 standard for electronic starters defines AC53a and AC53b Utilisation Categories for detailing a soft starter's current capability.

AC53a Utilisation Code

The AC53a Utilisation Code defines the current rating and standard operating conditions for a non-bypassed soft starter.

The soft starter's current rating determines the maximum motor size it can be used with. The soft starter's rating depends on the number of starts per hour, the length and current level of the start, and the percentage of the operating cycle that the soft starter will be running (passing current).

The soft starter's current rating is only valid when used within the conditions specified in the utilisation code. The soft starter may have a higher or lower current rating in different operating conditions.



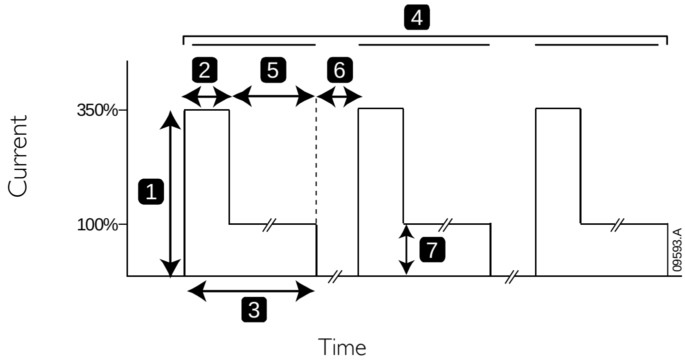
Starter current rating: The full load current rating of the soft starter given the parameters detailed in the remaining sections of the utilisation code.

Start current: The maximum available start current.

Start time: The maximum allowable start time.

On-load duty cycle: The maximum percentage of each operating cycle that the soft starter can operate.

Starts per hour: The maximum allowable number of starts per hour.



1	Start current
2	Start time
3	On-load time
4	Starts per hour
5	Run time
6	Off time
7	Nominal motor current

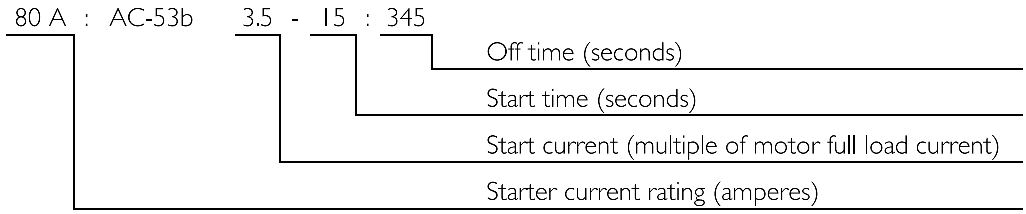
$$\text{Duty cycle} = \frac{\text{Start time} + \text{Run time}}{\text{Start time} + \text{Run time} + \text{Off time}}$$

AC53b Utilisation Code

The AC53b utilisation code defines the current rating and standard operating conditions for a bypassed soft starter (internally bypassed, or installed with an external bypass contactor).

The soft starter's current rating determines the maximum motor size it can be used with. The soft starter's rating depends on the number of starts per hour and the length and current level of the start.

The soft starter's current rating is only valid when used within the conditions specified in the utilisation code. The soft starter may have a higher or lower current rating in different operating conditions.

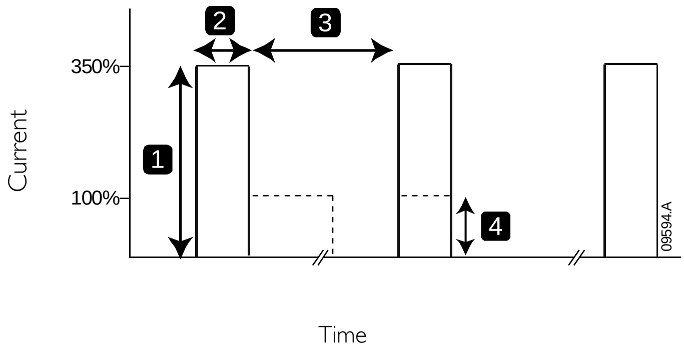


Starter current rating: The full load current rating of the soft starter given the parameters detailed in the remaining sections of the utilisation code.

Start current: The maximum available start current.

Start time: The maximum allowable start time.

Off time: The minimum allowable time between the end of one start and the beginning of the next start.



1	Start current
2	Start time
3	Off time. This includes time while the starter is running but the SCRs are bypassed (not conducting)
4	Nominal motor current

NOTE
AuCom MVS and MVX soft starters are AC53b rated and must always be used with a bypass contactor or circuit breaker.

3.6 Calculations

What is the minimum start current with a soft starter?

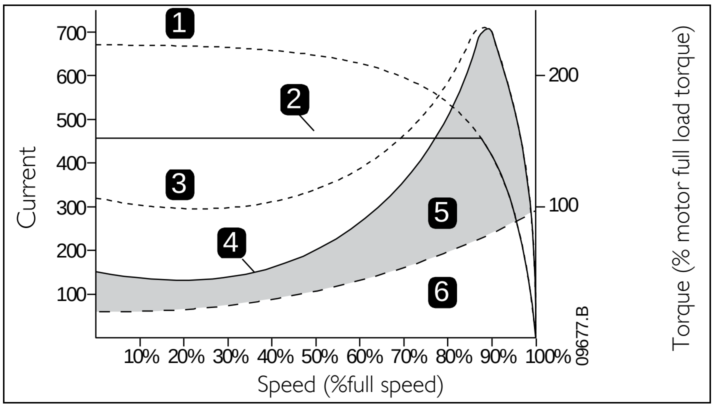
Soft starters can limit start current to any desired level. However, the minimum level of start current for a successful start depends on the motor and load.

To start successfully, the motor must produce more acceleration torque than the load requires, throughout the start.

Reducing the start current also reduces the torque produced by the motor. The start current can only be lowered to the point where the torque output remains just greater than the load torque requirement.

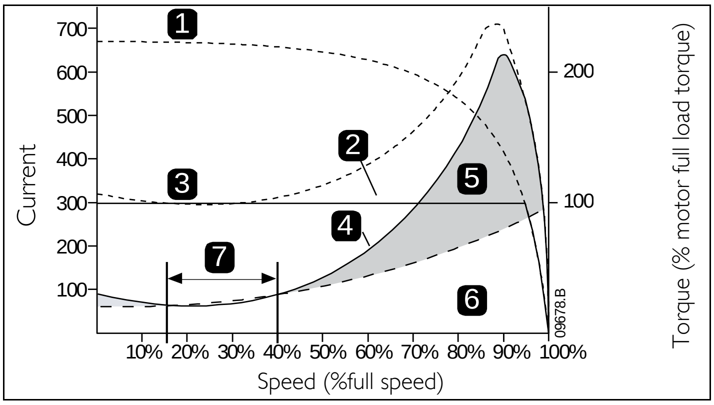
The likely start current can be estimated from experience, but more precise predictions require analysis of motor and load speed/torque curves.

Successful soft start



1	Full voltage start current
2	Current limit
3	Full voltage start torque
4	Torque output at current limit
5	Acceleration torque
6	Load torque

Unsuccessful soft start



1	Full voltage start current
2	Current limit
3	Full voltage start torque
4	Torque output at current limit
5	Acceleration torque
6	Load torque
7	Stall

Calculating required start current for new or existing AC induction motor installations

A number of methods are available to estimate the level of start current a particular machine will require. These methods range from generalisations producing approximations, through to advanced calculations which yield precise predictions.

Typical Start Current Estimate

Where motor and load start characteristics are unknown and an estimate of typical start current is sufficiently accurate, basic application information can allow experienced personnel to estimate the typical start current.

Required information:

- Motor size (kW / HP)
- Machine type and class (eg Compressor - Screw, Pump - Centrifugal)
- Machine starting condition (eg Conveyor - Unloaded Start)

Assessed Start Current Estimate

If information is available about the intended motor's locked rotor current (LRC) and locked rotor torque (LRT), the motor's start performance can also be factored into the assessment. Even better estimates are obtained where information on the machine start torque requirement are also known.

Required information:

- Motor size (kW / HP)
- Motor locked rotor current (LRC)
- Motor locked rotor torque (LRT)
- Machine starting torque (% FLT)

Calculation

Calculations use percentages of full load torque and full load current.

Minimum required start current

$I_{STR} = LRC \times \sqrt{\frac{T_{STR}}{LRT}}$	Where: I_{STR} = minimum required start current (% motor FLC) LRC = Motor locked rotor current (% motor FLC) T_{STR} = Minimum required start torque to accelerate machine from standstill (% motor FLT) LRT = Motor locked rotor torque (% motor FLT)

Example

A 1100 kW / 3.3 kV motor has a full load current of 235 A and a locked rotor current of 500% FLC. The motor is required to start a pump with a minimum start current of 15% motor FLT. The motor's locked rotor torque is 150% FLT.

$$\begin{aligned} I_{STR} &= 500\%\ FLC \times \sqrt{\frac{15\%\ FLT}{150\%\ FLT}} \\ &= 500 \times 0.316 \\ &= 158\%\ FLC \\ &= \frac{158}{100} \times 235\ A \\ &= 371\ A \end{aligned}$$

Start Current and Torque Curve Analysis

To accurately calculate an application's start current requirements, torque and current curves for both the motor and the load are required. Information from these curves is used to assess the minimum start current requirements.

With the following information, specific application software can accurately estimate the minimum required start current (I_{STR}) and start time (t_{STR}):

- Motor datasheet (including kW, full load speed and motor shaft inertia)
- Motor speed/current curve
- Motor speed/torque curve
- Load speed/torque curve
- Load inertia

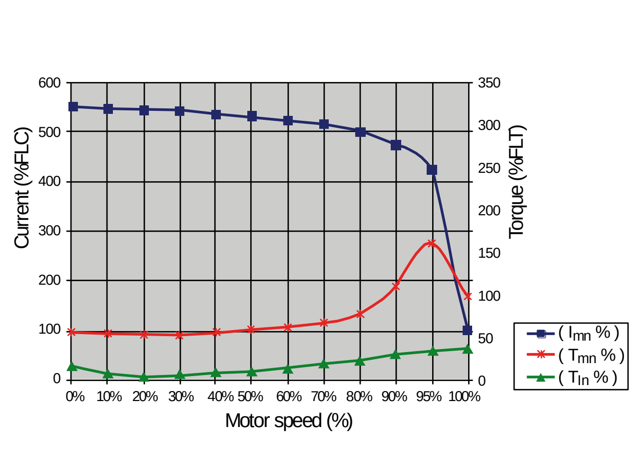
Motor, load and application data

Application Data:

Motor (kW)	3200
Full speed (rpm)	1481
Total load inertia at motor shaft (kg.m2)	168

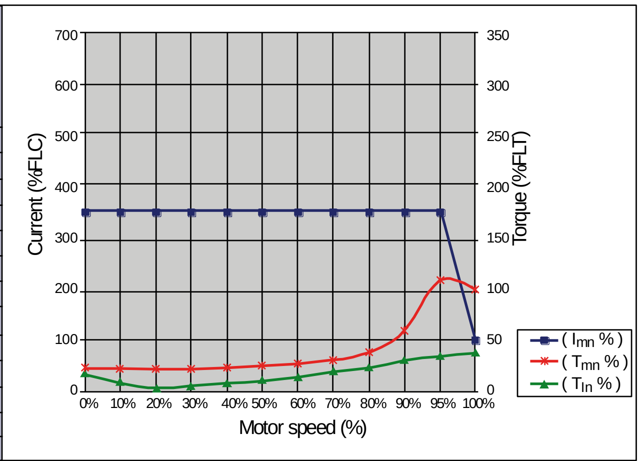
Current and torque curve data:

Motor speed as % of rated speed	Motor current at speed n as % motor FLC	Motor torque at speed n as % motor FLT	Load torque at speed n as % motor FLT
(n %)	(I_{mn} %)	(T_{mn} %)	(T_{ln} %)
0%	550	55	17.0
10%	548	54	8.0
20%	545	53	3.0
30%	541	53	5.0
40%	537	55	8.0
50%	531	58	10.0
60%	525	61	14.0
70%	518	67	19.0
80%	500	77	23.0
90%	475	110	30.0
95%	425	160	34.0
100%	100	100	37.0



Motor current & torque curves at 3.5 x FLC

Motor speed as % of rated speed	Motor current at speed n as % motor FLC	Motor torque at speed n as % motor FLT	Load torque at speed n as % motor FLT	Load accelerating torque at speed n as % motor FLT
(n %)	(I_{mn} %)	(T_{mn} %)	(T_{ln} %)	(T_{an} %)
0%	350	22	17.0	5
10%	350	22	8.0	14
20%	350	22	3.0	19
30%	350	22	5.0	17
40%	350	23	8.0	15
50%	350	25	10.0	15
60%	350	27	14.0	13
70%	350	31	19.0	12
80%	350	38	23.0	15
90%	350	60	30.0	30
95%	350	109	34.0	75
100%	100	100	37.0	0



Acceleration time calculations

	1.5 x FLC		2.0 x FLC		2.5 x FLC		3.0 x FLC		3.5 x FLC	
Motor Speed as % Rated Speed	Average Load Accelerating Torque Over Speed Range n	Acceleration Time Over Speed Range n	Average Load Accelerating Torque Over Speed Range n	Acceleration Time Over Speed Range n	Average Load Accelerating Torque Over Speed Range n	Acceleration Time Over Speed Range n	Average Load Accelerating Torque Over Speed Range n	Acceleration Time Over Speed Range n	Average Load Accelerating Torque Over Speed Range n	Acceleration Time Over Speed Range n
(n %)	(% FLT)	(secs)	(% FLT)	(secs)	(% FLT)	(secs)	(% FLT)	(secs)	(% FLT)	(secs)
0-10%-8.4	-1.50	-5.3	-2.40	-1.2	-10.53	3.8	3.35	9.7	1.31	
10% - 20%	-1.5	-8.59	1.7	7.58	5.7	2.22	10.6	1.19	16.4	0.77
20% - 30%	0.0	283.04	3.2	3.96	7.2	1.75	12.2	1.04	18.0	0.70
30% - 40%	-2.3	-5.45	0.9	13.49	5.1	2.47	10.2	1.23	16.3	0.78
40% - 50%	-4.5	-2.78	-1.1	-11.78	3.4	3.73	8.8	1.43	15.3	0.83
50% - 60%	-7.2	-1.75	-3.5	-3.65	1.3	9.39	7.2	1.75	14.2	0.89
60% - 70%	-11.2	-1.13	-7.1	-1.78	-1.8	-7.09	4.7	2.69	12.3	1.02
70% - 80%	-14.7	-0.86	-9.8	-1.28	-3.6	-3.53	4.1	3.08	13.2	0.96
80% - 90%	-17.6	-0.72	-10.6	-1.19	-1.6	-7.70	9.3	1.36	22.2	0.57
90% - 100%	-11.8	-1.07	-1.9	-6.62	10.8	1.17	26.3	0.48	44.7	0.28
		259 secs		-4 secs		-8 secs		18 secs		8 secs

	4.0 x FLC		4.5 x FLC		5.0 x FLC		5.5 x FLC		6.0 X FLC	
(n %)	(% FLT)	(secs)	(% FLT)	(secs)	(% FLT)	(secs)	(% FLT)	(secs)	(% FLT)	(secs)
0-10%16.4	0.77	24.1	0.52	32.7	0.39	42.0	0.30	42.0	0.30	
10% - 20%	23.2	0.55	30.8	0.41	39.3	0.32	48.0	0.26	48.0	0.26
20% - 30%	24.8	0.51	32.4	0.39	40.9	0.31	49.0	0.26	49.0	0.26
30% - 40%	23.2	0.54	31.1	0.41	40.0	0.32	47.5	0.27	47.5	0.27
40% - 50%	22.7	0.56	31.1	0.41	40.6	0.31	47.5	0.27	47.5	0.27
50% - 60%	22.2	0.57	31.2	0.40	41.4	0.31	47.5	0.27	47.5	0.27
60% - 70%	21.2	0.60	31.2	0.40	42.4	0.30	47.5	0.27	47.5	0.27
70% - 80%	23.6	0.53	35.5	0.36	48.7	0.26	51.0	0.25	51.0	0.25
80% - 90%	37.1	0.34	54.0	0.23	67.0	0.19	67.0	0.19	67.0	0.19
90% - 100%	65.9	0.19	80.2	0.16	83.0	0.15	83.0	0.15	83.0	0.15
		5 secs		4 secs		3 secs		2 secs		2 secs

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Calculations performed by software

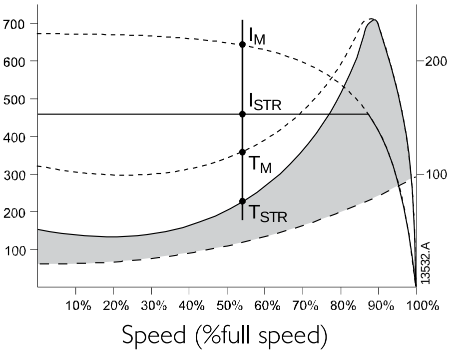
Revised motor torque (T_{STR})

This calculates the torque that the motor will supply at a reduced level of start current.

Calculations use percentages of full load torque and full load current.

$$T_{STR} = T_M \times \left(\frac{I_{STR}}{I_M} \right)^2$$

Where:
T_{STR} = revised motor torque
T_M = motor torque level at full voltage start
I_{STR} = motor start current limit level
I_M = motor current level at full voltage start



Example

At 50% motor speed, calculate the revised motor torque for a start current limit of 400% FLC, a DOL current level of 600% FLC and a DOL motor torque level of 120% FLT.

$$T_{STR} = 120 \times \left(\frac{400}{600} \right)^2$$
$$= 53\% \text{ FLT}$$

Acceleration time calculation

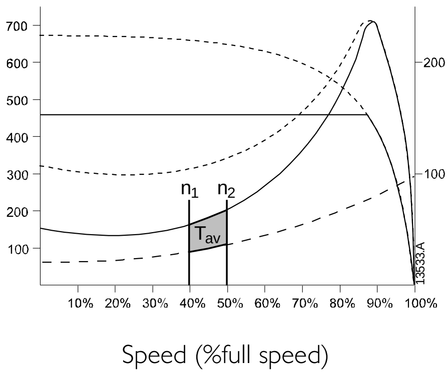
This calculates the time that the motor will take to accelerate from one speed to another specified speed (typically calculated in 10% increments of motor full load speed).

The total acceleration time (from standstill to full load speed) is the sum of all incremental speed steps.

Calculations use actual values.

$$t_{acel} = \frac{J_T \times \Delta n}{9.55 \times T_{av}}$$

Where:
t_{acel} = time to accelerate from one speed to another (seconds)
J_T = total inertia of the motor rotor and load, coupled together (kg·m^2). To convert GD^2 to kg·m^2, divide by 4.
Δn = speed difference from n1 to n2 (rpm)
T_{av} = average acceleration torque from n1 to n2 (Nm).
Acceleration torque is the difference between the developed motor torque and the required load torque as seen at the motor shaft



Example

Calculate the acceleration time of a 2000 kW motor driving a pump load from 40% to 50% full speed. The full load speed is 2990 rpm. Average acceleration torque from 40% to 50% full speed is 20% motor FLT. The motor shaft inertia is 60 kg·m^2 and the pump inertia is 12 kg·m^2.

Total inertia is motor plus load inertia:

$$\begin{aligned} J_T &= 60 + 12\,\text{kg·m}^2 \\ &= 72\,\text{kg·m}^2 \end{aligned}$$

Speed difference is 10% of full load speed:

$$\begin{aligned} \Delta n &= (n2 - n1) \times \text{full load speed} \\ &= (50\% - 40\%) \times 2990\ \text{rpm} \\ &= 299\ \text{rpm} \end{aligned}$$

Average acceleration torque is 20% of motor FLT.

$$\begin{aligned} FLT &= \frac{kW \times 9550}{n} \\ &= \frac{2000 \times 9550}{2990} \\ &= 6388\ \text{Nm} \end{aligned}$$

$$\begin{aligned} T_{av} &= 6388 \times \frac{20}{100} \\ &= 1278\ \text{Nm} \end{aligned}$$

Calculate the acceleration time from 40% to 50% full load speed:

$$\begin{aligned} t_{acel} &= \frac{J_T \times \Delta n}{9.55 \times T_{av}} \\ &= \frac{72\,\text{kg·m}^2 \times 299\ \text{rpm}}{9.55 \times 1278\ \text{Nm}} \\ &= \frac{21528}{12205} \\ &= 1.76\ \text{sec} \end{aligned}$$

3.7 Special Applications

Forward/Reverse motor starting

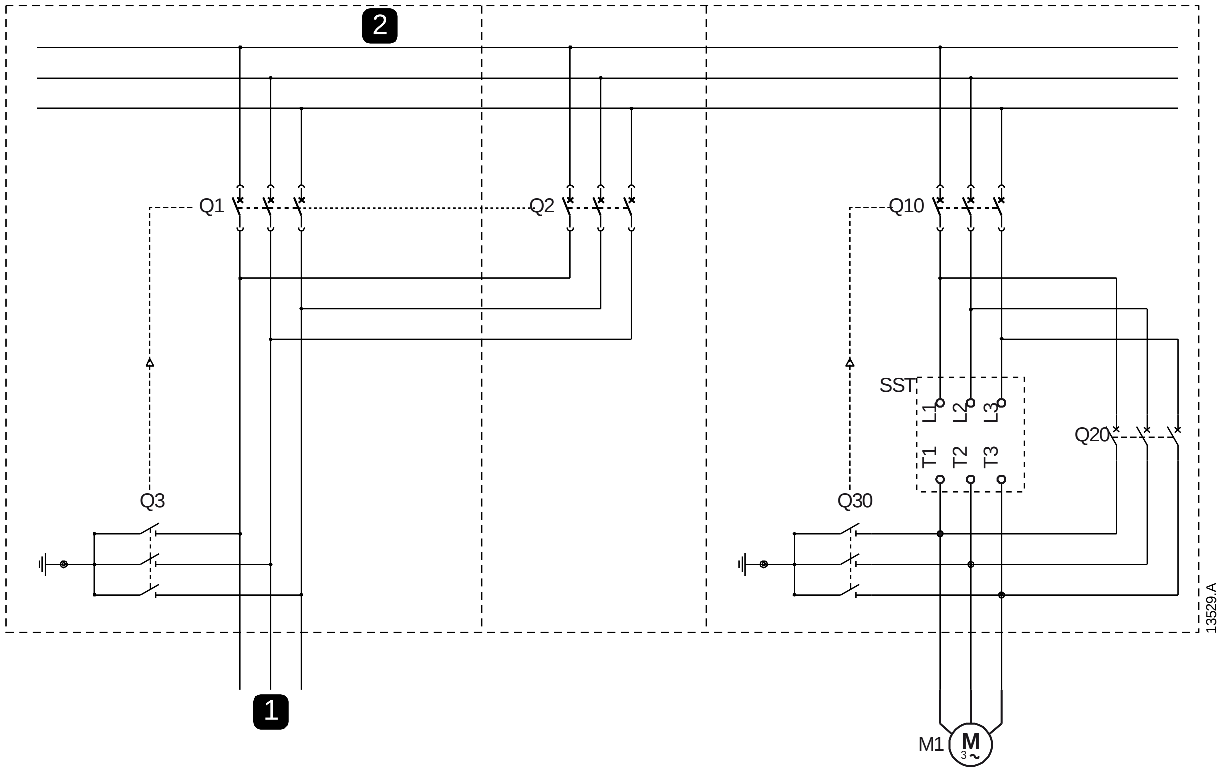
Forward and reverse operation is required for applications where it is necessary to change the mechanical direction of the machinery as part of normal operation (eg conveyors, ball and hammer mills, shredders and cutting machines).

The electrical principle is very simple. The phase sequence (direction) of the mains supply is preselected using two electrically interlocked switching devices connected in parallel. The output of one switching device is in phase with the mains supply while the output of the other switching device is anti-phase with the mains supply. In medium voltage installations, these switching devices are normally draw-out circuit breakers or fused contactors. Once the mains supply phase sequence has been preselected, the motor is started and will run in either the forward or reverse rotational direction (also referred to as positive or negative motor direction).

Commissioning of such applications is normally carried out with the motor initially uncoupled from the load. If motor rotation during commissioning is opposite to what is expected, this is rectified by exchanging any two incoming supply phases or any two output motor phases of the switchgear arrangement.

Typical AuCom medium voltage switchgear arrangement for a single forward-reverse motor starting system (10 kV~13.8 kV) with MVX soft starter.

For clarity, current transformers and motor protection relays are not shown.



1	Mains supply
2	Busbar system
Q1	Forward direction circuit breaker
Q2	Reverse direction circuit breaker
Q3	Earth switch (supply side)

Q10	Main circuit breaker (for SST)
Q20	Bypass circuit breaker (for SST)
Q30	Earth switch (motor side)
SST	MV soft starter
M1	MV induction motor

Operating Sequence

NOTE
The phase sequence of the incoming mains supply and the motor winding connections must be verified for correct motor rotation.

NOTE
The motor must be stopped before changing its operating direction. There is always a short time delay built into the selected changeover of the phase rotation. This is typically less than 3 seconds which is enough time to allow motor flux and thus any back EMF in the motor to decay. The soft starter SST can use the coast-to-stop or soft stop method.

Forward control sequence

Before starting, both the supply side earth switch (Q3) and the motor side earth switch (Q30) must be open and mains supply must be present.

1. The forward direction circuit breaker Q1 is closed. Electrical interlocking disables the reverse direction circuit breaker Q2 from closing.
2. The soft starter is given a start command and the main circuit breaker Q10 closes.
3. The soft starter performs a series of prestart checks, then starts the motor in the forward direction.
4. Once the motor has reached full speed, the soft starter SST is bypassed using circuit breaker Q20.

Reverse control sequence

Before starting in reverse, both the supply side earth switch (Q3) and the motor side earth switch (Q30) must be open and mains supply must be present.

1. The reverse direction circuit breaker Q2 is closed. Electrical interlocking disables the forward direction circuit breaker Q1 from closing
2. The soft starter is given a start command and the main circuit breaker Q10 closes.
3. The soft starter performs a series of prestart checks, then starts the motor in the reverse direction
4. Once the motor has reached full speed, the soft starter SST is bypassed using circuit breaker Q20.

Multi-motor starting

This standard method of starting several medium voltage motors is often found in the water and mining industries. Most multi-start control systems have 2 ~ 4 motors of the same kW size.

Each motor is started and stopped from the output of an electronic motor starter. The starter is usually a soft starter (SST), providing the utility system has the capacity to supply the maximum required current, without any significant disturbance. A guideline for maximum required current is [4+(n-1]) x motor FLC, where n = total number of motors in the system. If supply capacity is limited, a variable frequency drive (VFD) may be used instead of a soft starter.

Once a motor has reached full running speed, it is fed directly from an input bus. In this mode of operation, some form of motor protection is required for each motor.

A master controller is required to control and supervise the entire multi-start system. This can be a PLC or an integrated part of the starter.

There are typically two modes of operation.

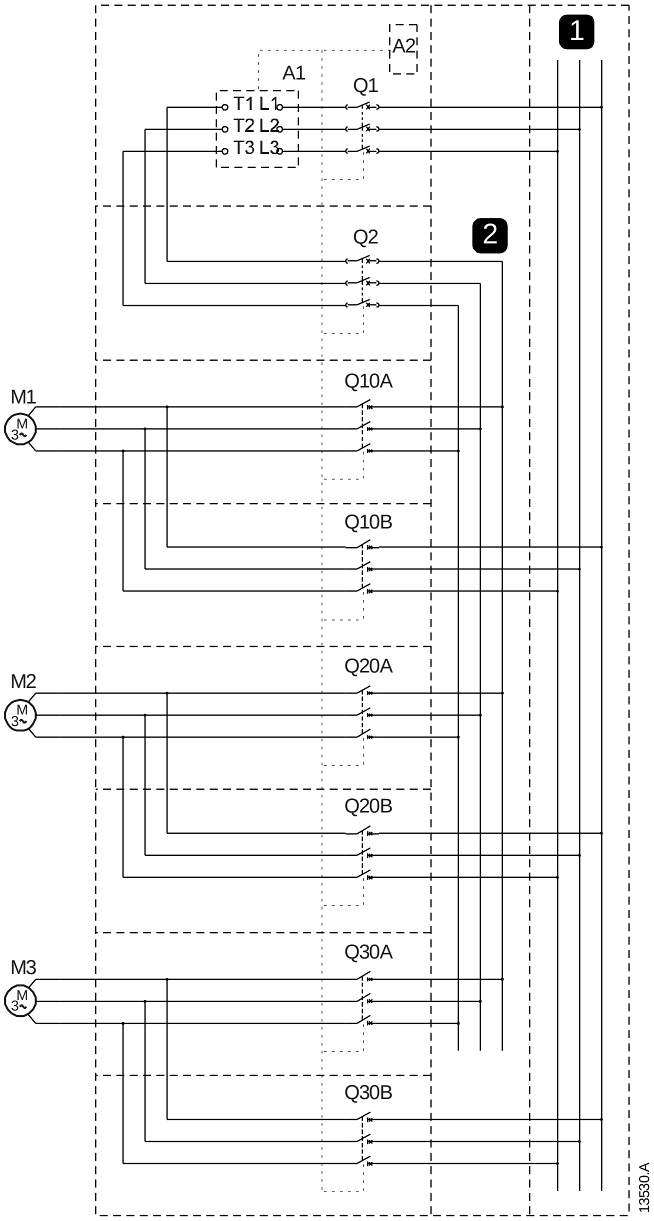
- In Auto mode, the start and stop sequence can be preselected and the master controller handles the entire switching procedure.
- In Manual mode, the starter is disabled and DOL control of each motor is provided by manual switching of each motor bypass circuit breaker or contactor.

The entire system relies on critical time switching of circuit breakers or contactors, which are usually fixed switching devices. Withdrawable switching devices are often used on the starter input and output to provide physical isolation. This allows the starter's input and output to be isolated for servicing, in the event of a fault.

NOTE
The following example shows a typical configuration. There are many different control methods available for multi-motor starting systems.

Typical multi-start system with 3 motors

For clarity, current transformers and motor protection relays are not shown.



1	Input bus
2	Output bus
M1	Motor 1
M2	Motor 2
M3	Motor 3
A1	Electronic motor starter (SST or VFD)
A2	Master controller (PLC or part of A1)

Q1	Main input circuit breaker (withdrawable)
Q2	Main output circuit breaker (withdrawable)
Q10A	Motor 1 start circuit breaker (fixed)
Q10B	Motor 1 bypass circuit breaker (fixed)
Q20A	Motor 2 start circuit breaker (fixed)
Q20B	Motor 2 bypass circuit breaker (fixed)
Q30A	Motor 3 start circuit breaker (fixed)
Q30B	Motor 3 bypass circuit breaker (fixed)

Auto-mode operating sequence

NOTE
In this example, the master controller (A2) has been preselected to start the motors in order 1,2,3 then stop them in the reverse order.

Starting control sequence

1. With the entire system enabled for Auto-mode operation, main input circuit breaker Q1 is closed.
2. The master controller (A2) issues a system start command. The main output circuit breaker Q2 closes.
3. Motor 1 start circuit breaker Q10A closes, then after a delay the starter A1 starts motor 1 and takes the motor to full running speed.
   - for a soft starter, full running speed is assumed when the motor's running current is equal to or less than motor full load current
   - for a VFD, full running speed is assumed when the output frequency has reached supply frequency
4. The master stops A1, motor 1 start circuit breaker Q10A is opened and after a delay, motor 1 bypass circuit breaker Q10B is closed.
5. Motor 2 start circuit breaker Q20A closes, then after a delay A1 starts motor 2 and takes the motor to full running speed.
6. The master stops A1, motor 2 start circuit breaker Q20A is opened and after a delay, motor 2 bypass circuit breaker Q20B is closed
7. Motor 3 start circuit breaker Q30A closes, then after a delay A1 starts motor 3 and takes the motor to full speed.
8. The master stops A1, motor 3 start circuit breaker Q30A is opened and after a delay, motor 3 bypass circuit breaker Q30B is closed.
9. The main output circuit breaker Q2 is opened and the starting sequence is complete.

Stopping control sequence

1. The master controller A2 issues a system stop command. The main output circuit breaker Q2 closes.
2. Motor 3 bypass circuit breaker Q30B opens and after a delay, motor 3 start circuit breaker Q30A closes.
3. Starter A1 takes control of motor 3 and controls its stopping (stop duration is programmed in A1).
4. The master stops A1 and motor 3 start circuit breaker Q30A is opened.
5. Motor 2 bypass circuit breaker Q20B opens and after a delay, motor 2 start circuit breaker Q20A closes.
6. A1 takes control of motor 2 and controls its stopping.
7. The master stops A1 and motor 2 start circuit breaker Q20A is opened.
8. Motor 1 bypass circuit breaker Q10B opens and after a delay, motor 1 start circuit breaker Q10A closes.
9. A1 takes control of motor 1 and controls its stopping.
10. The master stops A1 and motor 1 start circuit breaker Q10A is opened.
11. The main output circuit breaker Q2 is opened and the stopping sequence is complete.

Manual mode operating sequence

NOTE
In this example, the electronic motor starter (A1) is not used to control any motor starting or stopping.

- The main input circuit breaker Q1 and main output circuit breaker Q2 remain open
- Each motor is manually started in any order. This is usually via a start pushbutton for each motor, which is directly fed into an input of the master controller (A2).
- Each motor is started direct-on-line and fed from the main input bus via the motor's bypass circuit breaker (Q10B, Q20B, Q30B). Motor protection is provided in this circuit, via a set of current transformers and a dedicated motor protection relay for each motor.
- Each motor is manually stopped in any order. This is usually via a stop pushbutton for each motor, which is directly fed into an input of the master controller A2. Only a motor freewheel stop is available.

AuCom multi-motor starting solution

AuCom offers a proprietary solution that allows a single MVS or MVX soft starter to individually control up to 8 medium voltage motors. Each switchgear arrangement consists of a soft starter panel and a multi-start panel for each motor. Depending on the system, a transition panel may be required and a main incomer panel is optional.

The entire system is controlled using a PLC mounted in the transition or incomer panel. The proprietary PLC logic program provides the end user with flexible motor control options, selected via a touch-screen.

Typical arrangement of an MVS multi-start system for 2 motors.

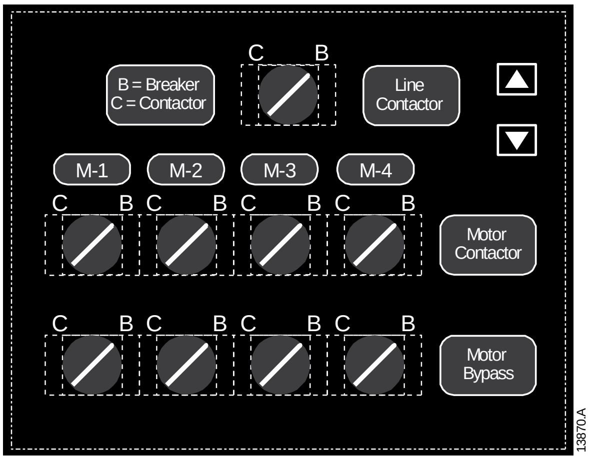
Key features

- User interface touch screen
- Selectable control options for individual motors
- Selectable command source options for individual motors
- Motor protection for individual motors
- Robust safety interlocking system
- Comprehensive panel indication and bus mimicking

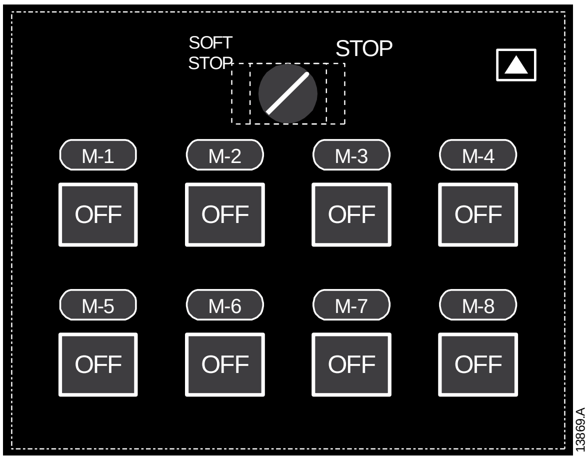
User interface touch-screen

The screen provides the user with direct access to all control options.

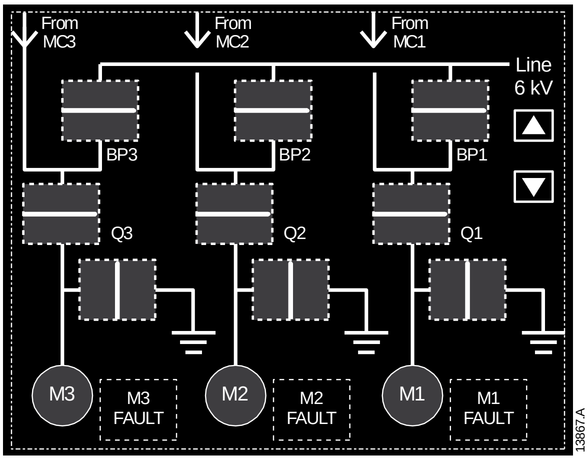
PW_1 screen selects between contactor or circuit breaker control of individual switchgear



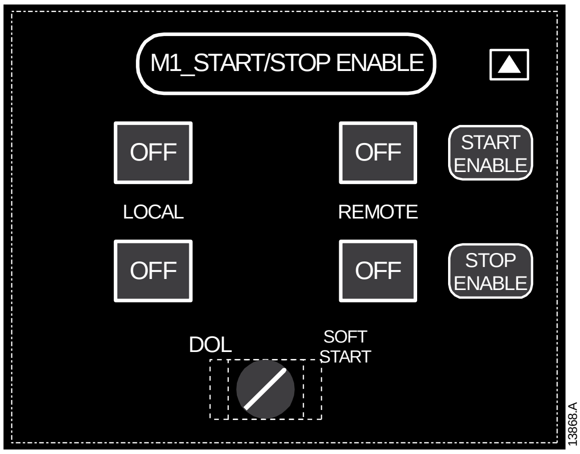
PW_2 screen selects between soft stop or coast to stop for individual motors



MIMIC screens emulate switchgear, soft starter and motor status



M-1 to M-8 screens select the command source for motor starting and stopping, and select between DOL or soft start for each motor (separate screen per motor)



Slip ring motor control

The principle of a slip-ring motor is that external rotor resistance provides the necessary motor torque during acceleration to full speed. Once the motor is close to full speed, the external rotor resistance is shorted out and the motor operates as a standard three phase induction motor.

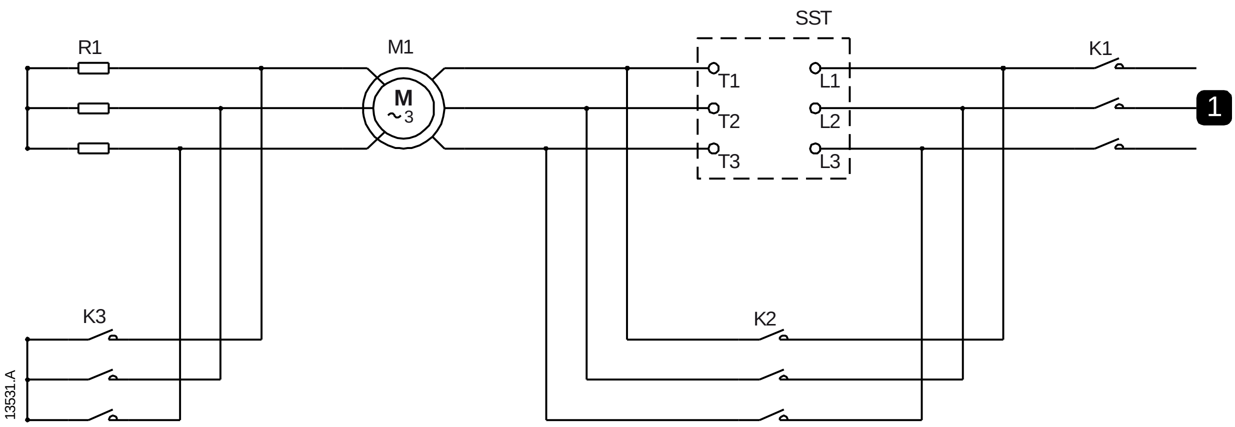
Old slip-ring motor systems typically consist of a liquid resistance tank with an electrode, or else a series of cast-iron or wire wound resistor banks with a changeover switch. These systems require mechanical intervention for motor starting, can become mechanically unreliable, and require regular maintenance.

AuCom medium voltage soft starters include a unique function specifically for slip-ring motor control. This function is not suitable for applications where a slip-ring motor is being used for speed control or to develop excess start torque (ie more than 100% motor full load torque to break away).

Some rotor resistance is required in order to start the motor. This rotor resistance (R1) is shorted when the motor is close to full speed, using rotor resistance contactor K3. The contactor must be AC2 rated for the nameplate rotor current.

AuCom medium voltage soft starters use a "Dual Ramp" start function. This provides a voltage ramp with constant current control while the rotor resistance is in the circuit. This is followed by a smooth transition when shorting out the rotor resistance. A second voltage ramp with constant current control is provided for acceleration to full running speed.

Typical slip-ring motor starting system using a soft starter for control



1	Mains supply
K1	Main contactor
K2	Bypass contactor
K3	Rotor resistance contactor

R1	Rotor resistance (single stage)
SST	Soft starter
M1	Slip ring (wound rotor) motor

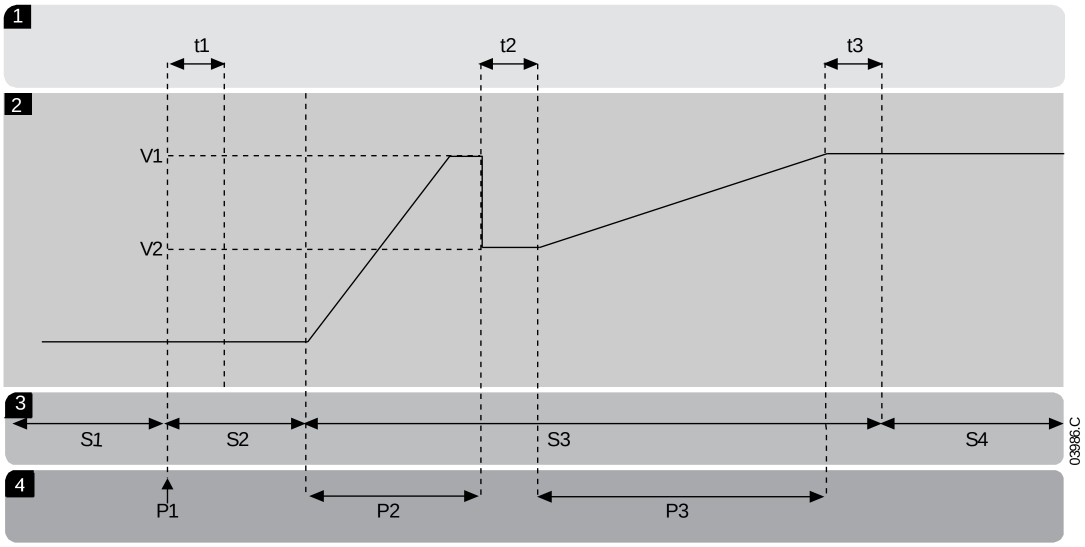
Operating sequence

NOTE
The rotor resistance must be engineered to provide the necessary acceleration torque during motor starting. This example assumes a soft starter which offers a dedicated slip-ring motor control function (eg AuCom MVS or MVX).

Starting control sequence

1. The soft starter SST is given a start command and main contactor K1 closes.
2. The soft starter performs a series of prestart checks, then ramps up to full voltage using Ramp 1
3. Once the rotor has reached a constant speed, the voltage on the output of the soft starter SST is backed off and rotor resistance contactor K3 closes, shorting out rotor resistance R1.
4. The output of the soft starter SST is ramped-up to full voltage using Ramp 2, accelerating the motor to full speed.
5. Bypass contactor K2 closes and the starting sequence is complete.

AuCom slip-ring motor control sub-states



1	Sub-states
t1	Main contactor close time
t2	Rotor resistance contactor close time
t3	Bypass contactor close time
2	Output voltage
V1	100% voltage
V2	Slip-ring retard voltage

3	States
S1	Ready
S2	Pre-start tests
S3	Starting
S4	Running
4	Phases of operation
P1	Start command
P2	Rotor resistance current ramp
P3	Shorted rotor current ramp

Rotor resistance sizing

When using a soft starter for slip-ring motor starting, a single stage, three phase resistance bank must be used.

For an existing installation with a multi-stage resistance bank, the existing final stage resistance can normally be used. To specify a new single-stage resistance bank, use the following guideline:

Slip-ring rotor resistance sizing formula:

$R_p = 0.2 \times \frac{U_r}{\sqrt{3} \times I_r}$ $P_p = 0.2 \times \frac{P_m}{3}$	Where: R_p = rotor resistance per phase (Ω) U_r = open circuit rotor voltage (V) I_r = rotor current (A) P_p = power rating of rotor resistance per phase (kW) P_m = motor shaft power (kW)

Slip-ring synchronous motors

Although they are rare, there are some older synchronous motors which use a special double winding rotor. One winding set is used for standard slip-ring rotor starting. The other winding set is a DC excitation winding used for synchronous speed running.

These motors can be started using a soft starter with final stage resistance, but the control system must include a synchronisation package. This package is supplied separately to the soft starter and must be integrated into the entire system. This control method becomes complex and expensive and in most cases an upgrade will involve a complete replacement of the synchronous motor for a standard squirrel cage induction motor.

3.8 Common standards for MV soft starters and switchgear panels

MV soft starters and switchgear panels are commonly designed to meet the following international standards.

NOTE
This information is an overview of the most common conformance standards used in the medium voltage industry. For specific equipment conformance, always refer to the technical data supplied by the manufacturer.

Item	Title	Standard
Switchgear and apparatus	High Voltage switchgear & control gear – Part 1: Common Specifications	IEC62271-1
	High Voltage switchgear & control gear – Part 200: AC metal enclosed switchgear and control gear for rated voltages from 1 kV to 52 kV	IEC62271-200
	High-voltage switchgear and controlgear - Part 304: Design classes for indoor enclosed switchgear and controlgear for rated voltages above 1 kV up to and including 52 kV to be used in severe climatic conditions	IEC62271-304
	AC metal enclosed switchgear (Chinese standard)	GB3906 (2006)
	AC Metal-enclosed Switchgear and Control Equipment for rated voltage from 1 kV to 52 kV (Chinese standard)	DL-T-404
	General Technology Requirements of High-voltage Switchgear and Control Equipment. (Chinese standard)	DL-T-593
	IEEE Standard for Metal-Clad Switchgear	IEEE C37.20.2
Internal arc resistance	High Voltage switchgear & control gear – Part 200: AC metal enclosed switchgear and control gear for rated voltages from 1 kV to 52 kV	IEC62271-200 Annex A.6, criteria 1 to 5
	IEEE Guide for Testing Medium-Voltage Metal-Enclosed Switchgear for Internal Arcing Faults	IEEE C37.20.7 (NEC)
Insulation	Insulation coordination – Part 1: Definitions, principles and rules	IEC60071-1
	Insulation coordination – Part 1: Application guide	IEC60071-2
	Evaluation and qualification of electrical insulation systems	IEC60505
	Insulation coordination for equipment within low-voltage systems - Part 1: Principles, requirements and tests	IEC60664-1
	Dry, solid insulating materials - Resistance test to high-voltage, low-current arc discharges	IEC61621
Degrees of protection	Degrees of protection provided by enclosures (IP ratings & tests)	IEC60529
Classification of groups of environmental parameters and their severities	Storage	IEC60721-3-1
	Transportation	IEC60721-3-2 IEC60068-2-32
	Stationary use at weather protected locations	IEC60721-3-3
Safety	UL (2.3kV, 4.2kV and 13.8kV only)	UL347B

4 Switchgear

This section provides information and guidance on the design of metal-enclosed medium voltage switchgear panels and associated switchgear apparatus. If further information is required, refer to the appropriate international standards or contact your local AuCom representative.

