SOLUTION GUIDE

MOTOR STARTING SOLUTIONS

ENGINEERED
TO OUTRUN

Introduction

Today, there are hundreds of millions of motors in use in the industrial sector, powering equipment such as pumps, compressors, conveyor belts, fans, and robotics. Furthermore, it is estimated that electric motors account for approximately 70 percent of the electricity consumed in industrial applications.

Why motor starting is so important

ABB is not only a long-standing advocate of the need for high efficiency in motors; its policy is to offer high-efficiency motors as standard while also ensuring that motors and loads are properly controlled and protected, with a focus on user safety.

ABB is constantly monitoring changes in the market for electrical motors to ensure timely adaptation of relevant products to meet the requirements of the latest motor generations and their applications.

This solution guide serves as a general guide for professionals working with low-voltage switchgear and control gear in motor applications. It makes no claim to completeness, instead, it briefly outlines the most important motor starter types for the most widely used motor type in industrial applications: low voltage asynchronous induction motors.

Its primary aim is to simplify the selection of the appropriate motor starting method by offering a comprehensive overview of the most commonly used starter types, along with a detailed list of their advantages and disadvantages.

Before describing the most important motor starters, there is a brief introduction to the other two main components of a motor application: the motor and the mechanical machinery (motor loads). All the information provided in this application note is only general, and each application must be treated as a specific case. Be sure to always follow all national and local installation regulations and codes for your specific application.

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Motor starters are an essential for reliable operation in industry

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Overview
Main characteristics of the motor starters

Criteria	Fixed speed			Variable speed
	DOL	**Star-Delta (Y/D)**	**Softstarter**	**VFD**
Equipment cost	lowest	low	medium	high
Installation cost / complexity	low	medium	medium	high
Commissioning	low	medium	medium	high
Maintenance / Repair	low	low	medium	medium
Space requirements	low	medium	medium	high
Inrush / starting current	high	reduced	controlled	controlled
Starting torque	high	reduced	adjustable	controlled
Number of starts / hour	low	medium	medium	highest
Galvanic isolation	yes	yes	no	no
Power loss / heat dissipation	lowest	low	low-medium	high
Digital communication	with add. products	with add. products	yes	yes
Prevent slipping belts	no	reduced	yes	yes
Wear & tear of bearings, shaft, gear boxes	high	medium	low	lowest
Prevent water hammering / pressure surges in pipes	no	no	yes	yes
Reduce risk of damaged goods during start / stop	no	no	yes	yes
Basic & advanced protection possible	yes	yes	yes	yes
Safety features	with add. products	with add. products	with add.products	optionally built-in
Generation of harmonics[1]	no	no	no	yes
Soft start and stop	no	no	yes	yes
Process control (e.g. torque control)	no	no	yes	advanced

[1] only during start and stop ramp

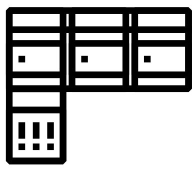
Summary
When to use which device

When to use ....

Direct-on-line starter

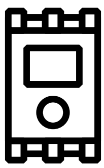
- The motor is small (typically < 15 kW / 20 hp)
- The motors will be started and stopped not too frequently
- Space is critical
- Price is essential
- A high torque is required to overcome the load inertia
- The application requires the motor to be at full speed fast

Star-delta starter



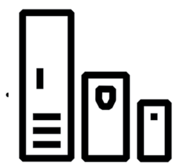
- The load has a low to moderate inertia
- Only a gradual acceleration is required during start-up
- High starting current peak is not permitted by the utility
- Current peaks are still acceptable
- A simple, reliable, and cost-effective starting method is needed
- The use of a softstarter or VFD is not desired

Softstarter



- The motor is continuously running at full speed
- Reduced inrush and starting currents are required to protect the network
- Reduced starting torque is required to reduce maintenance costs
- A star-delta starter should be replaced with a more sophisticated starter
- Advanced features to protect pumps and pipes are required (protection against water hammering, pump dry-run, etc)
- A complete starting solution is required that incorporates motor control and protection in a single device

Variable frequency drive



- The motor type requires a VFD to be started
- The process demands speed control
- The process requires advanced torque control
- Price and space is of limited importance
- The application has varying loads, and running the motor at full speed is unnecessary
- Regulations / laws require the use of a VFD to improve overall energy efficiency