AuCom offers MVS and MVX soft starters in their own unique panel styles. We also offer a range of metal-enclosed switchgear panels rated up to 36 kV and 2500 A, covering all standard industrial configurations:

- Incomer feeder panel
- Direct incomer panel
- Bus coupler panel
- Bus riser panel
- Metering panel
- Direct-on-line motor starting panel
- Power factor correction panel
- Transition (termination) panel

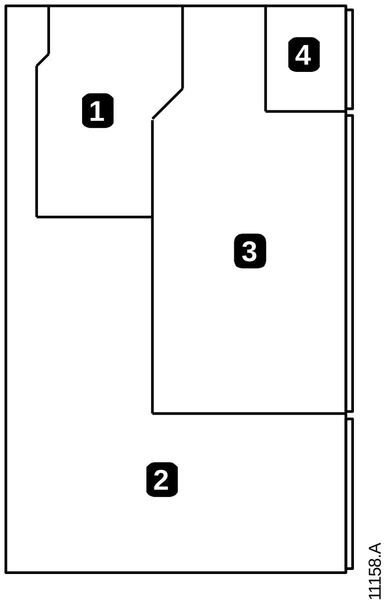
Metal-enclosed, medium voltage switchgear panels and associated apparatus, rated from 1 kV to 52 kV, are covered by IEC 62271-200 (this standard supersedes IEC 60298). Panel design and construction is determined by several key operating factors and classifications:

- Rated voltage U_r (kV)
  Determines the minimum insulation level requirements
- Rated current I_r (A)
- Rated frequency f_r (Hz)
- Short circuit power S_{SC} (MVA)
  Determines elements of mechanical panel design and selection of integrated switchgear apparatus
- Accessibility to panel compartments
- Continuation of service with main compartment open
- Necessary isolation and segregation of live parts
- Level of internal arc withstand

4.1 Switchgear Classifications

There are many different types of enclosure designs for medium voltage switchgear use. However, the most commonly accepted and used style is metal-enclosed, with segregated and insulated apparatus compartments. AuCom's MVX soft starter range and medium voltage distribution range are available in this style of enclosure.

Panel compartments



1	Busbar compartment
2	Cable compartment
3	Switching compartment
4	Low voltage compartment

Busbar Compartment

The busbar compartment houses the main busbar system, which is connected to the fixed upper isolating contacts of the main switchgear apparatus by means of branch connections. The main busbars are made of high conductivity copper. The busbar compartment of each panel is isolated from the busbar compartments of the neighbouring compartments.

Single or double busbar configuration is used depending on the current rating.

Cable Compartment

The cable compartment houses some of the following components:

- Branch connections
- Earthing busbar
- Earth switch
- Power cables
- Surge arrestors
- Instrument transformers (current transformers, voltage transformers)

Switching Compartment

The switching compartment houses the bushing insulators containing fixed contacts for the connection of the switching apparatus to the busbar and cable compartment. The bushings are single-pole type and are made of cast resin. They are covered by metallic shutters.

The metallic shutters operate automatically during movement of the switching apparatus from the test position (racked-out) to the service position (racked-in) and vice versa. Shutters may be locked if required.

The position of the switching apparatus can be seen from the front of the panel through an inspection window.

Low Voltage Compartment

The low voltage compartment provides safe isolation from any medium voltage equipment. This is used for installation of low voltage control equipment, including DIN rail mounted terminal blocks. Equipment can be panel mounted on the LV compartment door for customer interfacing.

IEC Switchgear Classification

IEC 62271-200 classifies metal-enclosed switchgear based on:

- compartment types
- method of access to compartments
- safety levels provided during access
- effect on continuation of service during access
- type of insulation barriers between compartments
- internal arc endurance (refer to section on internal arc classification)

The manufacturer must state which areas of the switchgear are accessible and provide a clearly defined switchgear classification.

Classification related to personnel safety in case of internal arc

Types of compartments with regard to accessibility		Features
Operator-accessible compartment	Interlocked-based accessible compartment. Intended to be opened for normal operation and maintenance.	No tools for opening – Interlocking allowing access only when HV parts are dead and earthed.
	Procedure-based accessible compartment. Intended to be opened for normal operation and maintenance.	No tools for opening – Provision for locking to be combined with operator procedures, to allow access only when HV parts are dead and earthed.
Special accessible compartment	Tool-based accessible compartment. Possible for user to open, but not intended to be for normal operation and maintenance.	Tools necessary for opening. No specific provision to address access procedure. Special procedures may be required to maintain performances.
Non-accessible compartment	Not possible for user to open (not intended to be opened).	Opening destroys compartment or clear indication to the user. Accessibility not relevant.
Switchgear classification with regard to the loss of service continuity when opening accessible compartments		**Features**
LSC1		Other functional units or some of them shall be disconnected.
LSC2	LSC2A	Other functional units can be energized.
	LSC2B	Other functional units and all cable compartments can be energized.
Switchgear classification with regard to the nature of the barrier between live parts and opened accessible compartment		**Features**
PM		Metallic shutters and partition between live parts and open compartment – (metal-enclosed condition maintained).
PI		Insulation-covered discontinuity in the metallic partitions/shutters between live parts and open compartment.
Switchgear classification with regard to mechanical, electrical and fire hazards in case of internal arc during normal operation		**Features**
IAC		No ejection of parts, no ignition of cloths, enclosure remains earthed.

Source: IEC 62271-200

ANSI-defined switchgear

ANSI defined switchgear is equivalent to IEC classification LSC2B-PM, with the following characteristics:

- the main switching device is withdrawable, with disconnecting auxiliary control circuits
- separate compartments are provided for voltage transformers and control power transformers
- busbar compartments are divided between adjacent enclosures
- metal barriers isolate the withdrawable compartment, when the main switching device is drawn-out into test position
- main circuit busbars and connections are covered with fire resistant insulating material
- mechanical interlocking prevents stored energy discharge of withdrawable parts
- a locking method prevents the withdrawable switching device from being moved into service position
- low voltage control parts are segregated from medium voltage apparatus
- all voltage transformers must have primary circuit current limiting fuses

Switchgear Ratings

Switchgear is rated according to IEC 62271-1. When choosing switchgear, its rating must be sufficient for the electrical characteristics at the point of installation, the environmental conditions it needs to operate under, and the safety requirements. Future expansion of the switchgear distribution system needs to be considered, as this may affect initial rating requirements.

Switchgear selection is determined by considerations including:

Electrical conditions

- System operating voltage (U)
- System operating frequency (f)
- Nominal operating current (I)
- Short circuit current levels at point of installation (I_{SC}, I_{dyn}, etc)
- Horizontal busbar arrangement

Environmental conditions

- Ambient temperature
- Altitude
- Pollution degree
- Indoor or outdoor installation

Personnel safety considerations

- Internal Arc Classification (IAC)
- Interlocking of access areas and switchgear apparatus
- Access method (eg tools, keys, process, etc)
- Withdrawable switchgear apparatus

Switchgear information for enquiries or ordering

When enquiring about, or ordering switchgear, the supplier should at minimum provide the following information. When enquiring, advise the supplier of any unusual operating condition requirements (eg altitude 1800 metres).

System characteristics

- nominal system voltage and frequency
- expected highest voltage
- type of neutral earthing system

Service conditions

- any non-standard service requirements which differ from normal routine

Installation specifics

- indoor or outdoor installation
- number of phases
- busbar arrangement details
- rated voltage (U_r)
- rated frequency (f_r)

- rated insulation level (U_d, U_p)
- rated nominal current of main busbars and feeders (I_r)
- rated short-time withstand current (I_k)
- duration of short time withstand (t_k)
- rated peak withstand current – typically 2.5 I_k at 50 Hz (I_p)
- protection degree for enclosure and apparatus

Operating device specifics

- types of operating devices
- rated auxiliary supply voltage (if any)
- rated auxiliary supply frequency (if any)
- rated gas pressure (if any)
- special interlocking requirements

Switchgear derating

Switchgear must be derated for altitudes exceeding 1000 metres and ambient temperatures exceeding 40 °C.

Insulation derating according to altitude

The relevant standards specify the derating required for equipment installed at an altitude greater than 1000 metres.

> Guideline: derate by 1.25% U peak, per 100 metres above 1000 metres.

This applies for lightning impulse withstand voltage and for power frequency withstand voltage 50 Hz - 1 minute.

Derating for altitude only applies to air-insulated switchgear, not vacuum or SF6-insulated equipment.

Current derating

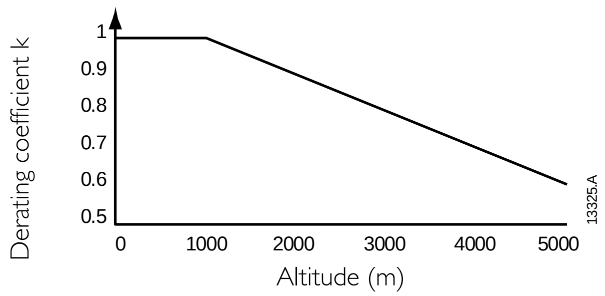
IEC 62271-1 defines the maximum permissible temperature rise for each device, material and dielectric medium, using a reference ambient temperature of 40 °C.

The actual temperature rise is affected by:

- the rated current
- the ambient temperature
- the cubicle type and its protection index (IP rating)

> Guideline: derate by 1% I_r per degree above 40 °C.

Current derating coefficient



4.2 Standard Enclosure Configurations

Incomer Feeder Panel (IFP)

As the name implies, this panel configuration serves two purposes:

- As an incomer panel. This switches the incoming main supply onto the common horizontal busbar system of a metal-enclosed switchgear arrangement
- As a feeder panel. This switches the main supply from the common horizontal busbar system of a metal-enclosed switchgear arrangement onto a specific feeder circuit.

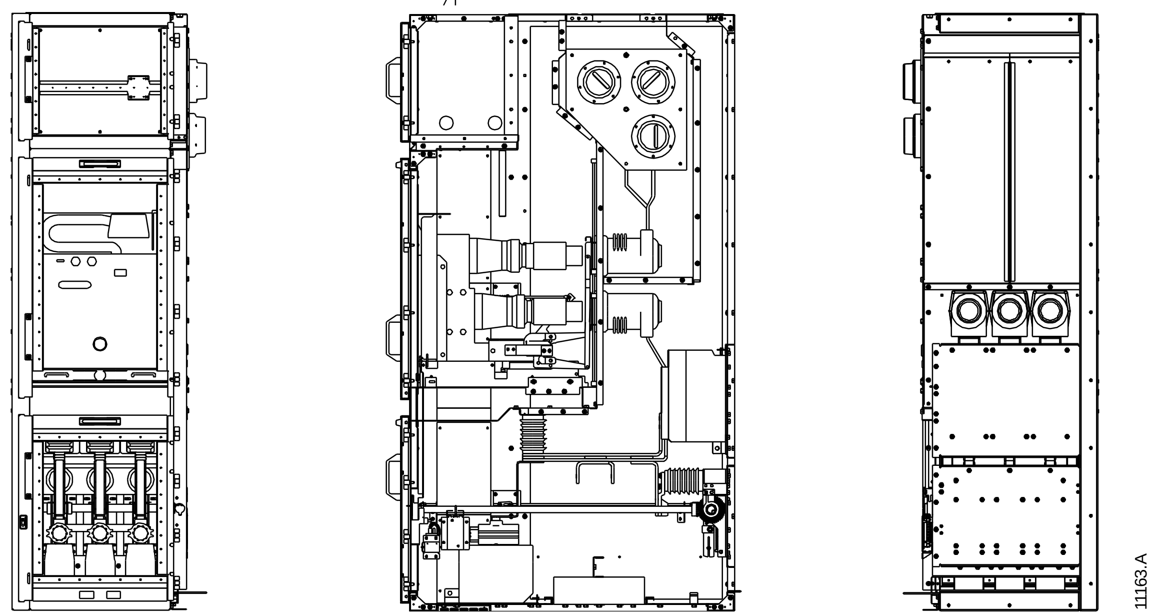
The enclosure will always have a main circuit breaker (normally withdrawable), housed in its own compartment of the panel. An earth switch at the cable termination end of the circuit provides isolation during shutdown and maintenance. Interlocking ensures that the earth switch cannot be closed until the main circuit breaker is open and racked-out into the test position. Current transformers are fitted to interface with a protection relay for circuit breaker trip operation.

Depending on the required function, voltage transformers can be supplied. These can be 3-phase or single phase, either fixed or withdrawable style. A variety of low voltage equipment is used, which is mounted in its own segregated compartment, situated at the top-front of the enclosure assembly.

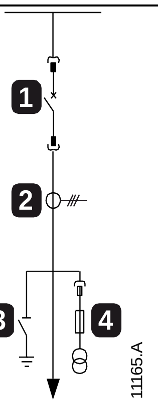
> AuCom provides an Incomer Feeder Panel as part of its L-Series switchgear range. This is rated at 12 kV from 630 A to 2000 A. An IAC classification of 31.5 kA for 1 second is achieved by double skin compartments, special locking door designs and top-exit arc flaps for pressure release.

Incomer Feeder Panel (IFP)

Typical Incomer Feeder Panel



Front view | Side view | Rear view



1	Circuit breaker (withdrawable)
2	Current transformer set
3	Earth switch
4	Voltage transformer (fused and withdrawable)

Direct Incomer Panel (DIP)

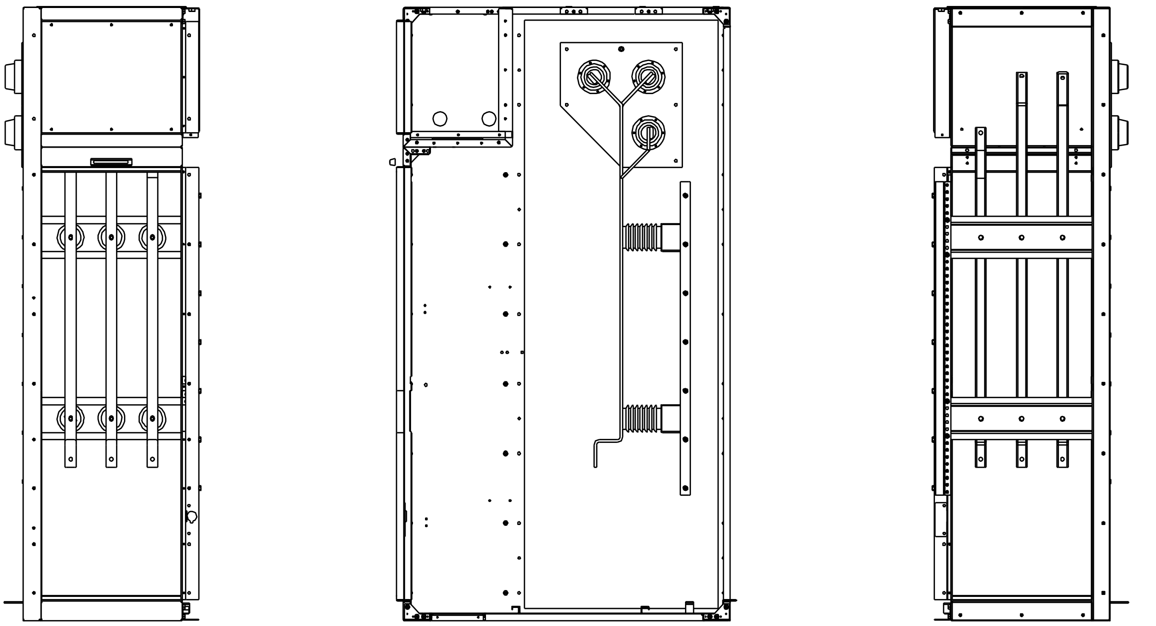
A direct incomer panel connects the incoming main supply onto the common horizontal busbar system of a metal enclosed switchgear arrangement, without any primary switching device.

An earth switch is typically provided at the cable termination end of the circuit for isolation during shutdown and maintenance. Access to earth switch operation must be interlocked with the supply end switchgear so that the earth switch cannot be closed onto a live circuit. Current and voltage transformers can be supplied as optional items, along with a variety of low voltage equipment, which is mounted in its own segregated compartment situated at the top-front of the enclosure assembly.

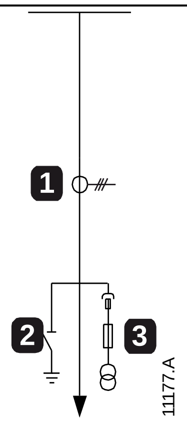
AuCom provides an Direct Incomer Panel as part of its L-Series switchgear range. This is rated at 12 kV from 630 A to 2000 A. An IAC classification of 31.5 kA for 1 second is achieved by double skin compartments, special locking door designs and top-exit arc flaps for pressure release.

Direct Incomer Panel (DIP)

Typical Direct Incomer Panel



Front view | Side view | Rear view



1	Current transformer set
2	Earth switch
3	Voltage transformer (fused and withdrawable)

Bus Coupler Panel (BCP)

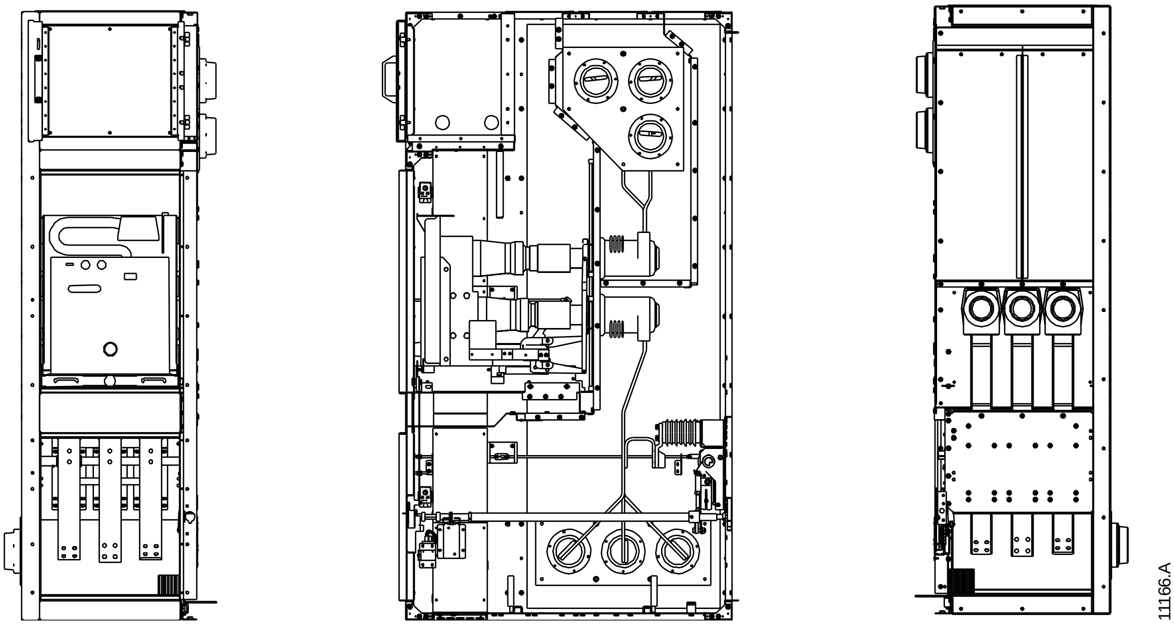
A bus coupler panel connects two adjacent horizontal busbar systems together using a main circuit breaker (normally a withdrawable type), which is housed in its own compartment of the panel. The horizontal busbar system of metal-enclosed switchgear is usually situated towards the top of the panel enclosure. In order to physically connect two adjacent busbar systems together, a bus coupler panel must be used alongside a bus riser panel.

A main earth switch, current and voltage transformers and low voltage equipment can all be supplied as optional extras.

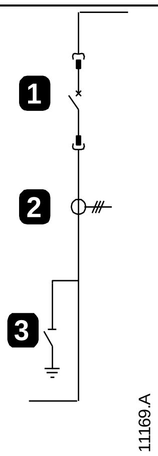
> AuCom provides a Bus Coupler Panel as part of its L-Series switchgear range. This is rated at 12 kV from 630 A to 2000 A. An IAC classification of 31.5 kA for 1 second is achieved by double skin compartments, special locking door designs and top-exit arc flaps for pressure release.

Bus Coupler Panel (BCP)

Typical Bus Coupler Panel



Front view Side view Rear view



1	Circuit breaker
2	Current transformer set
3	Earth switch

Bus Riser Panel (BRP)

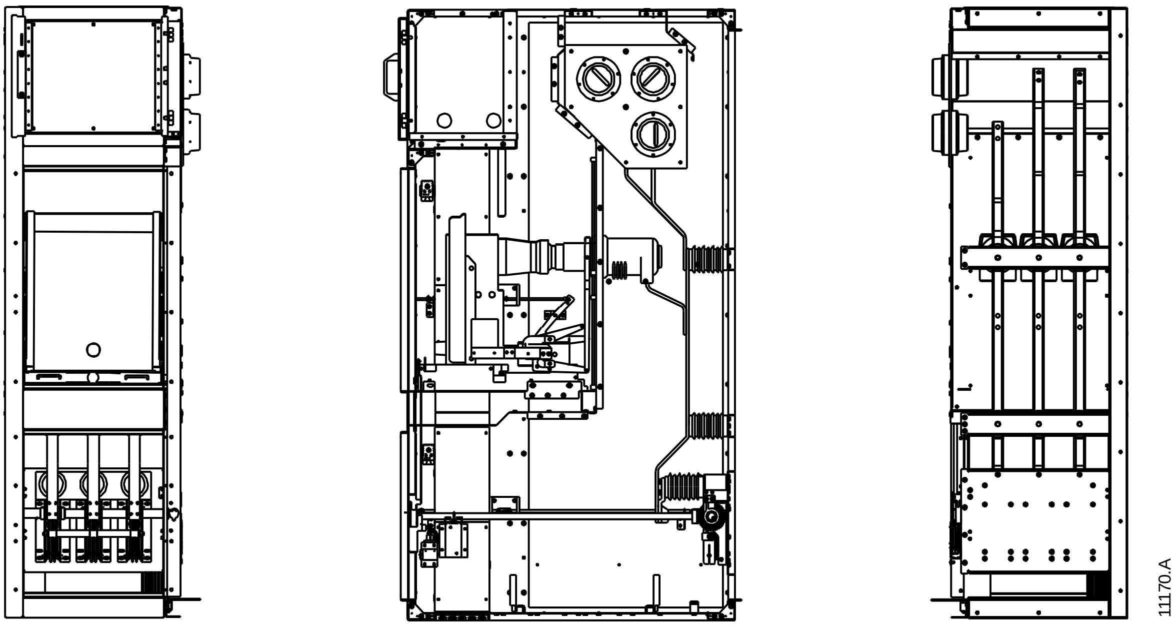
A bus riser panel contains a vertical 3-phase bus which connects the output of a bus coupler panel at the bottom of the enclosure, to a horizontal busbar system at the top of the enclosure. In order to physically connect two adjacent horizontal busbar systems together, a bus riser panel must be used alongside a bus coupler panel.

Voltage transformers, along with low voltage equipment, can be supplied as optional extras.

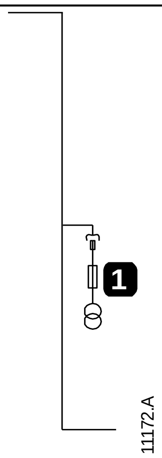
> AuCom provides a Bus Riser Panel as part of its L-Series switchgear range. This is rated at 12 kV from 630 A to 2000 A.   An IAC classification of 31.5 kA for 1 second is achieved by double skin compartments, special locking door designs and top-exit arc flaps for pressure release.

<u>Bus Riser Panel (BRP)</u>

Typical Bus Riser Panel



Front view   Side view   Rear view



1	Voltage transformer (fused and withdrawable)

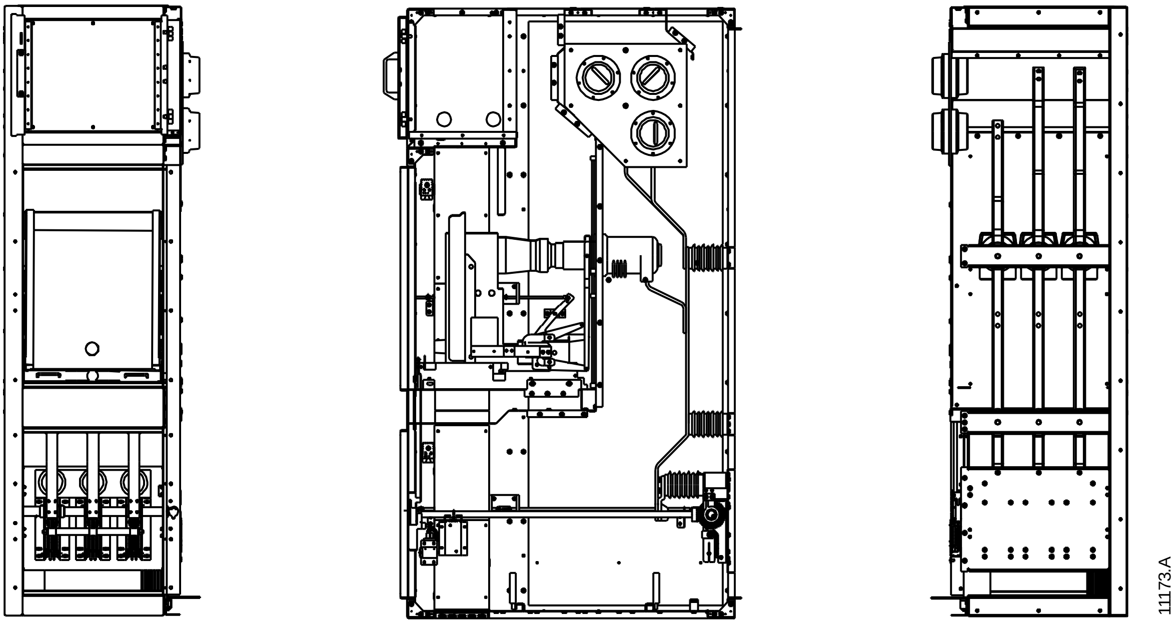
Metering Panel (MTP)

A metering panel contains a primary horizontal busbar system with a bus tap-off that drops vertically to the bottom of the enclosure. The vertical bus is connected to voltage transformers, which can be of the fixed or withdrawable type. Sometimes a main earth switch is supplied. Metering equipment is often contained within the segregated low voltage compartment, located at the top-front of the enclosure.

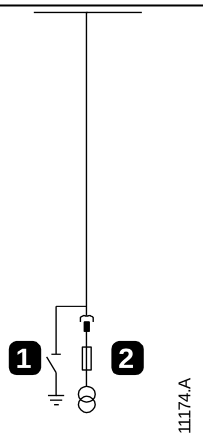
> AuCom provides a Metering Panel as part of its L-Series switchgear range. This is rated at 12 kV from 630 A to 2000 A. An IAC classification of 31.5 kA for 1 second is achieved by double skin compartments, special locking door designs and top-exit arc flaps for pressure release.

__Metering Panel (MTP)__

Typical Metering Panel



Front view Side view Rear view

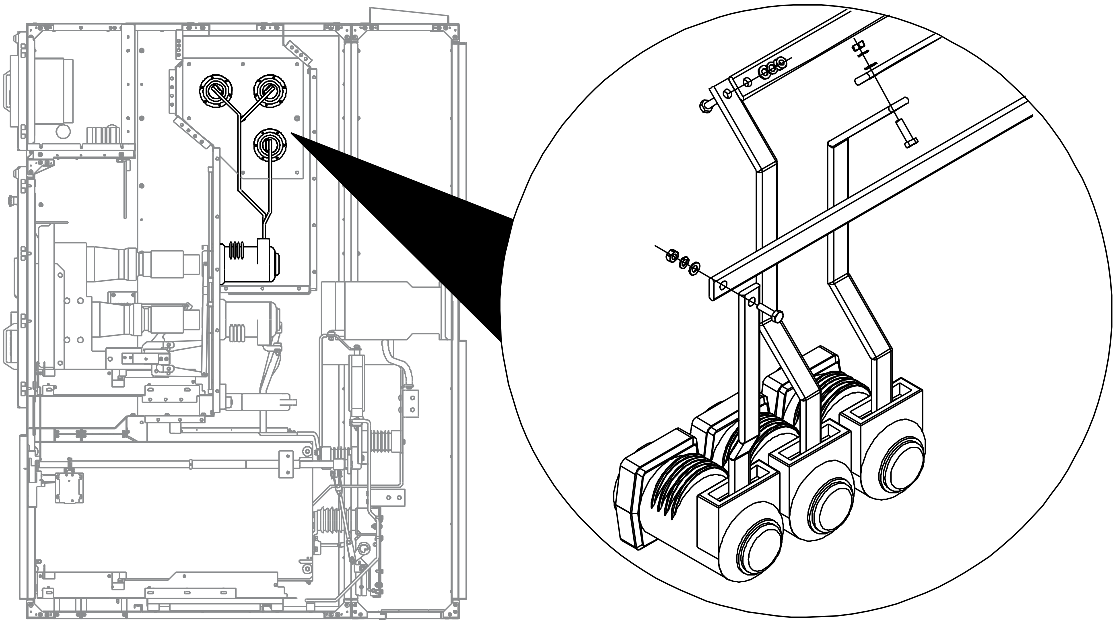


1	Earth switch
2	Voltage transformer (fused and withdrawable)

Busbar Systems

Overview

Medium voltage busbar systems consist of two general arrangements. The main switchgear distribution bus has three busbar sets (one set per phase) which run horizontally through all the panels in a line-up. These distribution busbars run through a dedicated chamber within each metal-enclosed panel. Segregation of busbar chambers, between adjacent panels, is provided by using insulated through-bushings. Inside the horizontal busbar chamber of each panel, a vertical feeder busbar system can be tapped off the main horizontal system, for incomer, feeder, bus-coupler, bus-riser, metering or motor starter circuit.



Ratings

The nominal current rating (I_r) of an incomer busbar system usually matches the rating of the main busbar system it is feeding. Likewise, bus-coupler and bus-riser systems have the same current rating as the main busbar system they are connecting. A feeder circuit busbar system has a nominal current rating to match the expected load.

> The nominal current rating is determined by the cross sectional area, shape and configuration of the individual phase bars.

The short-time withstand current rating (I_k) of the busbar system must be greater than the highest expected symmetrical fault current at the point of installation. This rating is for a short-time withstand period of 1 or 3 seconds (t_k). All busbar systems installed in the same switchgear line-up usually have the same short-time withstand current/time rating.

The nominal voltage rating (U_r) of a busbar system must be greater than the installation's operating voltage. This voltage rating determines the minimum phase-to-phase and phase-to-earth busbar clearances.

The nominal frequency rating (f_r) of a busbar system must match the installation's operating frequency.

NOTE

The nominal current must be derated for high ambient temperatures (usually above 40 °C).

The nominal voltage and insulation ratings of a busbar system must be adjusted for altitudes over 1000 metres.

Design

Busbar system design must consider:

- adequate minimum required clearance between phases and phase to earth
- selection of adequate busbar insulator standoffs
- bolting arrangements for continuous busbar connections
- thermal effects on busbar and insulator standoffs under normal and fault conditions
- electrodynamic forces applied to busbars and insulator standoffs under fault conditions
- avoidance of mechanical resonance under normal operating and fault conditions

Voltage ratings and clearance

IEC 62271-1 gives typical voltage ratings for busbar systems and insulator standoffs.

Typical voltage ratings and minimum clearances for busbar systems and insulator standoffs

Rated voltage Ur (kV)	Power frequency withstand voltage U_d (kV)	Lightning impulse withstand voltage U_p (kV)	Clearance – recommended P-P and P-E (mm)
7.2	20	60	70~90
12	28	75	120
17.5	38	95	160
24	50	125	220
36	70	170	320

Source: derived from IEC 62271-1

Current ratings and dimensions

The nominal current rating of a busbar is determined by the type of material, shape and cross sectional area of the bar and the maximum permissible temperature rise of the material. If the busbar is carrying AC current, the operating frequency has a slight effect on the busbar rating due to magnetic skin effect.

A busbar system has a short-time withstand current rating. The temperature rise in the event of a short circuit condition must not exceed the thermal limits of busbar standoffs.

Typical current ratings and nominal dimensions for medium voltage busbar systems

NOTE
Dimensions should be used as a guideline only and may vary.
The dimensions stated in this table are based on bare copper at ambient temperature of 40 °C, maximum permissible temperature rise of 50 °C, operating at 50 Hz.

<table>
<tr><th>Rated current
(A)</th><th>Bar dimensions - per phase
W x D (mm)</th><th>Rated short-time withstand current [1]
I_k (kA)</th><th>Rated short-time withstand period [1]
tk (seconds)</th></tr>
<tr><td>630</td><td>50 x 6</td><td rowspan="6">12.5/16/20/25/31.5/40/50</td><td rowspan="6">0.5/1/2/3</td></tr>
<tr><td>1250</td><td>80 x 10</td></tr>
<tr><td>1600</td><td>100 x 10</td></tr>
<tr><td>2000</td><td>100 x 6 (2 bars)</td></tr>
<tr><td>2500</td><td>100 x 10 (2 bars)</td></tr>
<tr><td>3150</td><td>100 x 3 (3 bars)</td></tr>
</table>

Source: current rating information is derived from IEC 62271-1

[1] Most medium voltage switchgear including busbar systems have short-time withstand ratings of 16 kA, 20 kA, 25 kA or 31.5 kA for 3 seconds.

Temperature rise

During short circuit conditions the busbar will rise in temperature, depending on the level of short circuit current and time duration. This temperature rise must not exceed the thermal limits of any equipment in contact with the busbar.

Maximum permissible temperature rise for bolt-connected devices, including busbars

Material and dielectric medium	Maximum permissible temperature (°C)	Temperature rise above 40 °C ambient (°C)
Bolted connection (or equivalent)		
Bare copper, bare copper alloy or bare aluminium alloy		
In air	90	50
In sulphur hexafluoride (SF_6)	115	75
In oil	100	60
Silver or nickel coated		
In air	115	75
In sulphur hexafluoride (SF_6)	115	75
In oil	100	60
Tin-coated		
In air	105	65
In sulphur hexafluoride (SF_6)	105	65
In oil	100	60

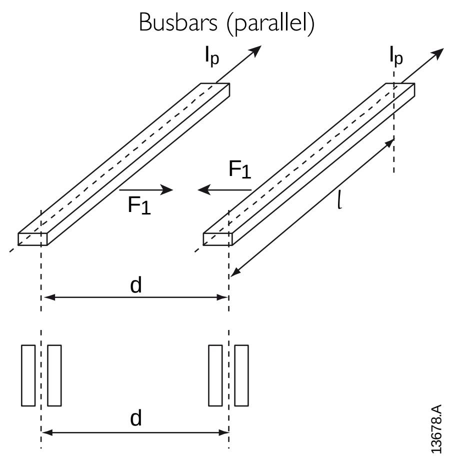
Source: derived from IEC 62271-1

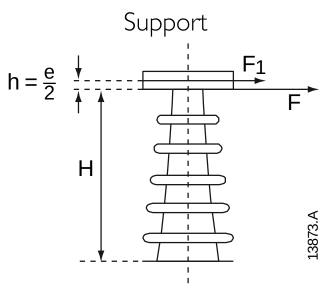
NOTE
When engaging parts with different coatings, or where one part is of bare material, the permissible temperature and temperature rise shall be those of the surface material having the lowest permitted value.

Electrodynamic withstand

During short circuit conditions, the peak current associated with the first loop of the fault current produces electrodynamic forces which stress the busbar and insulator standoff supports. Stress on the busbars must not exceed the limits of the material used. Bending forces must not exceed the mechanical limits of the insulator standoffs.

Electrodynamic forces





d	Distance between phases (cm)
l	Distance between insulators on a single phase (cm)
F_l	Force on busbar centre of gravity (daN)
I_p	Peak value of short circuit current (kA)

H	Insulator height
h	Distance from head of insulator to busbar centre of gravity
F	Force on head of insulator stand-off (daN)

NOTE: 1 daN (dekanewton) is equal to 10 newtons.

Resonant frequency

The busbar system must be checked for potential resonance under normal operating conditions and fault conditions. This is done by calculating the natural resonant frequency of the system, which must meet the following criteria:

- 50 Hz supply: not within the ranges 48 Hz to 52 Hz and 96 Hz to 104 Hz
- 60 Hz supply: not within the ranges 58 Hz to 62 Hz and 116 Hz to 124 Hz

Calculation requirements

Busbar systems are subjected to thermal and electrodynamic stresses under normal operating conditions, but more so under short circuit fault conditions. It is important to ensure the busbar system will function safely under all known conditions. When checking the design, the most important considerations are the nominal operating current, expected fault current at the point of installation, average ambient temperature and the altitude of the installation.

To check the safety of a busbar system:

- Check that the current rating of the busbar system (I_r) exceeds the expected nominal current. Main factors affecting the busbar rating are busbar material and configuration, ambient temperature and maximum permissible temperature rise.
- Check the maximum expected temperature rise of the busbar during a short circuit fault. In the event of short circuit current flow (I_{th}), the surface temperature of a busbar must not exceed the thermal limits of any material coming in contact with it (ie insulator standoffs).
- Check the maximum expected electrodynamic forces imparted on the busbars and insulator standoffs, due to the peak short circuit fault current (I_{dyn}). Do not exceed the mechanical limitations of the material.
- Check that the busbar system will not resonate under normal operating and fault conditions.

Refer to *Busbar Calculations* on page 149 for calculation details and examples.

Busbar bolting arrangements

Typical busbar bolting details for single overlap copper bar

Bar width (mm)	Joint overlap (mm)	Joint area (mm^2)	Number of bolts[1]	Metric bolt size (coarse thread)	Bolt torque (Nm)	Hole size (mm)	Washer diameter (mm)	Washer thickness (mm)
16	32	512	2	M6	7.2	7	14	1.8
20	40	800	2	M6	7.2	7	14	1.8
25	60	1500	2	M8	17	10	21	2
30	60	1800	2	M8	17	10	21	2
40	70	2800	2	M10	28	11.5	24	2.2
50	70	3500	2	M12	45	14	28	2.7
60	60	3600	4	M10	28	11.5	24	2.2
80	80	6400	4	M12	45	14	28	2.7
100	100	10000	5	M12	45	15	28	2.7
120	120	14400	5	M12	45	15	28	2.7
160	160	25600	6	M16	91	20	28	2.7
200	200	40000	8	M16	91	20	28	2.7

Source: *Copper for Busbars http://www.copperinfo.co.uk/busbars/pub22-copper-for-busbars/homepage.shtml*

[1] Number of bolts based on using high-tensile steel or bronze (CW307G, formerly C104)

4.3 Safety Considerations

Switchgear interlocking systems

Interlocking between different switchgear apparatus and enclosure access covers and doors enhances personnel safety, as well as improving operational convenience. If a switching device can cause serious damage in an incorrect position, this must also have a locking facility.

Interlocking uses electrical and mechanical methods or a combination of both.

IEC 62271-200 states mandatory rules for switchgear interlocking:

For metal-enclosed switchgear with removable switching apparatus:

- the switching device must be in the open position before it can be withdrawn
- the switching device can only be operated in the positive service or test position
- the switching device cannot be closed unless the auxiliary control circuits required to open the switch are connected. Auxiliary control circuits cannot be disconnected with the switching device closed in the service position

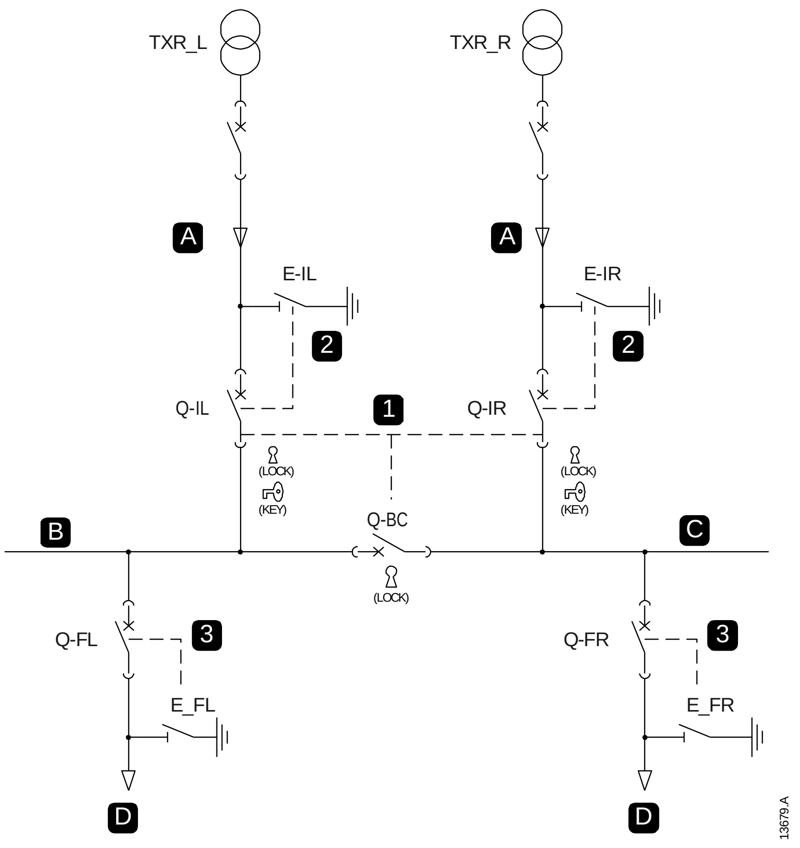
For metal-enclosed switchgear with disconnectors:

- a disconnector cannot be operated under conditions other than those for which it is intended to be used
- a disconnector cannot be operated unless the main switching device is open
- operation of a main switching device is prevented unless its associated disconnector is in a positive service, test or earth position
- disconnectors providing isolation for maintenance and servicing must have a locking facility

Methods

The illustration shows a common switchgear arrangement for a medium voltage power distribution system. This switchgear arrangement uses three separate interlocking methods.

Typical MV power distribution switchgear arrangement with interlocks



A	Incomer panel
B	Left bus
C	Right bus
D	Feeder panel
1	Interlock scheme 1 (typical)
2	Interlock scheme 2 (typical)
3	Interlock scheme 3 (typical)
Q-IL	Circuit breaker - left incomer
E-IL	Earth switch - left incomer
TXR_L	Supply transformer - left bus
Q-IR	Circuit breaker - right incomer
E-IR	Earth switch - right incomer
TXR_R	Supply transformer - right bus
Q-BC	Circuit breaker - bus coupler
Q-FL	Circuit breaker - left feeder
E-FL	Earth switch - left feeder
Q-FR	Circuit breaker - right feeder
E-FR	Earth switch - right feeder

Interlock scheme 1: Two incomers and bus coupler interlocking

The two incomers and the bus coupler circuit breakers use a standard "2 out of 3" interlocking system to prevent a parallel feed from the two incomers onto a common bus. Interlocking allows the following conditions:

1. The two incomer circuit breakers closed (Q-1L and Q-1R) with the bus coupler circuit breaker open (Q-BC).
2. Left incomer and bus coupler circuit breakers closed (Q-IL and Q-BC) with right incomer circuit breaker open (Q-IR).
3. Right incomer and bus coupler circuit breakers closed (Q-IR and Q-BC) with left incomer circuit breaker open (Q-IL).

Typically, these interlocking conditions are met using both a mechanical and electrical method.

Mechanical interlocking

Interlocking uses a key system which includes 3 identical locks and 2 identical keys.

Both incomer and the bus coupler circuit breakers (Q-IL, Q-IR, Q-BC) require an interlock key to be inserted into the circuit breaker body, and the circuit breaker racked into the service position, before the circuit breaker can be closed. This interlock key can only be removed when the circuit breaker is open and in the racked-out test position. When the circuit breaker is in service, the interlock key is not accessible.

Both incomer and the bus coupler circuit breakers (Q-IL, Q-IR, Q-BC) are fitted with identical locks but only two matching keys are available.

Under normal operating conditions, the two incomer circuit breakers are closed using the two available interlock keys. The bus coupler circuit breaker is not permitted to close. If one of the incomer supplies is lost, the associated circuit breaker is opened and racked-out to the test position. The interlock key can be moved to the bus coupler circuit breaker, allowing it to be racked into the service position and closed. When normal supply resumes, the bus coupler circuit breaker has to be opened before the revived incomer circuit breaker can be closed using the interlock key retrieved from the bus coupler circuit breaker.

This key interlock system only allows for any two circuit breakers to be closed at the same time.

Electrical interlocking

Normally closed auxiliary contacts from the two incomers and the bus coupler circuit breakers are used to electrically interlock the close command of each circuit breaker.

- Left incomer circuit breaker (Q-IL) has a normally closed auxiliary contact from the right incomer circuit breaker (Q-IR) and a normally closed contact from the bus coupler circuit breaker (Q-BC) connected in parallel to allow a close command.
- Right incomer circuit breaker (Q-IR) has a normally closed auxiliary contact from the left incomer circuit breaker (Q-IL) and a normally closed contact from the bus coupler circuit breaker (Q-BC) connected in parallel to allow a close command.
- Bus coupler circuit breaker (Q-BC) has a normally closed auxiliary contact from the left incomer circuit breaker (Q-IL) and a normally closed contact from the right incomer circuit breaker (Q-IR) connected in parallel to allow a close command.

This control method only allows for any two circuit breakers to be closed at the same time.

Interlock scheme 2: Incomer circuit breaker and earth switch interlocking

The incomer circuit breaker (Q-IL or Q-IR) and earth switch (E-IL or E-IR) are mechanically interlocked to prevent both being closed at the same time. The earth switch can only be closed once the circuit breaker is open and racked-out to the test position. The circuit breaker can only be racked-in for closing, once the earth switch is open.

An additional level of interlocking is required. The incomer earth switch cannot be mechanically operated until power is removed from the incoming supply. This prevents closing the earth switch onto a live supply. This interlocking is achieved in one of two ways:

1. Mechanically by using key access. The incomer earth switch (E-IL or E-IR) handle operation is only accessible by using a key, retrieved from the upstream circuit breaker when it is open and racked-out.
2. Electrically by using a solenoid. A solenoid is energised when the upstream circuit breaker is open and racked out, allowing access to the incomer earth switch (E-IL or E-IR) handle operation.

Interlock scheme 3: Feeder circuit breaker and earth switch interlocking

The feeder circuit breaker (Q-FL or Q-FR) and earth switch (E-FL or E-FR) are mechanically interlocked to prevent both being closed at the same time. The earth switch can only be closed once the circuit breaker is open and racked-out to the test position. The circuit breaker can only be racked-in for closing, once the earth switch is open.

Internal arc classification

Metal enclosed switchgear can suffer internal faults at numerous locations, causing a wide range of physical damage. Internal Arc Classification (IAC) of metal enclosed switchgear considers the damage that can affect covers, doors, inspection windows, ventilation openings etc, as a result of overpressure within panel compartments. IAC also takes into consideration damage from thermal effects, ejected hot gases and molten particles.

When selecting metal enclosed switchgear, the probability of internal arcing and the safety risk to operators and the general public needs to be considered. Where the safety risk is considered relevant, the switchgear should be IAC classified. The IAC classification indicates the maximum fault current level and duration to which the switchgear has been tested. When choosing switchgear, the IAC rating should exceed the expected fault current level and duration at the point of installation.

The rating also takes into account the accessibility of the switchgear. IAC tested and certified switchgear must always be clearly marked with the classification, fault level and duration, and accessibility of each side.

Relevant standards and testing

The primary standard for internal arc classification of medium voltage metal enclosed switchgear is IEC 62271-200; IEC 62271-202 is also relevant.

IEC 62271-200 details test procedures to assess damage to switchgear from internal arcing. Test results provide the switchgear with an IAC classification. Switchgear which passes indoor testing is also considered suitable for outdoor use with the same accessibility requirements.

Accessibility is divided into two categories, Type A is for authorised personnel dressed with adequate protective equipment and Type B for general public access. Equipment is also tested for different directions of access: front, rear or lateral (side).

Cotton cloth indicator panels are placed 2 m above ground level and on each accessible side of the equipment under test. If pressure relief ducts are part of the switchgear design, these must also be subjected to cloth indicator panel testing.

Tests are carried out by supplying a predetermined level of fault current for a specific duration. Using various test procedures, the applied fault current creates an internal arc to ground within a specific region of the switchgear. In general, test results are considered acceptable if:

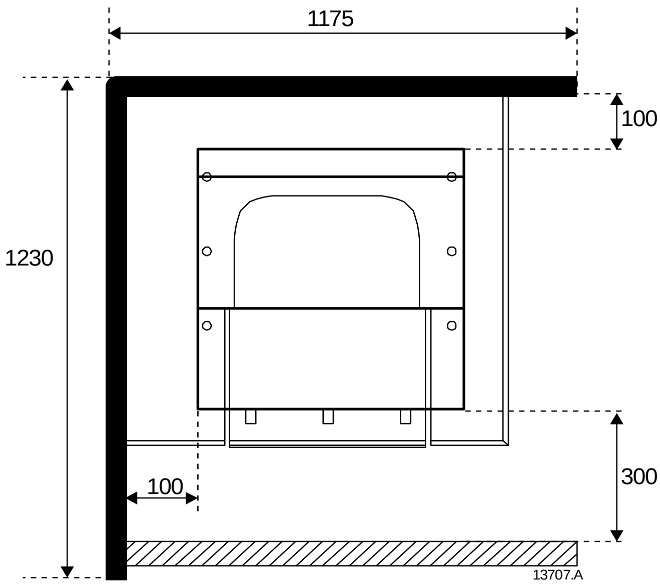
- correctly secured doors and covers do not open - deformation is acceptable, providing it doesn't protrude as far as the indicator panels
- no fragmentation of the enclosure occurs within the test time - small particles up to 60 g are acceptable
- arcing does not cause any holes in the accessible areas, up to a height of 2 metres
- indicator panels do not ignite due to hot gas emissions
- the enclosure remains connected to its earth point (verified by a continuity test)

IAC certification example

Indoor room testing
The room is simulated by a floor, ceiling and two walls perpendicular to each other.

Accessibility
Type A: restricted to authorised personnel
Type B: unrestricted accessibility
F = front access
L = lateral (side) access
R = rear access

IAC certification example
IAC classification: AF
Internal Arc: 31.5 kA, 1 s



Causes of internal arc

There are many potential causes for internal arcing within metal enclosed switchgear. Some of the more common causes are:

- foreign matter in the enclosure (eg vermin, metal swarf, tools)
- contamination and general degradation of insulation material
- inadequate insulation of cable terminations
- overheating of termination points due to inadequate preparation and tightening
- system overvoltage
- incorrect protection settings and coordination

Locations, causes and examples of measures to decrease the probability of internal faults

Locations where internal faults are most likely to occur	Possible causes of internal faults	Examples of possible preventive measures
Cable compartments	Inadequate design	Selection of adequate dimensions. Use of appropriate materials.
	Faulty installation	Avoidance of crossed cables connections. Checking of workmanship on site. Correct torque
	Failure of solid or liquid insulation (defective or missing)	Checking of workmanship and/or dielectric test on site. Regular checking of liquid levels, where applicable
Disconnectors Switches Earthing switches	Maloperation	Interlocks. Delayed reopening. Independent manual operation. Making capacity for switches and earthing switches. Instructions to personnel.
Bolted connections and contacts	Corrosion	Use of corrosion inhibiting coating and/or greases. Use of plating. Encapsulation, where possible.
	Faulty assembly	Checking of workmanship by suitable means. Correct torque. Adequate locking means.
Instrument transformers	Ferro-resonance	Avoidance of these electrical influences by suitable design of the circuit.
	Short circuit on LV side for VTs	Avoid short circuit by proper means for example, protection cover, LV fuses.
Circuit breakers	Insufficient maintenance	Regular programmed maintenance. Instructions to personnel.
All locations	Error by personnel	Limitation of access by compartmentation. Insulation embedded live parts. Instructions to personnel.
	Ageing under electric stresses	Partial discharge routine tests.
	Pollution, moisture, ingress of dust, vermin, etc	Measures to ensure that the specified service conditions are achieved. Use of gasfilled compartments.
	Overvoltages	Surge protection. Adequate insulation co-ordination. Dielectric tests on site.

Source: IEC 62271-200

Minimising the effects

Certain design techniques are used to provide a high level of safety to personnel, by minimising the effects of internal arcing:

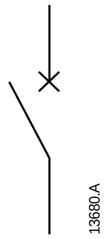
- compartmenting of enclosure
- pressure relief methods
- double skin panels
- arc venting away from access areas
- remote control of switchgear
- rapid fault clearance

Rapid fault clearance requires fast detection and isolation of the arc. This can be achieved using:

- light, heat or pressure sensors combined with a relay to trip a fast acting circuit breaker
- pressure operated earth switch capable of diverting the internal arc to ground (arc eliminator)
- fast acting, current limiting line supply fuses

4.4 Switchgear Apparatus

Medium Voltage Circuit Breakers

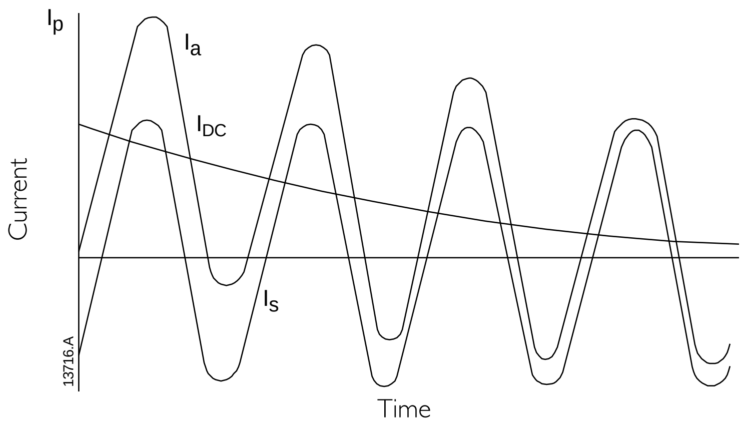


A circuit breaker is a main switching device, providing control and protection of an electrical circuit. It is a very fast acting device, capable of switching high fault current levels. Some medium voltage circuit breakers have integrated current monitoring and protection facilities, but in most cases external current transformers and a protection relay are required to trip the circuit breaker under abnormal conditions.

A circuit breaker must operate under various conditions without damage or safety risk to personnel:

- a circuit breaker operates mostly in the closed position and must continuously sustain its rated current without exceeding its thermal limits
- in the closed position, a circuit breaker must sustain a specific fault current level (I_k) for a short time period (t_k). A circuit breaker's short-time withstand fault current rating must exceed the expected rms symmetrical fault current level (I_s) at the point of installation
- a circuit breaker must be capable of sustaining electrodynamic and thermal stresses associated with the peak let-through energy of a fault. The circuit breaker's make rating must exceed the expected peak fault current level (I_p) at the point of installation.

I_p = 2.5 × I_s (for a 50 Hz supply with a 45 ms DC time constant) I_p = 2.6 × I_s (for a 60 Hz supply with a 45 ms DC time constant)	Where: I_p = asymmetrical peak let-through fault current, from the first fault loop (kA) I_s = rms symmetrical fault current level, with no DC component (kA)



I_a	asymmetrical rms current
I_{DC}	DC component
I_s	symmetrical rms component
I_p	instantaneous peak current

Construction

Main switching contact design has two primary components:

- a suitable insulation medium to minimise the physical size of the apparatus
- a method to reduce any arc and extinguish it during contact breaking

Modern medium voltage circuit breakers tend to be either vacuum or SF6 gas-insulated (sulphur hexafluouride). Oil filled circuit breakers are less common.

Vacuum circuit breakers

Typical characteristics
Environment: Indoor
Operating current: ≤ 3000 A
Operating voltage: ≤ 36 kV
Fault current rating: ≤ 31.5 kA
Contacts: One fixed and one moveable copper/chromium switching contact per pole, with a contact separation distance of 10-15 mm. Contacts reside in a vacuum, within a totally sealed cast resin enclosure.
Arc-extinguishing properties: good

SF6 gas-insulated circuit breakers

Typical characteristics
Environment: Indoor/outdoor
Operating current: ≤ 4000 A
Operating voltage: ≤ 52 kV
Fault current rating: ≤ 50 kA
Contacts: One fixed and one moveable copper/chromium switching contact per pole, with a contact separation distance of 10-15 mm.
Arc-extinguishing properties: quick and efficient. Special design techniques use compressed sulphur hexafluoride gas to extinguish the arc.

Oil circuit breakers

These circuit breakers use an oil blast method to extinguish the arc. When the switching contacts separate, the arc vaporises the oil surrounding it. This produces a gas which inhibits arc ionisation. At the same time, convectional movement of the oil aids in cooling after the arc has been extinguished.

Due to oil fire hazard, these circuit breakers are generally used for outdoor applications only, and are being replaced in indoor applications.

Mechanical operation

Circuit breakers are electromechanically driven using magnetic or stored energy techniques.

- magnetic technique: uses an open and close armature, permanently energised in one of the two states. The energy required to maintain constant magnetic field strength, in either the open or closed state, is stored using capacitance. Energised armatures interact with mechanical linkages to operate the main switching contacts. This operating technique provides extremely fast operation and is very energy efficient.
- stored energy technique: incorporates an opening and closing spring. Each spring is charged with potential energy, by motor operation, or by using a manually operated handle in case of auxiliary power loss. Mechanical operation of the main switching contacts occurs by releasing the potential energy from a charged spring. Spring release is activated electrically by the use of small opening and closing solenoids or by manual pushbuttons which operate mechanical latches.

Withdrawable circuit breakers

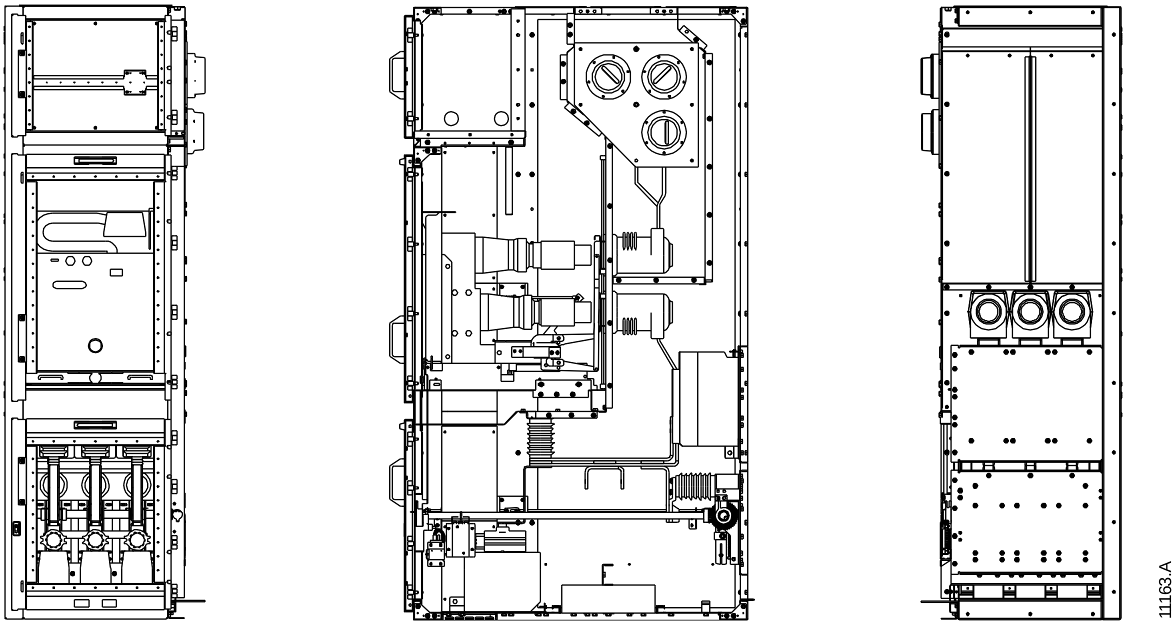
Most indoor switchgear installations use withdrawable circuit breakers. These are also referred to as rack style or draw-out units (DOU).

The main circuit breaker body is fitted on a trolley arrangement known as a truck, which is moved horizontally by means of a crank handle. By moving the circuit breaker towards the operator, the main contact points separate until a test position is reached. To reconnect the main contact points, the circuit breaker is moved away from the operator until the service position is reached. The circuit breaker position cannot be changed unless the circuit breaker main poles are electrically open.

When a withdrawable circuit breaker is integrated into a metal-enclosed switchgear compartment, electromechanical interlocking is used to ensure safe operation, such as:

- the circuit breaker switchgear compartment door cannot be opened unless the circuit breaker is electrically open and physically racked out to the test position
- isolation barrier shutters are automatically operated, according to the circuit breaker truck position
- when an earth switch is incorporated into a metal-enclosed switchgear panel with a withdrawable circuit breaker, the earth switch can only be closed if the circuit breaker is electrically open and physically racked out to the test position

The main advantage of a withdrawable circuit breaker compared with fixed type circuit breakers is the ability to safely disconnect and isolate the main circuit for maintenance or circuit breaker replacement.



Control methods

Compatibility between circuit breaker types and control methods

Circuit breaker type	Electrical control method		Manual control
	Single command operated (SCO) control signal	Double command operated (DCO) control signal	Pushbuttons mounted on circuit breaker
Withdrawable, magnetically operated	●	●	●
Withdrawable, stored energy operated	●	●	●
Fixed, magnetically operated	●	●	X
Fixed, stored energy operated	●	●	X

SCO control uses a single contact. This contact is maintained open to trip the circuit breaker and maintained closed to close the circuit breaker.

DCO control uses two momentary, normally open contacts. One contact is pulsed closed to trip the circuit breaker. The other contact is pulsed closed to close the circuit breaker.

IEC Ratings

Medium voltage circuit breakers must be type tested to provide standard ratings. The most commonly used standards for this testing are IEC 62271-1 and IEC 62271-100.

The following information provides details of some of the more common ratings which must be marked on the circuit breaker nameplate after type testing.

Rated voltage, U_r (kV)

Maximum operating voltage (rms) the device can continuously withstand during normal operation. The rated voltage must be greater than or equal to the system's operating voltage.

Standard values for U_r : 3.6, 7.2, 12, 17.5, 24, 36 kV (source: IEC 62271-1)

Rated lightning impulse withstand rating, U_p (kV)

This is the peak voltage the device can withstand for a 1.2/50 µs standard test wave.

Standard values for U_p (source: IEC 62271-1):

U_r (kV)	3.6	7.2	12	17.5	24	36
U_p (kV)	40	60	75	95	125	170

Rated frequency, f_r (Hz)

This rating must match the system's operating frequency. Rated frequency only has to be marked on the device nameplate if it is not suitable for 50 Hz and 60 Hz operation.

Rated current, I_r (A)

This is the rms level of current which can continuously flow through a device without exceeding its maximum allowable contact temperature rise.

Temperature rise limits are defined in IEC 62271-1, for an ambient temperature of 40 °C.

The rated current must be greater than the maximum expected load current, at the point of installation.

Standard values for I_r : 630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000 A (source: IEC 62271-1)

Rated short-time withstand current, I_k (kA)

This is the maximum rms symmetrical fault current the device can withstand, for a short time period, without risk of damage. This rating must be higher than the prospective rms fault current at the point of installation.

$I_k \geq I_s$ $I_s = \frac{S_{SC}}{\sqrt{3} \times U}$	Where: I_k = short-time withstand current rating (kA) I_s = prospective rms fault current (kA) S_{SC} = system short circuit power (kVA) U = system operating voltage (kV)

Standard values for I_k : 6.3, 8, 10, 12.5, 16, 20, 25, 31.5, 40, 50, 63 kA (source: IEC 62271-1)

Rated short circuit duration, t_k (s)

This is the time the device can endure its rated short-time withstand current (I_k) without damage. This value must be greater than the total expected clearing time of a fault at the point of installation.

Standard values for t_k : 0.5, 1, 2, 3 seconds (source: IEC 62271-1)

If the value of t_k is not 1 second, the rated short circuit duration must be published on the circuit breaker nameplate.

Rated peak withstand current (kA)

This is the maximum peak fault current level which the device is able to close (make) on. This rating must be greater than the expected peak let-through fault current (I_p) at the point of installation.

Rated peak withstand current ≥ I_p

I_p = 2.5 × I_s (for a 50 Hz supply with a 45 ms DC time constant) I_p = 2.6 × I_s (for a 60 Hz supply with a 45 ms DC time constant)	Where: I_p = asymmetrical peak let-through fault current, from the first fault loop (kA) I_s = rms symmetrical fault current level, with no DC component (kA)

Source: IEC 62271-1, IEC 62771-100

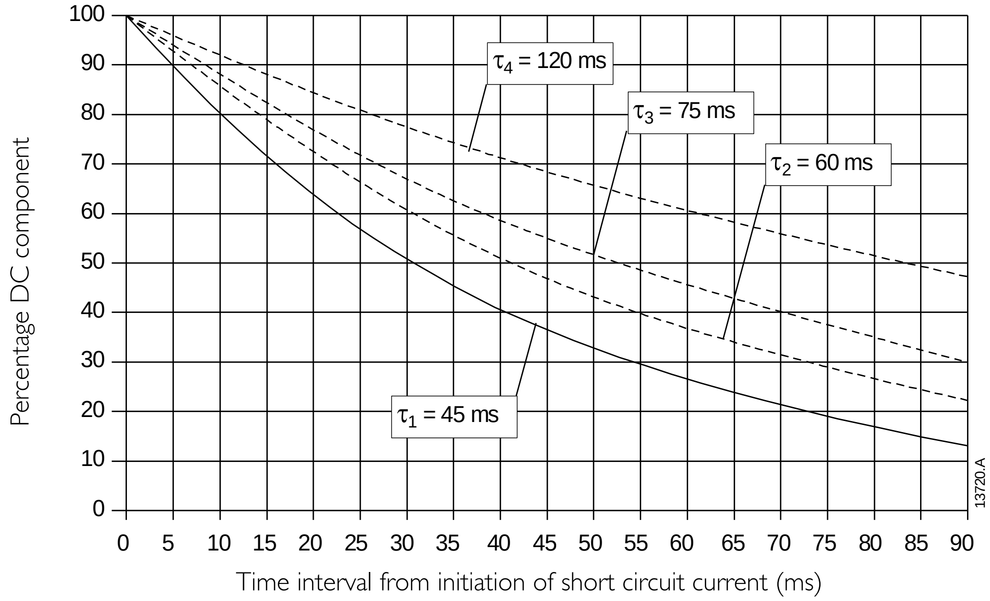
Rated short circuit breaking capacity, I_{sc} (kA)

This is the highest level of rms current which the circuit breaker can successfully open (break) on a fault, at its rated voltage. When a short circuit occurs in a 3-phase system, the initial fault current is asymmetrical and is made up of an AC symmetrical component and a decaying DC component. The rated short circuit breaking capacity must be greater than the expected asymmetrical fault current level when the circuit breaker poles are opened.

$I_{SC} \geq I_a$ $I_a = I_s + I_d$	Where: I_{sc} = rated short circuit breaking capacity of circuit breaker (kA) I_a = asymmetrical fault current level when circuit breaker poles are opened (kA) I_s = AC symmetrical fault current component (kA) I_d = DC fault current component (kA)

Standard values for I_{sc} = 6.3, 8, 10, 12.5, 16, 20, 25, 31.5, 40, 50, 63 kA (source: IEC 62271-100)

Percentage DC component in fault current



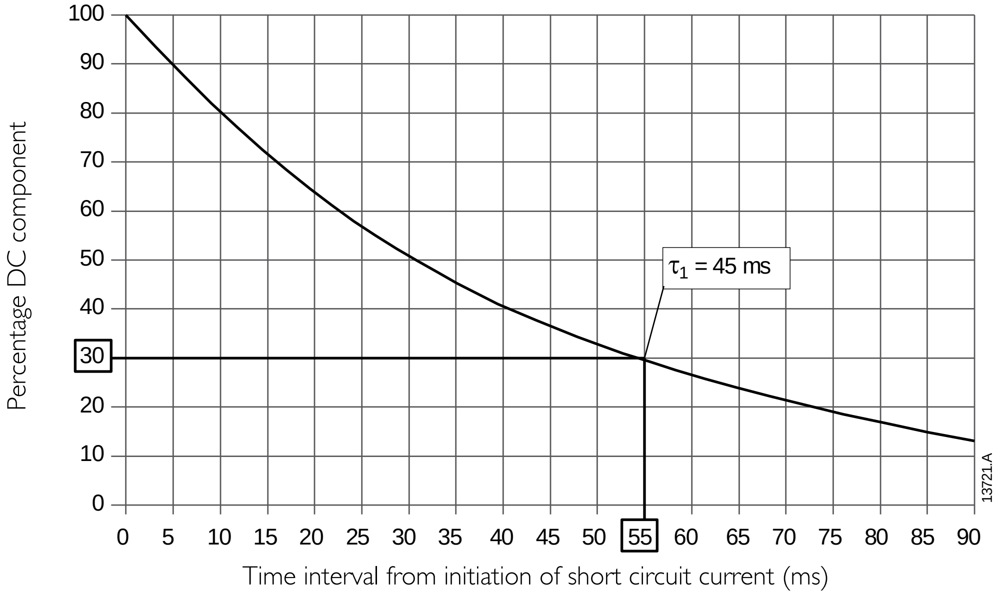
The graph illustrates the percentage DC component of a fault, over a period of time, for systems with various time constants. Most systems use the standard time constant (τ_1) of 45 ms. The total opening time of the circuit breaker is the pole opening time plus 10 ms for relay sensing, and this figure can be used to determine the percentage DC component of a fault at the instant of breaking.

Exercise

What is the required short circuit breaking capacity of a circuit breaker, with a pole opening time of 45 ms and an expected symmetrical short circuit fault level of 21 kA at the point of installation?

Total opening time of the circuit breaker: t = 10 + 45 = 55 ms

The percentage DC component at a total opening time of 55 ms is 30%:



$$I_a = I_s \times \sqrt{1+2\left(\frac{\%DC}{100}\right)^2}$$
$$= 21 \times \sqrt{1+2\left(\frac{30}{100}\right)^2}$$
$$= 21 \times 1.086$$
$$= 23 \text{ kA}$$

The asymmetrical fault current level is 23 kA. A circuit breaker with a rated short circuit breaking capacity (I_{sc}) of 25 kA can be used.

Transient recovery voltage, TRV

TRV is the voltage transient that appears across a circuit breaker pole when current flow is interrupted at its rated voltage. TRV waveforms vary, depending on the characteristics of the supply and the load.

IEC 62271-100 specifies test conditions under which the circuit breaker must endure standard TRV waveforms. The test results are published as specific circuit breaker nameplate ratings.

A circuit breaker must be able to break the current for any TRV condition likely to occur at the point of installation. An IEC classification can be given to a circuit breaker, depending on its likelihood to restrike (ie re-establish the current flow after the initial current has been disrupted). If restrike starts to occur on a regular basis, this usually indicates that the circuit breaker needs maintaining (the insulation medium may be degraded or the contact separation distance may need adjusting).

For 3-phase circuits, TRV refers to the voltage that will appear across the first pole to open. The ratio of TRV to single phase voltage is referred to as the first-pole-to-clear factor and is 1.5 for systems up to 72.5 kV.

Rated TRV (U_c) for circuit breakers intended for use on cable systems (Class S1)

IEC 62271-100 defines standard TRV peak voltage ratings.

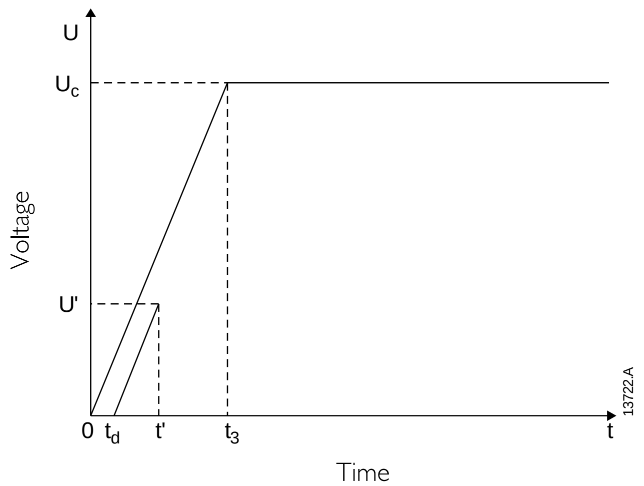
TRV withstand ratings for short circuit breaking current I_{sc}

U_r (kV)	3.6	7.2	12	17.5	24	36
U_c (kV)	6.2	12.3	20.6	30	41.2	61.7

Source: IEC 62271-100

$U_c = 1.715 \times U_r$	Where: U_c = TRV peak voltage value (kV) U_r = rated voltage (kV)

Voltage envelope for a two parameter TRV waveform on a cable system less than 100 kV



Source: IEC 62271-100

Rated out-of-phase breaking current, I_d (kA)

When a circuit breaker opens with its input and output voltages out-of-phase, larger than normal voltages will appear across the circuit breaker poles. This condition reduces the circuit breaker's maximum breaking current capability.

TRV withstand ratings for out-of-phase current I_d

U_r (kV)	3.6	7.2	12	17.5	24	36
U_c (kV)	9.2	18.4	30.6	44.7	61.2	91.9

Source: IEC 62271-100

$U_c = 2.551 \times U_r$	Where: U_c = TRV peak voltage value (kV) U_r = rated voltage (kV)

Rated capacitive switching currents

IEC 62271-100 recommends capacitive switching current ratings for circuit breakers, based on the following conditions:

I_c = rated cable charge breaking current (A)

I_{sb} = rated single capacitor bank breaking current (A)

I_{bb} = rated back-to-back capacitor bank breaking current (A)

I_{bi} = rated back-to-back capacitor bank inrush making current (kA)

NOTE
These ratings are recommendations only. Individual circuit breaker ratings may specify different values.

Preferred values of rated capacitive switching currents

Rated voltage Ur (kV rms)	Rated cable charging breaking current I_c (A rms)	Rated single capacitor bank breaking current I_{sb} (A rms)	Rated back-to-back capacitor bank breaking current I_{bb} (A rms)	Rated back-to-back capacitor bank inrush making current I_{bi} (kA)
3.6	10	400	400	20
7.2	10	400	400	20
12	25	400	400	20
17.5	34.5	400	400	20
24	31.5	400	400	20
36	50	400	400	20

Derived from IEC 62771-100

IEC Classifications

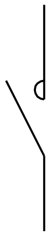
Medium voltage circuit breakers can be type tested and categorised according to the classifications in IEC 62271-100.

Classifications of switching devices

Class	Description
C1	low probability of restrike during capacitive switching
C2	very low probability of restrike during capacitive switching
E1	standard electrical endurance
E2	extended electrical endurance, designed so no maintenance of circuit interrupting parts is required during the expected operating life
M1	standard mechanical endurance (2000 operations)
M2	extended mechanical endurance (10000 operations)
S1	intended for use on cable systems
S2	intended for use on overhead line systems

Source: IEC 62271-100

Medium Voltage Contactors


13681.A

Contactors are a 3-pole load break switch with minimal short circuit making and breaking current capacity. Back-up short circuit protection fuses must be used; the contactor manufacturer will specify the maximum allowable fuse size. The switching contacts are sealed inside the vacuum interrupters and mechanical operation uses the magnetic technique.

Medium voltage contactors are suitable for high frequency switching (>10,000 operations), with continuous AC3 current ratings greater than 800 A and rated voltages from 1 kV to 12 kV. Manufacturers provide standard utilisation category ratings which can be matched to a specific application and the required number of operations.

Indoor contactors can be fixed or withdrawable style. Withdrawable style contactors can usually house primary protection fuses.

Withdrawable style contactor


13726.A

Fixed style contactor

13727.A

Construction

Medium voltage contactors usually consist of:

- flame retardant plastics to house the vacuum interrupters (and fuses, in the case of a withdrawable contactor)
- metal chassis (and truck, in the case of a withdrawable contactor)
- busbars for main power circuit connections (or cluster style power connections, in the case of a withdrawable contactor)
- magnetic and mechanical linkage components, for operation of the vacuum interrupter contacts
- auxiliary circuit components such as auxiliary contacts, truck position contacts, undervoltage or shunt trip coils, interlock coil etc

IEC Ratings

Medium voltage contactors must be type tested to provide standard ratings.

The contactor nameplate label must show the manufacturer's name, contactor model and serial number, and certain rating information. Many manufacturers also provide additional rating information.

MV contactor rating information

Rating		Description	Required on nameplate?
Voltage	U_r (kV)	Maximum operating voltage (rms) the device can continuously withstand during normal operation. The rated voltage must be greater than or equal to the system's operating voltage. Standard values for U_r : 3.6, 7.2, 12, 17.5, 24, 36 kV (source: IEC 62271-1)	Y
Insulation voltage	U_p (kV)	Power frequency withstand voltage is an indication of the insulation strength of the contactor.	
Frequency	fr (Hz)	This rating must match the system's operating frequency.	Y
Thermal current	I_{th} (A)	Maximum allowable continuous current, without the contactor temperature rise limits being exceeded.	Y
Service current	I_e (A)	Rated operational current, when being used for a specific utilisation category.	Y
Maximum making current	I_m (A)	Maximum making current, without welding or adverse erosion of contact material.	
Maximum breaking current	I_c (A)	Maximum breaking current, without welding or adverse erosion of contact material.	
Short-time withstand current	I_k (kA)	Current (rms) which can be sustained in the closed position, before external short circuit protection opens the circuit.	
Short-time withstand period	t_k (s)	Time that the contactor can sustain I_k before damage is likely to occur.	
Auxiliary supply voltage	U_a (V)	Control supply voltage. Typical values are: • 110, 120, 220, 230, 240 VAC • 24, 48 VDC • 24-250 VAC/VDC (universal supply) Operating voltage tolerance: +10/-15% Drop-out range: >70/50%	Y
Utilisation category		Operational current rating, dependent on the device's use and required number of operations.	Y

Derived from IEC 62271-1 and IEC 62271-106.

Contactors are primarily selected by their rated voltage (U_r) and rated current for a specific utilisation category (I_e).

Medium voltage contactor utilisation categories

Utilisation category	Typical application
AC1	Resistive or slightly inductive loads
AC2	Starting and running slip-ring motors
AC3	Starting and running induction motors
AC4	Reversing, plugging and inching induction motors
AC6b	Switching single or back-to-back capacitor banks

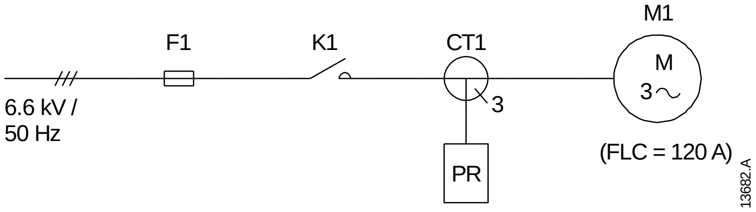
Source: IEC 62271-106

Circuit Design (Motor circuit with fuses)

A contactor always needs some form of back-up short circuit protection. Although circuit breakers can be used for this purpose, it is more common to use MV HRC fuses. Fuses have higher fault breaking capacity, are very fast acting and are a good current limiting device.

Consider the following direct-on-line motor circuit, which includes a line contactor, short circuit protection fuses and a motor protection relay, providing overload protection. Assume an operating supply of 6.6 kV/50 Hz and a motor FLC of 120 A.

Typical DOL circuit with contactor, fuses and relay



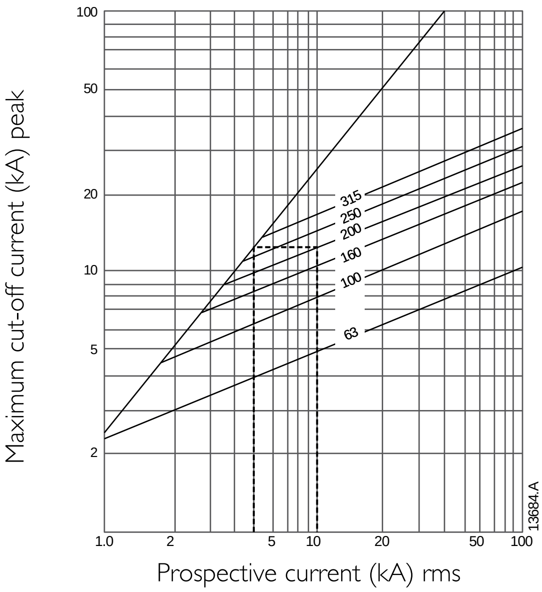
Step 1: Select the contactor

- Rated voltage U_r ≥ operating voltage U and AC3 rating I_e ≥ motor FLC
  A 7.2 kV/50 Hz contactor with an AC3 rating of 200 A will be adequate

Step 2: Select the fuse

- The manufacturer will specify the maximum allowable fuse size. As a general rule, the nominal rating of the fuse should be 1.5 times the motor FLC.
  In this case
  $I_{(fuse)}$ = 1.5 x 120
  = 180 A
  Use a 200 A fuse.
- On a time-current curve, check that the contactor thermal withstand curve lies outside the total clearing curve of the fuse.
- From the fuse cut-off curve, the "limited" prospective short circuit current of the fuse must be less than the short-time withstand current rating of the contactor.
  $I_{sc'}$ (fuse) ≤ I_k (contactor)

Assume the 7.2 kV/50 Hz, 200 A contactor has a short-time withstand current rating I_k of 8 kA and the prospective rms fault current level I_{sc} at the point of installation is 10 kA.



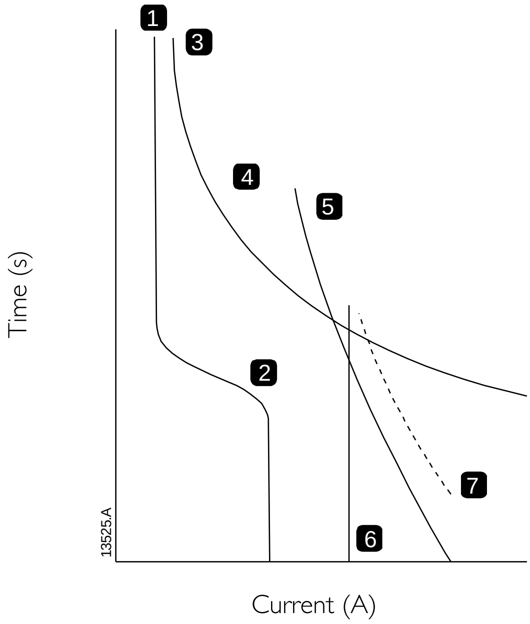
From the fuse cut-off curve, we can see that a prospective rms fault current of 10 kA (I_{sc}) will be limited to 4 kA ($I_{sc'}$) by the 200 A fuse. Check that $I_{sc'}$ (fuse) ≤ I_k (contactor).

4 kA ≤ 8 kA The fuse is suitable for use with the contactor.

Step 3: Select an overload curve

- The nominal current setting of the curve is set for the motor FLC. In this case, set overload protection so that I_n = 120 A

The overload curve (hot curve) needs to lie outside the motor start curve and intersect with the fuse curve at a point before the maximum breaking current I_c of the contactor.

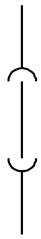
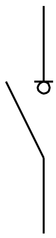
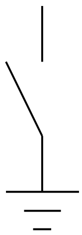
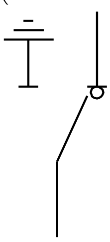
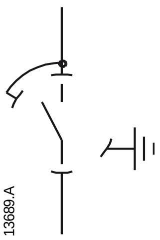


1	Motor FLC
2	Motor start current
3	Overload curve - nominal setting (In)
4	Overload curve - hot
5	Fuse total clearing curve
6	Contactor maximum break current (Ic)
7	Contactor thermal withstand curve

Medium Voltage Switches

Medium voltage switches for use on 1 kV to 52 kV indoor systems are predominantly used for isolation and earthing. Although the majority of these switches are air insulated, gas insulated (SF6) combination switches are available, which are designed for load and fault current switching.

Operation of a switch can be manual or motorised. International standards provide maximum torque levels required to operate manual disconnect and earth switches. There must be a visual indication of the switch position (by viewing the contacts or an indicator driven directly from the contacts).

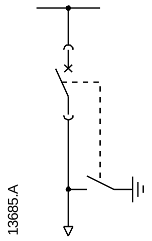
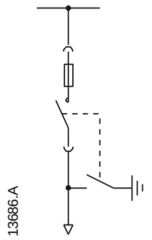
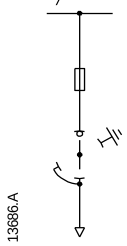
Switch type	Main function	Description
Disconnector (fixed or withdrawable)  13692.A  13693.A	Isolation	• Rated for carrying continuous load current with a short-time withstand fault current rating (I_k) • No continuous overload capability • No switching capability • Used with a circuit breaker or contactor and fuse combination
Switch-Disconnector (load-break isolator)  13690.A	Switching and isolation	• Rated for carrying continuous load current with a short-time withstand fault current rating (I_k) • Can switch rated current (I_r) but has no fault make capability • Used with line fuses or a circuit breaker
Earth switch  13691.A	Earthing	• Rated for carrying continuous load current with a short-time withstand fault current rating (I_k) • No load switching capability, but can make on a fault (I_p) • Used with a circuit breaker or contactor and fuse combination
Gas insulated Earth-disconnector (fixed or rotary)  13688.A  13689.A	Switching, isolation and earthing	• Rated for carrying continuous load current with a short-time withstand fault current rating (I_k) • Can switch rated load current (I_r) • Can make on fault current (I_p) • Used with line fuses or a circuit breaker

Applications

A typical medium voltage metal-enclosed switchgear feeder circuit will have a combination of switchgear able to provide the following functions:

- switching of load current
- short circuit protection
- means of isolation
- means of earthing

In most cases, air insulated earth switches or gas insulated earth-disconnectors, are used. The following examples show common configurations for medium voltage, metal-enclosed switchgear feeder circuits.

Single line diagram	Description
Withdrawable circuit breaker 	• The withdrawable circuit breaker provides load switching, short circuit protection and circuit isolation when opened and in the draw-out position. • The cable-side earth switch is interlocked with the circuit breaker and can only be closed when the circuit breaker is in the drawn-out position. • A protection device is required to provide overload and short circuit protection.
Withdrawable contactor 	• The withdrawable contactor with integrated fuses provides load switching and circuit isolation when opened and in the draw-out position. The fuses provide short circuit protection. • The cable-side earth switch is interlocked with the contactor and can only be closed when the contactor is in the drawn-out position.
Gas insulated rotary disconnector 	• The gas insulated rotary disconnector has three physical operating positions. It provides load switching in the ON position, isolation in the OFF position and earthing in the EARTH position. • Short circuit protection is provided by fuses, but a fixed type circuit breaker could be used instead.

IEC Ratings

Disconnectors and earth switches are type tested to specific IEC standards. IEC 62271-1 provides standard ratings and IEC 62271-102 details test methods and specific requirements for medium voltage disconnectors and earth switches.

The nameplate label must show the manufacturer's name, equipment model and serial number, and certain rating information. Many manufacturers also provide additional rating information.

Rated voltage, U_r (kV)

Maximum operating voltage (rms) the device can continuously withstand during normal operation. The rated voltage must be greater than or equal to the system's operating voltage.

Standard values for U_r : 3.6, 7.2, 12, 17.5, 24, 36 kV (source: IEC 62271-1)

MV switches tend to have a maximum U_r of 36 kV.

Rated lightning impulse withstand rating, U_p (kV)

This is the peak voltage the device can withstand for a 1.2/50 μs standard test wave.

Standard values for U_p (source: IEC 62271-1):

U_r (kV)	3.6	7.2	12	17.5	24	36
U_p (kV)	40	60	75	95	125	170

Rated frequency, f_r (Hz)

This rating must match the system's operating frequency. Rated frequency only has to be marked on the device nameplate if it is not suitable for 50 Hz and 60 Hz operation.

Rated current, I_r (A)

This is the rms level of current which can continuously flow through a device without exceeding its maximum allowable contact temperature rise.

Temperature rise limits are defined in IEC 62271-1, for an ambient temperature of 40 °C.

The rated current must be greater than the maximum expected load current, at the point of installation.

Standard values for I_r : 630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000 A (source: IEC 62271-1)

MV switches tend to have a maximum I_r of 2500 A.

Rated short-time withstand current, I_k (kA)

This is the maximum rms symmetrical fault current the device can withstand, for a short time period, without risk of damage. This rating must be higher than the prospective rms fault current at the point of installation.

$I_k \geq I_s$ $I_s = \frac{S_{SC}}{\sqrt{3} \times U}$	Where: I_k = short-time withstand current rating (kA) I_s = prospective rms fault current (kA) S_{SC} = system short circuit power (kVA) U = system operating voltage (kV)

Standard values for I_k : 6.3, 8, 10, 12.5, 16, 20, 25, 31.5, 40, 50, 63 kA (source: IEC 62271-1)

MV switches tend to have a maximum I_k of 31.5 A.

Rated short circuit duration, t_k (s)

This is the time the device can endure its rated short-time withstand current (I_k) without damage. This value must be greater than the total expected clearing time of a fault at the point of installation.

Standard values for t_k : 0.5, 1, 2, 3 seconds (source: IEC 62271-1)

MV switches tend to have a t_k rating of 1 second.

Rated peak withstand current (kA)

This is the maximum peak fault current level which the device is able to close (make) on. This rating must be greater than the expected peak let-through fault current (I_p) at the point of installation.

Rated peak withstand current ≥ I_p

I_p = 2.5 × I_s (for a 50 Hz supply with a 45 ms DC time constant) I_p = 2.6 × I_s (for a 60 Hz supply with a 45 ms DC time constant)	Where: I_p = asymmetrical peak let-through fault current, from the first fault loop (kA) I_s = rms symmetrical fault current level, with no DC component (kA)

Source: IEC 62271-1, IEC 62771-100

MV earth switches tend to have a maximum I_p of 82 kA.

Electrical endurance class

This class defines the fault making capability of earth switching devices.

E0 (Standard electrical endurance): No fault making capability

E1 (Extended electrical endurance): Capable of 2 fault making operations without damage

E2 (Highest electrical endurance): Capable of 5 fault making operations without damage

Mechanical endurance class

This class defines the mechanical endurance of no-load disconnectors.

M0 (Standard electrical endurance): 1000 operating cycles without maintenance

M1 (Extended electrical endurance): 2000 operating cycles without maintenance

M2 (Highest electrical endurance): 10000 operating cycles without maintenance

Medium Voltage HRC Fuses

Medium voltage high-rupturing-capacity (HRC) fuses are constructed of narrow conductor bands which are shaped to melt in overload or short circuit conditions. The conductor bands are configured in a spiral, embedded in quartz sand filling and totally sealed within a high thermally resistive ceramic housing. Each end of the fuse has either end caps for fitting into fuse bases or bolt style terminations for busbar fixing. Most fuse types come with the option of a striker pin or fuse-blow pin, which is activated immediately after the fuse has ruptured. The striker pin can directly trip a disconnect switch or operate auxiliary contacts.
Although fuses provide a form of overload protection, their main use is for short circuit protection. One of the major advantages of fuses over circuit breaker protection is their ability to limit the rms and peak values of the prospective short circuit current immediately downstream at the point of installation.

Fuse selection depends on the maximum load current, type of load, prospective fault current, system voltage and ambient temperature of the installation. In a 3-phase installation, it is assumed that all three fuses are subjected to the same rate of degradation. If one fuse ruptures, it is highly recommended that all three be replaced.

Two categories of fuses are commonly use for medium voltage primary and secondary switchgear installations.

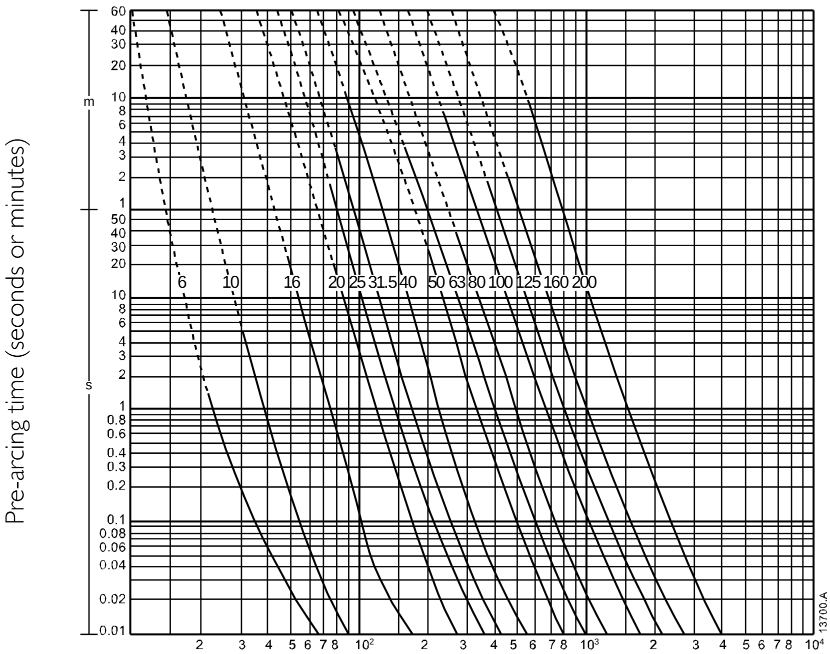
- General purpose fuses (also called E-rated fuses by NEMA) are typically used in combination with contactors or switch-disconnectors.
- Motor rated fuses (also called R-rated fuses by NEMA) are used for motor feeder circuits, and must be used in conjunction with a thermal overload protective device. Motor rated fuses have time delayed, time-current curves and higher minimum melt characteristics to accommodate the high currents associated with motor starting.

Fuse characteristics

Pre-arcing curves

Pre-arcing curves are sometimes referred to as time-current curves. They indicate minimum break currents and the ability for a fuse to pass through medium level overload current, such as motor starting current. The dashed part of each fuse curve indicates an area of uncertain fuse interruption.

Sample fuse pre-arcing curves



Source: example curves based on ABB CEF fuse links

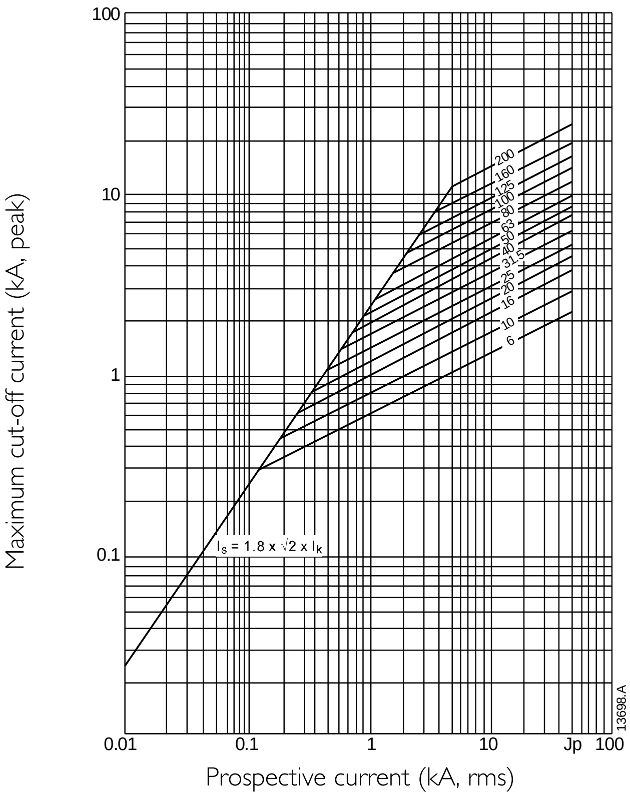
Example

A fuse with a nominal rating of 50 A has a minimum break current of 200 A and is capable of passing an overload current of 240 A for 10 seconds.

Let-through curves

Sometimes referred to as cut-off curves, they indicate the ability of a fuse to limit the peak let-through and rms values of short circuit current, immediately downstream of the fuse installation.

Sample fuse let-through curves



Source: example curves based on ABB CEF fuse links

Example

If the prospective rms fault current was 5 kA, the peak let-through current would be approximately 12 kA without a fuse. If a 50 A fuse was installed, the rms fault current would be limited to 1.5 kA and the peak let-through current would be 3.8 kA downstream of the fuse.

I^2t data

Fuse data sheets provide two I^2t figures:

- minimum I^2t is the amount of let-through energy required to start a fuse melt and create an arc
- maximum I^2t is the total amount of let-through energy required to extinguish an arc and completely rupture (open circuit) a fuse.

This data is important for fuse discrimination. The maximum I^2t of the downstream fuse must be less than the minimum I^2t of the upstream fuse.

If a fuse is selected to protect a cable, the maximum I^2t of the fuse must be greater than the A^2S^2 thermal rating of the cable.

Ratings

Irrespective of which standard a fuse has been type tested too, the following generic ratings usually apply. Different standards require different rating information to be published on the fuse nameplate.

Nominal current, I_n (A)

This is the maximum continuous current a fuse can sustain without risk of rupturing. It takes into account the method of installation and the expected ambient temperature. Manufacturers provide derating factors for high ambient and special mounting configurations.

Typical nominal current ratings:
I_n = 1, 2, 4, 6, 10, 16, 20, 25, 31.5, 40, 50, 63, 80, 100, 125, 160, 200, 250, 315 A

For a given fuse type and size, the maximum possible nominal current reduces as the nominal voltage increases.

Example:

For a 12 kV general purpose 442 mm style fuse, it is common to have a maximum nominal current rating of 200 A.

However, for the equivalent 7.2 kV fuse, the maximum nominal current rating might be 315 A.

Minimum breaking current (A)

This is the minimum current guaranteed to rupture the fuse and can be obtained from the pre-arcing curves or the fuse data sheet. This is determined by the overload characteristics of the fuse. Depending on the fuse type, it can be anywhere from 2 to 4 times the nominal rating of the fuse. Overload currents below the minimum breaking current are not guaranteed to rupture the fuse.

Maximum breaking current (kA)

This is the maximum safe rupturing current, determined by the short-circuit characteristics of the fuse. The maximum breaking current must be higher than the prospective short circuit current at the point of installation. The current limiting nature of a fuse means the equipment downstream can have a short circuit withstand rating which is much less than the prospective short circuit current.

Nominal voltage, U_n (kV)

This is the rated voltage of the fuse and must be greater than or equal to the operating voltage of the system. In the case of capacitor applications, it is recommended that the fuse's nominal voltage be twice the rated voltage of the capacitor bank.

Typical nominal voltage ratings:
U_n = 3.6, 7.2, 12, 17.5, 24, 36 kV

Selection

Cable protection

The nominal current rating of the fuse must be equal to or less than the current rating of the cable after cable derating factors have been applied.

$I_{n\ (FUSE)} \leq I_{\_CABLE}$

The maximum I^2t (total clearing I^2t) of the fuse must be less than the A^2S^2 thermal rating of the cable.

$I^2t_{\ (FUSE)} \leq A^2S^2_{\ (CABLE)}$

Switchgear apparatus

If a medium voltage fuse is used in combination with a switch-disconnector or contactor, the nominal current rating of the fuse is determined predominantly by the load. However, such switching devices have a relatively low maximum breaking current compared with fuses, so switchgear manufacturers stipulate a maximum sized fuse which can be used with their switching device.

Power transformers

Fuse manufacturers provide selection tables for the primary input of a medium voltage power transformer. These tables consider the transformer's power rating S (kVA) and nominal primary voltage rating $U_{\_PRIM}$ (kV). The information may also specify the maximum sized fuse required on the low voltage transformer secondary output, for coordination with the primary input fuse.

If the manufacturer's selection tables are not available, select a general purpose (E-rated) fuse with a nominal current rating of 1.5 to 2 times the primary current rating of the transformer:

$I_{n\ (FUSE)} = (1.5 \times I_{\_PRIM}) \sim (2.0 \times I_{\_PRIM})$

Where

$$I_{\_PRIM} = \frac{S}{\sqrt{3} \times U_{\_PRIM}}$$

Exercise

Select the primary input fuses required to protect an 11 kV/400 VAC, 1000 kVA, 3-phase power transformer.

$$I_{\_PRIM} = \frac{1000\ kVA}{\sqrt{3} \times 11\ kV}$$
$$= 53\ A$$

$$1.5 \times 53 = 97.5\ A$$
$$2 \times 53 = 106\ A$$

The range of $I_{n(FUSE)}$ *is 97.5~106 A. Use 100 A/12 kV, E-rated primary fuses.*

Capacitor banks

Two primary factors affect fuse ratings when used with capacitor banks:

- the peak inrush current which flows when a capacitor bank is energised. This can be up to 100 times the nominal current rating of the capacitor bank.
- transient voltages produced during capacitor bank switching.

Individual 3-phase capacitor bank

$I_{n\ (FUSE)} = 2 \times I_{\_CAP}$
$U_{n\ (FUSE)} = 2 \times U_{\_CAP}$

Back-to-back 3-phase capacitor bank

$I_{n\ (FUSE)} = 3 \times I_{\_CAP}$
$U_{n\ (FUSE)} = 2 \times U_{\_CAP}$

Exercise

Select the protection fuse required for a 300 kVAr/7.2 kV individual 3-phase capacitor bank.

$$I_{\_CAP} = \frac{300}{\sqrt{3} \times 7.2}$$
$$= 24\ A$$
$$I_{n(FUSE)} = 2 \times I_{\_CAP}$$
$$= 2 \times 24$$
$$= 48\ A$$
$$U_{n(FUSE)} = 2 \times U_{\_CAP}$$
$$= 2 \times 7.2$$
$$= 14.4\ kV$$

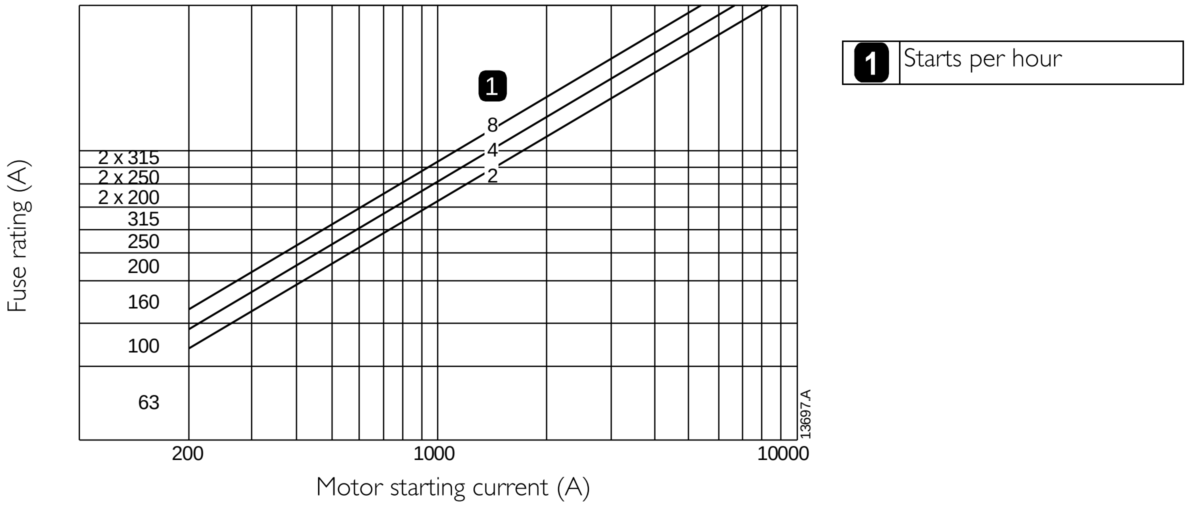
Use 50 A/17.5 kV, general purpose fuses

Motor circuits

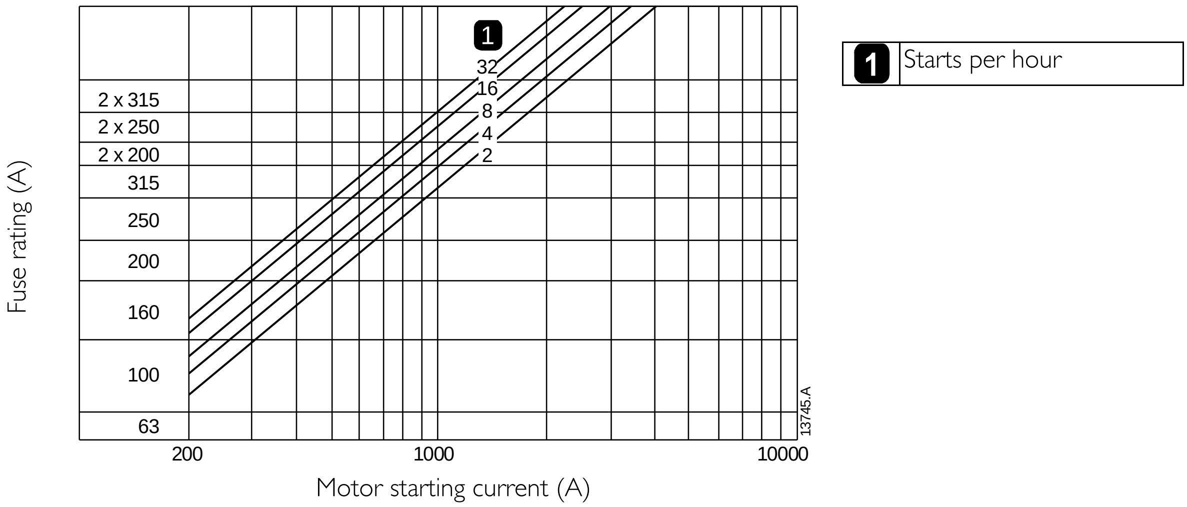
Special motor rated fuses are used for motor starting. These fuses can sustain repeated motor start overload currents without degradation. Fuses are installed to provide short circuit protection only and the motor circuit must have separate overload protection.

Fuse selection for a motor application is typically carried out using graphs provided by the fuse manufacturer. These graphs consider motor starting current (A), motor run-up time (s) and starts per hour.

Typical fuse ratings for 2, 4 or 8 starts per hour, starting time ≤ 60 seconds



Typical fuse ratings for 2, 4, 8, 16 or 32 starts per hour, starting time ≤ 15 seconds



Source: example curves based on ABB CMF fuse links

Exercise

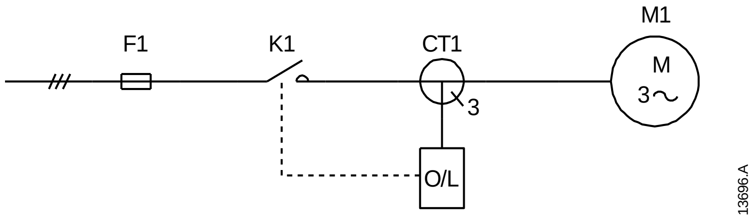
A 3.3 kV motor has a full load current of 150 A. Its expected start current is 5.5 times full load current for 10 seconds and it operates at 2 starts per hour. Select the required protection fuse.

Use the graph for Starting time ≤ 15 seconds. The start current will be 5.5 x 150 A = 825 A.
For motor starting current of 825 A, at 2 starts per hour, the required motor rated fuse is 250 A/3.6 kV.

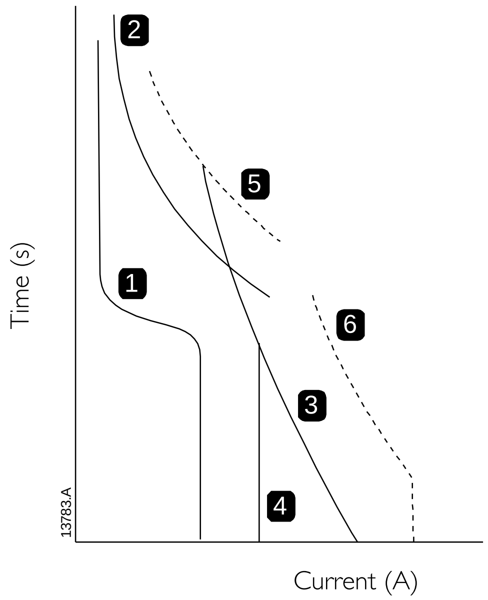
Motor circuit coordination

Consider the following motor branch circuit.

Motor circuit with fuse and contactor



The circuit components and protection must be coordinated to achieve the following results



1	Motor start current
2	Thermal relay protection curve
3	Fuse trip curve
4	Contactor maximum break current
5	Motor thermal withstand
6	Cable thermal withstand

Coordination requirements:

- The expected motor start current curve (1) must sit inside (to the left) of the thermal relay protection curve (2) and the fuse trip curve (3).
- The intersection of the thermal relay protection curve and the fuse trip curve must have a lower current value that the maximum breaking current of the contactor (4).
- The fuse rating must not exceed the maximum size stated by the contactor manufacturer.
- The thermal withstand curves of the motor (5) and the cable (6) must sit outside (to the right) of the thermal relay protection curve and the fuse trip curve.
- The short circuit withstand current rating of the contactor must exceed the expected rms short circuit current downstream of the fuse after current limiting.
- If a back-up fuse is installed upstream, its minimum I^2t value must be greater than the maximum I^2t value of the motor branch fuse.

Current Transformers

A current transformer (CT) is designed to produce a secondary current which is accurately proportional to the primary current. It consists of a single primary winding, which an external busbar or cable runs through, or it can have a single primary bar, brought out to two ends for termination. A medium voltage current transformer can have up to three independent secondary winding sets. The entire current transformer assembly is encapsulated in resin, inside an insulated casing

Current transformers are used for metering or protection purposes. The accuracy class and size depends on the individual application - for example, revenue metering would use high accuracy metering CTs.

NOTE
Never leave the secondary winding of a CT open circuit. This creates extremely high voltages which pose a real danger to personnel.

Ring style CT

DIN style CT

IEC Ratings

Rated primary current, I_{pr} (A)

The primary current rating of a CT must be greater than the expected maximum operating current it is monitoring.

- a metering CT's primary current rating should not exceed 1.5 times the maximum operating current
- a protection CT's primary current rating needs to be chosen so that the protection pick-up level is attained during a fault

Standard values for I_{pr} : 10, 12.5, 15, 20, 25, 30, 40, 50, 60, 75 A, and decimal multiples of these values (source: IEC 60044-1)

Rated secondary current, I_{sr}

The secondary current rating of a CT is either 1 A or 5 A. CTs with a 5 A secondary rating are becoming less common as more CT driven equipment becomes digital. For long secondary cable runs, CTs with 1 A secondary windings can minimise the transformer and secondary cable size.

Transformer ratio, K_n

This is the ratio of secondary to primary winding turns.

$$K_n = \frac{N_s}{N_p} = \frac{I_{pr}}{I_{sr}}$$

Rated thermal short-time withstand current, I_{th} (kA)

This is the highest level of rms primary fault current which the CT can endure, both thermally and dynamically, for 1 second without damage. When used in a medium voltage enclosure, the I_{th} rating should match the short-time withstand rating of the entire switchgear.

Overcurrent coefficient, K_{si}

This is the ratio of a CT's short-time withstand current rating to its primary current rating.

$$K_{si} = \frac{I_{th}}{I_{pr}}$$

This coefficient indicates how difficult it would be to manufacture a CT. A higher coefficient means a physically larger CT, which is more difficult to manufacture.

K_{si} < 100 : easy to manufacture

K_{si} 100 ~ 500 : difficult to manufacture, with certain limitations

K_{si} > 500 : extremely difficult to manufacture

Rated primary circuit voltage, U_p (kV)

The primary circuit voltage rating indicates the level on insulation provided by the CT. If a ring type CT is installed around a cable or bushing, the insulation level can be provided by the cable or bushing.

Rated primary voltage U_{pr} (kV)	Suitable operating range U (kV)	Power frequency withstand voltage (kV) rms for 1 minute	Lightning impulse withstand voltage (kV) peak, 1.2/50 µs
7.2	3.3~7.2	20	60
12	6~12	28	75
17.5	10~17.5	38	95
24	12~24	50	125
36	20`36	70	170

Source: IEC 62271-1

Rated frequency, f_r (Hz)

This rating must match the system's operating frequency. Standard frequencies are 50 Hz and 60 Hz.

> A 50 Hz CT can be used on a 60 Hz system, but a 60 Hz CT cannot be used on a 50 Hz system.

Rated real output power (VA)

The maximum power a CT secondary can deliver, to guarantee its accuracy and performance. The total sum VA (including cable, connectors and load) must not exceed the rated real output power of the CT.

Standard values are: 1, 2.5, 5, 10, 15 VA

- Cable burden

$VA_{\_CABLE} = k \times \frac{L}{S}$	Where: k = 0.44 for 5 A secondary, = 0.0176 for 1 A secondary L = total feed/return length of cable (metres) S = cross sectional area of copper cable (mm^2)

- Metering instrument burden

Metering instrument (digital) = 1 VA (approx)
Metering instrument (electromagnetic or induction) = 3 VA (approx)
Transducer (self powered) = 3 VA (approx)

- Protection instrument burden

Protection instrument (digital) = 1 VA (approx)
Protection instrument (electromagnetic overcurrent) = 3-10 VA (approx)

Exercises

1. A CT with a 1 A secondary is connected to an electromagnetic ammeter located10 metres away, using 2.5 mm^2 copper cable. Calculate the minimum required VA rating of the CT.

$$
\begin{aligned}
VA_{\_CABLE} &= k \times \frac{L}{S} \\
&= 0.0176 \times \frac{20}{2.5} \\
&= 0.14\ VA \\
VA_{\_AMMETER} &= 3\ VA \\
VA_{\_TOTAL} &= 0.14 + 3 \\
&= 3.14\ VA
\end{aligned}
$$

The total burden is 3.14 VA. Use a 5 VA CT.

2. A CT with a 5 A secondary is connected to a digital protection relay located 2 metres away, using 1.5 mm^2 copper cable. Calculate the minimum required VA rating of the CT.

$$
\begin{aligned}
VA_{\_CABLE} &= k \times \frac{L}{S} \\
&= 0.44 \times \frac{4}{1.5} \\
&= 1.17\ VA \\
VA_{\_AMMETER} &= 1\ VA \\
VA_{\_TOTAL} &= 1.17 + 1 \\
&= 2.17\ VA
\end{aligned}
$$

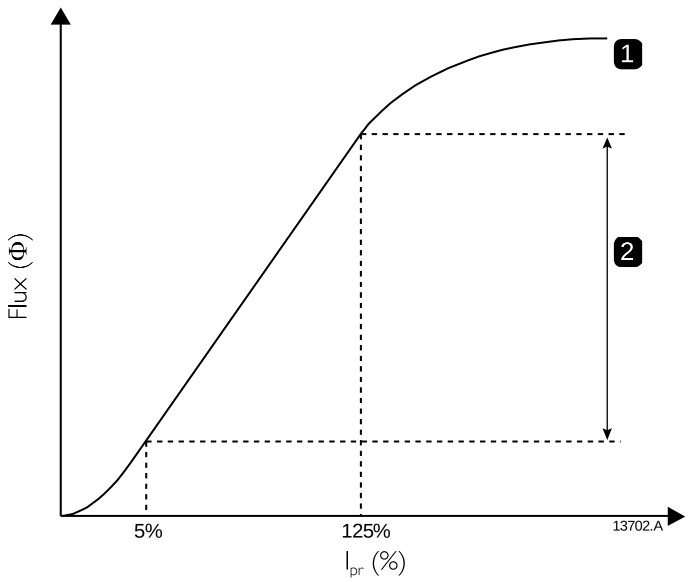
The total burden is 2.17 VA. Use a 2.5 VA CT.

Metering class

A metering class indicates the accuracy of the CT secondary current at 5 to 125% of rated primary current. Above this level, the CT starts to saturate and the secondary current is clipped to protect the inputs of a connected metering instrument.

- general metering CT would use a metering class CL 0.5 – 1.0
- revenue metering CT would use a metering class CL 0.2 – 0.5

Operating range for metering class current transformer



1	Saturation
2	Linear operating range, at accuracy class tolerance

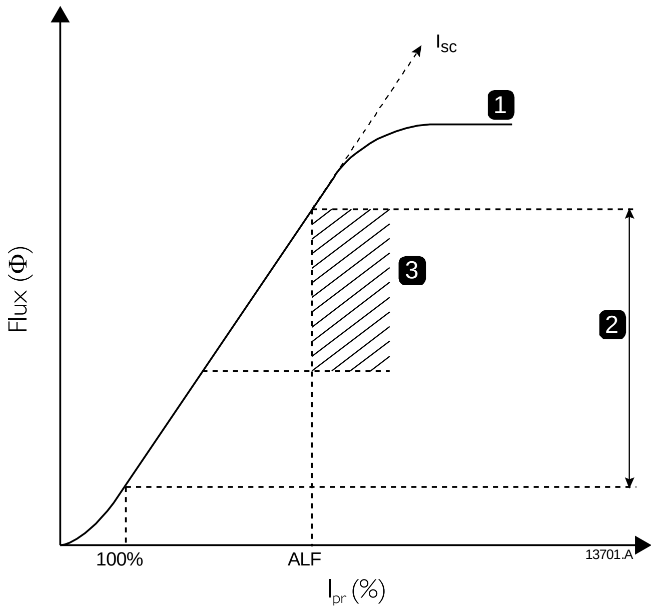
Protection class CT

A protection class CT provides a linear transformation of the primary to secondary current at high overload levels. This characteristic makes them suitable for use with overcurrent protection relays. A relay trip setting is normally 10~15 times the maximum load current and this level should fall on the linear part of the CT secondary current curve. If a CT saturates before the relay trip level is reached, the fault will remain undetected, leading to equipment damage and serious danger to personnel.

The most commonly used protection class is a 5PX, where X is the accuracy limit factor (ALF) or multiplication factor of the rated primary current. The secondary current is +/-1% accurate at rated primary current and +/-5% accurate at X times rated primary current.

Typical protection class CT ratings are 5P10, 5P15, 5P20.

Operating range for protection class current transformer



1	Saturation
2	Linear operating range, at accuracy class tolerance
3	Ideal protection setting trip zone 50%~100% ALF

Example

A 200/1 A CT has a protection class rating of 5P15.

The secondary current is guaranteed to be linear up to 15 times the rated primary current. The secondary current will be 1 A (+/-1%) at 200 A primary current and 15 A (+/-5%) at 3000 A primary current. For guaranteed operation, any overcurrent trip setting should be between 7.5 ~ 15 A secondary current.

Selection

The main considerations for selecting a CT are the primary and secondary current ratio, real output power rating (VA) and accuracy class. Secondary selection considerations are rated primary voltage, frequency and thermal short-time withstand current.

Primary and secondary current ratio

Rated primary current, I_{pr} (A)

Incomer from transformer: $I_{pr} \geq$ 1.0-1.25 of nominal source current
Feeder to transformer: $I_{pr} \geq$ 1.0-1.25 of transformer's rated primary current
Feeder to motor: $I_{pr} \geq$ 1.0-1.5 of motor full load current
Feeder to capacitor bank: $I_{pr} \geq$ 1.3-1.5 of nominal capacitor current

Rated secondary current, I_{sr} (A)

Use 1 A and 5 A for local installation.
Use 1 A for remote installation.

Real output power (VA)

The real output rating of the CT must be the next highest nominal size above the expected total burden on the CT secondary. Total burden is the sum of output cable, connectors and instruments.

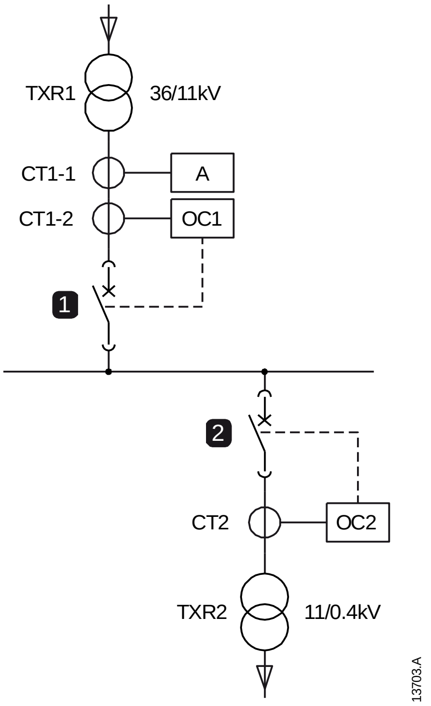
Class type

Use a metering class CT for metering and indication. A higher class CT gives greater accuracy between the primary and secondary currents.

Use a 5PX protection class CT for current based protection relay inputs. The ALF must be selected so that the relay trip point lies on the linear part of the secondary current curve, between 50% and 100% of the ALF.

Exercise

Select appropriate CTs for the following transformer incomer and feeder circuits.



1	Transformer Incomer • MV/MV transformer (TXR1): 5 MVA, 36/11 kV, 10% Z • Instantaneous overcurrent trip setting = 15 x I_n for digital protection relay (OC1) driven off CT1-2 • Electromagnetic ammeter (A) is driven off CT1-1
2	Transformer Feeder • MV/LV transformer (TXR2): 2 MVA, 11/0.4 kV, 5% Z • Instantaneous overcurrent trip setting = 10 x I_n for digital protection relay (OC2) driven off CT2

Exercise 1: Metering CT1-1 for transformer incomer circuit:

Step1: Calculate transformer TXR1 nominal secondary current, I_n (A)

$$I_n = \frac{S}{\sqrt{3} \times U} = \frac{5000}{\sqrt{3} \times 11} = 262 \text{ A}$$

The secondary current for TXR1 is 262 A

Step 2: Calculated maximum expected short circuit current at CT1 installation, I_{sc} (A)

Ignoring any power cable or busbar impedances:

$$I_{sc} = I_n \times \frac{100}{Z} = 262 \times \frac{100}{10} = 2620 \text{ A}$$

The maximum expected short circuit current at CT1 is 2620 A

Step 3: Select metering CT1-1 ratings

Primary rated current, I_{pr} = (1.0-1.25) x I_n = (1.0-1.25) x 262 A
Use a rating of 300 A

Secondary rated current, I_{sr}
Use a rating of 1 A

Short-time withstand rating, $I_{th} \geq I_{sc}$
Use a rating of 10 kA

Primary circuit voltage, $U_p \geq U$
Use a rating of 12 kV

Real output power: typically > 3 VA for electromagnetic type meter
Use 5 VA (this allows 2 VA for cable burden, etc)

Accuracy Class
Use Class 1.0 (common class for general metering)

Exercise 2: Protection CT1-2 for transformer incomer circuit:

Step1: Select ratings common to both the metering and protection CTs

Primary/secondary rated current = Use 300/1 A
Short-time withstand rating, I_{th} = Use 10 kA rating
Primary circuit voltage, U_p = Use 12 kV rating

Step 2: Select real output power

Real output power: typically > 1VA for digital type protection relay
= Use 2.5 VA (this allows 1.5 VA for cable burden, etc)

Step 3: Calculate protection class 5PX

The instantaneous trip current level of protection relay OC1 is set to 15 × I_n.

I_{TRIP} = 15 × 262

= 3930 A (primary current)

(Note: In most digital protection relays, the trip current levels are set with respect to the secondary current. In this case

$$I\_{SEC} = \frac{3900}{300} \times 1$$
$$= 13.1 \text{ A}$$

The instantaneous trip current level for the CT secondary is 13.1 A

The trip current level should fall between 100 to 50% of the accuracy limit factor (ALF).

Using an ALF of 10 (5P10), the trip current level of 3930 A falls outside the range 100% to 50% ALF, so a 5P10 protection class CT is not suitable.

$$100\% \text{ (ALF)} = 1.0 \times 10 \times 300$$
$$= 3000 \text{ A}$$
$$50\% \text{ (ALF)} = 0.5 \times 10 \times 300$$
$$= 1500 \text{ A}$$

$$1500 \leq 3930 \geq 3000 \text{ A}$$

Using an ALF of 15 (5P15), the trip current level of 3930 A falls within the range 100% to 50% ALF so a 5P15 protection class CT is suitable.

$$100\% (\text{ALF}) = 1.0 \times 15 \times 300$$
$$= 4500 \text{ A}$$
$$50\% (\text{ALF}) = 0.5 \times 15 \times 300$$
$$= 2250 \text{ A}$$

$$2250 \leq 3930 \leq 4500 \text{ A}$$

Use protection class 5P15

Exercise 3: Protection CT2 for transformer feeder circuit:

Step1: Calculate transformer TXR2 nominal primary current, In (A)

$$I_n = \frac{S}{\sqrt{3} \times U} = \frac{2000}{\sqrt{3} \times 11} = 105\ A$$

The primary current for TXR2 is 105 A

Step 2: Calculated maximum expected short circuit current at CT2 installation, Isc (A)

Ignoring any power cable or busbar impedances:

$$I_{sc} = I_n \times \frac{100}{Z} = 105 \times \frac{100}{5} = 2100\ A$$

The maximum expected short circuit current at CT2 is 2100 A

Step 3: Select protection CT2 ratings

Primary rated current $I_{pr} = (1.0\text{-}1.25) \times I_n = (1.0\text{-}1.25) \times 105$

Use a rating of 150A

Secondary rated current I_{sr}

Use a rating of 1 A

Short-time withstand rating, $I_{th} \geq I_{sc}$

Use a rating of 10 kA

Primary circuit voltage $U_p \geq U$

Use a ratings of 12 kV

Real output power: typically > 1 VA for digital type protection relay.

Use 2.5 VA (this allows 1.5 VA for cable burden, etc)

Step 4: Calculate protection class 5PX

The instantaneous trip current level of protection relay OC2 is set to $10 \times I_n$

I_trip = 10 × 105

= 1050 A (primary current)

(Note: In most digital protection relays, the trip current levels are set with respect to the secondary current. In this case

$$I\_{SEC} = \frac{1050}{150} \times 1 = 7\ A$$

The instantaneous trip current level for the CT secondary is 7 A

The trip current level should fall between 100 to 50% of the accuracy limit factor (ALF).

Using an ALF of 10 (5P10), the trip current level of 1050 A falls within the range of 100% to 50% ALF so a 5P10 protection class CT is suitable.

$$100\%\ (ALF) = 1.0 \times 10 \times 150 = 1500\ A$$

$$50\%\ (ALF) = 0.5 \times 10 \times 150 = 750\ A$$

$$750 \leq 1050 \leq 1500\ A$$

Use protection class 5P10

NEMA/IEEE Ratings

These ratings are typically used for current transformers manufactured or used in North American installations. As well as a stated primary to secondary nominal current ratio, the device also carries an overall accuracy rating in the format

AC-CR-BU	Where: AC = accuracy class CR = class rating BU = maximum burden (ohms)

Accuracy class

Designates the accuracy of the secondary current with respect to the primary rated current. This accuracy is only guaranteed provided the maximum burden is not exceeded.

Accuracy class	Tolerance at 100% primary current
1.2	±1.2%
0.6	±0.6%
0.5	±0.5%
0.3	±0.3%

Class rating

Designates the intended application of the device.

B = for metering applications

H = for protection applications. The CT secondary accuracy is guaranteed at 5 to 20 times the nominal primary rated current

Burden

The maximum load allowed to be connected to the current transformer secondary, to guarantee the accuracy class. The maximum burden includes secondary cable/wire, connectors and the load. The following table converts burden in ohms to VA, for a 5 A secondary.

Ω	0.04	0.06	0.08	0.12	0.16	0.20	0.24	0.28	0.32	0.36	0.40	0.48	0.56	0.64	0.72	0.80
VA	1	1.5	2	3	4	5	6	7	8	9	10	12	14	16	18	20

Examples

0.5-B-0.1 indicates a current transformer with an accuracy of ±0.5%, and a maximum allowable secondary burden of 0.1 Ω (or 2.5 VA on a 5 A secondary CT). This is a metering class rated current transformer.

1.2-H-0.2 indicates a current transformer with an accuracy of ±1.2%, and a maximum allowable secondary burden of 0.2 Ω (or 5 VA on a 5 A secondary CT). This is a protection class rated current transformer.

Current Sensors

The basic principle of any current sensor is to produce a small level of secondary voltage, within a specific accuracy range, which is directly proportional to the measured primary current. In medium voltage applications, isolation between the primary and secondary circuits is critical.

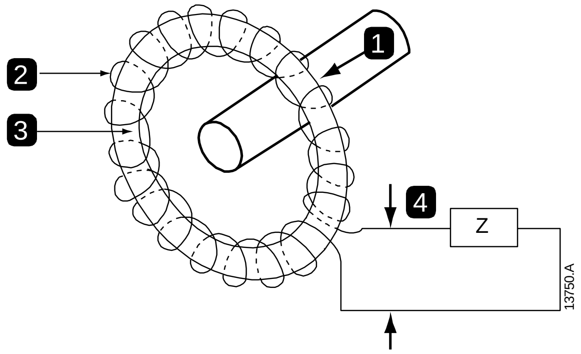
Although current transformers are the most commonly used device for measuring current, there are a number of other methods available. Current sensors are usually designed and supplied by manufacturers as proprietary equipment to match a digital metering or protection relay. Low power current sensors are ideal for use with modern digital relays, which provide a low burden. Sometimes referred to as hybrid current sensors, each type has its own merits.

Rogowski coil

A rogowski coil consists of a single primary winding, which is normally a copper bar with termination points at both ends. The secondary winding is made up of multiple turns on a toroidal, non-ferrous core. The entire construction is encased in a dielectric insulation material.

The basic operating principle is that the voltage produced across a high impedance secondary load is directly proportional to the primary current. Accuracy is typically ±1% up to 10 times the rated primary current and ±5% up to 200 times the rated primary current.

The customer must specify the required nominal primary current, short-time fault current withstand rating and the insulation level requirements. No other specifications apply, as rogowski coils are supplied by the manufacturer as a matched item with the associated relay device.



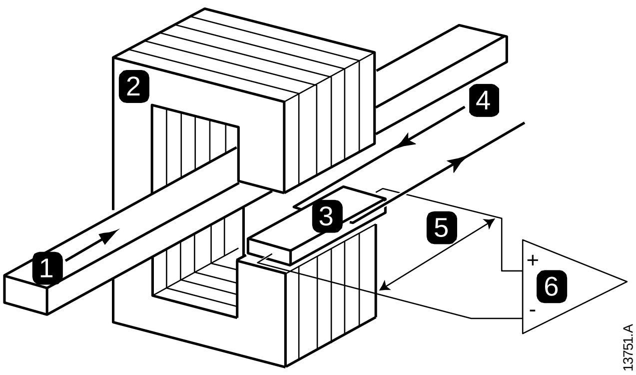
1	Current to be measured
2	Secondary winding
3	Non-ferromagnetic support
4	Output voltage

Hall effect sensor

Hall effect sensors consist of a semiconductor hall cell placed in the air-gap of a magnetic circuit. The strength of the magnetic circuit is directly influenced by the primary current. The hall cell is supplied by a steady-state current and the generated secondary output voltage is proportional to the magnetic field strength.

Inaccuracies in this measurement method are compensated for by using integrated digital circuitry.

Hall effect sensors are usually integrated into other equipment for measurement of AC and DC primary current.

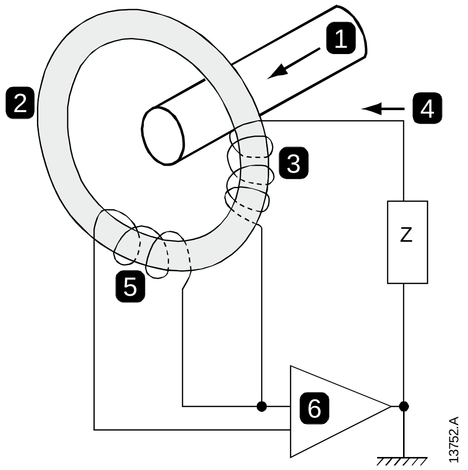


1	Current to be measured
2	Magnetic circuit
3	Hall cell
4	Hall cell supply current
5	Hall output voltage
6	Voltage or current amplifier

Zero flux current transformer

A zero flux current transformer consists of a single primary winding and a secondary made up of two windings on a toroidal magnetic core. The first secondary winding cancels out the flux in the magnetic core (hence the name zero flux). The second winding generates a current in the secondary load, which is directly proportional to the measured primary current.

This method is very accurate with a tolerance in the order of ±0.02%. A zero flux CT can only be used to measure DC primary current.



1	Current to be measured
2	Magnetic circuit
3	Secondary winding
4	Secondary circuit current
5	Zero flux detection winding
6	Current amplifier

Protection Devices

Protection devices are used in medium voltage distribution systems to protect line and cable feeders, busbar systems, transformers, motors, generators and power factor correction banks. Abnormal conditions can be detected based on secondary current and voltage measurement, or temperature monitoring using thermal devices. When an abnormal condition is detected, correct coordination of the protection devices will rapidly isolate the fault to a specific zone in the system.

Older protection devices relied on electromechanical relays to measure system parameters. Modern protection devices are exclusively low consumption, digital, and microprocessor based, with many communication options available. Modern high-end protection devices incorporate many parameter settings along with programmable logic control which provides not only protection functions, but switchgear control and interlocking.

Protection devices are primarily covered by IEC 60255-1.

Protection functions

Overcurrent

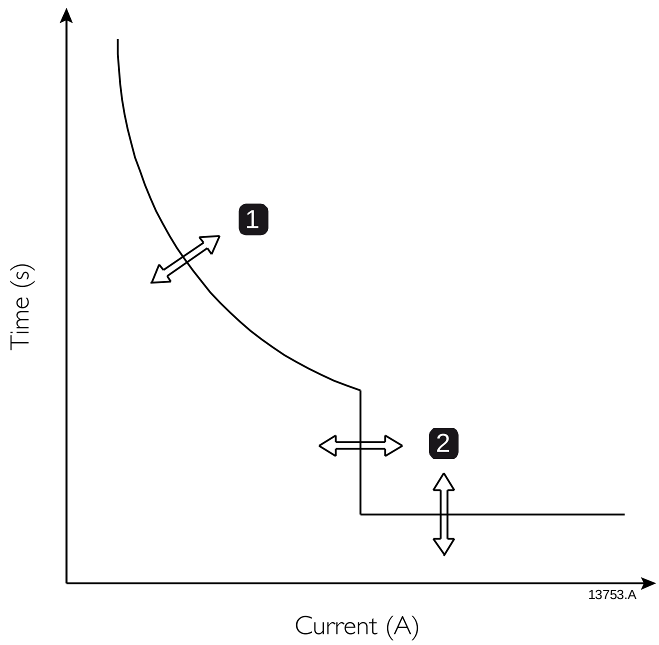
This is the most widely used form of protection. In a 3-phase power system, all three line currents are measured using current transformers. The secondary output of a 1 A or 5 A current transformer is connected to the current input of a protection device. Within the protection device, analog signals are filtered and sampled before being converted to digital signals for processing. A trip condition occurs if a preset current level is exceeded for a specific time.

There are two basic methods of overcurrent protection:

- Time-overcurrent protection - provides overload protection similar to a bimetallic thermal overload device, except thermal modelling adjusts the trip curve shape to allow for dynamic heating and cooling conditions. If the measured current reaches a point on the overload curve, a trip will occur. Time-overcurrent is also referred to as "inverse" (I) protection
- Instantaneous overcurrent protection - provides medium level and high level short circuit protection. If a set current level is exceeded for set time period, a trip will occur. This protection is also referred to as definite minimum time (DMT) protection.

Devices may combine time-overcurrent and instantaneous overcurrent protection. Time-overcurrent is normally only applied to electrical machines such as transformers and motors, whereas instantaneous overcurrent is applied to cables, busbar systems etc. Overcurrent protection can be directional, which is sometimes used for more advanced selective isolation of faults.

Overcurrent protection

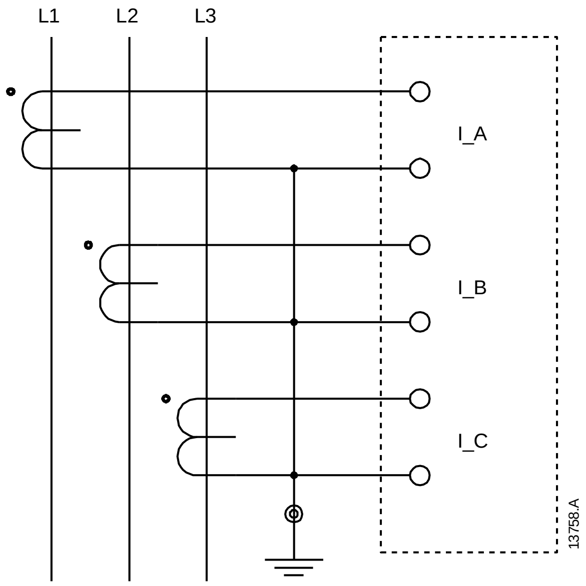


1	Time overcurrent (I)
2	Instantaneous overcurrent (DMT)

Overcurrent protection based on measuring the 3-phase line currents, produces positive sequence current (I_1, indicative of phase-to-phase faults) or negative phase sequence current (I_2, indicative of phase loss or phase imbalance). Overcurrent protection based on measuring the residual or ground current, produces zero sequence current (I_0, indicative of ground fault or earth leakage).

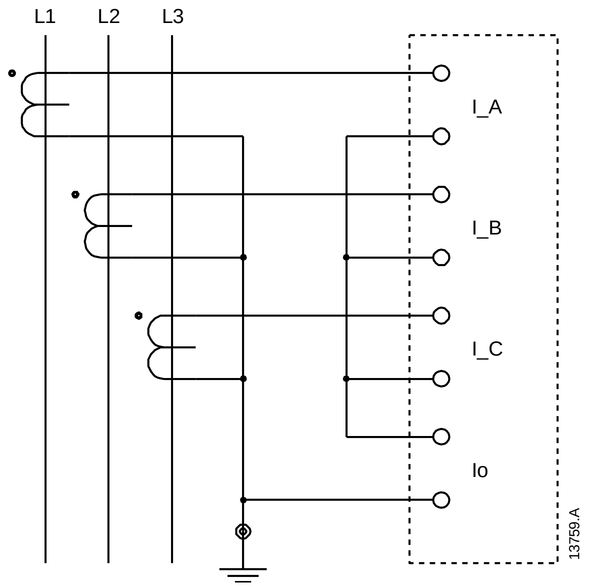
The configuration of the CTs depends on the functionality of the protection device:

Line current protection



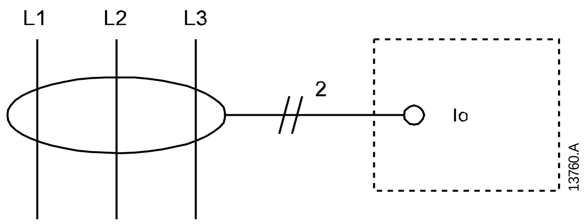
Positive sequence current, I_1
Negative sequence current, I_2

Line current and residual current protection



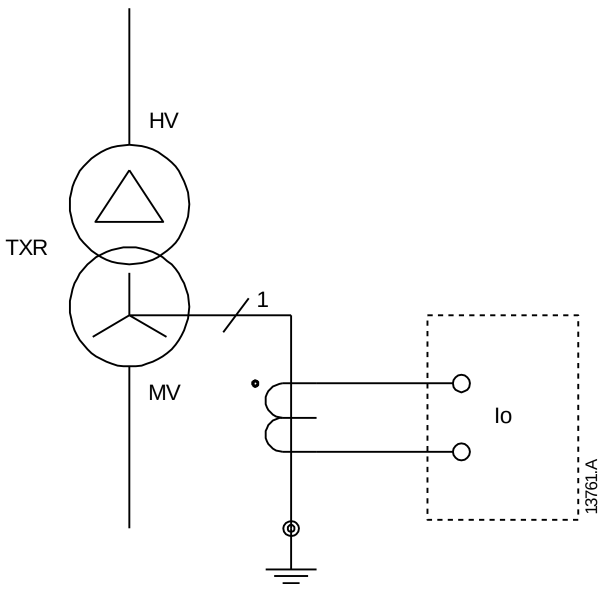
Positive sequence current, I_1
Negative sequence current, I_2
Zero sequence current, I_0

Ground current protection



Zero sequence current, I_0

Ground current protection

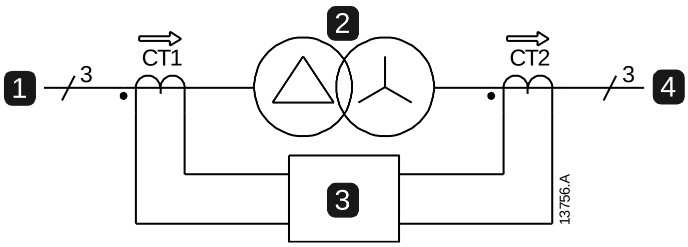


Zero sequence current, I_0

Differential

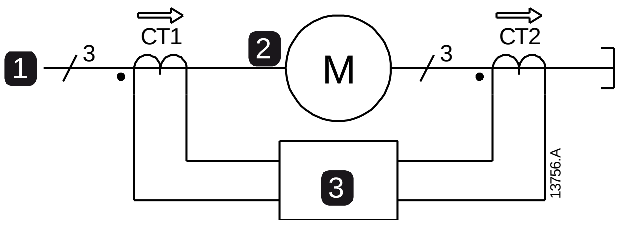
In medium voltage installations, differential protection is mainly used on transformers, motors and generators. Line currents are measured on both sides of the device, to determine the difference between the input and output currents (individual or 3-phase average). If the difference exceeds a preset limit, this indicates a phase loss or short circuit fault condition. A trip will occur, isolating the affected electrical device from the rest of the system.

Transformer application



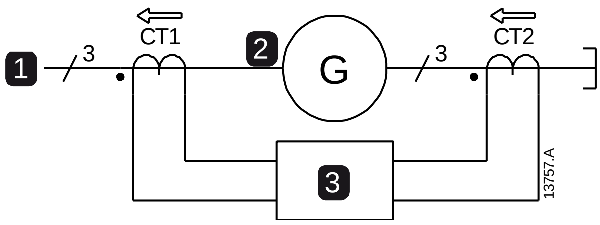
1	HV supply
2	Transformer
3	Differential protection device
4	MV supply

MV motor application



1	Incoming supply
2	MV motor
3	Differential protection device

MV generator application



1	Output supply
2	MV generator
3	Differential protection device

Bus zone

This protection is used on bus distribution systems. The 3-phase line currents are measured on all feeders connected to a busbar system. The sum of currents entering should equal the sum of currents leaving the busbar system. If the difference in individual or 3-phase average currents is not close to zero, a trip will occur.

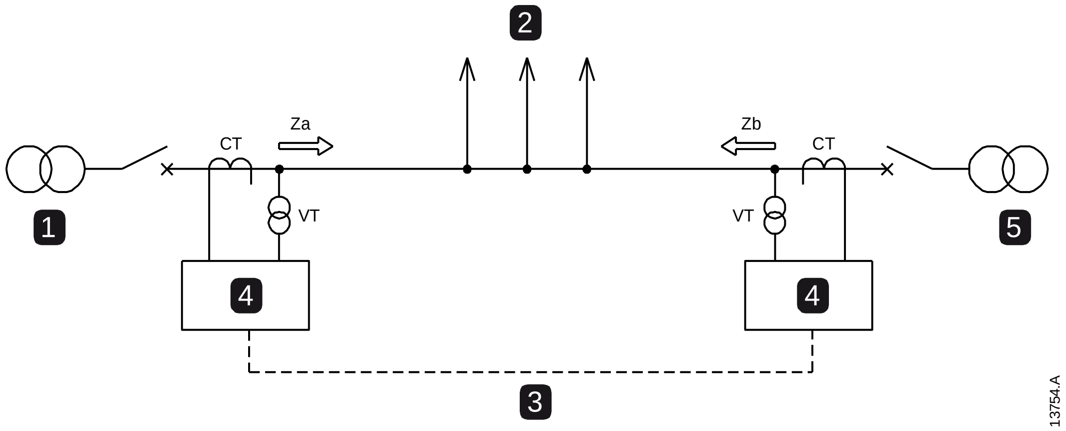
Bus configurations can be complex, but by using the status information of all the switching devices on a busbar system, logic within the protection device can selectively isolate the faulty zone.

Distance

This protection is predominantly used on long transmission lines running between primary substations, with radial feeders along the length of the transmission line. The distance to a fault is determined by calculating the line fault impedance with a healthy line impedance. Both line voltages and currents are measured to calculate the fault impedance.

Selective line isolation is achieved by setting a trip zone within the protection device. This trip zone covers a specific distance along the length of the transmission line from where the protection device is installed. Protection devices are used in pairs installed at each end of a transmission line, and a fast speed, real-time communication link is required between devices.

Distance protection system



1	Substation A	4	Distance protection device
2	Radial feeders	5	Substation B
3	Communication link		

Voltage

Voltage protection is often used on transformers, motor, generators and power factor banks which can be damaged due to long term undervoltage or overvoltage conditions.

If the average 3-phase or any individual line voltage falls outside a specific range for a specific period, a trip will occur. A time delay is used to override temporary surges and dips in the mains voltage.

ANSI protection codes

The American National Standards Institute developed a standardised table of numerical codes indicating specific protection functions. These codes are internationally recognised, and are often used in single line diagrams or tender documents as part of a project specification.

ANSI codes commonly specified for medium voltage feeders, transformers, motor and power factor banks.

ANSI code	Function	Description	Application				Components required	
			Incomer feeder panel	Transformer	Motor	Power factor bank	CT	VT
24	Volts per hertz relay	Activates if the Volts/Hertz ratio falls outside a preset range.		X				X
25	Synchronising or synch-check device	Operates when the voltage, frequency, and phase angles between two AC systems are within a preset acceptable range.	X					X
26	Apparatus device	Activates if the monitored apparatus exceeds a preset temperature.		X	X	X		
27	Undervoltage relay	Activates if the voltage falls below a preset level.		X	X	X		X
37	Undercurrent/ power relay	Activates if the current or power falls below a preset level.			X		X	
38	Bearing protective device	Activates when the upper temperature limit of a machine bearing is exceeded or abnormal bearing wear is detected.			X			
46	Phase reversal or current imbalance relay	Monitors line currents and activates when phase reversal is detected or when line current imbalance of negative phase sequence currents fall outside a preset range.	X		X		X	
47	Phase sequence voltage relay	Monitors line voltages and activates when phase reversal is detected.			X			X
48	Incomplete sequence relay	Trips or turns off a device if a particular sequence has not been completed within a preset time period.			X			
49 (P,R)	Machine or transformer thermal relay	Activates if the monitored machine or transformer part exceeds a preset temperature. (P = PTC, R = RTD)		X	X	X		
50 (N,G)	AC instantaneous or di/dt relay	Activates if the current or di/dt values exceed a preset level. Normally indicates a medium to high level fault condition. (N = neutral, G = ground)	X	X	X	X	X	
51 (N,G)	AC time-overcurrent relay	Activates when the current exceeds a preset level based on a thermal overload trip curve. (N = neutral, G = ground)	X	X	X	X	X	
59	Overvoltage relay	Activates if the voltage exceeds a preset level.		X	X	X		X
64	Ground (earth) detector relay	Activates when earth current flow is detected from the frame, chassis, case or structure of a device, indicating a breakdown of insulation in an electrical machine or transformer.		X	X		X	

ANSI code	Function	Description	Application				Components required	
			Incomer feeder panel	Transformer	Motor	Power factor bank	CT	VT
67	AC directional current relay	Activates when the current, flowing in a specific direction, exceeds a preset level. This protection is based on 50 and 51 functions.	X				X	
79	AC reclosing relay	Controls the automatic reclosing and locking-out of an AC circuit switching device.	X					
81	Frequency relay	Activates if the frequency falls outside a preset range.		X	X	X		X
86	Locking-out relay	Shuts down or holds equipment out of service under abnormal conditions. May be manually or electrically operated.	X					
87 (L, T, M)	Differential protection relay	Activates if the detected current on opposite sides of a machine or transformer are not equal to each other. (L = line, T = transformer, G = generator)		X	X		X	

AuCom soft starter ANSI protection functions

The following ANSI code protections are standard in AuCom medium voltage soft starters. For details of additional protections in MVS and MVX which are not listed in this table, refer to the relevant user manual.

ANSI Code	ANSI Function	MVS/MVX Trip
26	Apparatus device	Motor thermal model
27/59	Under/overvoltage relay	Undervoltage and overvoltage
37	Undercurrent/power relay	Undercurrent
46	Phase reversal or current imbalance relay	Phase sequence and current imbalance
48	Incomplete sequence relay	Excess start time
50	AC instantaneous or di/dt relay	Instantaneous overcurrent
51	AC time-overcurrent relay	Time-overcurrent
64	Ground (earth) detector relay	Ground fault
81	Frequency relay	Supply frequency

Temperature related protection functions such as motor winding and bearing protection require a separate protection device which can be installed in the LV section of the soft starter panel.

Voltage Transformers

A voltage transformer (VT) or instrument transformer is used to produce a lower secondary voltage which is directly proportional to the primary voltage both in value and phase angle.

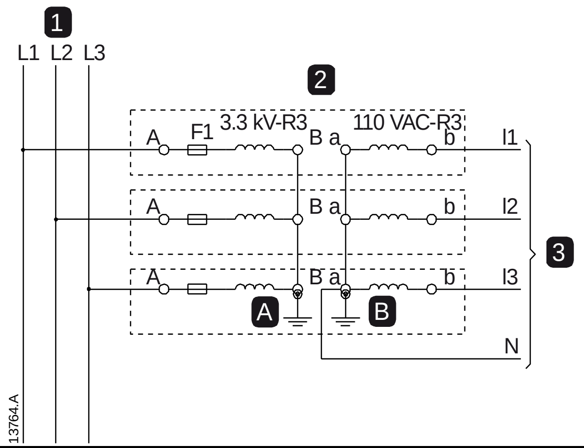
In medium voltage switchgear, a 3-phase voltage transformer arrangement is typically derived by using three, single phase transformer poles. Each pole consists of a single primary and secondary winding encapsulated in epoxy resin and encased with insulating material. In most single phase pole designs, the primary winding has integrated fusing. In a 3-phase arrangement, the primary windings of each individual pole are externally connected in star configuration. Each end of the secondary winding is brought out to a customer termination box. The secondary windings can be externally connected in star or delta configuration and must always be separately fused. Star connection of the secondary winding is preferable, as this provides voltage stability through solid earthing of the neutral point and 3-phase and neutral is available for voltage measurement.

Switchgear installations use either fixed or withdrawable voltage transformers. Withdrawable voltage transformers are mounted on a draw-out truck arrangement.

The power rating and accuracy of a transformer arrangement will depend on its application. For metering, protection and indication, power ratings are small, with accuracies in the range of ±0.5-3.0%. A voltage transformer used to provide a control supply may have a power rating above 5 kVA. In this case, accuracy is not as important.

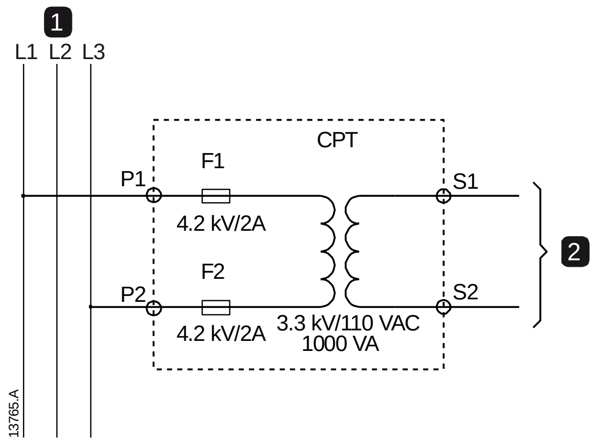
Relevant standards: IEC 61869-3, IEEE C57.13.

Voltage transformer (3-phase, fixed)



1	Mains supply
2	3 x single phase VT poles
A	Primary winding
B	Secondary winding
3	3-phase and neutral, 110 VAC phase-to-phase (external fusing required)

Control supply transformer (single phase, fixed)



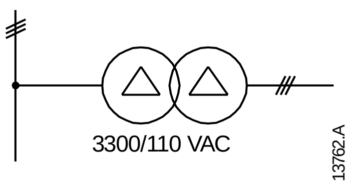
1	Mains supply
2	110 VAC secondary (external fusing required)

IEC ratings

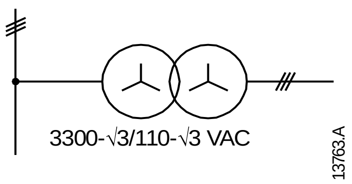
The main standard applying to MV voltage transformers is 61869-3.

Nominal voltage

Example: 3.3 kV/110 VAC
Denotes a primary phase-to-phase voltage rating of 3300 V and a secondary phase-to-phase voltage rating of 110 VAC.



Example: 3.3 kV-√3/110-√3 VAC
Denotes a primary phase-to-phase voltage rating of 3300 V and phase-to-earth rating of 1905 V
(ie: 3300 x √3), and a secondary phase-to-phase voltage rating of 110 VAC and phase-to-earth rating of 63.5 VAC (ie: 110 x √3)



Many manufacturers use a continuous overload rating of 1.2 times the primary voltage rating without exceeding thermal capabilities which can lead to winding and insulation failure.

Output power

This is the apparent output power rating of a transformer when nominal voltage is applied to the primary.

For a 3-phase voltage transformer arrangement, $S = \sqrt{3} \times U \times I$ For a single phase voltage transformer arrangement, $S = U \times I$	Where: S = apparent output power (VA) U = secondary line voltage rating (V) I = secondary line current rating (A)

Standard values are: 10, 15, 25, 30, 50, 75, 100, 120 VA

Control supply power transformers are usually single phase transformers, with an output power rating of 500 VA to 5000 VA. For further details, refer to *Control power supply transformer sizing* on page 128.

Accuracy class

Designates the maximum error of the transformed voltage and phase angles at rated primary voltage.

IEC 61869-3 specifies standard accuracy classes for voltage transformers.

Accuracy classes for metering applications

Class	Application
Metering class 0.2	High accuracy applications (eg revenue metering)
Metering class 0.5 and 1.0	General use
Metering class 3.0	Rarely used

Accuracy classes for protection applications

Class	Voltage error ±% (between 0.5~1.5 × U_p for earthed systems; between 0.5~1.9 × U_p for unearthed systems)	Phase shift in minutes (60 minutes = 1 degree) (between 0.5~1.5 × U_p for earthed systems; between 0.5~1.9 × U_p for unearthed systems)
3P	3	120
6P	6	24

Control supply power transformer sizing

Sizing a control supply power transformer (CPT) requires analysis of the expected secondary load.

Information required:

- total inrush VA of the load
- total sealed VA of the load
- acceptable voltage drop level on the secondary of the transformer at inrush stage.

In most cases, the inrush period is 20 to 100 milliseconds. The power factor of the inrush current is assumed to be 0.4 (for other values, use the adjustment factor in the table below).

To select a CPT:

1. Determine the acceptable voltage drop on the secondary of the transformer at inrush stage. In the appropriate voltage drop column, select an Inrush VA value larger than the calculated total inrush VA of the secondary load. Note: the total inrush VA of the secondary load must include any resistive loading.
2. Find the corresponding transformer power rating, in the Nominal VA rating column.
3. Check that the Nominal VA rating value is larger than the calculated total sealed VA of the transformer secondary load.
4. If the inrush VA power factor is different from 0.4, multiply the Nominal VA rating by the Power Factor Adjustment factor.

CPT selection - Inrush VA at selected voltage drop

Inrush VA			Nominal VA rating
85% voltage drop	90% voltage drop	95% voltage drop	
347	289	216	63
338	290	229	80
907	745	541	130
1267	1039	754	200
1394	1116	781	250
2870	2298	1584	350
3786	3013	2065	500
7360	5763	3786	750
7360	5763	3786	800
8837	6785	4329	1000
14921	11328	7070	1600
20500	14850	9100	2000

CPT selection - power factor adjustment factor

Power factor	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Adjustment factor	1.5	1.29	1.11	1.00	0.91	0.82	0.78	0.71	0.67	0.64

Exercise

A transformer with its primary connected to 7.2 kV, has a 110 VAC secondary with a total inrush loading of 850 VA and a resistive load of 100 VA. The total sealed VA of the load is 200 VA.

A voltage drop of 85% is acceptable during the inrush stage. The power factor of the inrush current is 0.3.

Calculate the necessary power rating of the control supply power transformer.

1. The total inrush loading is 950 VA (850 VA + 100 VA). The next highest Inrush VA figure in the 85% volt drop column is 1267 VA.
2. An Inrush VA of 1267 VA equates to a Nominal VA rating of 200 VA.
3. 200 VA seems acceptable as this is equivalent to the total sealed load VA.
4. The inrush current has a power factor of 0.3. Using the power factor adjustment factor, the transformer has a revised Nominal VA rating of 222 VA (200 x 1.11). The next highest standard size would be 250 VA.

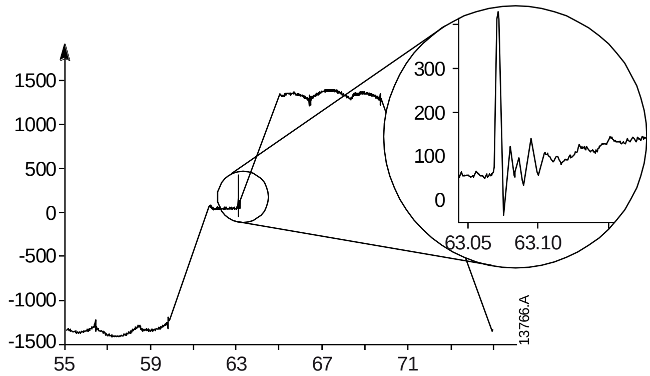
Use a 7.2 kV/110 VAC, 250 VA single phase control supply power transformer.

Transformer primary fuses must withstand the inrush magnetising current which flows when a transformer primary is switched on. With a medium voltage primary, E-rated fuses are used and often selected to withstand 25 times the nominal primary current for 0.01 second and 12 times the nominal primary current for 0.1 second.

Motor Line Inductors on Soft Starter Applications

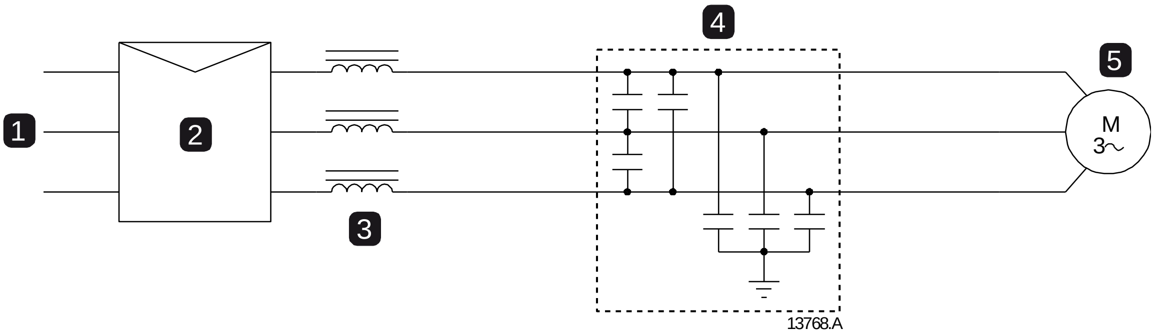
Long motor cables on the output of a soft starter are seen as a capacitive load which creates a di/dt current transient at each SCR turn-on event. If the current transient repeatedly exceeds the di/dt rating of the SCR, failure will occur.

Soft starter start current waveform



The current transient, peak value and rate-of-rise are are installation dependent, and are determined by many factors external to the soft starter. The di/dt value of the current transient is proportional to the system voltage (for example, the value for a 6.6 kV system will be approximately twice as much as a 3.3 kV system).

At a critical cable length, the cable capacitance must be negated by line inductance to avoid damaging current transients. Air-core line inductors are specified according to the installation and are fitted close to the soft starter output terminals.



1	3-phase supply
2	Soft starter
3	Line inductors
4	Cable capacitance
5	MV motor

Soft starter SCRs are most vulnerable to current transient damage at two stages of the motor starting procedure:

- in the initial ramp-up to the start current (current limit) level.
- when the SCRs reach full conduction and just before the motor current falls to the running current level.

The latter stage is potentially more damaging. AuCom medium voltage soft starters are bypassed in run state and the SCRs are turned off, minimising the risk of current transient damage.

Current transient influences

The di/dt current transients that occur at SCR turn-on are influenced by the following factors:

- System voltage and frequency
- Total cable capacitance upstream and downstream of the soft starter
- Motor characteristics (kW, efficiency, starting power factor)
- Soft starter snubber component values (RC network components)
- Control stage of the motor start-up period
- Start current (current limit) level

Line inductor sizing

Various software tools and calculation methods are used to determine the inductance value required for a specific soft starter application. In most cases, the required inductance per phase will be at least 100 µH. The required inductance increases as the mains supply voltage increases.

The following rating information is usually provided with line inductors:

Voltage	must be at least equal to system voltage
Frequency	must equal system frequency
Current	must at least equal motor FLC
Inductance	(as calculated)

Sizing guidelines for AuCom MV soft starter applications

For AuCom MV soft starter installations with output motor cable runs exceeding 100 metres, compensation inductance may be required. Consult AuCom for advice on these applications.

As a general guideline, compensation inductance required (per phase) can be calculated as:

$L_{COMP} \geq \frac{\sqrt{3} \times \sqrt{2} \times U_s}{2 \times didt}$	Where: L_{COMP} = compensation inductance per phase (µH) U_s = line supply voltage (V) didt = SCR maximum didt rating (A/µs)

NOTE
This calculation involves many assumptions. Double the required compensation inductance before selecting the output inductors.

Exercise:

Calculate the compensation inductance required for a 4.2 kV MVS soft starter installation. Assume the maximum SCR didt rating to be 100 A/µs.

$$L_{COMP} \geq \frac{\sqrt{3} \times \sqrt{2} \times U_s}{2 \times didt}$$

$$\geq \frac{\sqrt{3} \times \sqrt{2} \times 4200}{2 \times 100}$$

$$\geq 51\ \mu H$$

This calculation should be doubled to use a minimum compensation inductance of 102 µH per phase.

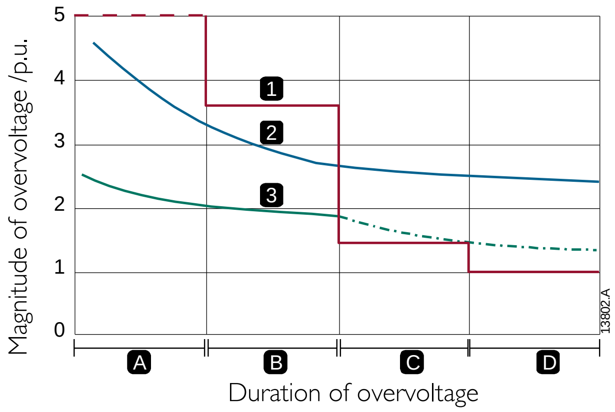
Medium Voltage Surge Arrestors

Any system is designed with a maximum withstand voltage rating, and exceeding this rating will lead to catastrophic failure. Overvoltage protection devices are used in medium voltage systems to protect electrical machinery, cables, lines, etc against damage from overvoltage transients.

Overvoltage transients are caused by two main events:

- A lightning strike causes a very fast, high energy voltage transient. This can produce a 8/20 μs current transient in the order of 1.5 to 20 kA, depending on the installation
- Equipment switching causes a medium level voltage transient. This can produce a 30/60 μs current transient in the order of 125 to 1000 A, depending on the installation.

A protection device earths the current associated with an overvoltage transient. This limits the terminal voltage at the point of installation to a level below the withstand voltage of the equipment.

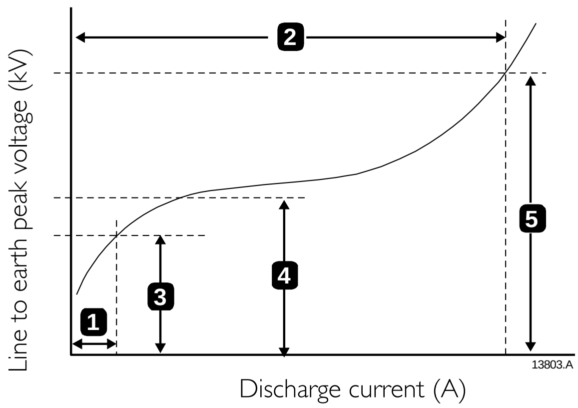


1	Possible voltage without arrestors
2	Withstand voltage of equipment
3	Voltage limited by arrestors
A	Lightning overvoltages (microseconds)
B	Switching overvoltages (milliseconds)
C	Temporary overvoltages (seconds)
D	Highest system voltage (continuous)

In the past, overvoltage protection was provided using spark-gap arrestors. Today, most indoor medium voltage systems use metal-oxide (MO) arresters which provide a compact and dependable solution for overvoltage protection. MO arresters are covered by IEC 60099-4 and IEEE C62.22-2009. MO arresters are often used in gas insulated, indoor switchgear to avoid restrike during equipment switching

Application and selection

MO arrestors are usually connected from each phase line to earth, at close proximity to the equipment being protected. When the system voltage is within the normal operating range, the arrestor's resistance is high. At a predetermined knee-point, the resistance reduces rapidly in response to rising voltage. This provides a low resistance path for current to be diverted to earth. When this happens, a residual protection voltage (U_{res}) appears across the arrestor terminals. An MO arrestor is selected so that the lightning impulse-withstand voltage level (U_p) or BIL of the equipment is 1.4 times the residual protection voltage (U_{res}) developed when maximum transient current is flowing to earth.



1	Leakage current, I_l (mA)
2	Nominal discharge current, I_n (kA)
3	Continuous operating voltage, U_c (kV)
4	Rated voltage, U_r (kV)
5	Residual protection voltage, U_{res} (kV)

Selection Ratings

There are four ratings to consider when selecting MO arrestors for an installation.

Nominal discharge current (I_n)

Maximum discharge current the MO arrestor can shunt to earth, without exceeding its thermal and mechanical limits. Manufacturers usually state two discharge current ratings:

- Current produced as a result of a lightning strike voltage transient. This discharge current is assumed to be an 8/20 µs waveform with the following standard ratings:
  1.5 kA, 2.5 kA, 5 kA, 10 kA, 20 kA
  For the majority of secondary indoor switchgear systems, a rating of 10 kA is used for selection (sometimes referred to as "distribution class")
- Current produced as a result of an equipment switching voltage transient. This discharge current is assumed to be a 30/60 µs waveform with standard ratings from 125 A to 1000 A.
  For the majority of secondary indoor switchgear systems, a rating of 500 A is used for selection (sometimes referred to as "distribution class")

Continuous operating voltage (U_c)

This is based on the maximum-peak operating voltage likely to occur in the system when a single phase-to-earth fault occurs. IEEE standards refer to this rating as MCOV (maximum continuous operating voltage).

For a solidly earthed neutral system:

$$U_c \geq 1.05 \times \frac{U_s}{\sqrt{3}}$$

For a high impedance or isolated earthed neutral system:

$U_c \geq U_s$

Where U_s = system phase-to-phase line voltage (kV)

Rated voltage (U_r)

This rating is based on the thermal capabilities of the MO arrestor to endure short-term overvoltage transients exceeding the continuous operating voltage limits.

For all types of earthed neutral systems:

$U_r \geq 1.25 \times U_c$

Residual protection voltage (U_{res})

This is the voltage which appears across the MO arrester when it is shunting the maximum nominal discharge current to ground. Using a safety margin, the residual protection voltage must be somewhat less than the lightning-impulse withstand voltage rating (U_p) of the equipment is it protecting.

$$U_{res} \leq \frac{U_p}{1.4}$$

Guideline for MO arrestor voltage ratings

Us	Uc		Ur		Up	Ures
System voltage (kV)	Earthed neutral system (kV_min)	Isolated earthed neutral system (kV_min)	Earthed neutral system (kV_min)	Isolated earthed neutral system (kV_min)	Lightning impulse withstand rating or BIL (kV)	Residual protection voltage (kV_max)
3.6	2.16	3.6	2.7	4.5	40	28
7.2	4.32	7.2	5.4	9	60	42
12	7.2	12	9	15	75	52
17.5	10.5	17.5	13	22	95	66
24	14.4	24	18	30	125	88
36	21.6	36	22	45	170	120

Exercise

A 17.5 kV secondary distribution, indoor switchgear system requires MO arrestors to be fitted on the incomer side. The system supply is 15 kV/50 Hz and is isolated from earth. Use calculated ratings and the manufacturers' data sheet for selection.

The highlighted numbers 1~4 refer to the solution page.

Step 1: Calculate the MO arrestor ratings

- Continuous operating voltage **1**

  For an isolated earthed neutral system, continuous operating voltage (U_c) ≥ system voltage (U_s)

  $U_c \geq 15$ kV

- Rated voltage **2**

  Rated voltage (U_r) ≥ 1.25 times continuous operating voltage (U_c)

  $U_r \geq 1.25 \times 15$

  $U_r \geq 18.75$ kV

- Nominal discharge current **3**

  For a secondary distribution system, use a lightning-impulse nominal discharge current rating (I_n) of 10 kA.

- Residual protection voltage **4**

  The residual protection voltage (U_{res}) developed across the MO arrester, when discharging 10 kA, must be less than 70% of the equipment lightning-impulse rating (U_p)

  $U_{res} \leq U_p \times 0.7$

  $\leq 95 \times 0.7$

  ≤ 66 kV

Step 2: Using the calculated ratings, select an MO arrestor from the manufacturer's data sheet

Type	U_r Rated voltage	U_c Continuous operating voltage	Residual voltage (U_{res}) in kV pk at a specified impulse current										
			Wave 1/.. µs			Wave 8/20 µs				Wave 30/60 µs			
MWD	kV rms	kV rms	1 kA pk	5 kA pk	10 kA pk	1 kA pk	5 kA pk	10 kA pk	20 kA pk	125 A pk	250 A pk	500 A pk	1 kA pk
04	5.0	4	10.5	12.8	14.5	10.4	11.6	12.3	13.6	9.0	9.5	9.8	10.2
05	6.3	5	13.1	16.0	18.1	13.0	14.5	15.4	17.0	11.3	11.9	12.3	12.8
06	7.5	6	15.7	19.2	21.7	15.6	17.4	18.4	20.4	13.6	14.3	14.8	15.4
07	8.8	7	18.3	22.4	25.3	18.2	20.3	21.5	23.8	15.8	16.7	17.2	17.9
08	10.0	8	21.0	25.6	29.0	20.8	23.2	24.6	27.2	18.1	19.0	19.7	20.5
09	11.3	9	23.6	28.9	32.6	23.4	26.1	27.6	30.6	20.3	21.4	22.1	23.0
10	12.5	10	26.2	32.1	36.2	26.0	29.0	30.7	34.0	22.6	23.8	24.6	25.6
11	13.8	11	28.8	35.3	39.8	28.6	31.9	33.8	37.4	24.9	26.2	27.1	28.2
12	15.0	12	31.4	38.5	43.4	31.2	34.8	36.8	40.8	27.1	28.6	29.5	30.7
13	16.3	13	34.1	41.7	47.1	33.8	37.7	39.9	44.2	29.4	30.9	32.0	33.3
14	17.5	14	36.7	44.9	50.7	36.4	40.6	43.0	47.6	31.7	33.3	34.5	35.8
15	18.8	15	39.3	48.1	54.3	39.0	43.5	46.1	51.0	33.9	35.7	36.9	38.4
16	20.0	16	41.9	51.3	57.9	41.6	46.4	49.1	54.4	36.2	38.1	39.4	41.0
17	21.3	17	44.5	54.5	61.5	44.2	49.3	52.2	57.8	38.4	40.5	41.8	43.5
18	22.5	18	47.2	57.7	65.2	46.8	52.2	55.3	61.2	40.7	42.9	44.3	46.1
19	23.8	19	49.8	60.9	68.8	49.4	55.1	58.3	64.6	43.0	45.2	46.8	48.6
20	25.0	20	52.4	64.1	72.4	52.0	58.0	61.4	68.0	45.2	47.6	49.2	51.2
21	26.3	21	55.0	67.3	76.0	54.6	60.9	64.5	71.4	47.5	50.0	51.7	53.8
22	27.5	22	57.6	70.5	79.6	57.2	63.8	67.5	74.8	49.7	52.4	54.1	56.3
23	28.8	23	60.3	73.7	83.3	59.8	66.7	70.6	78.2	52.0	54.8	56.6	58.9
24	30.0	24	62.9	76.9	86.9	62.4	69.6	73.7	81.6	54.3	57.1	59.1	61.4
25	31.3	25	65.5	80.1	90.5	65.0	72.5	76.8	85.0	56.5	59.5	61.5	64.0
26	32.5	26	68.1	83.4	94.1	67.6	75.4	79.8	88.4	58.8	61.9	64.0	66.5
27	33.8	27	70.7	86.6	97.7	70.2	78.3	82.9	91.8	61.0	64.3	66.4	69.1
28	35.0	28	73.4	89.8	101.4	72.8	81.2	86.0	95.2	63.3	66.7	68.9	71.7
29	36.3	29	76.0	93.0	105.0	75.4	84.1	89.0	98.6	65.6	69.0	71.4	74.2
30	37.5	30	78.6	96.2	108.6	78.0	87.0	92.1	102.0	67.8	71.4	73.8	76.8
31	38.8	31	81.2	99.4	112.2	80.6	89.9	95.2	105.4	70.1	73.8	76.3	79.3
32	40.0	32	83.9	102.6	115.8	83.2	92.8	98.2	108.8	72.3	76.2	78.7	81.9
33	41.3	33	86.5	105.8	119.5	85.8	95.7	101.3	112.2	74.6	78.6	81.2	84.5
34	42.5	34	89.1	109.0	123.1	88.4	98.6	104.4	115.5	76.9	80.9	83.7	87.0
35	43.8	35	91.7	112.2	126.7	91.0	101.5	107.5	118.9	79.1	83.3	86.1	89.6
36	45.0	36	94.3	115.4	130.3	93.6	104.4	110.5	122.3	81.4	85.7	88.6	92.1
37	46.30	37	97.0	118.6	134.0	96.2	107.3	113.6	125.7	83.7	88.1	91.1	94.7
38	47.50	38	99.6	121.8	137.6	98.8	110.2	116.7	129.1	85.9	90.5	93.5	97.3
39	48.80	39	102.2	125.0	141.2	101.4	113.1	119.7	132.5	88.2	92.8	96.0	99.8
40	50.00	40	104.8	128.2	144.8	104.0	116.0	122.8	135.9	90.4	95.2	98.4	102.4
41	51.30	41	107.4	131.4	148.4	106.6	118.9	125.9	139.3	92.7	97.6	100.9	104.9
42	52.50	42	110.1	134.6	152.1	109.2	121.8	128.9	142.7	95.0	100.0	103.4	107.5
43	53.80	43	112.7	137.9	155.7	111.8	124.7	132.0	146.1	97.2	102.4	105.8	110.1

Solution:

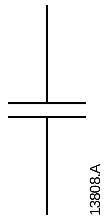
A type MWD15 meets the selection criteria.

Type	U_r	U_c	Residual voltage (U_{res}) in kV pk at a specified impulse current											
	Rated voltage	Continuous operating voltage	Wave 1/.. µs			Wave 8/20 µs				Wave 30/60 µs				
MWD	kV rms	kV rms	1 kA pk	5 kA pk	10 kA pk	1 kA pk	5 kA pk	10 kA pk	20 kA pk	125 A pk	250 A pk	500 A pk	1 kA pk
04	5.0	4	10.5	12.8	14.5	10.4	11.6	12.3	13.6	9.0	9.5	9.8	10.2
05	6.3	5	13.1	16.0	18.1	13.0	14.5	15.4	17.0	11.3	11.9	12.3	12.8
06	7.5	6	15.7	19.2	21.7	15.6	17.4	18.4	20.4	13.6	14.3	14.8	15.4
07	8.8	7	18.3	22.4	25.3	18.2	20.3	21.5	23.8	15.8	16.7	17.2	17.9
08	10.0	8	21.0	25.6	29.0	20.8	23.2	24.6	27.2	18.1	19.0	19.7	20.5
09	11.3	9	23.6	28.9	32.6	23.4	26.1	27.6	30.6	20.3	21.4	22.1	23.0
10	12.5	10	26.2	32.1	36.2	26.0	29.0	30.7	34.0	22.6	23.8	24.6	25.6
11	13.8	11	28.8	35.3	39.8	28.6	31.9	33.8	37.4	24.9	26.2	27.1	28.2
12	15.0	12	31.4	38.5	43.4	31.2	34.8	36.8	40.8	27.1	28.6	29.5	30.7
13	16.3	13	34.1	41.7	47.1	33.8	37.7	39.9	44.2	29.4	30.9	32.0	33.3
14	17.5	14	36.7	44.9	50.7	36.4	40.6	43.0	47.6	31.7	33.3	34.5	35.8
15	18.8	15	39.3	48.1	54.3	39.0	43.5	46.1	51.0	33.9	35.7	36.9	38.4
16	20.0	16	41.9	51.3	57.9	41.6	46.4	49.1	54.4	36.2	38.1	39.4	41.0
17	21.3	17	44.5	54.5	61.5	44.2	49.3	52.2	57.8	38.4	40.5	41.8	43.5
18	22.5	18	47.2	57.7	65.2	46.8	52.2	55.3	61.2	40.7	42.9	44.3	46.1
19	23.8	19	49.8	60.9	68.8	49.4	55.1	58.3	64.6	43.0	45.2	46.8	48.6
20	25.0	20	52.4	64.1	72.4	52.0	58.0	61.4	68.0	45.2	47.6	49.2	51.2
21	26.3	21	55.0	67.3	76.0	54.6	60.9	64.5	71.4	47.5	50.0	51.7	53.8
22	27.5	22	57.6	70.5	79.6	57.2	63.8	67.5	74.8	49.7	52.4	54.1	56.3
23	28.8	23	60.3	73.7	83.3	59.8	66.7	70.6	78.2	52.0	54.8	56.6	58.9
24	30.0	24	62.9	76.9	86.9	62.4	69.6	73.7	81.6	54.3	57.1	59.1	61.4
25	31.3	25	65.5	80.1	90.5	65.0	72.5	76.8	85.0	56.5	59.5	61.5	64.0
26	32.5	26	68.1	83.4	94.1	67.6	75.4	79.8	88.4	58.8	61.9	64.0	66.5
27	33.8	27	70.7	86.6	97.7	70.2	78.3	82.9	91.8	61.0	64.3	66.4	69.1
28	35.0	28	73.4	89.8	101.4	72.8	81.2	86.0	95.2	63.3	66.7	68.9	71.7
29	36.3	29	76.0	93.0	105.0	75.4	84.1	89.0	98.6	65.6	69.0	71.4	74.2
30	37.5	30	78.6	96.2	108.6	78.0	87.0	92.1	102.0	67.8	71.4	73.8	76.8
31	38.8	31	81.2	99.4	112.2	80.6	89.9	95.2	105.4	70.1	73.8	76.3	79.3
32	40.0	32	83.9	102.6	115.8	83.2	92.8	98.2	108.8	72.3	76.2	78.7	81.9
33	41.3	33	86.5	105.8	119.5	85.8	95.7	101.3	112.2	74.6	78.6	81.2	84.5
34	42.5	34	89.1	109.0	123.1	88.4	98.6	104.4	115.5	76.9	80.9	83.7	87.0
35	43.8	35	91.7	112.2	126.7	91.0	101.5	107.5	118.9	79.1	83.3	86.1	89.6
36	45.0	36	94.3	115.4	130.3	93.6	104.4	110.5	122.3	81.4	85.7	88.6	92.1
37	46.30	37	97.0	118.6	134.0	96.2	107.3	113.6	125.7	83.7	88.1	91.1	94.7
38	47.50	38	99.6	121.8	137.6	98.8	110.2	116.7	129.1	85.9	90.5	93.5	97.3
39	48.80	39	102.2	125.0	141.2	101.4	113.1	119.7	132.5	88.2	92.8	96.0	99.8
40	50.00	40	104.8	128.2	144.8	104.0	116.0	122.8	135.9	90.4	95.2	98.4	102.4
41	51.30	41	107.4	131.4	148.4	106.6	118.9	125.9	139.3	92.7	97.6	100.9	104.9
42	52.50	42	110.1	134.6	152.1	109.2	121.8	128.9	142.7	95.0	100.0	103.4	107.5
43	53.80	43	112.7	137.9	155.7	111.8	124.7	132.0	146.1	97.2	102.4	105.8	110.1

13806.A

Source: example data based on ABB MWD surge arrestors

Power Factor Capacitors



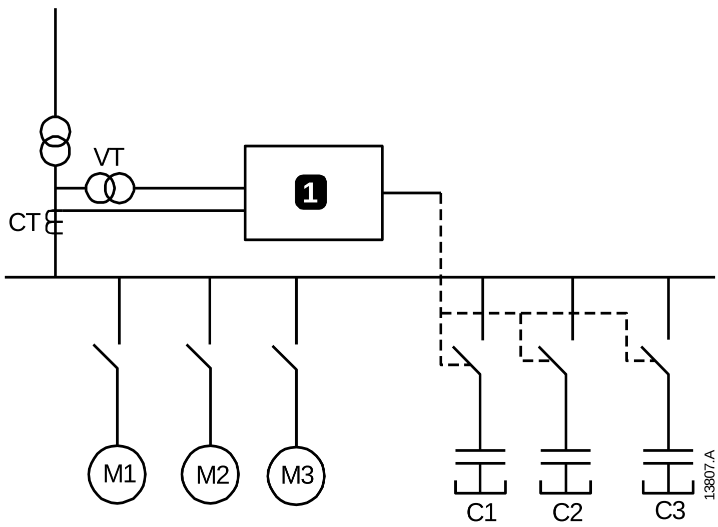
Power factor correction (PFC) capacitor banks are used to improve the overall power factor of a medium voltage distribution system or an individual installation.

Bulk power factor correction

This is installed at the point of common coupling, which is typically on the main busbar system in a medium voltage network.

If the loading on the network was constant, with a fixed inductance, bulk power factor correction could be of a fixed value and permanently connected to the system. However, this is often not the case. Most network loading is variable and if the bulk of the load is inductive, the amount of power factor correction required to maintain a target power factor also needs to vary. This is achieved by using a master PFC controller, which monitors the system's power factor and switches in nominal values of capacitance as needed to maintain a target value.

Circuit with bulk power factor correction



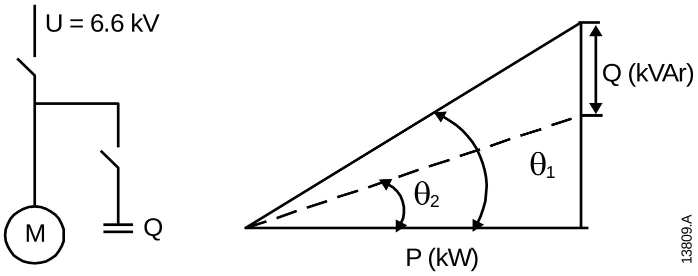
1	PFC controller

Individual power factor correction

A very common method of maintaining a target power factor for a motor is to install an individual power factor bank of fixed capacitance. The PFC bank is specifically sized for the motor installation and is switched in once the motor has reached full speed. This method is often used on large motors running fully loaded for extended periods of time.

Calculations: fixed capacitor bank for individual motor

To calculate the fixed capacitor bank power (Q) required to improve the power factor of an individual motor:



P = 1500 kW

η = 0.96

pf_1 = 0.88 (initial power factor)

pf_2 = 0.95 (target power factor)

$Q = \frac{P}{\eta} \times (\tan\theta_1 - \tan\theta_2)$	Where: Q = capacitor bank power (kVAr) P = motor shaft power (kW) η = motor efficiency at full load θ_1 = phase angle of motor power factor at full load (=$\cos^{-1} \times pf_1$) θ_2 = phase angle of target power factor at full load (=$\cos^{-1} \times pf_2$)

$$Q = \frac{P}{\eta} \times (\tan\theta_1 - \tan\theta_2)$$
$$= \frac{1500}{0.96} \times (\tan 28.4 - \tan 18.2)$$
$$= 1562.5 \times (0.54 - 0.33)$$
$$= 1562.5 \times 0.21$$
$$= 328 \text{ kVAr}$$

Required power is 325 kVAr

Calculations: PFC capacitor bank

To calculate the capacitor value (C) and nominal current value (I_{nom}) for a power factor correction capacitor bank:

- Capacitance

$C = \frac{Q}{U^2 (2\pi f)} \times 1000$	Where: C = capacitance (μF) Q = capacitor bank power (kVAr) U = supply voltage (kV) f = supply frequency (Hz)

- Nominal current

$I_{nom} = \frac{Q}{\sqrt{3} \times U}$

Exercise

Calculate the total capacitance and nominal current of a 500 kVAr power factor bank operating on a 6.6 kV/50 Hz supply system.

$$C = \frac{Q}{U^2(2\pi f)} \times 1000$$

$$= \frac{500}{6.6^2(2\pi 50)} \times 1000$$

$$= \frac{500}{43.56 \times 314.16} \times 1000$$

$$= 36\ \mu F$$

The capacitance is 36 μF.

$$I_{nom} = \frac{Q}{\sqrt{3} \times U}$$

$$= \frac{500}{\sqrt{3} \times 6.6}$$

$$= \frac{500}{8.33}$$

$$= 44\ A$$

The nominal current is 44 A.

Capacitor peak inrush current

When a capacitor bank is initially switched on, a large inrush current flows for several cycles, before settling down to a steady nominal current value.

The peak value and duration of the inrush current is determined by:

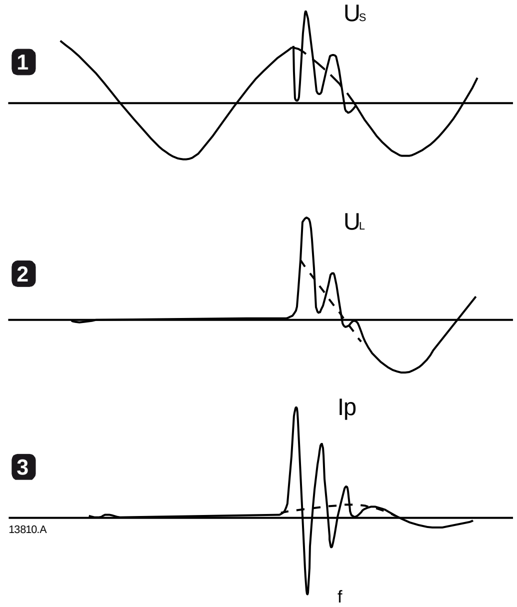
- system voltage, U
- system short circuit power, S_{sc}
- capacitor bank power, Q
- number of back-to-back capacitor banks feeding back into the system

The values of peak inrush current and oscillation frequencies are typically in the order of a few kA at some 100 Hz for a single capacitor bank, and a few 10 kA at some 100 kHz for multiple back-to-back capacitor banks.

Voltage switching transients

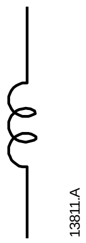
Capacitor bank switching produces oscillating voltage transients which are reflected back onto the network supply. The severity of this phenomenon can be lessened by reducing the capacitor bank peak inrush current.

Capacitor bank switching transients



1	Network voltage
2	Capacitor voltage
3	Capacitor current
U_s	Supply side overvoltage
U_L	Load side overvoltage
I_p	Inrush current
f	Oscillation frequency

Inrush reactors



IEC 60871-1 specifies that the peak inrush current of a capacitor bank must not exceed 100 times its rated nominal current.
If this value is likely to be exceeded, extra inductive reactance must be installed in-line with the capacitor bank. This not only reduces the peak inrush current, but also dampens the effect of transient overvoltages which occur at switch-on.
Fuse pre-melt figures and the making capacity of associated switchgear need to account for the expected peak inrush current.

Inrush reactors are constructed of a primary coil encapsulated in a resin case. Classified as an air core inductor, they are rated according to the following electrical characteristics:

- nominal voltage (kV) - must be equal to or greater than the system voltage
- nominal current (A) - must be equal to or greater than the capacitor bank nominal current
- inductance (μH)

Calculations: Re-rating a capacitor bank for specific voltage

To re-rate the power (Q) of a capacitor bank to match a specific system voltage:

$\frac{Q_1}{Q_2} = \left(\frac{U_1}{U_2}\right)^2$ $Q_1 = Q_2 \times \left(\frac{U_1}{U_2}\right)^2$	Where: Q_1 = re-rated capacitor bank power at required system voltage (kVAr) Q_2 = capacitor bank power at manufacturer's specified nominal voltage (kVAr) U_1 = system voltage U_2 = capacitor bank nominal voltage

Exercise

A capacitor bank has a nominal power rating of 500 kVAr at 7.2 kV. Calculate the re-rated capacitor bank power if used on a 6.6 kV system.

$$Q_1 = Q_2 \times \left(\frac{U_1}{U_2}\right)^2$$

$$= 500 \times \left(\frac{6.6}{7.2}\right)^2$$

$$= 500 \times 0.92^2$$

$$= 500 \times 0.84$$

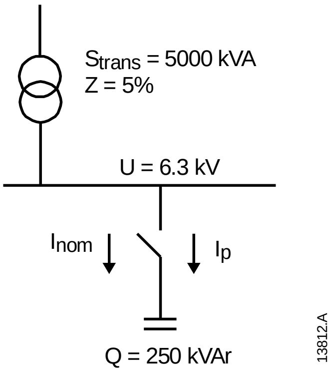
$$= 420 \text{ kVAr}$$

The re-rated power at 6.6 kV is 420 kVAr.

NOTE
The capacitor bank nominal voltage rating is typically 1.2 times the system voltage, to protect against transient and harmonic voltages. The capacitor bank power must be re-rated after selection.

Calculations: peak inrush current of a fixed capacitor bank

To calculate the peak inrush current (I_p) of a fixed capacitor bank with no extra inrush reactance:



Step 1: Calculate capacitor bank nominal current, I_{nom}

Q = capacitor bank power (kVAr)

U = system voltage (kV)

$$I_{nom} = \frac{Q}{\sqrt{3} \times U}$$

$$= \frac{250}{\sqrt{3} \times 6.3}$$

$$= \frac{250}{10.91}$$

$$= 22.89 \text{ A}$$

The capacitor bank's nominal current is 23 A.

Step 2: Calculate the short circuit power of the system, S_{sc}

S_{trans} = transformer nominal power rating (kVA)

Z = transformer impedance (%)

$$S_{SC} = \frac{S_{trans}}{Z} \times 100$$

$$= \frac{5000}{5} \times 100$$

$$= 100000 \text{ kVA}$$

The system short circuit power is 100,000 kVA.

Step 3: Calculate the peak inrush current, I_p

I_{nom} = capacitor bank nominal current (A)

S_{sc} = transformer short circuit power (kVA)

Q = capacitor bank power (kVA)

$$I_p = \sqrt{2} \times I_{nom} \times \sqrt{\frac{S_{sc}}{Q}}$$

$$= \sqrt{2} \times 23 \times \sqrt{\frac{100000}{250}}$$

$$= \sqrt{2} \times 23 \times \sqrt{400}$$

$$= \sqrt{2} \times 23 \times 20$$

$$= 650.54 \text{ A}$$

The peak inrush current is 650 A.

To be suitable, the peak inrush current (I_p) must be less than 100 times the capacitor's nominal current (I_{nom}).

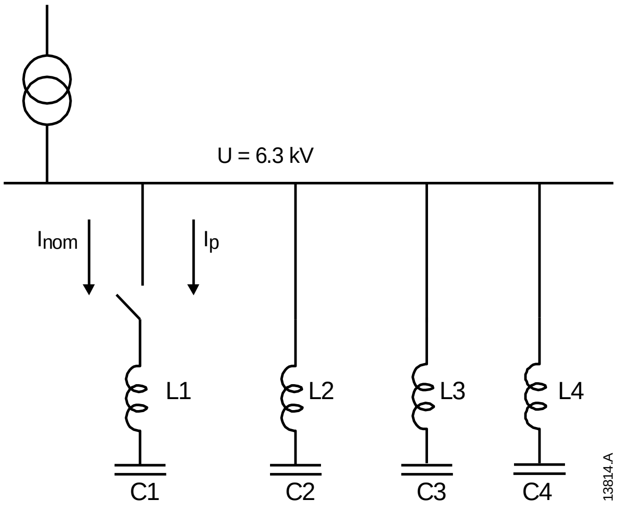
$I_p \leq 100 \times I_{nom}$

In this example, $650 \leq 100 \times 23$ A

This installation is acceptable.

Calculations: peak inrush current for multiple capacitor banks

To calculate the peak inrush current (I_p) of a number of capacitor banks with extra inrush reactance:



- capacitor banks C1, C2, C3, C4 are each rated for 900 kVAr at 7.2 kV.
- inrush reactance L1, L2, L3, L4 are each rated at 40 μH.

Step 1: Calculate the re-rated capacitor bank power (Q_1) at system voltage (U_1)

Q_1 = re-rated capacitor bank power at required system voltage (kVAr)
Q_2 = capacitor bank power at manufacturer's specified nominal voltage (kVAr)
U_1 = system voltage
U_2 = capacitor bank nominal voltage

$$\frac{Q_1}{Q_2} = \left(\frac{U_1}{U_2}\right)^2$$

$$Q_1 = Q_2 \times \left(\frac{U_1}{U_2}\right)^2$$

$$= 900 \times \left(\frac{6.3}{7.2}\right)^2$$

$$= 900 \times 0.766$$

$$= 689 \text{ kVAr}$$

The re-rated power at 6.3 kV is 689 kVAr.

Step 2: Calculate the individual capacitance of each power bank

C = capacitance (μF)
Q = capacitor bank power (kVAr)
U = system voltage (kV)
f = system frequency (Hz)

$$C = \frac{Q}{U^2(2\pi 50)} \times 1000$$

$$C_1 = C_2 = C_3 = C_4 = \frac{689}{6.3^2(2\pi 50)} \times 1000$$

$$= \frac{689}{39.69 \times 314.16} \times 1000$$

$$= \frac{689}{12469.01} \times 1000$$

$$= 55.26\,\mu F$$

The capacitance of each bank is 55 μF.

Step 3: Calculate the equivalent capacitance of banks which are switched in (C_{eq})

$$\begin{aligned} C_{eq} &= C_2 + C_3 + C_4 \\ &= 55+55+55 \\ &= 165\ \mu F \end{aligned}$$

The equivalent capacitance is 165 µF.

Step 4: Calculate the equivalent inductance of banks which are switched in (L_{eq})

$$\begin{aligned} L_{eq} &= \frac{1}{\frac{1}{L_2}+\frac{1}{L_3}+\frac{1}{L_4}} \\ &= \frac{1}{\frac{1}{40}+\frac{1}{40}+\frac{1}{40}} \\ &= \frac{40}{3} \\ &= 13.3\ \mu H \end{aligned}$$

The equivalent inductance is 13.3 µH.

Step 5: Calculate the peak inrush current, I_p

$$\begin{aligned} I_p &= U \times \sqrt{\frac{2}{3} \times \left(\frac{C_1 \times C_{eq}}{C_1 + C_{eq}}\right) \times \left(\frac{1}{L_1 + L_{eq}}\right)} \\ &= 6300 \times \sqrt{\frac{2}{3} \times \left(\frac{55 \times 165}{55 + 165}\right) \times \left(\frac{1}{40 + 13.3}\right)} \\ &= 6300 \times \sqrt{\frac{2}{3} \times \left(\frac{9075}{220}\right) \times \left(\frac{1}{53.3}\right)} \\ &= 6300 \times \sqrt{0.67 \times 41.25 \times \left(\frac{1}{53.3}\right)} \\ &= 6300 \times \sqrt{0.67 \times 41.25 \times 0.019} \\ &= 6300 \times \sqrt{0.52} \\ &= 4543\ A \end{aligned}$$

The peak inrush current is 4543 A.

To be suitable, the peak inrush current (I_p) must be less than 100 times the capacitor's nominal current: $I_p \leq 100 \times I_{nom}$

$$\begin{aligned} I_{nom} &= \frac{Q}{\sqrt{3} \times U} \\ &= \frac{689}{\sqrt{3} \times 6.3} \\ &= \frac{689}{10.91} \\ &= 63.15\ A \end{aligned}$$

In this example, $4543 \leq 100 \times 63.15$ A

This installation is acceptable.

NOTE

When selecting line fuses for upstream protection, the fuse pre-melt figure must be greater than the capacitor bank's peak inrush current.

If using a circuit breaker for upstream protection, the circuit breaker's making capacity at rated voltage must be at least equal to the capacitor bank's peak inrush current.

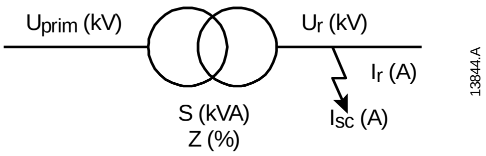
4.5 Calculations

Transformer Calculations

Rated secondary current, I_r

A transformer's rated secondary current (I_r) is the maximum current it can supply before the output terminal voltage starts to drop below its rated voltage (U_r). The rated secondary current can be calculated using the following formula (assuming the applied primary voltage, U_{prim}, is at its rated value).

$I_r = \frac{S}{\sqrt{3} \times U_r}$	Where I_r = rated secondary current (A) S = transformer power (kVA) U_r = rated secondary voltage (kV)

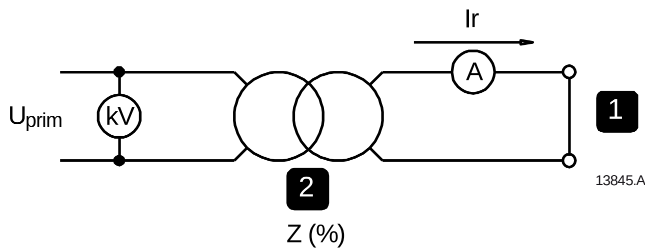


Short circuit current, I_{sc}

Assuming the transformer is fed from an unlimited supply, the maximum short circuit current across the output terminals (I_{sc}) is determined by the impedance of the transformer (expressed as a percentage).

Percentage impedance (Z%) is calculated by shorting the output terminals of the transformer and increasing the applied primary voltage (U_{prim}) from zero to a value where the rated current, I_r, flows through the secondary. Percentage impedance is the ratio of applied primary voltage to rated primary voltage.

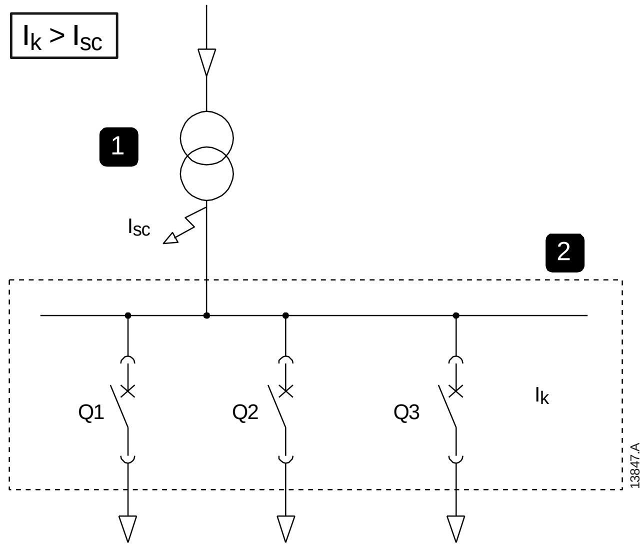
Example: If it takes 10% of the rated primary voltage to cause rated current to flow in the shorted secondary, the percentage impedance Z=10%



1	Short circuit
2	Primary/secondary

$I_{sc} = \frac{I_r \times 100}{Z\%}$	Where I_{sc} = transformer's maximum output short circuit current (A) I_r = rated secondary current (A) Z% = percentage impedance

The calculated short circuit current of a transformer, I_{sc} is often used to rate the downstream distribution switchgear it is feeding. In reality, the expected short circuit current at the switchgear installation will be less than the calculated short circuit current, due to any impedance in the feeder circuit (ie impedance of feeder cables, switchgear, busbars etc). All switchgear has a short-time withstand current rating (I_k), which is typically type tested for 3 seconds (t_k).



1	Transformer
2	Switchgear installation

Example

To calculate the short-time withstand current rating of the downstream switchgear, I_k, we must calculate the rated secondary current and the short circuit current of the feeder transformer.

Transformer power S = 20 MVA
Secondary rated voltage U_r = 11 kV
Impedance Z% = 8%
Assume infinite power system.

Rated secondary current, I_r

$$I_r = \frac{S}{\sqrt{3} \times U_r} = \frac{20000}{\sqrt{3} \times 11} = 1050\ \text{A}$$

The transformer rated secondary current is 1050 A.

Short circuit current, I_{sc}

$$I_{sc} = \frac{I_r \times 100}{Z\%} = \frac{1050 \times 100}{8} = \frac{105000}{8} = 13125\ \text{A}$$

The transformer short circuit current is 13125 A.

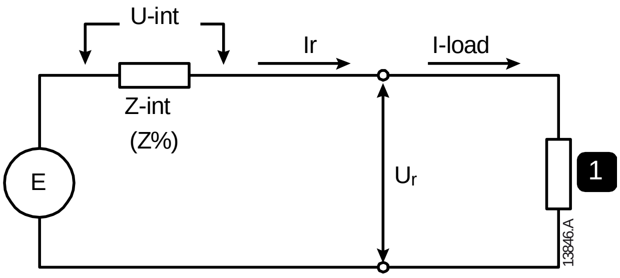
Switchgear rating, I_k/t_k

$I_k \geq I_{sc}$
$I_k \geq 13125$ A
An appropriate switchgear rating is 16 kA / 3 seconds.

Terminal voltage drop

If a load draws more current than the transformer's rated secondary current (I-load > I_r), the transformer's output voltage will drop from its rated value, U_r. The amount of voltage drop is determined by the internal impedance of the transformer and the level of overload.

Voltage drop analysis is useful for determining the suitability of a transformer, when a motor is a large portion of the load. It is recommended that the transformer output voltage should not drop more than 10% of its nominal value when using a soft starter to start a motor.



1	Load

$I_r = \frac{S}{\sqrt{3} \times U_r}$ $E = U_r \times \frac{100}{100 - Z\%}$ $Z\text{-int} = \frac{E - U_r}{I_r} \times 1000$ $U\text{-int} = \frac{I\text{-load} \times Z\text{-int}}{1000}$ $U_{r'} = E - U\text{-int}$	Where I_r = rated secondary current (A) S = transformer power (kVA) U_r = rated secondary voltage (kV) E = transformer internally generated EMF (kV) Z% = percentage impedance (%) Z-int = transformer internal impedance (Ω) U-int = internal voltage drop (kV) I-load = load current (A) $U_{r'}$ = secondary output voltage due to overload (kV)

Example

Transformer power	S = 30 MVA
Secondary rated voltage	U_r = 6.6 kV
Impedance	Z% = 10%
Assume infinite power system	

Rated secondary current, I_r

$$I_r = \frac{S}{\sqrt{3} \times U_r} = \frac{30000}{\sqrt{3} \times 6.6} = \frac{30000}{11.43} = 2624.32 \text{ A}$$

The rated secondary current is 2625 A.

Transformer internally generated EMF, E

$$E = U_r \times \frac{100}{100 - Z\%} = 6.6 \times \frac{100}{100 - 10} = 6.6 \times \frac{100}{90} = 6.6 \times 1.11 = 7.33 \text{ kV}$$

The internally generated EMF is 7.33 kV.

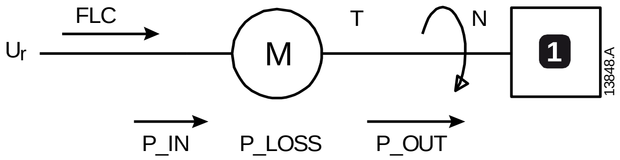
Transformer internal impedance, Z-int	$$\text{Z-int} = \frac{E - U_r}{I_r} \times 1000$$ $$= \frac{7.33 - 6.6}{2625} \times 1000$$ $$= \frac{0.73}{2625} \times 1000$$ $$= 0.28\ \Omega$$ *The internal impedance is 0.28 Ω.*

Exercise

Calculate the transformer's output terminal voltage drop if the load was drawing 6000 A (I-load).

Internal voltage drop, U-int	$$\text{U-int} = \frac{\text{I-load} \times \text{Z-int}}{1000} = \frac{6000 \times 0.28}{1000} = \frac{1680}{1000} = 1.68\ \text{kV}$$ *The internal voltage drop is 1.68 kV.*
Secondary output voltage due to overload, $U_{r'}$	$$U_{r'} = E - \text{U-int} = 7.33 - 1.68 = 5.65\ \text{kV}$$ *The secondary output voltage is 5.65 kV.*
Output voltage drop	$$U_r - U_{r'} = 6.6 - 5.65 = 0.95\ \text{kV}$$ *The output voltage drop is 0.95 kV, or 14% U_r.*

Motor Calculations



1	Load

			Where:	
Input power	$P_{\_IN}$	$=\sqrt{3}\times U_r\times FLC\times p.f.$	$P_{\_IN}$	= electrical input power (kW)
Output power	$P_{\_OUT}$	$=P_{\_IN}\times eff$	$P_{\_OUT}$	= mechanical output shaft power (kW)
	$P_{\_OUT}$	$=\frac{N\times T}{9550}$	$P_{\_LOSS}$	= motor losses (kW), ie iron, copper, magnetic, friction, windage losses
Motor losses	$P_{\_LOSS}$	$=P_{\_IN}-P_{\_OUT}$	U_r	= motor rated supply voltage (kV)
	$P_{\_LOSS}$	$=P_{\_OUT}\times\left(\frac{1}{eff}-1\right)$	f	= nominal rated supply frequency (Hz)
Motor efficiency	eff	$=\frac{P_{\_OUT}}{P_{\_IN}}$	eff	= motor full load efficiency (p.u.)
			FLC	= motor full load current (A)
Motor full load current	FLC	$=\frac{P_{\_OUT}}{\sqrt{3}\times U_r\times p.f.\times eff}$	p.f.	= motor full load power factor (p.u.)
			N	= motor full load speed (rpm)
Motor full load speed	N	$=N_s\times(1-slip)$	N_s	= motor synchronous speed (rpm)
Motor synchronous speed	N_s	$=\frac{f\times 120}{poles}$	poles	= number of motor stator poles
			T	= full load motor shaft torque (Nm)
			slip	= motor slip at full load (p.u.)

Exercise

For a motor running at full load, calculate the full load current, the total electrical input power and the amount of full load slip, given that:

P_{OUT}	= 2000 kW
U_r	= 3.3 kV
f	= 50 Hz
eff	= 0.95
p.f.	= 0.88
N	= 1485 rpm
poles	= 4

Motor full load current

$$FLC = \frac{P_{OUT}}{\sqrt{3} \times U_r \times p.f. \times eff} = \frac{2000}{\sqrt{3} \times 3.3 \times 0.88 \times 0.95} = \frac{2000}{4.78} = 418\ A$$

Input power

$$P_{IN} = \sqrt{3} \times U_r \times FLC \times p.f. = \sqrt{3} \times 3.3 \times 418 \times 0.88 = 2105\ kW$$

(alternative calculation)

$$P_{OUT} = P_{IN} \times eff$$

$$P_{IN} = \frac{P_{OUT}}{eff} = \frac{2000}{0.95} = 2105\ kW$$

Motor slip at full load

$$N_s = \frac{f \times 120}{poles} = \frac{50 \times 120}{4} = \frac{6000}{4} = 1500\ rpm$$

$$N = N_s \times (1 - slip)$$

$$\frac{N}{N_s} = 1 - slip$$

$$slip = 1 - \frac{N}{N_s} = 1 - \frac{1485}{1500} = 1 - 0.99 = 0.01\ p.u.$$

Busbar Calculations

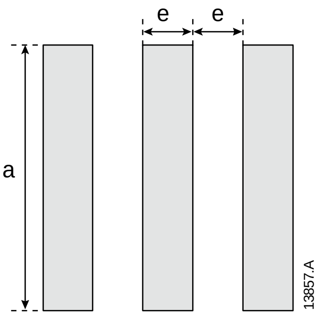
Busbar calculations verify the thermal and electrodynamic design limits, and check that no resonance will occur.

Thermal withstand

Rated current, I_r (A)

The rating of a busbar system depends on the material, shape, size and configuration of the individual busbars, as well as the operating conditions. The calculated busbar rating per phase must be greater than the maximum expected operating current.

$$I = K \times \frac{24.9 \times (\theta - \theta_n)^{0.61} \times S^{0.5} \times P^{0.39}}{\sqrt{p20 \times [1 + \alpha (\theta - 20)]}}$$



Where

- I = maximum allowable current per phase (A)
- K = total coefficient factor
- θ = maximum allowable busbar temperature (°C)
- θ_n = nominal ambient temperature (≤40 °C)
- p20 = resistivity at 20 °C:
  copper = 1.83 μΩ cm; aluminium = 2.90 μΩ cm
- α = temperature coefficient of resistivity = 0.004
- P = busbar perimeter, 2(e+a) (cm)
- S = busbar cross-section, e · a (cm^2)

The permitted busbar temperature rise is defined in IEC 62271-1.

Maximum permissible temperature rise for bolt-connected devices, including busbars

Material and dielectric medium	Maximum permissible temperature (°C)	Temperature rise above 40 °C ambient (°C)
Bolted connection (or equivalent)		
Bare copper, bare copper alloy or bare aluminium alloy		
In air	90	50
In sulphur hexafluoride (SF_6)	115	75
In oil	100	60
Silver or nickel coated		
In air	115	75
In sulphur hexafluoride (SF_6)	115	75
In oil	100	60
Tin-coated		
In air	105	65
In sulphur hexafluoride (SF_6)	105	65
In oil	100	60

Source: derived from IEC 62271-1

NOTE
When engaging parts with different coatings, or where one part is of bare material, the permissible temperature and temperature rise shall be those of the surface material having the lowest permitted value.

The total coefficient factor, K, is derived from six individual factors:

K = K1·K2·K3·K4·K5·K6

- K1 is a function of the number of bars per phase and their shape:
  The table below lists the value for K1, according to the shape ratio for the busbar system (e/a) and the number of bars per phase.

	Shape ratio e/a								
	0.05	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20
1	1	1	1	1	1	1	1	1	1
2	1.63	1.73	1.76	1.80	1.83	1.85	1.87	1.89	1.91
3	2.40	2.45	2.50	2.55	2.60	2.63	2.65	2.68	2.70

- K2 corresponds to the surface finish of the busbars:

Finish	K2
bare	1
painted	1.15

- K3 is a function of the mounting arrangement:

Mounting	K3
edge-mounted	1
one bar base-mounted	0.95
multiple bars base-mounted	0.75

- K4 is a function of the installed location:

Location	K4
outdoors	1.2
indoors	1.0
enclosed	0.80

- K5 is a function of any artificial ventilation:

Ventilation	K5
no ventilation	1
ventilation	requires validation

- K6 is a function of the type of current:

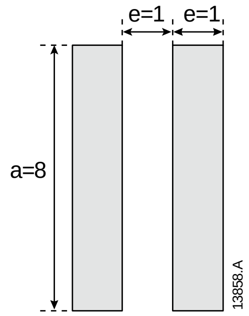
  The table below lists the value for K6 for an AC supply (50 Hz and 60 Hz), where the separation between busbars is equal to the thickness of each bar.

Number of bars	K6
1	1
2	1
3	0.98

Exercise

Check that the busbar rating (per phase) is greater than the required nominal rating of I_r = 2000 A. The busbar system is installed in an enclosed duct.

Characteristics: two edge-mounted bare copper bars per phase.
Width = 8 cm, thickness = 1 cm, spacing = 1 cm.



$$
\begin{aligned}
K &= K1 \cdot K2 \cdot K3 \cdot K4 \cdot K5 \cdot K6 \\
&= 1.83 \cdot 1 \cdot 1 \cdot 0.8 \cdot 1 \cdot 1 \\
&= 1.464 \\
I &= K \times \frac{24.9 \times (\theta - \theta_n)^{0.61} \times S^{0.5} \times P^{0.39}}{\sqrt{p20 \times [1 + \alpha(\theta - 20)]}} \\
&= 1.464 \times \frac{24.9 \times (90 - 40)^{0.61} \times 8^{0.5} \times 18^{0.39}}{\sqrt{1.83 \times [1 + 0.004 \times (90 - 20)]}} \\
&= 1.464 \times \frac{24.9 \times 10.87 \times 2.83 \times 3.09}{\sqrt{1.83 \times 1.28}} \\
&= 1.464 \times \frac{2366.87}{\sqrt{2.34}} \\
&= 1.464 \times 1546.97 \\
&= 2264.77 \text{ A}
\end{aligned}
$$

This system is adequate. I > Ir, 2265 A > 2000 A.

Short-time withstand current, I_{th} (A)

The temperature rise during a short circuit needs to be calculated, assuming the current flows for the busbar's entire rated short circuit duration, t_k.

The total busbar temperature, θ_T, is the calculated temperature rise during a short circuit period, $\Delta\theta_{sc}$, added to the maximum allowable temperature of the busbar, θ.

$$\theta_T = \Delta\theta_{sc} + \theta$$

Short circuit temperature rise is calculated as:

$\Delta\theta_{sc} = \dfrac{0.24 \times p20 \times I_{th}^2 \times t_k}{(n \times S)^2 \times c \times \delta}$	Where $\Delta\theta_{sc}$ = temperature rise during a short circuit (°C) p20 = resistivity at 20 °C: copper = 1.83 µΩ cm; aluminium = 2.90 µΩ cm I_{th} = I_k, short-time withstand current (kA) t_k = short-time withstand duration (s) n = number of busbars per phase S = busbar cross-section (cm^2) c = specific heat (°C): copper = 0.091 kcal/kg°C; aluminium = 0.23 kcal/kg°C δ = density of metal: copper = 8.9 g/cm^3; aluminium = 2.7 g/cm^3 θ = maximum allowable temperature of the busbar (°C): bare copper = 90 °C

Exercise

A busbar system has two copper bars per phase, with a short-time withstand rating of 31.5 kA for 3 seconds. Each busbar is 8 cm wide and 1 cm deep. Calculate the total temperature of the busbar after a short circuit.

$$\begin{aligned}\Delta\theta_{sc} &= \frac{0.24 \times p20 \times I_{th}^2 \times t_k}{(n \times S)^2 \times c \times \delta} \\ &= \frac{0.24 \times 1.83 \times 31.5^2 \times 3}{(2 \times 8)^2 \times 0.091 \times 8.9} \\ &= \frac{0.24 \times 1.83 \times 992.25 \times 3}{256 \times 0.091 \times 8.9} \\ &= \frac{1307.39}{207.33} \\ &= 6.31 \text{ °C}\end{aligned}$$

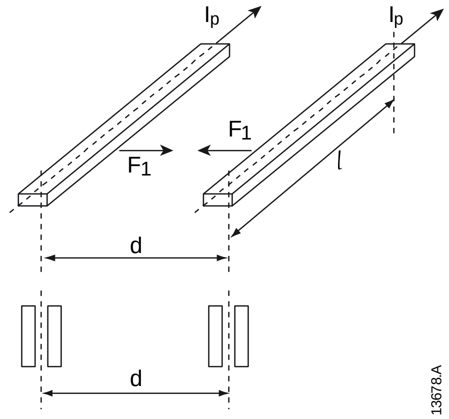
The short circuit temperature rise is 6.3 °C. The maximum allowable continuous temperature of the busbar system is 90 °C. The potential total temperature after short circuit is 96.3 °C.

Insulator stand-offs and all other items in physical contact with the busbar must be able to withstand this temperature.

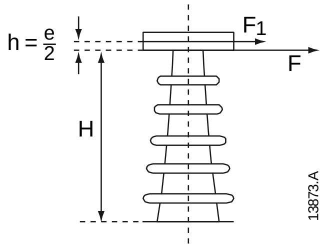
Electrodynamic withstand

Electrodynamic forces

Busbars (parallel)



Support



d	Distance between phases (cm)
l	Distance between insulators on a single phase (cm)
F_l	Force on busbar centre of gravity (daN)
I_p	Peak value of short circuit current (kA)

H	Insulator height
h	Distance from head of insulator to busbar centre of gravity
F	Force on head of insulator stand-off (daN)

NOTE: 1 daN (dekanewton) is equal to 10 newtons.

Forces on parallel busbars

Maximum forces between parallel busbars occur as a result of the peak asymmetrical fault current (I_p). The maximum peak fault current can be calculated from the busbar system's short-time withstand rating (I_k).

I_p values for a system with 45 ms DC time constant

System frequency (Hz)	I_p
50	$2.5 \times I_k$
60	$2.6 \times I_k$

When short circuit current flows in a busbar, the electrodynamic force exerted on a parallel busbar is:

$F_1 = 2 \times \frac{l}{d} \times I_p^2 \times 10^{-2}$	Where: I_p = maximum peak fault current (kA) I_k = short-time withstand current (kA)

Forces on insulator stand-offs

Insulator stand-offs must also withstand the forces imparted on the parallel busbars during a short circuit fault.

$F = F_1 \times \frac{H+h}{H}$	Where: F = force absorbed by head of insulator stand-off (daN) F_l = force on busbar centre of gravity (daN)

The force absorbed at the head of each insulator stand-off is derived using a multiplication factor, K_n, according to the total number of evenly-spaced insulator stand-offs per phase.

Multiplication factor K_n

Number of stand-offs	2	3	4	≥5
Multiplication factor K_n	0.5	1.25	1.10	1.14

The absorbed force per insulator stand-off (daN) is:

$$F' = F \times K_n$$

The bending resistance of an individual insulator stand-off must be greater than the calculated absorbed force, F´.

Mechanical strength of busbars

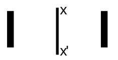
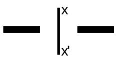
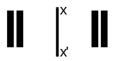
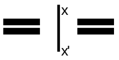
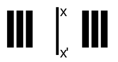
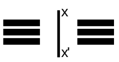
The maximum allowable stress which a busbar can absorb, η, is determined by the busbar material.

$\eta = \frac{F_1 \times l}{12} \times \frac{V}{I}$	Where: l = distance between insulator stand-offs on the same phase (cm) V/I = inverse modulus of inertia for bars of the same phase (cm^3)

Maximum allowable values for η for different busbar materials

Material	Maximum η (daN/cm^2)
Copper ¼ hard	1200
Copper ½ hard	2300
Copper 4/4 hard	3000
Aluminium	1200

Moment of inertia (I) and modulus of inertia (I/V) of busbars

			100 x 10	**80 x 10**	**80 x 6**	**80 x 5**	**80 x 3**	**50 x 10**	**50 x 8**	**50 x 6**	**50 x 5**
	S	cm2	10	8	4.8	4	2.4	5	4	3	2.5
	m	Cu	0.089	0.071	0.043	0.036	0.021	0.044	0.036	0.027	0.022
	(daN/cm)	A5/L	0.027	0.022	0.013	0.011	0.006	0.014	0.011	0.008	0.007
	I	cm^4	0.83	0.66	0.144	0.083	0.018	0.416	0.213	0.09	0.05
	I/v	cm^3	1.66	1.33	0.48	0.33	0.12	0.83	0.53	0.3	0.2
	I	cm^4	83.33	42.66	25.6	21.33	12.8	10.41	8.33	6.25	5.2
	I/v	cm^3	16.66	10.66	6.4	5.33	3.2	4.16	3.33	2.5	2.08
	I	cm^4	21.66	17.33	3.74	2.16	0.47	10.83	5.54	2.34	1.35
	I/v	cm^3	14.45	11.55	4.16	2.88	1.04	7.22	4.62	2.6	1.8
	I	cm^4	166.66	85.33	51.2	42.66	25.6	20.83	16.66	12.5	10.41
	I/v	cm^3	33.33	21.33	12.8	10.66	6.4	8.33	6.66	5	4.16
	I	cm^4	82.5	66	14.25	8.25	1.78	41.25	21.12	8.91	5.16
	I/v	cm^3	33	26.4	9.5	6.6	2.38	16.5	10.56	5.94	4.13
	I	cm^4	250	128	76.8	64	38.4	31.25	25	18.75	15.62
	I/v	cm^3	50	32	19.2	16	9.6	12.5	10	7.5	6.25

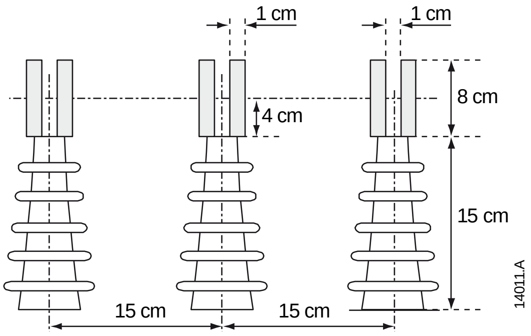
14009.A

Source: Schneider Electric 2000.

Exercise

A busbar system has two end-mounted busbars per phase, made of ¼ hard copper (maximum allowable stress of 1200 daN/cm^2). Each bar is 8 cm high and 1 cm wide, with a gap of 1 cm between bars of the same phase. The phase centres are 15 cm and each phase has 6 insulator stand-offs at 80 cm spacing. The insulator stand-offs are 15 cm high, with a bending resistance of 1000 daN.

Check that the busbars and insulator stand-offs are suitable for the installation.



Step 1: Calculate the forces between the parallel busbars of different phases.

Assume a short-time withstand current rating, I_k, of 31.5 kA at 50 Hz.

$$I_p = 2.5 \times I_k$$
$$= 2.5 \times 31.5$$
$$= 78.75 \text{ kA}$$

$$F_1 = 2 \times \frac{l}{d} \times I_p^2 \times 10^{-2}$$
$$= 2 \times \frac{80}{15} \times 78.75^2 \times 10^{-2}$$
$$= 2 \times 5.33 \times 6201.5625 \times 0.01$$
$$= 661.09 \text{ daN}$$

The force between busbars is 661 daN.

Step 2: Calculate the forces absorbed at the head of each insulator stand-off.

$$F = F_1 \times \frac{H+h}{H}$$
$$= 661 \times \frac{15+4}{15}$$
$$= 661 \times 1.267$$
$$= 837.27 \text{ daN}$$

The force to be absorbed by each individual standoff:

$$F' = F \times K_n$$
$$= 837 \times 1.14$$
$$= 954.18 \text{ daN}$$

The force imparted on each stand-off is 954 daN.

The imparted force is less than the bending resistance of the insulator stand-off: 954 < 1000 daN.
The insulators are suitable for the application.

Step 3: Calculate the maximum stress exerted on the busbars.

According to the selection table, the modulus of inertia, l / V, for 8 cm × 1 cm end-mounted copper busbar pairs is 11.55 cm^3.

$$\eta = \frac{F_1 \times l}{12} \times \frac{V}{I}$$
$$= \frac{661 \times 80}{12} \times \frac{1}{11.55}$$
$$= 4406.67 \times \frac{1}{11.55}$$
$$= 381.53 \text{ daN/cm}^2$$

The stress imparted on the busbars is 381 daN/cm^2.

The imparted stress is less than the maximum allowable stress for ¼ hard copper busbars: 381 < 1200 daN/cm^2.
The busbar dimensions and material are suitable for the application.

Resonant frequency

The busbar system must be designed to avoid resonance at the nominal system frequency and twice this value. The calculations should include some tolerance:

$f = 112\sqrt{\frac{E \times I}{m \times l^4}}$	Where: f = resonant frequency (Hz) E = modulus of elasticity: copper = 1.3×10^6 daN/cm^2 aluminium = 0.67×10^6 daN/cm^2 m = linear mass of busbar (daN/cm) I = moment of inertia of the busbar cross-section, relative to the perpendicular vibrating plane (cm^4) l = distance between insulator stand-offs of the same phase (cm)

Exercise

Verify the resonant frequency of the busbar system in the Exercise above.

$$f = 112\sqrt{\frac{E \times I}{m \times l^4}}$$

$$= 112\sqrt{\frac{(1.3 \times 10^6) \times 17.33}{0.071 \times 80^4}}$$

$$= 112\sqrt{\frac{22529000}{2908160}}$$

$$= 112\sqrt{7.75}$$

$$= 112 \times 2.78$$

$$= 311.36 \text{ Hz}$$

The resonant frequency is well away from 50 Hz and 100 Hz. The busbar solution is suitable.

Short Circuit Calculations

Short circuit fault currents at different points on a system are determined by the power feeding into the fault and the equivalent short circuit impedance seen by the fault.

Power sources feeding a fault include supply networks, transformers, generators and motors. Impedance is a vital factor in limiting the level of short circuit current. Sources of impedance include all electrical machines, as well as cables, overhead lines, busbars and switching apparatus.

There are numerous methods to calculate short circuit current levels, such as impedance, per-unit and point-to-point. The most commonly used and widely understood is the impedance method (see below). These calculation methods were widely used before calculation software became available. These programs allow very accurate results to specific conformance standards.

Short circuit calculations serve two main functions:

- to determine the required make and break ratings of switchgear, and the mechanical withstand of all equipment
- to inform fuse selection and protection relay settings, in order to achieve adequate circuit discriminations

Formulae

Short circuit

Where the short circuit power of a network, S_{sc}, is known:

$$I_{sc} = \frac{S_{sc}}{\sqrt{3} \times U}$$

Where the short circuit impedance of a network, Z_{sc}, is known:

$$I_{sc} = \frac{U}{\sqrt{3} \times Z_{sc}}$$

$$Z_{sc} = \sqrt{R_{sc}^2 + X_{sc}^2}$$

Where:

- I_{sc} = short circuit current (kA rms)
- I_p = peak fault current (kA peak)
  - $I_p = 2.5 \times I_{sc}$ (for a 50 Hz supply with a 45 ms DC time constant)
  - $I_p = 2.6 \times I_{sc}$ (for a 60 Hz supply with a 45 ms DC time constant)
- Z_{sc} = total short circuit impedance (Ω)
- S_{sc} = short circuit power (MVA)
- U = system voltage (kV)
- R_{sc} = total short circuit resistance (Ω)
- X_{sc} = total short circuit reactance (Ω)

NOTE
The switchgear "make rating" must be greater than the peak fault current, and the "break rating" must be greater than the short circuit current..

Upstream network

$$Z_{sc} = \frac{U^2}{S_{sc}}$$

Where:

- Z = network short circuit impedance (Ω)
- S_{sc} = short circuit power (MVA)
- U = system voltage (kV)

Reflecting the short circuit impedance of the upstream network through to the secondary of the transformer:

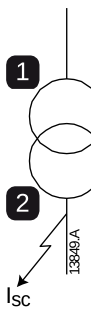
$$Z_{sc-sec} = Z_{sc-prim} \times \left(\frac{U_{sec}}{U_{prim}}\right)^2$$

Where:

- $Z_{sc\text{-}sec}$ = network short circuit impedance at the secondary of the transformer (Ω)
- $Z_{sc\text{-}prim}$ = network short circuit impedance at the primary of the transformer (Ω)
- U_{sec} = transformer secondary voltage (kV)
- U_{prim} = transformer primary voltage (kV)

The total impedance seen by a short circuit fault at the secondary terminals of the transformer is the sum of the transformer impedance, $Z_{sc\text{-}TR}$, and the short circuit network impedance at the transformer secondary ($Z_{sc\text{-}sec}$).

$$I_{sc} = \frac{U_{sec}}{\sqrt{3} \times (Z_{sc-sec} + Z_{sc-TR})}$$



1	Primary
2	Secondary

Transformers

$$Z_{sc-TR} = \frac{U_{sec}^{\ 2}}{S_{TR}} \times \frac{Z_{TR}}{100}$$

Where:

- $Z_{sc\text{-}TR}$ = transformer output short circuit impedance (Ω)
- Z_{TR} = transformer impedance (%)
- U_{sec} = transformer secondary voltage (kV)
- S_{TR} = transformer power (MVA)

Synchronous generator

$Z_{sc-syn} = \frac{U_{syn}^2}{S_{syn}} \times \frac{X_{syn}}{100}$	Where: Z_{sc-syn} = synchronous machine short-circuit impedance (Ω) X_{syn} = synchronous reactance (%) U_{syn} = synchronous machine output voltage (kV) S_{syn} = synchronous machine output power (MVA)

A synchronous machine has three stages of reactance during a short-circuit fault. The reactance is lowest at the beginning of a fault, causing the highest level of short circuit current. From this level, the short circuit current decays to a steady state.

Subtransient stage

This is usually the first few cycles of a fault occurrence. The peak short circuit current at this stage determines the fault "make rating" of a circuit breaker, and the mechanical withstand.

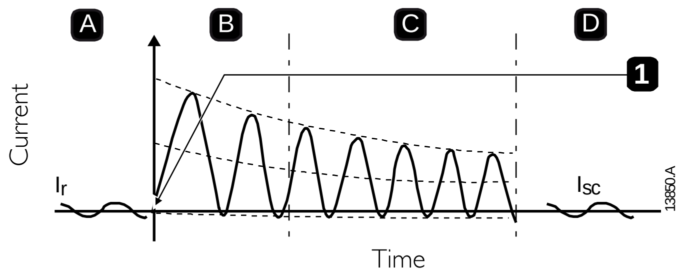
Transient stage

This stage typically lasts for 10 to 20 power cycles and determines the thermal withstand and "break rating" of a circuit breaker.

Permanent stage

This is the short circuit current level until the fault is interrupted by protection and clearing of the fault. In reality, this stage never occurs as the fault is cleared beforehand.

Stages of a short circuit



1	Point at which fault occurs
A	Healthy
B	Subtransient stage
C	Transient stage
D	Permanent stage

Transient levels for a synchronous generator

Type	Subtransient Xd´´	Transient Xd´	Permanent Xd
Turbo	10%~20%	15%~25%	200%~350%
Exposed poles	15%~25%	25%~35%	70%~120%

Transient levels for a synchronous motor

Type	Subtransient Xd´´	Transient Xd´	Permanent Xd
High speed > 1500 rpm	15%	25%	80%
Low speed < 1500 rpm	35%	50%	100%

Asynchronous motors

$Z_{sc-mtr} = \frac{U_{mtr}^2}{P_{mtr}} \times 200$	Where: Z_{sc-mtr} = motor output short circuit impedance (Ω) U_{mtr} = motor input voltage (kV) P_{mtr} = motor rated power (kW)

An asynchronous motor will contribute approximately 4 to 6 times its rated current into a short circuit fault.

Cables

Z_{sc} = 0.1 Ω/km

Busbars

Z_{sc} = 0.15 Ω/km

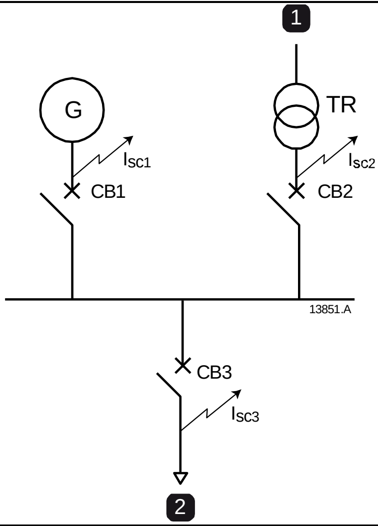
Impedance Method Calculations

Case 1

Source (Network):
U_p = 36 kV
S_{sc} = 1000 MVA

Transformer (TR):
U_p = 36 kV
U_s = 11 kV @ 50 Hz
S = 20 MVA
Z% = 10%

Generator (G):
U = 11 kV @ 50 Hz
S = 15 MVA
$X_{d''}$ = 15%
$X_{d'}$ = 20%



1	Source
2	Feeder

For the purposes of this calculation, ignore all impedances of circuit breakers, cables and busbars.

The first step is to calculate the individual impedances.

Generator impedance (Z_G):

$$Z_{d''} = \frac{U^2}{S} \times \frac{X_{d''}}{100} = \frac{11^2}{15} \times \frac{15}{100} = 1.21\ \Omega$$

The subtransient impedance is 1.2 Ω.

$$Z_{d'} = \frac{U^2}{S} \times \frac{X_{d'}}{100} = \frac{11^2}{15} \times \frac{20}{100} = 1.6\ \Omega$$

The transient impedance is 1.6 Ω.

Transformer impedance (Z_{TR}):

$$Z_{TR} = \frac{U_s^2}{S} \times \frac{Z\%}{100} = \frac{11^2}{20} \times \frac{10}{100} = 0.61\ \Omega$$

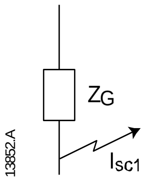
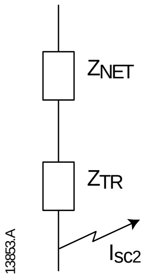
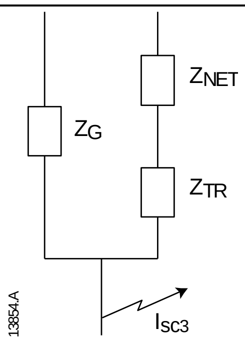
The permanent impedance is 0.6 Ω.

Network impedance (Z_{NET}), as seen on the secondary side of the transformer:

$$Z_{NET} = \frac{U_p^2}{S_{sc}} \times \left(\frac{U_s}{U_p}\right)^2 = \frac{36^2}{1000} \times \left(\frac{11}{36}\right)^2 = 1.30 \times 0.31^2 = 0.12\ \Omega$$

The permanent impedance is 0.12 Ω.

Short circuit impedances and ratings of switchgear devices

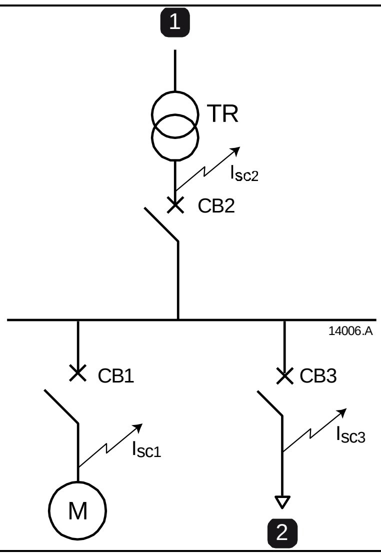
Device	Equivalent circuit	Short circuit impedance (Ω)	Break rating (kA rms)	Make rating (kA peak)
CB1		Transient stage $Z_{sc'} = 1.6\ \Omega$	$I_{sc} = \frac{11}{\sqrt{3} \times 1.6}$ $= \frac{11}{2.77}$ $= 3.97$ kA	
		Subtransient stage $Z_{sc''} = 1.2\ \Omega$	$I_{sc} = \frac{11}{\sqrt{3} \times 1.2}$ $= \frac{11}{2.08}$ $= 5.29$ kA	$I_p = 2.5 \times 5.29$ $= 13.23$ kA
CB2		$Z_{sc} = Z_{NET} + Z_{TR}$ $= 0.12 + 0.6$ $= 0.72\ \Omega$	$I_{sc} = \frac{11}{\sqrt{3} \times 0.72}$ $= \frac{11}{1.25}$ $= 8.82$ kA	$I_p = 2.5 \times 8.82$ $= 22.05$ kA
CB3		Transient stage $Z_{sc'} = \frac{Z_G \times (Z_{NET} + Z_{TR})}{Z_G + (Z_{NET} + Z_{TR})}$ $= \frac{1.6 \times 0.72}{1.6 + 0.72}$ $= 0.50\ \Omega$	$I_{sc} = \frac{11}{\sqrt{3} \times 0.5}$ $= \frac{11}{0.87}$ $= 12.70$ kA	
		Subtransient stage $Z_{sc''} = \frac{1.2 \times 0.72}{1.2 + 0.72}$ $= 0.45\ \Omega$	$I_{sc} = \frac{11}{\sqrt{3} \times 0.45}$ $= \frac{11}{0.78}$ $= 14.11$ kA	$I_p = 2.5 \times 14.11$ $= 35.28$ kA

Case 2

Source (Network):
U_p = 36 kV
S_{sc} = 1000 MVA

Transformer (TR):
U_p = 36 kV
U_s = 11 kV @ 50 Hz
S = 20 MVA
Z% = 10%

Motor (M):
U = 11 kV @ 50 Hz
P = 2000 kW



1	Source
2	Feeder

For the purposes of this calculation, ignore all impedances of circuit breakers, cables and busbars.

The first step is to calculate the individual impedances.

Motor impedance (Z_M):

$$Z_M = \frac{U^2}{P} \times 200 = \frac{11^2}{2000} \times 200 = 12.1\ \Omega$$

The motor impedance is 12.1 Ω.

Transformer impedance (Z_{TR}):

$$Z_{TR} = \frac{U_s^{\,2}}{S} \times \frac{Z\%}{100} = \frac{11^2}{20} \times \frac{10}{100} = 0.61\ \Omega$$

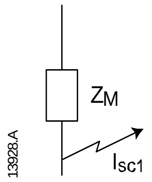
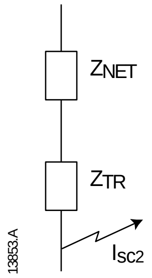
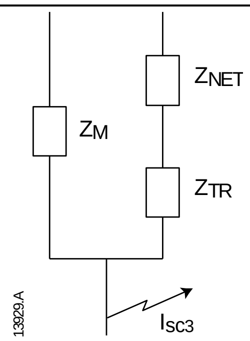
The permanent impedance is 0.6 Ω.

Network impedance (Z_{NET}), as seen on the secondary side of the transformer:

$$Z_{NET} = \frac{U_p^{\,2}}{S_{sc}} \times \left(\frac{U_s}{U_p}\right)^2 = \frac{36^2}{1000} \times \left(\frac{11}{36}\right)^2 = 1.30 \times 0.31^2 = 0.12\ \Omega$$

The permanent impedance is 0.12 Ω.

<u>Short circuit impedances and ratings of switchgear devices</u>

<table>
<tr><th>Device</th><th>Equivalent circuit</th><th>Short circuit impedance (Ω)</th><th>Break rating (kA rms)</th><th>Make rating (kA peak)</th></tr>
<tr><td>CB1</td><td></td><td>$Z_{sc} = 12.1\ \Omega$</td><td>$I_{sc} = \frac{11}{\sqrt{3} \times 12.1} = \frac{11}{20.96} = 0.525\text{ kA}$
$(= 525\text{ A})$</td><td>$I_p = 2.5 \times 0.525 = 1.312\text{ kA}$
$(= 1312\text{ A})$</td></tr>
<tr><td>CB2</td><td></td><td>$Z_{SC} = Z_{NET} + Z_{TR} = 0.12 + 0.6 = 0.72\ \Omega$</td><td>$I_{sc} = \frac{11}{\sqrt{3} \times 0.72} = \frac{11}{1.25} = 8.82\text{ kA}$</td><td>$I_p = 2.5 \times 8.82 = 22.05\text{ kA}$</td></tr>
<tr><td>CB3</td><td></td><td>$Z_{sc} = \frac{Z_M \times (Z_{NET} + Z_{TR})}{Z_M + (Z_{NET} + Z_{TR})} = \frac{12.1 \times 0.72}{12.1 + 0.72} = 0.68\ \Omega$</td><td>$I_{sc} = \frac{11}{\sqrt{3} \times 0.68} = \frac{11}{1.18} = 9.34\text{ kA}$</td><td>$I_p = 2.5 \times 9.34 = 23.35\text{ kA}$</td></tr>
</table>

4.6 Switchgear Inspection Checklists

These checklists outline the typical minimum electro-mechanical inspections, for a new switchgear installation.

Mechanical Inspection

Location:	
Date:	
Inspection staff:	
Cubicle serial number:	
Contract:	

Description	Passed (Y/N)	Comments
Eye bolts fitted		
Explosion vent flaps: screws fitted, holes taped		
Holes not used for arc duct: filled with fixings		
LV doors: cutouts		
LV doors: opening and closing		
VCB doors: opening and closing		
Cable compartment doors: opening and closing		
Door locks		
Racking label		
VCB locking label		
Danger labels (front and rear)		
Cable compartment door: "unlocking" label		
VCB compartment: padlocking mechanism fitted and operating		
Shutter operation		
Shutter danger labels		
Earth switch: interlock with VCB		
Earth switch: interlock with solenoid (use 'N/A/ if not fitted)		
Earth switch: operation		
Earth switch auxiliaries (check alignment and operation)		
VCB: test racking		
VCB: mechanical interlock		
VT: test racking		
Busbar GPO3 bushing plates		
Screw bushings horizontal busbar (small / large)		
All internal copper work		
Horizontal busbar copper work and joints		
Earth bars		
Earth bar links		
Rear cover		
Fixings for rear cover		
Panel builder check sheets		
Keys for all access doors		
Earth switch handle		
Standard VCB racking handle		
Rear busbar chamber covers and fixings		
Cubicle joining bolts supplied		

Electrical Inspection

Location:	
Date:	
Inspection staff:	
Cubicle serial number:	
Contract:	
Electrical schematic drawing number	
Control voltages required for testing	

Description	Passed (Y/N)	Comments
LV door apparatus		
Voltage indicators		
Selector switches		
Keys for selector switches (Fortress or other)		
Pushbuttons		
Indicators (colours)		
Control device door labels (functions)		
Device numbering (internal)		
Terminal numbering		
CT test block assemblies		
VT test block assemblies		
Check MCB ratings		
Power supply ratings and operation		
110 VAC distribution		
220 VAC distribution		
110 VDC distribution		
24 VDC distribution		
LV door earth link		
Heaters and thermostats		
Heater operation		
Check CT rating plates		
Earth connection at CTs		
Check VT rating plates		
Earth switch auxiliary labels		
VT fuses fitted in fixed VTs		
Test sheets: VCB		
Test sheets: withdrawable VT		
Test sheets: fixed VT		
Solenoid for earth switch interlock (use 'N/A' if not fitted)		
Solenoid on cable compartment door (use 'N/A' if not fitted)		
Programming relays		
Test control wiring and VCB operation		
Voltage test on fixed VTs		
Voltage test on withdrawable VTs		
Bushings for holes between cubicles		
Drawings as-built information		
Inter-cubicle cabling marked and ready for termination		To be done on site

Commissioning Tools and Equipment (Typical)

- Crimp tool for VCB socket
- Terminal screwdriver (for LV terminals)
- Ferrule crimp tool
- Pin punch (removing sockets VCB plug)
- Multimeter
- Insulation tester
- Torch
- Scotch pad
- De-burring tool
- Wedges for cubicle alignment
- Plumb-bob and string
- Appropriate spanner and/or socket set
- Appropriate allen key set
- Appropriate screwdriver set
- Torque wrench
- Commissioning sheets
- Spare parts
- As built electrical and mechanical drawings

4.7 Switchgear-Related IEC Standards

IEC Standard Number	Title	Supersedes old standards
60044-1	Instrument transformers: Current transformers	
60044-8	Instrument transformers: Electronic current transformers	
60060-1	High voltage test techniques: General definitions and test requirements	
60071-2	Insulation coordination: Application guide	
60529	Degrees of protection provided by enclosures (IP Code)	
60909-0	Short-circuit currents in three-phase AC systems: Calculation of currents	
61869-3	Instrument transformers: Additional requirements for inductive voltage transformers	60044-2, 60186
62262	Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts (IK Code)	
62271-1	High voltage switchgear and controlgear: Common specifications	60694
62271-100	High voltage switchgear and controlgear: Alternating current circuit-breakers	61633, 62271-308
62271-101	High voltage switchgear and controlgear: Synthetic testing	
62271-102	High voltage switchgear and controlgear: Alternating current disconnectors and earthing switches	60129, 61128, 61129, 61259
62271-103	High voltage switchgear and controlgear: Switches for rated voltages above 1 kV up to and including 52 kV	60265-1
62271-104	High voltage switchgear and controlgear: Alternating current switches for rated voltages of 52 kV and above	
62271-105	High voltage switchgear and controlgear: Alternating current switch-fuse combinations	
62271-106	High voltage switchgear and controlgear: Alternating current contactors, contactor-based controllers and motor-starters	
62271-107	High voltage switchgear and controlgear: Alternating current fused circuit-switchers for rated voltages above 1 kV up to and including 52 kV	
62271-108	High voltage switchgear and controlgear: High-voltage alternating current disconnecting circuit-breakers for rated voltages of 72.5 kV and above	
62271-109	High voltage switchgear and controlgear: Alternating-current series capacitor bypass switches	
62271-110	High voltage switchgear and controlgear: Inductive load switching	
62271-111	High voltage switchgear and controlgear: Overhead, pad-mounted, dry-vault, and submersible automatic circuit reclosers and fault interrupters for alternating current systems up to 38 kV	
62271-200	High voltage switchgear and controlgear: AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV	
62271-201	High voltage switchgear and controlgear: AC insulation-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV	
62271-202	High voltage switchgear and controlgear: High-voltage/low voltage prefabricated substation	
62271-203	High voltage switchgear and controlgear: Gas-insulated metal-enclosed switchgear for rated voltages above 52 kV	
62271-204	High voltage switchgear and controlgear: Rigid gas-insulated transmission lines for rated voltage above 52 kV	
62271-205	High voltage switchgear and controlgear: Compact switchgear assemblies for rated voltages above 52 kV	
62271-206	High voltage switchgear and controlgear: Voltage presence indicating systems for rated voltages above 1 kV and up to and including 52 kV	61958
62271-207	High voltage switchgear and controlgear: Seismic qualification for gas-insulated switchgear assemblies for rated voltages above 52 kV	62271-2
62271-300	High voltage switchgear and controlgear: Seismic qualification of alternating current circuit-breakers	
62271-301	High voltage switchgear and controlgear: Dimensional standarisation of high-voltage terminals	

62271-302	High voltage switchgear and controlgear: Alternating current circuit breakers with intentionally non-simultaneous pole operation	
62271-303	High voltage switchgear and controlgear: Use and handling of sulphur hexafluoride (SF_6)	61634
62271-304	High voltage switchgear and controlgear: Design classes for indoor enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV to be used in severe climatic conditions	60932
62271-305	High voltage switchgear and controlgear: Capacitive current switching capability of air-insulated disconnectors for rated voltages above 52 kV	
62271-310	High voltage switchgear and controlgear: Electrical endurance testing for circuit breakers above a rated voltage of 52 kV	

NOTE
Edition dates have been deliberately omitted from the IEC Standard Number. When referring to a standard, always ensure you are using the latest edition.

4.8 Comparison of IEC and IEEE Standards

Although the IEC (International Electrotechnical Commission) is the main international organisation publishing international standards relating to medium voltage switchgear, the Institute of Electrical and Electronics Engineers (IEEE) and the American National Standards Institute (ANSI) also publish standards.

IEC and IEEE have a cooperation agreement and some standards are jointly developed.

ANSI is the US representative to IEC.

In some cases, the requirements of similar standards from different organisations may conflict, or one standard may include requirements not present in another standard.

NOTE
If equipment must comply with more than one standard, the requirements of each standard should be individually checked.

Examples of differences in rating requirements

Similar standards may have differences in ratings specifications, design requirements and test procedures.

NOTE
This list gives some examples of differences between major standards. Always refer to the specific standard(s) for full details.

- The standard value of rated duration for short-time withstand current is 1 second for IEC 62271-1, but 2 seconds for ANSI C37.20.3.
- The acceptable limits for temperature rise of busbars are more stringent in ANSI C37.20.3 than IEC 62271-1.
- ANSI C37.20.3 stipulates design requirements (including materials, fusing and interlocking) that are not present in IEC 62271.
- ANSI and IEC stipulate different testing requirements and procedures.

4.9 IEC Switchgear Rating Definitions

IEC 62271-1 defines standard ratings for medium voltage switchgear. These ratings allow selection of equipment to match the electrical characteristics at the point of installation.

Voltage

Operating voltage, U (kV)

This is the system's operating voltage at the point where the switchgear is installed. The operating voltage must always be less than or equal to the rated voltage of the switchgear equipment.

Rated voltage, U_r (kV)

This is the maximum rms voltage the switchgear equipment can continuously operate at, under normal conditions. The rated voltage is always higher than the systems operating voltage and determines the insulation levels of the equipment.

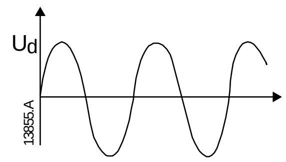
Medium voltage, metal-enclosed switchgear is defined for use on operating voltages from1 kV to 52 kV. Within this voltage range, IEC 62271-1 defines standard switchgear rated voltages as:

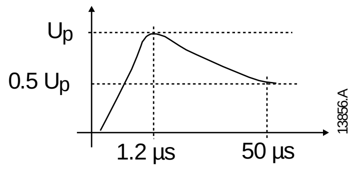
- Series I equipment (used in European 50 Hz installations): 3.6, 7.2, 12, 17.5, 24, 36, 52 kV
- Series II equipment (used in Non-European 60 Hz installations): 4.76, 8.25, 15, 15.5, 25.8, 27, 38, 48.3 kV

Insulation level voltages, U_d (kV rms 1 min) and U_p (kV peak)

The defined levels are stated for phase-to-earth and phase-to-phase limits under standardised ambient conditions. For installations above 1000 metres, these insulation levels must be derated.

- Power frequency withstand voltage, U_d
  This is the maximum rms voltage that the equipment can withstand at mains frequency for 1 minute. It simulates power surges originated from within a power system from such events as switching transients, resonance, etc.
- Lightning impulse withstand voltage, U_p
  This is the peak transient voltage that the equipment can withstand from power surges originating from atmospheric conditions such as lightning. It is simulated using a standard voltage waveform





Standard values for insulation level voltages

U_r (kV)	U_d (kV rms)	U_p (kV peak)
7.2	20	60
12	28	75
17.5	38	95
24	50	125
36	70	170

Current

Operating current, I (A)

This is the maximum rms current expected to flow through the equipment. The operating current must always be less than or equal to the rated current of the equipment.

Rated current, I_r (A)

This is the maximum rms current the equipment can continuously operate at, under normal conditions. This rating is based on an ambient operating temperature of 40°C, within an allowable maximum temperature rise. For temperatures above 40°C, switchgear rated current must be derated.

IEC 62271-1 specifies standard ratings as base 10 multiples of 1, 1.25, 1.6, 2, 2.5, 3.15, 4, 5, 6.3, 8

Maximum permissible temperature rise

Material and dielectric medium	Maximum permissible temperature (°C)	Temperature rise above 40 °C ambient (°C)
Contacts, in air		
Bare copper, bare copper alloy or bare aluminium alloy	75	35
Silver or nickel coated	105	65
Tin-coated	90	50
Bolted connection (or equivalent), in air		
Bare copper, bare copper alloy or bare aluminium alloy	90	50
Silver or nickel coated	115	75
Tin-coated	105	65

Source: derived from IEC 62271-1

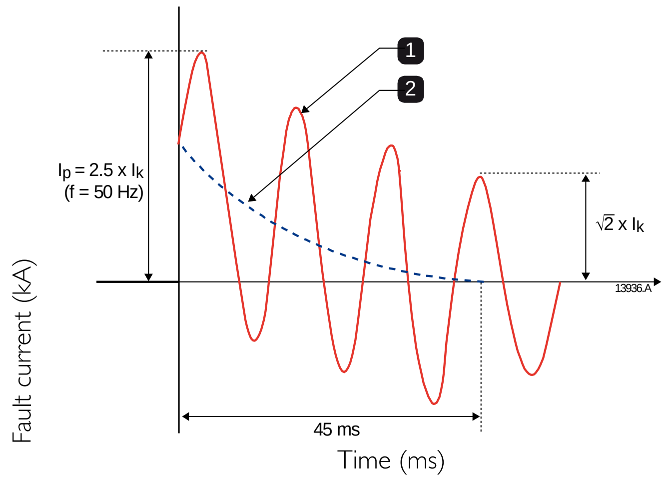
Peak withstand current, I_p (kA)

This is the peak current the equipment can withstand in the closed position from the first loop of a short circuit fault. This current contains a symmetrical AC component, superimposed on a decaying DC component. Peak withstand current is defined as 2.5 times the rated short-time withstand current for 50 Hz installations and 2.6 times the rated short-time withstand current for 60 Hz installations.

The switchgear peak withstand current rating must be higher than the calculated peak dynamic current (I_{dyn}) expected if a short circuit fault occurred at the point of installation.

NOTE
Switchgear peak withstand current rating is commonly referred to as rated short circuit making capacity.

Peak withstand current



1	AC component
2	DC component

Short-time withstand current, I_k (kA)

This is the level of symmetrical rms fault current the switchgear can carry in the closed position for a short time period (typically 1 second), without temperature rise exceeding predefined levels.

IEC 62271-1 specifies standard ratings as base 10 multiples of 1, 1.25, 1.6, 2, 2.5, 3.15, 4, 5, 6.3, 8

Short-time withstand duration, t_k (seconds)

This is the period of time that the equipment is rated to carry the short-time withstand current.

IEC 62271-1 specifies a standard rating of 1 second, although durations of 0.5, 2 and 3 seconds are allowed.

Frequency, fr (Hz)

This is the rated test frequency of the switchgear and must match the operating frequency of the installation. Two medium voltage mains supply frequencies are used globally:

- 50 Hz in European systems
- 60 Hz in American systems

4.10 Protection index

IP Ratings

IEC 60529 specifies levels of protection against the ingress of different items. Ingress protection (IP) codes are composed of up to four elements:

- Characteristic 1: Solid foreign objects
- Characteristic 2: Harmful ingress of liquid
- Additional letter (optional): Object used for access
- Supplementary letter (optional): Application specific

IP rating components

	Characteristic 1	Characteristic 2	Additional Letter	Supplementary Letter
0	Non-protected	Non-protected	A = back of hand	H = high voltage apparatus
1	≥ 50 mm diameter	Vertically dripping	B = finger	M = motion during water test
2	≥ 12.5 mm diameter	Dripping at 15 ° tilt	C = tool	S = stationary during water test
3	≥ 2.5 mm diameter	Spraying	D = wire	W = weather conditions
4	≥ 1.0 mm diameter	Splashing		
5	Dust-protected	Jetting		
6	Dust-tight	Powerful jet		
7		Temporary immersion		
8		Continuous immersion		

Source: IEC 60529

IEC 62271-1 specifies protection ratings for enclosures. Equipment designed for indoor installation is not typically IP rated against ingress of water (a placeholder X is used instead of a rating for this characteristic):

IP ratings for equipment installed indoors

Degree of Protection	Protection against ingress of solid foreign objects	Protection against access to hazardous parts
IP1XB	Protected against solid objects greater than 50 mm	Access with a finger (test-finger 12 mm diameter, 80 mm length)
IP2X	Protected against solid objects greater than 12.5 mm	Access with a finger (test-finger 12 mm diameter, 80 mm length)
IP2XC	Protected against solid objects greater than 12.5 mm	Access with a tool (test rod 2.5 mm diameter, 100 mm length)
IP2XD	Protected against solid objects greater than 12.5 mm	Access with a wire (test wire 1.0 mm diameter, 100 mm length)
IP3XC	Protected against solid objects greater than 2.5 mm	Access with a tool (test rod 2.5 mm diameter, 100 mm length)
IP3XD	Protected against solid objects greater than 2.5 mm	Access with a wire (test wire 1.0 mm diameter, 100 mm length)
IP4X	Protected against solid objects greater than 1 mm	Access with a wire (test wire 1.0 mm diameter, 100 mm length)
IP5X	Protection against harmful entry of dust	Access with a wire (test wire 1.0 mm diameter, 100 mm length)

Source: IEC 62271-1

NEMA Ratings

NEMA 250 is a product standard that addresses many aspects of enclosure design and performance.

NEMA	Protection against solid objects	Closest IP equivalent *
1	Indoor, protection from contact.	IP 20
2	Indoor, limited protection from dirt and water.	IP 22
3	Outdoor, some protection from rain, sleet, windblown dust and ice.	IP 55
3R	Outdoor, some protection from rain, sleet and ice.	IP 24
4	Indoor or outdoor, some protection from windblown dust, rain, splashing water, hose-directed water and ice.	IP 66
4X	Indoor or outdoor, some protection from corrosion, windblown dust, rain, splashing water, hose-directed water and ice.	IP 66
6	Indoor or outdoor, some protection from ice, hose-directed water, entry of water when submerged at limited depth.	IP 67
12	Indoor, protection from dust, falling dirt and dripping non-corrosive liquids.	IP 54
13	Indoor, protection from dust, spraying water, oil and non-corrosive liquids.	IP 54

NOTE

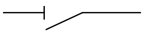
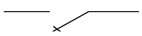
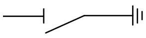
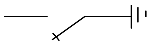
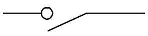
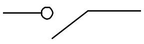
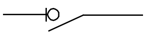
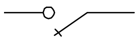
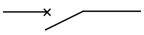
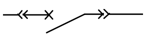
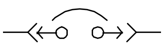
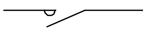
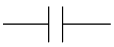
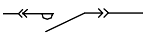
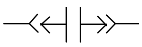
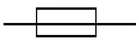
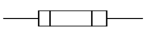
* NEMA and IP ratings are not directly equivalent and this information provides an approximate correlation only.

5 Schematic Diagrams

5.1 Electrical Symbols - Common Switching Functions

The following table shows the standard IEC and ANSI symbols for common switching functions

IEC 60617-2 is a European standard. ANSI Y32.2 is a North American standard. As a general rule, countries using a 50 Hz supply normally adhere to IEC standards and countries using a 60 Hz supply normally adhere to ANSI standards.

Designation and symbol (IEC)	Symbol (ANSI)	Function	Switches operating current	Switches fault current
Disconnector 		Isolates		
Earthing disconnector 		Earths		(short circuit making capacity)
Switch 		Switches	●	
Disconnector switch 		Switches and isolates	●	
Fixed circuit breaker 		Switches and protects	●	●
Withdrawable circuit breaker 		Switches and protects; isolates if withdrawn	●	●
Fixed contactor 		Switches	●	
Withdrawable contactor 		Switches; isolates if withdrawn	●	
Fuse 		Protects but does not isolate		● (once)

5.2 Circuit Breaker Control (Typical)

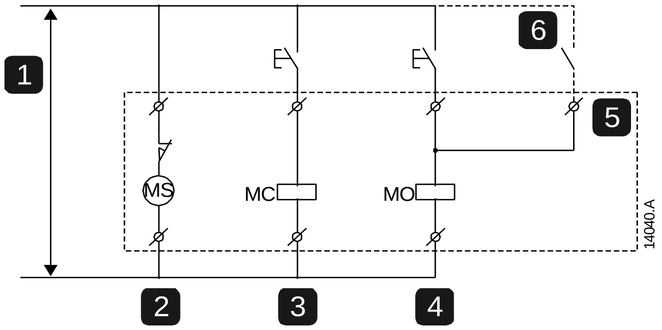
This information focuses on the double command operated (DCO) method of circuit breaker control.

DCO control uses normally-open momentary contacts (ie pushbuttons) or a bistable relay to operate the shunt closing and opening coils. Some circuit breakers use voltage fed open and close command signals while others use volt-free signals.

Medium voltage circuit breakers can be vacuum or gas (SF6) insulated, with magnetic or motor charged spring operation.

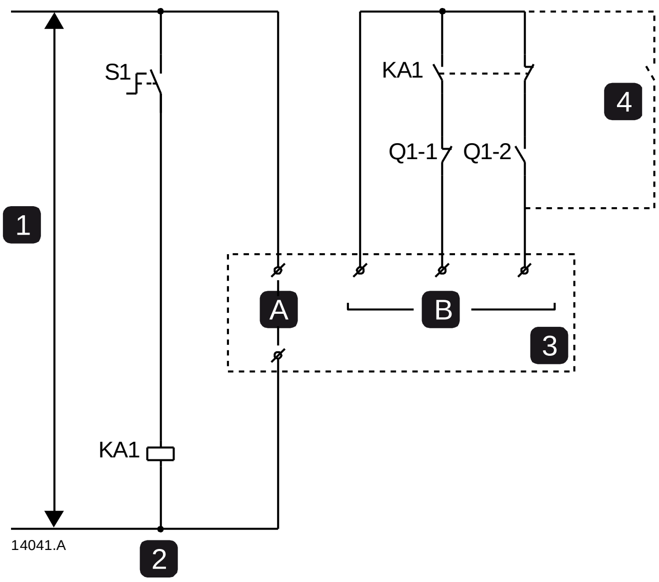
Here are some examples of various double command operated (DCO) control methods:

Motor operated circuit breaker using voltage fed open and close command signals via momentary contact pushbuttons



1	Auxiliary supply
2	Motor (spring charge)
3	Close shunt coil
4	Open shunt coil
5	Circuit breaker controller
6	External trip contact (eg from MPR)

Magnetic operated circuit breaker using volt-free open and close command signals via bistable relay contacts



1	Auxiliary supply
2	Circuit breaker control (open/close)
3	Circuit breaker controller
4	External trip contact (eg from MPR)
A	Control supply
B	Command inputs (common, close, open)

5.3 Contactor Control (Typical)

Medium voltage contactors have two methods of control.

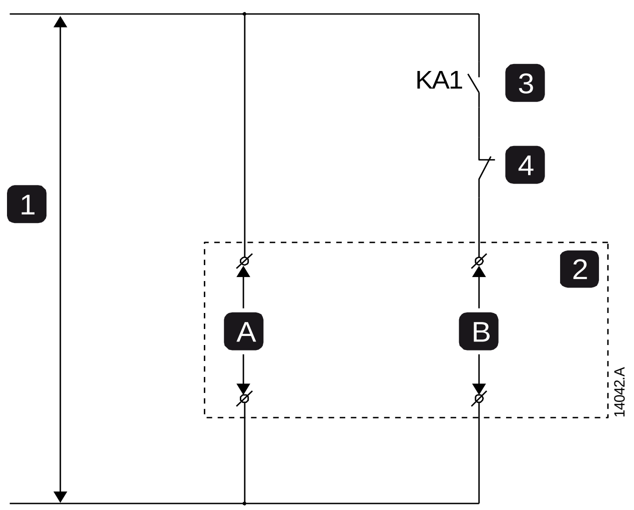
- single command operated control (SCO) - this requires a permanent signal to close and maintain the contactor in the closed position. Removal of the control signal will open the contactor.
- double command operated control (DCO) - this requires two separate momentary contacts; one for the close command and one for the open command. The DCO control method typically uses normally open, spring return pushbuttons for both the open and close commands.

Typically, command signals require an external voltage source and the contactor controller itself requires a separate auxiliary voltage source. Depending on the contactor make and model, electrical options are available. Some examples are:

Undervoltage shunt trip	only used with DCO control
Lock-out solenoid	needs to be externally energised before contactor main poles can be electrically operated
Racking solenoid	needs to be externally energised before a withdrawable contactor can be moved between the test and service positions
Auxiliary contacts	indicate the electrical state of the main contactor poles
Racking contacts	indicate whether a withdrawable contactor is in the service or test position
Fuse blow indicator contacts	indicate fuse condition. - operated by striker pin and only available on contactors with integral medium voltage fuses

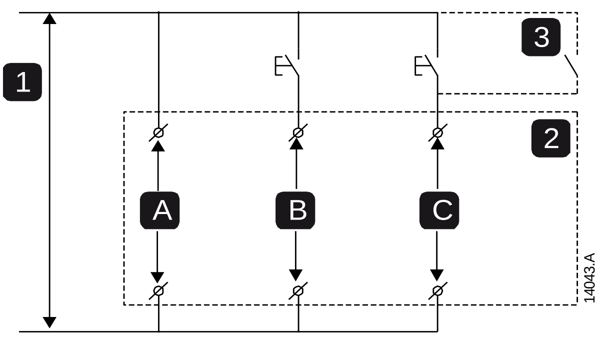
The following examples show typical contactor control circuits:

Single command operated contactor control (typical)



1	Auxiliary supply
2	Contactor controller
3	Control signal (maintained)
4	External trip contact (eg from MPR)
A	Control supply
B	Control input

Double command operated contactor control (typical)



1	Auxiliary supply
2	Contactor controller
3	External trip contact (eg from MPR)
A	Control supply
B	Close input
C	Open input

5.4 Automatic Changeover Systems

In medium voltage distribution networks, it is important to maintain a high level of reliability. Industry relies on the continuous operation of critical plant, which requires no or little disruption to the electrical supply. There are various methods for building redundancy of supply into a system. The most commonly used methods are a dual transformer fed supply and/or a standby generator sized to keep critical plant online.

Automatic changeover systems are designed to monitor and maintain continuous supply. Today's technology allows the supervision and control of an entire distribution system from a single controller, referred to as an automatic transfer switch (ATS) or automatic changeover unit (ACU). Although there are a wide range of products available, they all have the same primary function.

The equipment monitors 3-phase voltages on all power sources. Power supply sources are often prioritised and if any phase voltage on the primary power source falls outside a predetermined range for a specific amount of time, the power source is switched over to a back-up supply. Once the primary power source is re-established, the power source is switched back to the primary power source. In medium voltage systems, switching is performed using either contactors or circuit breakers. Most ATS controllers can control both types of switching devices.

Automatic changeover systems range from simple main/standby set-ups to highly complex distribution systems and this is where the selection of an appropriate ATS controller is important. Systems can be operated in automatic or manual mode.

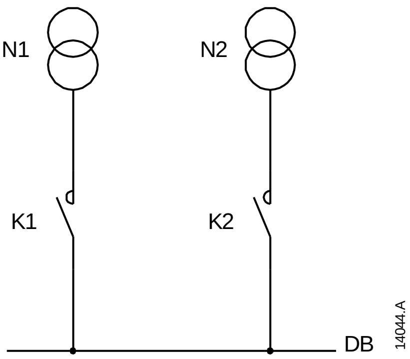
- In AUTO mode, supervision and power source switching is carried out entirely by the ATS controller.
- In MANUAL mode, power source switching is carried out by manual selection via the ATS controller.

NOTE
For safety reasons, manual mode cannot be used in certain network configurations.

Overview

The following are examples of common operating modes in automatic changeover systems. Most ATS controllers can be programmed to operate in any one of these modes.

N1+N2



AUTO mode with line priority:

N1 is the prioritised power source and, if healthy, will always supply the receiving network (DB). If N1 is lost, the controller switches over to power source N2. The controller switches back to N1 once it has been re-established.

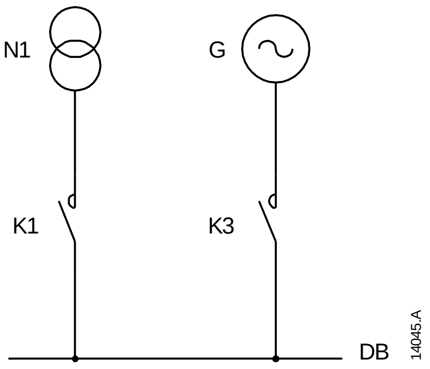
AUTO mode without line priority:

The first power source verified as healthy will supply the receiving network (DB). If this power source is lost, the other power source will be selected and remain as the supply as long as it is healthy. If both power sources are lost, both sources N1 and N2 are isolated from the receiving network (DB)

MANUAL mode:

Select N1 or N2 as the power source

N1+G



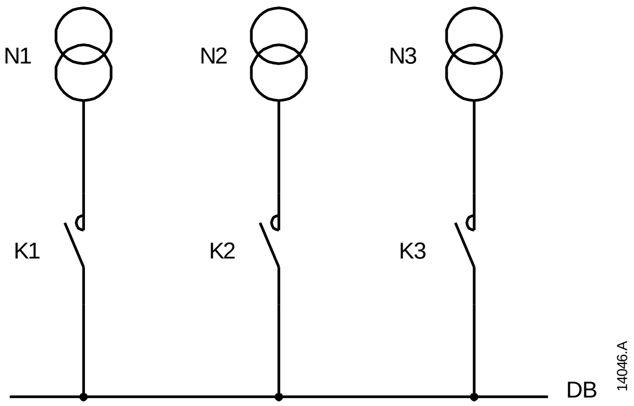
AUTO mode:

N1 is the prioritised power source and, if healthy, will always supply the receiving network (DB). If power source N1 is lost, the controller commands the standby generator to start. Once the generator is at correct voltage and frequency, power source G is switched in to supply the receiving network (DB). The controller switches back to N1 once it has been re-established.

MANUAL mode:

Select N1 or G as the power source.

N1+N2+N3



AUTO mode with line priority:

N1 is the prioritised power source and, if healthy, will always supply the receiving network (DB). If N1 is lost, the controller switches over to power source N2. If power source N2 is lost, the controller switches over to power source N3. The controller switches back to N1 once it has been re-established.

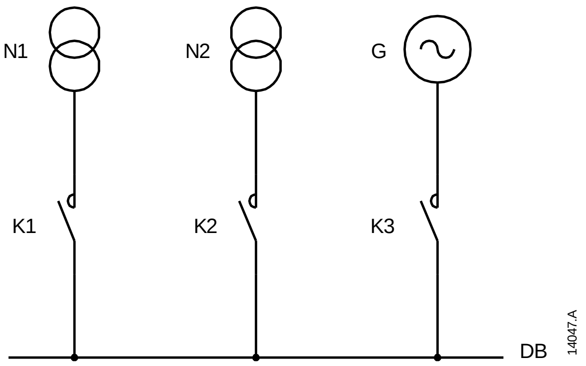
AUTO mode without line priority:

The first power source verified as healthy will supply the receiving network (DB). If this power source is lost, the next healthy power source is selected and will remain as the supply as long as it is healthy. The order of power source selection is normally predetermined, eg N1 then N2 then N3.

MANUAL mode:

Select N1 or N2 or N3 as the power source.

N1+N2+G



AUTO mode with line priority:

N1 is the prioritised power source and, if healthy, will always supply the receiving network (DB). If N1 is lost, the controller switches over to power source N2. The controller switches back to N1 once it has been re-established.

If both power sources N1 and N2 are lost, the controller commands the standby generator to start. Once the generator is at correct voltage and frequency, power source G is switched in to supply the receiving network (DB). The controller switches back to the first re-established power source N1 or N2.

AUTO mode without line priority:

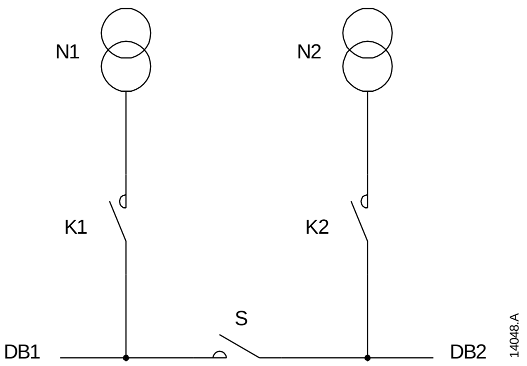
The first power source verified as healthy will supply the receiving network (DB). If this power source is lost, the other power source will be selected and remain as the supply as long as it is healthy.

If both power sources N1 and N2 are lost, the controller commands the standby generator to start. Once the generator is at correct voltage and frequency, power source G is switched in to supply the receiving network (DB). The controller switches back to the first re-established power source N1 or N2.

MANUAL mode:

Select N1 or N2 or G as the power source.

N1+N2+S



AUTO mode:

Providing power sources N1 and N2 are healthy, N1 will supply network DB1 and N2 will supply network DB2. Bus coupler S will remain open.

If power source N1 is lost, this supply is isolated and bus coupler S is closed. Power source N2 now supplies networks DB1 and DB2. Once power source N1 is re-established, bus coupler S is opened and N1 will supply network DB1 and N2 will supply network DB2.

If power source N2 is lost, this supply is isolated and bus coupler S is closed. Power source N1 now supplies networks DB1 and DB2. Once power source N2 is re-established, bus coupler S is opened and N1 will supply network DB1 and N2 will supply network DB2.

MANUAL mode:

Select N1 and N2 as power sources with bus coupler S open.

Select power source N1 with bus coupler S closed and power source N2 isolated.

Select power source N2 with bus coupler S closed and power source N1 isolated.

5.5 MVS Schematic Diagrams

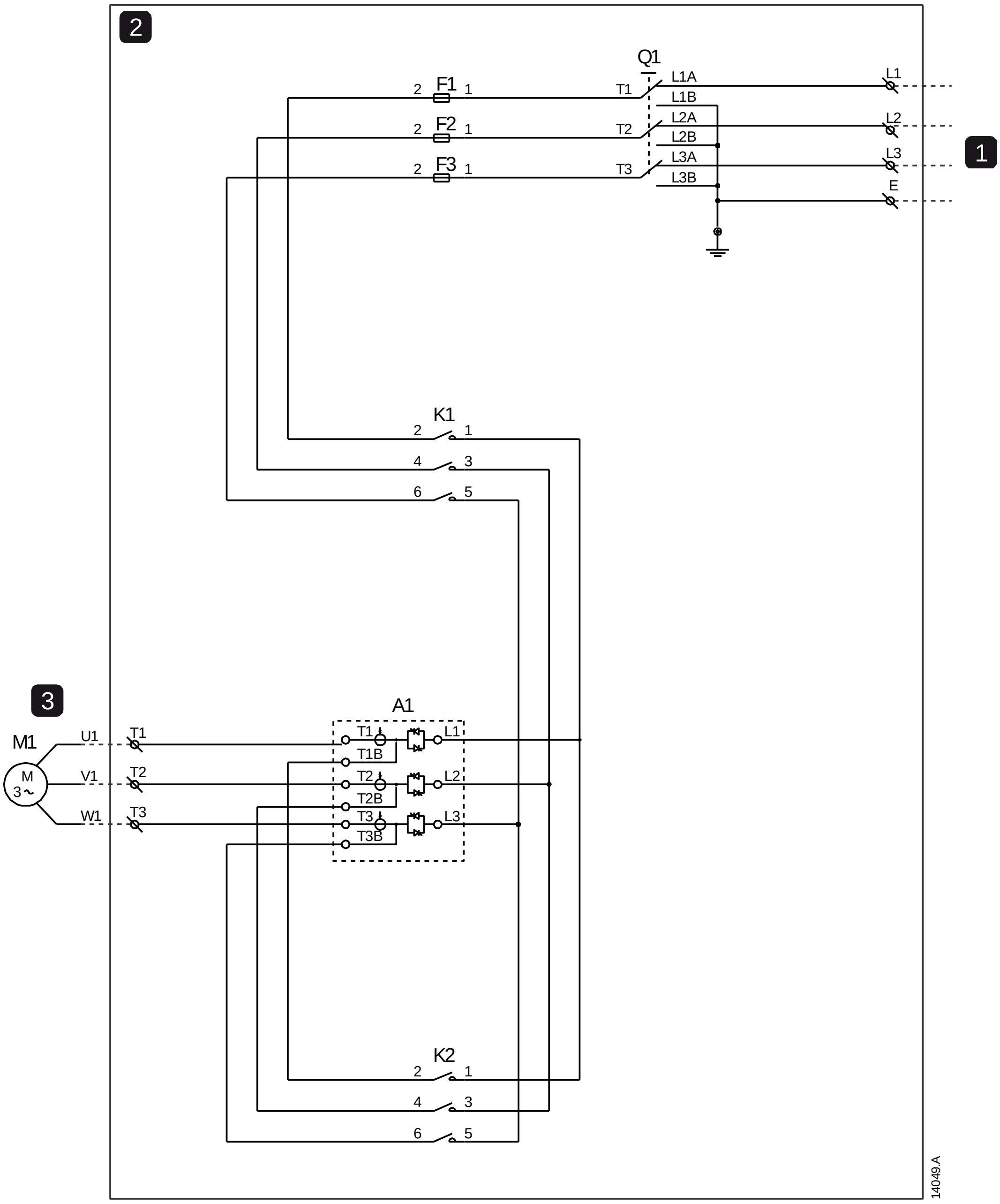
The MVS medium voltage soft starter is rated for 80 A to 321 A at 2.3 kV to 7.2 kV. AuCom can supply the soft starter in an IP54 or IP42 style panel with two switchgear configurations. These are referred to as E3 and E2 panel options.

E3 panel option

The standard E3 panel option consists of a combined main isolator/earth switch, a main and bypass contactor and a set of MV fast-acting line fuses (R-rated). Refer to the MVS section for details of optional panel equipment.

The panel can be supplied in a stand-alone format or with rear, horizontal busbars for an MCC switchgear line-up.

Typical MVS E3 panel

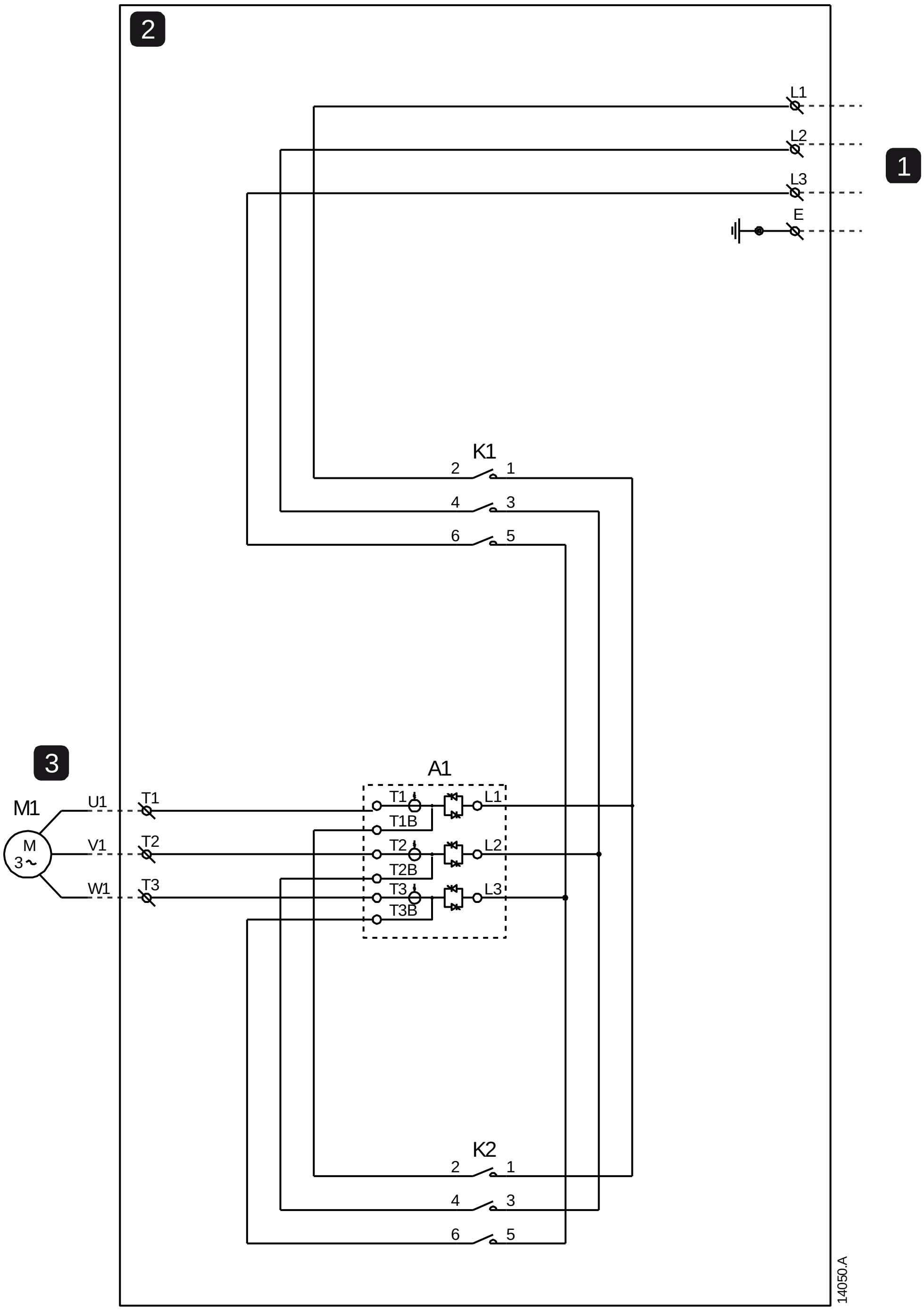


1	Mains supply		F1-3	MV protection fuses
2	MVS E3 panel		K1	Main contactor
3	Motor cables		K2	Bypass contactor
A1	MVS soft starter		Q1	Isolator/earth switch

E2 panel option

The standard E2 panel option consists of a main and bypass contactor. A means of isolation and earthing, as well as some form of line protection, must be supplied and installed separately, upstream of the E2 panel. Refer to the MVS section for details of optional panel equipment.

Typical MVS E2 panel



1	Mains supply		A1	MVS soft starter
2	MVS E2 panel		K1	Main contactor
3	Motor cables		K2	Bypass contactor

5.6 MVX Schematic Diagrams

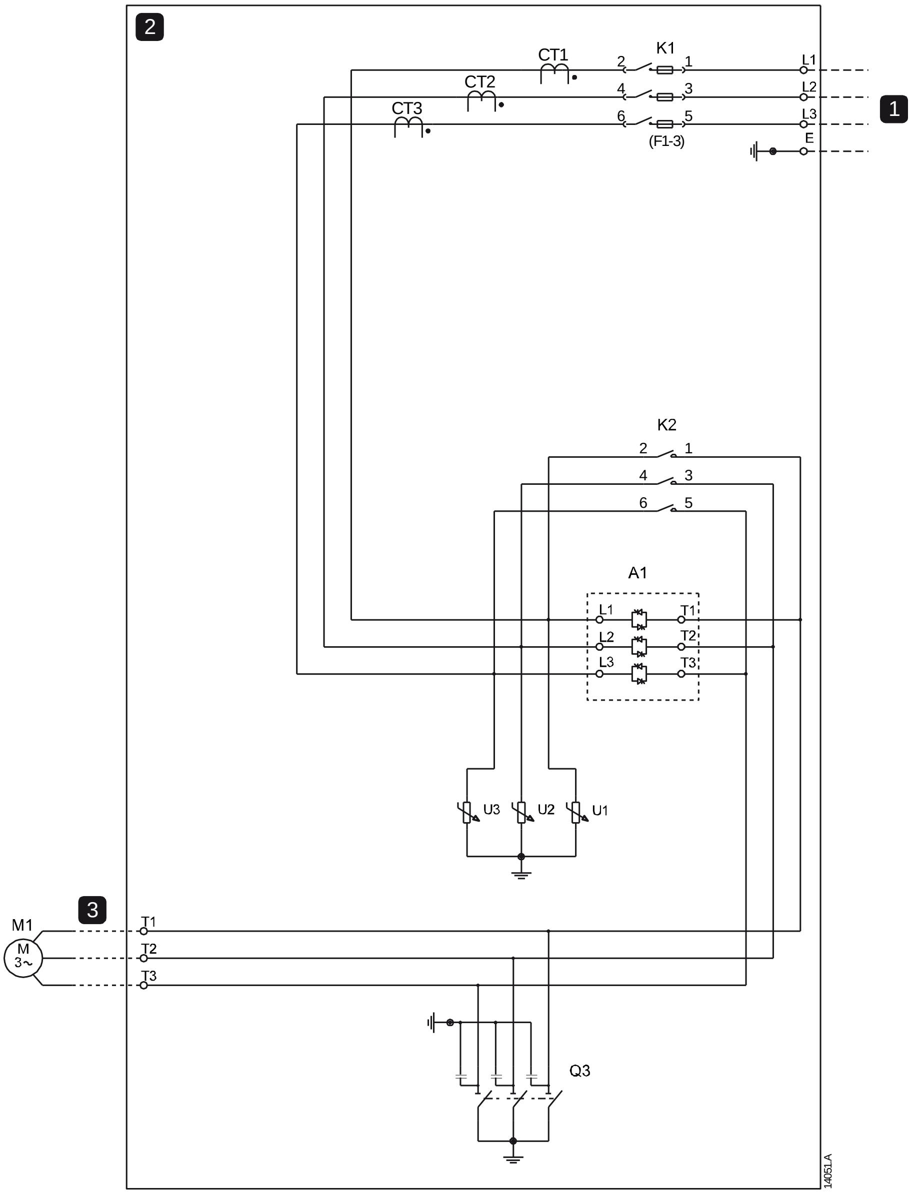
The MVX medium voltage soft starter is rated up to 200 A at 11 kV. AuCom supplies the soft starter in an IP4X metal-clad style panel with two switchgear configurations. These are referred to as the contactor or circuit breaker panel options.

Contactor panel option

This panel option is limited by the contactor fuse rating to a maximum motor FLC of 160 A. It consists of a withdrawable, fused contactor as a main switching device, a fixed bypass contactor, overvoltage MOVs on the line side and an earth switch on the motor side. Refer to the MVX section for details of optional panel equipment.

The panel can be supplied as a stand-alone format or with an upper, horizontal busbar system for an MCC switchgear line-up.

Typical MVX contactor panel



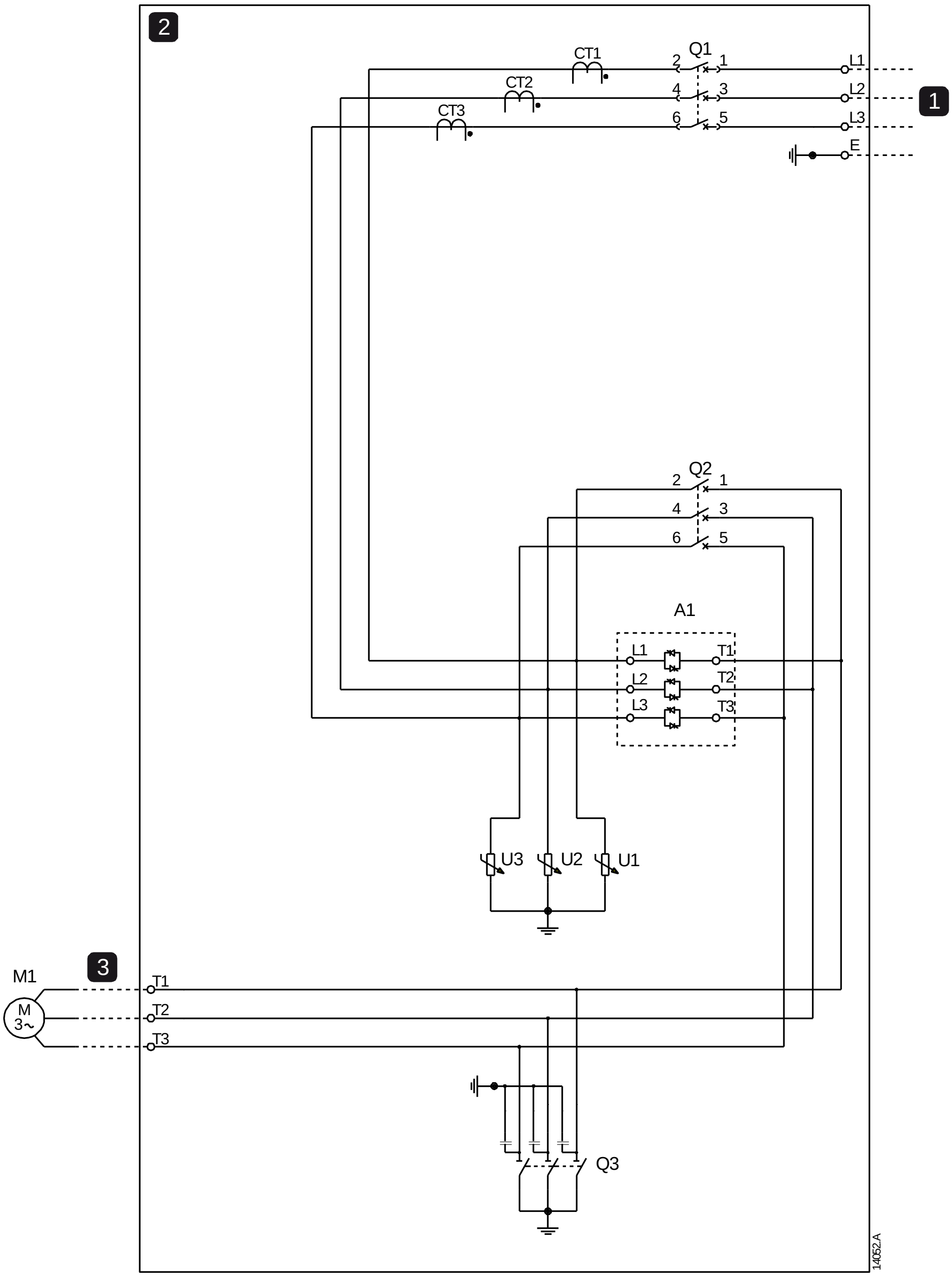
1	Three-phase supply		F1-3	MV protection fuses (x3)
2	MVX contactor panel		K1	Main contactor (withdrawable, fused)
3	Motor cables		K2	Bypass contactor (fixed)
A1	MVX soft starter		Q3	Earth switch
CT1-3	Current transformers		U1-3	Overvoltage MOVs

Circuit breaker panel option

This panel option is currently supplied for a maximum motor FLC of 400 A. It consists of a withdrawable circuit breaker as a main switching device, a separate motor protection relay (MPR), a fixed bypass circuit breaker, overvoltage MOVs on the line side and an earth switch on the motor side. Refer to the MVX section for details of optional panel equipment.

The panel can be supplied as a stand-alone format or with an upper, horizontal busbar system for an MCC switchgear line-up.

Typical MVX circuit breaker panel



1	Three-phase supply	Q1	Main circuit breaker (withdrawable)
2	MVX circuit breaker panel	Q2	Bypass circuit breaker (fixed)
3	Motor cables	Q3	Earth switch
A1	MVX soft starter	U1-3	Overvoltage MOVs
CT1-3	Current transformers		

6 Resources

6.1 Equipment Specifications

The following soft starter and power factor panel specifications provide detail of AuCom supplied equipment. The switchgear specification is more generic. These specifications can be used entirely or in part when tendering for a project.

NOTE
AuCom reserves the right to modify or change the specification of its products at any time without notice.

SPECIFICATION:

MVS Solid State
Reduced Voltage Motor Starter

MEDIUM VOLTAGE

Contents

Introduction

1.1 Scope

This document specifies the minimum requirements for a solid state reduced voltage motor starter for medium voltage application.

This specification is intended as a guideline for suppliers wishing to supply their product to <**customer name**> for their <**project name/outline of requirement**>.

The solid state reduced voltage starter shall control three phases at ____ **V**, ___ **Hz** and shall be rated to suit the application and motor characteristics. Where possible motor and load curves will be provided and the supplier will use this data to justify selection. The starter shall provide soft starting and soft stopping of the motor as required.

1.2 Supplier Qualifications

The equipment shall have been manufactured by a single vendor.

The manufacturer shall be certified under ISO9000.

The manufacturer shall have produced solid state reduced voltage starters for a minimum of 20 years.

Environmental Specifications

2.1 Environmental Specifications

The equipment shall be suitable for storage at temperatures from -25 ºC to +55 ºC.

The equipment shall be suitable for use at temperatures from -10 ºC to +60 ºC.

The equipment shall be suitable for use at temperatures up to 40 ºC without derating.

The equipment shall be suitable for operation at altitudes up to 1000 m above sea level without derating.

The equipment shall be suitable for use in environments with relative humidity between 5% and 95% (non-condensing).

2.2 Physical Specifications

The equipment shall be suitable for supply in IP00 format or integrated into a stand-alone package.

The equipment shall be modular in design and construction.

The thyristor assembly for each phase shall consist of a discrete module, and be individually replaceable

Replacement of a thyristor assembly by a qualified service technician shall not take longer than 10 minutes.

No single module of the equipment shall exceed 80 kg in weight.

The integrated starter must be enclosed up to IP54 and include:

- Line contactor
- Bypass contactor
- Line fuses (optional)
- A pad-lockable earthing Isolator (optional)

2.3 Safety

The equipment shall employ only air insulation between phases.

The IP00 starter should be capable of being enclosed without any additional clearances at the side of the product.

The equipment shall employ fibre-optic cabling to ensure complete isolation between low voltage and high voltage circuitry.

The equipment shall provide means to safely test its correct installation:

- The equipment shall provide a means to test the installation using a low voltage motor.
- The equipment shall provide a means to test operation of all control circuitry and protection mechanisms, without connection to medium voltage. Functions to be tested include, at minimum:
  - motor starting
  - motor stopping
  - protection activation

Logic Control Configuration

3.1 Control Interface

The equipment shall be suitable for being supplied as a lose item with an IP00 unit for flush mounting into the control portion of a cubicle.

The controller must have a minimum environmental rating of IP55.

The user interface shall comprise, at minimum:

- an LCD screen for information feedback
- be able to be multilingual
- status LEDs indicating
  - motor state
  - starter control state
  - trip status
  - output relay activity
- local pushbuttons to control:
  - motor start
  - motor stop
  - starter reset
  - menu access
  - parameter configuration

Remote control of the starter shall be possible using either two or three wire control.

Have multi level password protection system, to prevent unauthorized parameter access; but still allowing access for operators to metering functions and logs.

All terminals shall be of the pluggable type.

The control interface shall provide a means for an operator to quickly access and configure parameters.

The control interface shall provide an operator with a short list of critical parameters for common applications, including:

- pump
- fan
- compressor
- generic

The equipment shall permit the operator to save the current configuration to an internal file. There shall be two files available.

The equipment shall permit the operator to reload a previously saved configuration set from an internal file. There shall be two files available.

The equipment shall permit the operator to restore default settings.

The equipment shall support remote management via a control network with a choice of Modbus, Profibus and Devicenet as a minimum.

The equipment shall provide an on-board real-time clock; but failure of this clock due to low battery shall not trip the starter.

3.2 Operating Configurations

The equipment shall permit the user to select between multiple profiles for starting the motor.

The equipment shall provide a kickstart option for starting the motor.

The equipment shall permit the user to select between multiple profiles for stopping the motor.

The equipment shall provide a feedback ramp option for stopping the motor.

The equipment shall provide a means of automatically stopping the motor at a predetermined time or after a predetermined period of operation.

The equipment shall be suitable for use with dual-speed and slip-ring motors

Thermal modeling that allows the soft starter to dynamically calculate the motor temperature, predict the motors available thermal capacity, to predict whether the motor can successfully complete a start.

3.3 Motor and System Protection Features

The starter shall have the following adjustable protection functions included as standard. (ANSI Codes):

The equipment's sensitivity and response for protection functions shall be programmable.

- Overload (49/51)
- Undercurrent (37)
- Instantaneous Over-current (50)
- Current Imbalance (46)
- Frequency (81)
- Auxiliary Trip A (86/97)
- Auxiliary Trip B (86/97)
- Excess start time (66)
- Maximum start Time (48)
- Starter Communications Failure (3)
- Battery/Clock Failure (3)
- SCR Temperature
- Ground Fault (50G)
- Overvoltage (59)
- Under-voltage (27)
- Phase sequence (47)
- Phase Loss (47)
- Power Loss (32)

The following protection states are also provided:

- Motor not detected
- Auxiliary trip A
- Auxiliary trip B
- Network communications
- EEPROM failure
- Gate drive failure
- Conduction 1 invalid
- Conduction 2 invalid
- Conduction 3 invalid
- Assembly control voltage low

The equipment's possible responses to protection activation shall include, at minimum:

- trip: cease operation and disable the motor
- warn: notify the condition to the operator and continue operating
- ride through: write the event to memory

3.4 Programmable Relay Outputs

The equipment shall provide output relays to control operation of:

- main contactor
- bypass contactor
- power factor correction capacitor bank

The equipment shall provide an output relay to indicate that the unit is operating.

The equipment shall provide at least three additional relays with user-selectable functionality, enabling indication of:

- Ready state
- Low current state
- High current state
- Motor temperature state
- Trip states (with adjustable delays);
    - Motor overload
    - Current imbalance
    - Undercurrent
    - Instantaneous overcurrent
    - Mains frequency
    - Ground fault
    - Time-overcurrent
    - SCR overtemperature
    - Phase loss
    - Motor thermistor
    - Undervoltage

3.5 Programmable Control Inputs

The equipment shall provide at least two programmable inputs with the following functionality:

- Parameter set selection
- Auxiliary Trip (N/O)
- Auxiliary Trip (N/C)
- Local/Remote Select
- Emergency Mode Operation
- Emergency Stop (N/C)

Each input must be able to be set for N/O or N/C operation and must have selectable delays.

3.6 Metering and Performance Monitoring

The equipment shall include comprehensive metering and monitoring functions.

The equipment shall provide real-time feedback of operating conditions, including:

- average current
- L1, L2 & L3 currents
- average voltage
- L1, L2 & L3 voltages
- mains frequency
- motor real power consumption (kVA)
- motor active power consumption (kW)
- motor power factor
- elapsed running time
- time to run before programmed stop (when running)

The equipment shall provide feedback of historical operating information, including:

- lifetime hours run
- lifetime start count
- resettable hours run
- resettable start count
- resettable kWh count

The control interface shall allow the user to select which parameters to display on the LCD.

The equipment shall record full details of its state at the time of every protection activation. The recorded details shall include, at minimum:

- time and date stamp.
- protection type
- motor operating status
- mains frequency
- line current
- line voltage

The equipment's protection log shall store no fewer than eight trips.

The equipment shall record all changes to its configuration.

The equipment's change log shall store no fewer than 99 events.

3.7 Remote Communications

The starter must have the ability to download parameters and monitor via a computer during commissioning.

Optional Remote communications be available for the following interfaces to both monitor and control the soft starter.

- Modbus RTU
- Profibus
- Devicenet

Support and Services

4.1 Commissioning

The equipment supplier shall be capable of providing commissioning of the equipment.

4.2 Documentation

The equipment shall be provided with a complete set of user and support documentation, including:

- User manual
- Recommended list of spare parts
- Schematic & GA drawings

4.3 Training

The equipment supplier shall be capable of providing a complete training schedule with the equipment.

The equipment supplier shall undertake to deliver the complete training programme if required by the customer.

The training programme shall be delivered at the customer's premises or at the supplier's premises, as required by the customer.

The training programme shall deliver to the customer the skills to:

- appropriately programme the equipment to meet customer requirements
- safely commission the equipment
- safely operate the equipment
- identify and rectify operating problems caused by incorrect programming
- identify and diagnose operating problems caused by faulty equipment

4.4 Warranty and Repair

The supplier shall guarantee the equipment against faults of materials or manufacture workmanship for a period of not less than 18 months from the date of manufacture..

The supplier shall guarantee to provide servicing support for the equipment for a period of not less than 10 years.

4.5 Standards and Approvals

The equipment must, as a minimum comply with and be certified to:

- UL /cUL UL508,UL347
- CE EMC EU Directive
- C -tick EMC Requirements
- Marine Lloyds

SPECIFICATION:

MVX Solid State
Reduced Voltage Motor Starter

MEDIUM VOLTAGE

Contents

Introduction

1.1 Scope

This document specifies the minimum requirements for a solid state reduced voltage motor starter for medium voltage application.

This specification is intended as a guideline for suppliers wishing to supply their product to <**customer name**> for their <**project name/outline of requirement**>.

The solid state reduced voltage starter shall control three phases at ____ **V**, ___ **Hz** and shall be rated to suit the application and motor characteristics. Where possible motor and load curves will be provided and the supplier will use this data to justify selection. The starter shall provide soft starting and soft stopping of the motor as required.

1.2 Supplier Qualifications

The equipment shall have been manufactured by a single vendor.

The manufacturer shall be certified under ISO9000.

The manufacturer shall have produced solid state reduced voltage starters for a minimum of 20 years.

1.3 Starter Ratings

The ratings of the equipment shall be stated as per IEC 60947-4-2

The supplier must be able to provide documentation confirming that the equipment is correctly rated and fit for purpose.

Environmental Specifications

2.1 Environmental Specifications

The equipment shall be suitable for storage at temperatures from -25 ºC to +55 ºC.

The equipment shall be suitable for use at temperatures from -10 ºC to +60 ºC.

The equipment shall be suitable for use at temperatures up to 40 ºC without derating.

The equipment shall be suitable for operation at altitudes up to 1000 m above sea level without derating.

The equipment shall be suitable for use in environments with relative humidity between 5% and 95% (non-condensing).

2.2 Physical Specifications

The equipment shall be modular in design and construction.

The thyristor assembly for each phase shall consist of a discrete module, and be individually replaceable

Replacement of a thyristor assembly by a qualified service technician shall not take longer than 10 minutes.

The integrated starter must be enclosed up to IP4X and include:

- Withdrawable Vacuum, fused Line contactor with ratings:
- Fixed Vacuum Bypass contactor

  All contactors shall have the following ratings:
  1. Class: indoor withdrawable
  2. Rated Voltage: 12 kV
  3. Rated lightning impulse withstand voltage: 75 kV (peak)
  4. Rated 1-minute power frequency withstand voltage: 28 kV (rms)
  5. Rated Frequency: 50 Hz/60 Hz
  6. Rated short circuit breaking current: 20 kA (with fuses)
  7. Rated short circuit making current: 62.5 kA (with fuses)
  8. Duty: continuous
  9. Utilisation factor: AC3
  10. Protection coordination: Type 2
  11. Minimum Service Life: 100,000 operations at full operating current.

- A pad-lockable earthing switch
- All panels must provide separate chambers for all main sections including Bus bars, Line Contactor, Soft starters and LV control. The entire panel, including inter-chamber, must be arc fault certified to 31.5kA for 1 seconds.
- All panels shall have the following ratings:
  1. IAC classified AFLR
  2. Rated short term withstand current: 31.5 kA for 3 seconds
  3. BIL: 75 kV
- The equipment shall employ fibre-optic cabling to ensure complete isolation between low voltage and high voltage circuitry.

ENVIRONMENTAL SPECIFICATIONS

The equipment shall provide means to safely test its correct installation:

1. The equipment shall provide a means to test the installation using a low voltage motor.
2. The equipment shall provide a means to test operation of all control circuitry and protection mechanisms, without connection to medium voltage. Functions to be tested include, at minimum:
   - motor starting
   - motor stopping
   - protection activation

NOTE
For installations with motor FLC >160 A, the line and bypass contactors must be replaced by a withdrawable and fixed circuit breaker respectively.

Logic Control Configuration

3.1 Control Interface

The controller must have a minimum environmental rating of IP55.

The user interface shall comprise, at minimum:

- an LCD screen for information feedback in plain English
- be able to be multilingual
- status LEDs indicating
  - motor state
  - starter control state
  - trip status
  - output relay activity
- local pushbuttons to control:
  - motor start
  - motor stop
  - starter reset
  - menu access
  - parameter configuration

Remote control of the starter shall be possible using either two or three wire control.

Have multi level password protection system, to prevent unauthorized parameter access; but still allowing access for operators to metering functions and logs.

All terminals shall be of the pluggable type.

The control interface shall provide a means for an operator to quickly access and configure parameters.

The control interface shall provide an operator with a short list of critical parameters for common applications, including:

- pump
- fan
- compressor
- generic

The equipment shall permit the operator to save the current configuration to an internal file. There shall be two files available.

The equipment shall permit the operator to reload a previously saved configuration set from an internal file. There shall be two files available.

The equipment shall permit the operator to restore default settings.

The equipment shall support remote management via a control network with a choice of Modbus, Profibus and DeviceNet as a minimum.

The equipment shall provide an on-board real-time clock; but failure of this clock due to low battery shall not trip the starter.

3.2 Operating Configurations

The equipment shall permit the user to select between multiple profiles for starting the motor.

The equipment shall provide a kick-start option for starting the motor.

The equipment shall permit the user to select between multiple profiles for stopping the motor.

The equipment shall provide a feedback ramp option for stopping the motor.

The equipment shall provide a means of automatically stopping the motor at a predetermined time or after a predetermined period of operation.

The equipment shall be suitable for use with dual-speed and slip-ring motors

Thermal modeling that allows the soft starter to dynamically calculate the motor temperature, predict the motors available thermal capacity, to predict whether the motor can successfully complete a start.

3.3 Motor and System Protection Features

The starter shall have the following adjustable protection functions included as standard. (ANSI Codes):

The equipment's sensitivity and response for protection functions shall be programmable.

- Overload (49/51)
- Undercurrent (37)
- Instantaneous Over-current (50)
- Current Imbalance (46)
- Frequency (81)
- Auxiliary Trip A (86/97)
- Auxiliary Trip B (86/97)
- Excess start time (66)
- Maximum start Time (48)
- Starter Communications Failure (3)
- Battery/Clock Failure (3)
- SCR Temperature
- Ground Fault (50G)
- Overvoltage (59)
- Under-voltage (27)
- Phase sequence (47)
- Phase Loss (47)
- Power Loss (32)

The following protection states are also provided:

- Motor not detected
- Auxiliary trip A
- Auxiliary trip B
- Network communications
- EEPROM failure
- Gate drive failure
- Conduction 1 invalid
- Conduction 2 invalid
- Conduction 3 invalid

- Assembly control voltage low

The equipment's possible responses to protection activation shall include, at minimum:

- trip: cease operation and disable the motor
- warn: notify the condition to the operator and continue operating
- ride through: write the event to memory

3.4 Programmable Relay Outputs

The equipment shall provide output relays to control operation of:

- main contactor
- bypass contactor
- power factor correction capacitor bank

The equipment shall provide an output relay to indicate that the unit is operating.

The equipment shall provide at least three additional relays with user-selectable functionality, enabling indication of:

- Ready state
- Low current state
- High current state
- Motor temperature state
- Trip states (with adjustable delays);
  - Motor overload
  - Current imbalance
  - Undercurrent
  - Instantaneous Overcurrent
  - Mains frequency
  - Ground fault
  - Time-overcurrent
  - SCR over temperature
  - Phase loss
  - Motor thermistor
  - Undervoltage

3.5 Programmable Control Inputs

The equipment shall provide at least two programmable inputs with the following functionality:

- Parameter set selection
- Auxiliary Trip (N/O)
- Auxiliary Trip (N/C)
- Local/Remote Select
- Emergency Mode Operation
- Emergency Stop (N/C)

Each input must be able to be set for N/O or N/C operation and must have selectable delays.

3.6 Metering and Performance Monitoring

The equipment shall include comprehensive metering and monitoring functions.

The equipment shall provide real-time feedback of operating conditions, including:

- average current
- L1, L2 & L3 currents
- average voltage
- L1, L2 & L3 voltages
- mains frequency
- motor real power consumption (kVA)
- motor active power consumption (kW)
- motor power factor
- elapsed running time
- time to run before programmed stop (when running)

The equipment shall provide feedback of historical operating information, including:

- lifetime hours run
- lifetime start count
- resettable hours run
- resettable start count
- resettable kWh count

The control interface shall allow the user to select which parameters to display on the LCD.

The equipment shall record full details of its state at the time of every protection activation. The recorded details shall include, at minimum:

- time and date stamp.
- protection type
- motor operating status
- mains frequency
- line current
- line voltage

The equipment's protection log shall store no fewer than eight trips.

The equipment shall record all changes to its configuration.

The equipment's change log shall store no fewer than 99 events.

3.7 Remote Communications

The starter must have the ability to download parameters and monitor via a computer during commissioning.

Optional Remote communications be available for the following interfaces to both monitor and control the soft starter.

- Modbus RTU
- Profibus
- DeviceNet

Support and Services

4.1 Commissioning

The equipment supplier shall be capable of providing commissioning of the equipment.

4.2 Documentation

The equipment shall be provided with a complete set of user and support documentation, including:

- User manual
- Recommended list of spare parts
- Schematic & GA drawings

4.3 Training

The equipment supplier shall be capable of providing a complete training schedule with the equipment.

The equipment supplier shall undertake to deliver the complete training programme if required by the customer.

The training programme shall be delivered at the customer's premises or at the supplier's premises, as required by the customer.

The training programme shall deliver to the customer the skills to:

- appropriately programme the equipment to meet customer requirements
- safely commission the equipment
- safely operate the equipment
- identify and rectify operating problems caused by incorrect programming
- identify and diagnose operating problems caused by faulty equipment

4.4 Warranty and Repair

The supplier shall guarantee the equipment against faults of materials or manufacture workmanship for a period of not less than 18 months from the date of manufacture.

The supplier shall guarantee to provide servicing support for the equipment for a period of not less than 10 years.

4.5 Standards and Approvals

The equipment must, as a minimum, comply with and be certified to:

- IEC 62271-200
- IEC 60947-4-2
- IEC 60664
- IEC 60529
- NZS4219
- IEEE 242
- CE EMC EU Directive
- C -tick EMC Requirements
- Marine Lloyds

SPECIFICATION:

Power factor Correction

MEDIUM VOLTAGE

Contents

Introduction

1.1 Scope

This document specifies the minimum requirements for power factor correction when used in conjunction with electronic soft starters.

This specification is intended as a guideline for suppliers wishing to supply their product to <**customer name**> for their <**project name/outline of requirement**>.

1.2 Supplier Qualifications

The equipment shall have been manufactured by a single vendor.

The manufacturer shall be certified under ISO9000.

The manufacturer shall be able to demonstrate previous successful application of power factor correction with soft starters

Environmental Specifications

2.1 Environmental Specifications

The equipment shall be suitable for storage at temperatures from -25 ºC to +55 ºC.

The equipment shall be suitable for use at temperatures from -10 ºC to +60 ºC.

The equipment shall be suitable for use at temperatures up to 40 ºC without derating.

The equipment shall be suitable for operation at altitudes up to 1000 m above sea level without derating.

The equipment shall be suitable for use in environments with relative humidity between 5% and 95% (non-condensing).

2.2 Physical Specifications

The equipment shall be modular in design and construction.

The power factor correction components must be installed in a dedicated panel and not the soft starter panel.

The integrated power factor panel must be enclosed up to IP4X and include:

- Withdrawable Vacuum, fused contactor with ratings:
  1. Class: indoor withdrawable
  2. Rated Voltage: 12 kV
  3. Rated lightning impulse withstand voltage: 75 kV (peak)
  4. Rated 1-minute power frequency withstand voltage: 28 kV (rms)
  5. Rated Frequency: 50 Hz
  6. Rated short circuit breaking current: 20 kA (with fuses)
  7. Rated short circuit making current: 62.5 kA (with fuses)
  8. Duty: continuous
  9. Utilisation factor: AC6
  10. Protection coordination: Type 2
  11. Minimum Service Life: 100,000 operations at full operating current.
- Inrush reactors designed to reduce the inrush current to that required by IEC60871-1. The supplier must provide calculations for the correct selection of the reactors.
- Capacitors shall be selected to improve the power factor to the level required by the local utility.
- The capacitor shall have a voltage rating 20% above the nominal operating voltage so as to be able to withstand high voltages associated with capacitor switching.
- The capacitor circuit must be supplied from the line side of the soft starter.
- All panels must provide separate chambers for all main sections including Busbars, Contactor, Capacitors. The entire panel, including inter-chamber, must be arc fault certified to 31.5kA for 3 seconds.
- All panels shall have the following ratings:
  1. IAC classified AFLR
  2. Rated short term withstand current: 31.5kA for 3 seconds
  3. BIL: 75kV

Support and Services

3.1 Documentation

The equipment shall be provided with a complete set of user and support documentation, including:

- User manual
- Recommended list of spare parts
- Schematic & GA drawings

3.2 Training

The equipment supplier shall be capable of providing a complete training schedule with the equipment.

The equipment supplier shall undertake to deliver the complete training programme if required by the customer.

The training programme shall be delivered at the customer's premises or at the supplier's premises, as required by the customer.

The training programme shall deliver to the customer the skills to:

- appropriately programme the equipment to meet customer requirements
- safely commission the equipment
- safely operate the equipment
- identify and rectify operating problems caused by incorrect programming
- identify and diagnose operating problems caused by faulty equipment

3.3 Warranty and Repair

The supplier shall guarantee the equipment against faults of materials or manufacture workmanship for a period of not less than 18 months from the date of manufacture.

The supplier shall guarantee to provide servicing support for the equipment for a period of not less than 10 years.

3.4 Standards and Approvals

The equipment must, as a minimum comply with and be certified to:

IEC 62271-200
IEC 60947-4-2
IEC 60664
IEC 60529
NZS4219
IEEE 242
IEC60871

CE	EMC EU Directive
C -tick	EMC Requirements
Marine	Lloyds

SPECIFICATION:

Switchgear

MEDIUM VOLTAGE

Contents

Introduction

1.1 General

This Section defines the general requirements for MV switchgear and associated electrical works. This specification, used in conjunction with purchase documents, data sheets, and / or drawings establishes the minimum requirements for the design, fabrication and testing of the switchgear aspects of the work for the Plant.

- Reference to other industrial standards for compliance shall be interpreted as an integral part of this specification.
- The Contractor / Supplier shall be responsible for obtaining from the Client all necessary approvals and information required to complete the Works.
- All electrical work shall be carried out in accordance with local regulations or other recognized international standards.
- The approval of equipment and material by the relevant authority shall not prejudice the rights of the Client to reject such equipment or material that does not comply with the specification.
- If required the Contractor / Supplier shall engage professionally qualified specialists/experts to carry out any special activities associated with the provision of special electrical equipment and to comply with all local relevant regulations.

1.2 Submission

The Contractor / Supplier shall submit designs, drawings, data, documents and other such information as specified and required for the Client's review.

All submittals shall be in *English*.

The Client will either:

1. Review the submittal; or

2. Review the submittal subject to notations; or

Where the submittal is reviewed, it will be so endorsed by the Client and one copy returned to the Contractor / Supplier.

The Contractor / Supplier shall make the required alterations and transmit the required copies of the altered submittal.

All work under the Contract shall comply in all respects with the submittals reviewed by the Client described above.

Review by the Client of any drawing, method of work, or any information regarding materials and equipment the Contractor proposes to furnish, shall not relieve the Contractor / Supplier of responsibility for any errors therein and shall not be regarded as an assumption of risks or liability.

Such acceptance shall be considered to mean only that the Client has no objection to the Contractor / Supplier using, upon the Contractor's own full responsibility, the plan or method of work proposed, or furnishing the materials and equipment proposed.

1.3 Quality Assurance

The Contractor / Supplier shall be ISO 9000 certified. The Contract / Supplier must provide certification compliance and demonstrate this to the Client.

Documentation

2.1 Drawings

Unless approved by the Client, all drawings shall be prepared using AutoCAD or an approved computer aided drafting (CAD) package. All drawings shall be A3 size

CAD files of all the Contract Drawings will be provided to the Contractor / Supplier upon receipt of the Contractor's / Suppliers written request.

Electrical wiring and circuit diagrams shall be neat, clear, un-crowded and shall show all equipment using standard symbols. All electrical equipment wiring and terminals shall be numbered in accordance with the Specification requirements.

2.2 Project Manuals

The Contractor / Supplier shall supply manuals for the operation and maintenance of all electrical and instrumentation and control systems supplied under the Contract. In addition, the Contractor shall provide comprehensive manuals, which detail the programming and configuration of any programmable systems.

The Contractor / Supplier shall also provide an electronic copy of the manual.

In general, sufficient information shall be provided to enable the plant's operations and maintenance personnel to understand the function of all equipment and its components and to correctly perform the required operation and maintenance.

2.3 Factory Testing & Commissioning Test Sheets

Contractor / Supplier shall prepare detailed check sheets to record each phase and item of testing and commissioning as required by the Client.

The check sheets shall include separate items for each test and check of each input/output; and each step and sequence of functional operation. Each item on the check sheets shall have provision for recording the date of the activity and name and signature of the Contractor's personnel who carried out the activity.

Electrical Supply

3.1 General

The main power supply to the plant shall be from the power supply authority at XXkV

All equipment provided under this Contract shall be suitable for continuous operation at the voltage and conditions noted below. Compliance is required to clause 9.101 of IEC 62271-200; "Information with enquiries and orders"

All equipment and work associated with the Contract shall be entirely suitable for operation on the plant power supply systems as specified; and tabled below

Nominal voltage between phases	*xxkV*
Number of Phases	3
System fundamental frequency	*TBA* Hz
System Neutral	*TBA*
Design Fault Level	*xx kA for xx sec*
Loss of Service Continuity Category	*TBA*
Internal Arc Classification	*TBA*

3.2 Standards

The work, equipment and other items shall comply with the requirements of relevant IEC and other nominated standards, codes and regulations; including those referenced throughout the Specification and any other Authorities having jurisdiction over any portion of the work, and on the method of performing such work.

Where there is any discrepancy between the referenced standards and this Specification (and associated Contract Drawings), the requirements of this Specification (and associated Contract Drawings) shall have precedence.

3.2.1 Switchgear

		Designed to:
a)	Switchgear and apparatus	IEC62271-1 IEC62271-200 IEC62271-304 GB3906 (2006) DL-T-404 DL-T-593
b)	Internal arc resistance	IEC62271-200 Annex A.6, criteria 1 to 5
c)	Levels of insulation (coordination guide)	IEC60071
d)	Degrees of protection	IEC60529
e)	Seismic	The Uniform Building code, Section 1629.6.8 IEC60721-2-6, Table 1 for static load test
f)	Drilled holes and screw connections for busbars	DIN43673-1
g)	Classification of groups of environmental parameters and their severities – Storage	IEC60721-3-1
h)	Classification of groups of environmental parameters and their severities – Transportation	IEC60721-3-2 IEC60068-2-32
i)	Classification of groups of environmental parameters and their severities – Stationary use at weather protected locations	IEC60721-3-3

3.2.2 MV Equipment

a)	Circuit breakers	IEC62271-100
b)	Alternating current disconnectors and earthing switches	IEC62271-102
c)	Contactors	IEC60470
d)	Fuses	IEC60282-1
e)	PFC capacitors	IEC60871-1
f)	Current transformers	IEC60044-1
g)	Voltage transformers	IEC60044-2
h)	Current sensors	IEC60044-8
i)	Voltage sensors	IEC60044-7

3.2.3 LV Equipment

a)	LV Switchgear and Controlgear Part 1 General Rules	IEC60947-1
b)	LV Switchgear and Controlgear Part 2 Circuit breakers	IEC60947-2
c)	LV Switchgear and Controlgear Part 5-1 Control circuit devices etc	IEC60947-5-1
d)	LV Switchgear and Controlgear Part 7-1 Auxiliary equipment, terminal blocks	IEC60947-7-1

3.3 Service Conditions

All equipment provided under this Contract shall be suitable for operation and standby duties, for the nominated operating conditions, under the following service and climatic conditions:

Climate	*TBA*
Ambient air temperature	*minimum -5°C, maximum +60°C (derate above 40°C)*
Altitude	*1000 m above mean sea level*
Relative humidity	*minimum 35%, maximum 95%*
Atmosphere	*TBA*
Seismic Zone	*TBA*

Ventilation and thermostatically controlled heaters shall be provided, where necessary, to prevent condensation of moisture on idle or stored materials and equipment.

Ventilation shall be provided to dissipate heat from heat producing electrical equipment and keep them and other materials and equipment in the affected area within the safe temperature limits recommended by the respective manufacturers.

3.3.1 Corrosion Protection

All equipment provided shall be painted or protected against nominated corrosive environments. The Contractor /Supplier to specify the coating system provided.

Anti-corrosive paint to a minimum thickness of 50 micron shall be applied to the cleaned metal surface. The finish shall be resistant to the harmful effects of the specified environment.

3.3.2 Enclosure Protection

Unless otherwise specified or shown on the Drawings, all electrical, control system and instrumentation equipment and enclosures shall have the following minimum protection ratings:

- IP4X for equipment, cubicles, panels and switchgear enclosures mounted in indoor air conditioned switch rooms or other non-process conditioned rooms.

3.4 Material Quality

Materials selected shall be new, free from manufacturing defects, and suitable for undiminished performance for the design life of the plant.

Materials shall be “fire resistant”, non-flame-propagating and waterproof.

Glass fiber and plastic material shall withstand the operating temperatures and exposure to sunlight.

Appropriate measures shall be taken to prevent chemical deterioration of the contact surfaces.

MV SWITCHBOARD

1. The “metal enclosed” MV Switchboard under this contract shall comprise the panels as shown on the drawings and / or schedules.
2. The switchboard shall comply with the latest issue of IEC 62271-1 and IEC 62271-200 and with the nominated IP rating against the external environment
3. The switchboard shall be of the modular “metal enclosed” floor mounted, extensible type equipped with circuit breakers, busbars. instruments. relays and all accessories as is described in the specifications hereinafter and the Drawings.
4. All cubicles shall be of standard pattern and dimensions, robust in construction; dust and vermin proof. and suitable for indoor use. The design of the cubicles and associated equipment shall be such as to enable extensions to be made at either end.
5. The switchboard cubicles shall have separate compartments for the switchgear, busbars, cable termination, relays and controls. The compartment shall restrict access to that area described above only.
6. Pressure relief flaps shall be provided on the top of each HV cubicle to relief excess pressure deeming an internal fault.
7. All circuit breakers or contactors shall be of the withdrawable isolating type. with the trucks identical and interchangeable in every switchgear cubicle. A positive guide shall be provided for the truck entry into the cubicle and clear indications given when the truck is at the engaged position.

3.5 Busbar System

1. Busbars and electrical connections between pieces of apparatus shall be of electrolytic copper and shall be sufficiently insulated from earth and from each other to withstand the specified high voltage tests.
2. Busbars shall be air-insulated. All busbars shall be suitable for normal operations at rated voltage, conditions and working environment without secondary insulation. The busbars, connections and their insulated supports shall be of approved construction, mechanically strong, and shall withstand all the stresses which may be imposed upon them due to fixing, vibration, fluctuations in temperature, short circuits or other causes.
3. The busbars shall be so arranged that they may be extended in length without difficulty. Connections shall be kept as short and straight as possible, and any joints shall not increase the resistance of the connection. When dissimilar metals are connected, approved means shall be provided to prevent electro-chemical corrosion.
4. The busbars and connections shall be so arranged and supported that under no circumstances, including short circuit conditions, can the clearances from earthed metalwork or other conductors be less than the distances required in the standards.

3.6 Circuit Breakers

1. CB’s shall be Vacuum type for new MV Switchboards. CB’s must comply with IEC 62271-100.
2. The CB breaking capacity shall be equal to, or greater than the busbar Isc.
3. The circuit breaker shall be of the trip free, vertical or horizontal isolation, horizontal drawout carriage mounted type. The number of electrical and mechanical operations must be stated.
4. The various parts of the circuit breaker shall be of substantial construction, carefully fitted to reduce mechanical shock during operation to a minimum and to prevent inadvertent operation due to vibration or other causes.
5. The circuit breaker shall be arranged for trip free, independent manual operation.
6. The CB method of operation to be provided as part of the submission.
7. The circuit breakers shall have been subjected to impulse voltage tests for the rated voltage.
8. The circuit breaker shall be provided with automatic locking devices to lock the movable portion of the unit in either the 'engaged' or fully 'isolated' position, The interlocking mechanisms shall be provided to satisfy the following requirements:

9. Circuit breaker truck shall only be ***movable*** from engaged position to isolated position and vice *versa* only when the circuit breaker is open.
10. Circuit breaker truck shall be locked in cubicle panel while the circuit breaker remains closed,
11. Circuit breaker cannot be closed unless the circuit breaker truck is in the fully engaged position.

3.7 Shutters

1. During the isolation of the circuit breaker, the busbars and cable orifices shall be automatically covered by self-closing shutters. The shutters for the busbar and cable orifices shall be independent of each other so that one can be opened manually without interfering with the other.
2. Provision shall also be provided for padlocking the shutters. All busbars or cable orifices shall *have* prominent markings or labelling to clearly identify them. The safety shutters shall be metallic type and shall be earthed.

3.8 Earthing & Earth Switch

1. All metal parts shall be earthed in an approved manner to the earthing system. The necessary terminals on each part of the equipment shall be provided.
2. An integral earthing device shall be provided to connect each outgoing cables of each outgoing circuit breaker to earth when required without the use of loose attachments. It shall be possible to switch the device only when the circuit breaker is in the open and isolated position by means of a mechanical interlocking system.
3. The earthing device shall have sufficient capacity to withstand full fault level at the point of installation.
4. Provisions shall be provided for prominent indication when any of the earthing devices has been activated.
5. The cross sectional area and construction of the earthing busbar shall be capable of withstanding the full rated short circuit current of the switchgear for 3 seconds.

3.9 Cable Termination

1. Power cable terminating compartment shall be suitable for reception of the specified cable type, number of cables and direction of entry.
2. Upon completion the cable termination compartment shall be sealed by approved method to prevent ingress of rodents and insects.
3. Entry into the control cable ducts for multi-core PVC/SWA/PVC cables, shall be provided and shall be in a readily accessible position in each switchgear panel.

3.10 Protection Relays

1. Electronic protection relays providing functions as stated in the Drawings are preferred.
2. All relays shall confirm to the relevant IEC standards or approved equivalent.
3. All relays shall be contained in dust proof cases. All cases shall be earthed, unless otherwise stated. The relays shall be mounted on the switchgear panel in a balanced and approved arrangement. They shall be of flush mounted type and shall be arranged so that replacements can be effected quickly and with minimum amount of labour. All relays except where otherwise stated shall be capable of breaking or making the max. current which can occur in the circuit which they have to control, and they shall not be affected by vibration or by external magnetic fields.
4. Permanent facilities shall be provided for testing protective equipment in-situ without having to remove any connecting wires.

3.11 Current & Voltage Transformers

1. The switchgear panels shall be provided with current and voltage transformers to the specifications provided or shown on the drawings; having ratios and quantity as shown in the drawings.
2. Only voltage transformers with proven reliability shall be used. In general voltage transformers shall be of epoxy-resin encapsulated type to the requirements of IEC 60044-2
3. The primary windings shall be connected to the switchgear through readily accessible renewable high rupturing capacity fuses of approved type. Secondary fuses or MCB's shall be provided for each transformer; and the secondary windings shall be earthed at one point.

4. All current transformers (C.Ts) shall be of the epoxy- resin encapsulated type and shall conform to the requirements of IEC 60044-1, for the type of duty required.
5. The CT’s shall be installed on the side of the circuit breaker remote from the busbars. The primary winding shall be of the bar type and of approved cross-section compatible with the circuit breaker rating.
6. The secondary windings of each set of C.Ts shall be earthed at one point.
7. C.Ts. for protective purposes shall be of the nominated protection Class, rated burden and saturation factor sufficient to cater for the normal relay settings and load burdens required in the protection scheme.
8. Current transformers used for metering and indicating instruments shall have accuracy not less than the nominated; typically Class 0.5 and Class 1.0 respectively. Each transformer shall be capable of providing the necessary VA to operate the related instruments.

3.12 Labels

1. Each item of equipment shall carry the manufacturer's rating plates, with information and compliance with the relevant standard.
2. Further labelling shall be provided to indicate the main functions of each service and control equipment item.
3. All wiring terminal positions and terminations shall be identified by local labels to indicate the group services, e.g. closing, tripping, etc. This shall be in addition to the cable ferrule method.

3.13 Control Wiring

1. Suitably rated terminal blocks shall be provided for all external cable connections.
2. Terminals for circuits carrying different voltages shall be segregated, labelled and separated with insulating barriers.
3. Control cabling inside electrical panels shall be with PVC V105 insulated stranded single-core copper cable. The minimum cross section shall be suitable for the load current and volt-drop for CT secondary wiring or small power circuits.
4. For other control circuits, the minimum size shall be 1.0 mm sq. Wiring shall be neatly run and shall be securely fixed in insulated ducting or harnesses with easy access for checking.
5. A suitable control wiring colour schedule shall be provided to differentiate voltages and functions.

6.2 Metric/Imperial Conversion Factors

Length					
1 mile	=	1.609 km	1 km	=	0.621 mile
1 yd	=	0.914 m	1 m	=	1.09 yd
1 ft	=	0.305 m	1 m	=	3.28 ft
1 in	=	25.4 mm	1 mm	=	0.039 in
Mass					
1 oz	=	28.3 g	1 g	=	0.0352 oz
1 lb	=	0.454 kg	1 kg	=	2.20 lb
Area					
1 in^2	=	6.45 cm^2	1 cm^2	=	0.155 in^2
1ft^2	=	0.093 m^2	1 m^2	=	10.8 ft^2
Volume					
1 in^3	=	16.4 cm^3	1 cm^3	=	0.061 in^3
1 ft^3	=	0.028 m^3	1 m^3	=	35.3 ft^3
1 pint	=	0.568 l	1 l	=	1.76 pint
1 gallon (imperial)	=	4.55 l	1 l	=	0.220 gallon
1 gallon (US)	=	3.79 l	1 l	=	0.264 gallon
Velocity					
1 mile/h	=	1.61 km/h	1 km/h	=	0.622 mile/h
1 knot	=	1.85 km/h	1 km/h	=	0.540 knot
Power					
1 hp	=	0.746 kW	1 kW	=	1.34 hp
1 kcal/h	=	1.16 W	1 W	=	0.860 kcal/h
Energy					
1 cal	=	4.187 J	1 J	=	0.239 cal
1 kWh	=	3.6 MJ	1 MJ	=	0.278 kWh
Force					
1 lbf	=	4.45 N	1 N	=	0.225 lbf
1 kgf	=	9.807 N	1 N	=	0.102 kgf
Moment of Inertia					
1 ft·lb^2	=	0.413 Nm^2	1 Nm^2	=	2.42 ft·lb^2
1 ft·lb^2	=	4.054 kgm^2	1 kgm^2	=	0.247 ft·lb^2
Temperature					
freezing point	=	32 °F		=	0 °C
boiling point	=	212 °F		=	100 °C
typical ambient	=	104 °F		=	40 °C

- to convert a temperature from Fahrenheit to degrees Celsius: C = (t°F - 32) x 0.556
- to convert a temperature from degrees Celsius to Fahrenheit: F = t°C x 1.8 +32

For additional information on the International System of Units, see http://www.bipm.org.

6.3 Wire Diameter Conversion

The American wire gauge (AWG) system is commonly used in the US and Canada to specify the diameter of electrical wires.

AWG number	Area (mm^2)	Nearest standard metric equivalent (mm^2)
4/0	107	120
3/0	85	95
2/0	67.4	70
1/0	53.5	70
1	42.4	50
2	33.6	35
3	26.7	35
4	21.2	25
5	16.8	25
6	13.3	16
7	10.5	16
8	8.37	10
9	6.63	10
10	5.26	6
11	4.17	6
12	3.31	4
13	2.62	4
14	2.08	2.5
15	1.65	2.5
16	1.31	1.5
17	1.04	1.5
18	0.823	1
19	0.653	0.75
20	0.518	0.75
21	0.41	0.5

Source: derived from ASTM (2002) and IEC 60228.

NOTE
This table does not provide a one-to-one correspondence between AWG and metric cables. This table states the smallest standard metric cable which will provde at least as much carrying capacity as the AWG cable. To substitute an AWG cable for a specified metric cable, use an AWG cable with the same or greater cross-section.

6.4 Incoterms

International Commercial terms (Incoterms) are published by the International Chamber of Commerce, and define the responsibilities, costs and risks associated with the transportation and delivery of goods.

Key Incoterms for AuCom supplied equipment are:

EXW Ex Works (named place of delivery)	• Buyer arranges carriage from named place of delivery. • Buyer assumes risk when goods are made available. • Buyer assumes costs when goods are made available.
CIP Carriage and Insurance Paid to (named place of destination)	• Seller arranges and pays for transportation and insurance to named port of destination. • Buyer assumes risk when goods are received at the carrier. • Buyer assumes costs when goods reach the named destination.
CIF Cost, Insurance and Freight (named port of destination)	• Seller arranges and pays for transportation and insurance to named destination. • Buyer assumes risk when goods are loaded on board the ship at the point of departure. • Buyer assumes costs when goods reach the named port of destination.
DDP Delivered Duty Paid (named place of destination)	• Seller arranges carriage to the named place of destination, ready for unloading. • Buyer assumes risks when goods are available for unloading at the named place of destination. • Buyer assumes costs when goods are available for unloading at the named place of destination.

6.5 Commonly Used Abbreviations

ACU	Automatic changeover unit
ANSI	American National Standards Institute
ATL	Across the line
ATS	Automatic transfer switch
BCP	Bus coupler panel
BRP	Bus riser panel
BIL	Basic lightning-impulse level (kV_peak)
DCO	Double command operated
DOL	Direct on line
FLA	Full load amps (A)
FLC	Full load current (A)
FLT	Full load torque (Nm)
f	Nominal frequency (Hz)
f_r	Rated frequency (Hz)
HP	Horse power
HRC	High rupturing capacity
IAC	Internal Arc Classification (classification for metal enclosed switchgear arc withstand)
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
I	Nominal current (A)
I_{asym} (I_a)	Asymmetrical fault current (kA_rms)
I_{sym} (I_s)	Symmetrical fault current (kA_rms)
I_{bb}	Rated back-to-back capacitor breaking current (A)
I_{bi}	Rated back-to-back capacitor inrush making current (kA)
I_c	Rated cable charging breaking current (A)
I_d	Rated out-of-phase breaking current (kA)
I_{sb}	Rated single capacitor bank breaking current (A)
I_k	Short-time withstand current (kA)
I_r	Rated current (A)
I_p (I_{dyn})	Peak let-through fault current of an installation (kA_peak)
I_{sc}	Short circuit rms current of an installation (kA)
I_{STP}	Stopping current
I_{STR}	Starting current
IFP	Incomer feeder panel
I_0	Zero sequence current
I_1	Positive sequence current
I_2	Negative sequence current
kVA	Apparent power unit
kVAr	Reactive power unit

kW	Active power unit
LRC	Locked rotor current (A)
LRT	Locked rotor torque (Nm)
LSC	Loss of service continuity (metal enclosed switchgear classification)
MTP	Metering panel
MV	Medium voltage
NEMA	National Electrical Manufacturers Association
OSI	Open systems interconnection
P	Active power (W)
pf	Power factor
PFC	Power factor correction
PFP	Power factor panel
rms	Root mean squared
Q	Reactive power (VAr)
SF6	Sulphur hexafluoride
S	Apparent power (VA)
S_{sc}	Short circuit power (VA)
SCO	Single command operated
SST	Soft starter
TCP/IP	Transmission control protocol – Internet protocol
TRV	Transient recovery voltage
T_A	Ambient temperature
t_k	Rated short-time withstand duration (s)
t_{STP}	Stopping time (s)
t_{STR}	Starting time (s)
U	Nominal voltage (kV)
U_d	Power-frequency withstand voltage (kV_rms for 1 minute)
U_r	Rated voltage (kV)
U_p	Lightning-impulse withstand voltage (kV_peak for 1.2/50us)
VFD	Variable frequency drive

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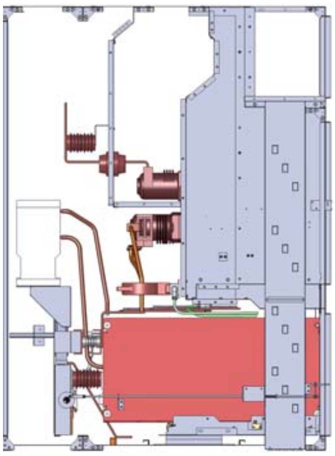

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