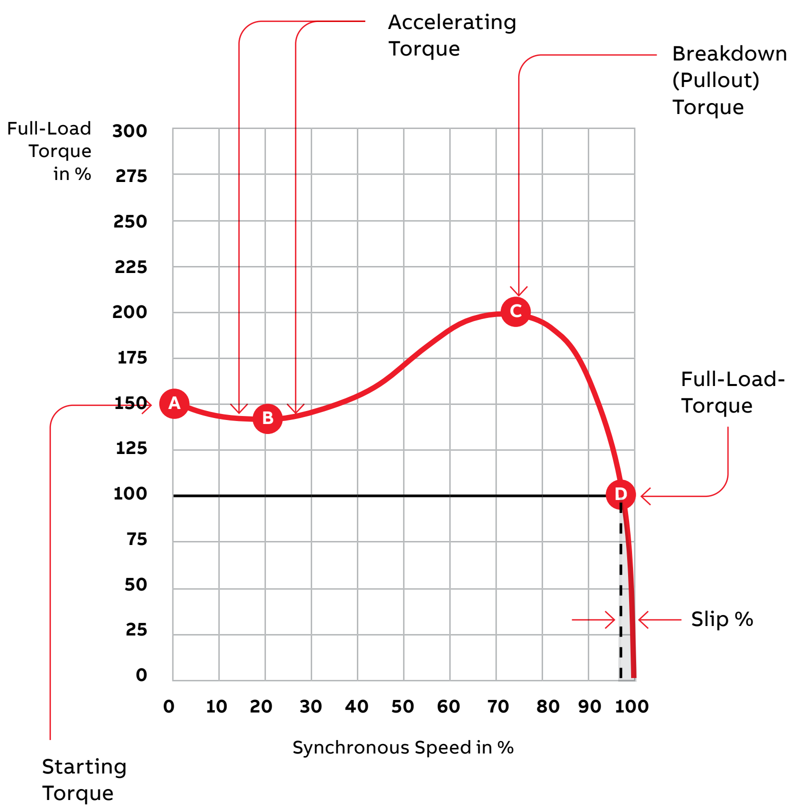
Motors

In general, motors are devices that generate motion. Electric motors, specifically, are machines that convert electrical into mechanical energy. Today, there are various types of electric motors, with three-phase squirrel cage low-voltage induction motors being the most widely used. This motor design is the primary type for industrial, commercial, and residential applications since over 130 years.

This solution guide aims to provide guidance on the selection of the most common starter types for low-voltage AC induction motors, helping users to make an informed decision about the best starter for their application. In this context, low voltage refers to motors operating at voltages of up to 2000 kW with a maximum power of ~1000 kW.

Low-voltage AC motors are typically single-speed electric motors available in single- and three-phase configurations with 2, 4, 6, or 8 poles. Their operating frequency, either 50 Hz or 60 Hz, primarily depends on the region where the motor is used.

For variable speed applications, special attention should be given to insulation (to protect against variable frequency drive spikes) and cooling (to manage heat from harmonics), ensuring motor suitability.



In addition to the previously mentioned criteria (such as kW or HP rating, voltage and frequency, speed and number of poles), several other key factors must be considered to ensure optimal performance and reliability:

- **Efficiency class** (IEC: IE3, IE4 etc.; NEMA: standard, high or premium efficiency)
- **Service factor** (indicating the motor's ability to handle occasional overloads)
- **IP rating** (defining the motor's resistance to dust and water)
- **Ambient air temperature** (max. temperature in which a motor can be used)
- **Starting Method** (DOL, star-delta, softstarter, variable frequency drive)
- **Torque / load** (starting & operating torque, load variations)

Furthermore, the motor type is relevant for the selection. Some of the most used low-voltage induction motors, can be categorized as follows:

- **General performance motors**
  - Cast iron and aluminum motors
- **Process performance motors**
  - Process performance induction motors, high speed motors
  - water cooled motors
- **Motors for explosive atmospheres**
  - Flameproof motors, increased safety motors
  - Non-sparking motors, dust ignition proof motors
- **Motors for specific industries and applications**
  - Marine motors, mining motors, motors for food & beverage
  - Motors for HVAC-R, motors for water & wastewater
  - Brake motors, roller table motors, smoke extraction motors

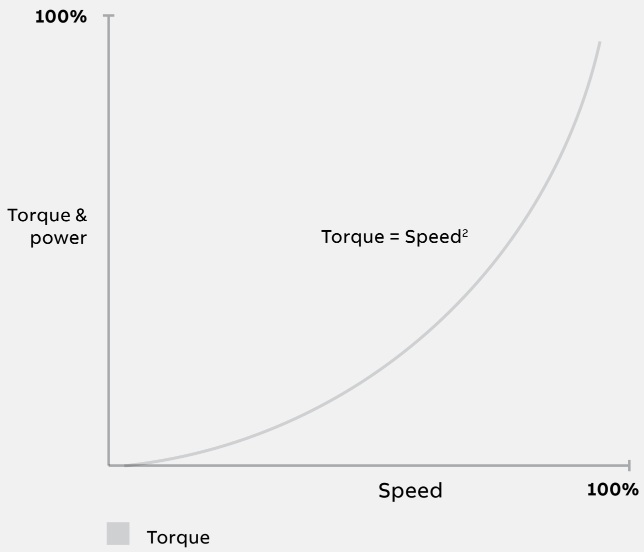
Typical motor loads

The type of motor load and the application are the main criteria for selection of the appropriate motor and consequently motor starter.

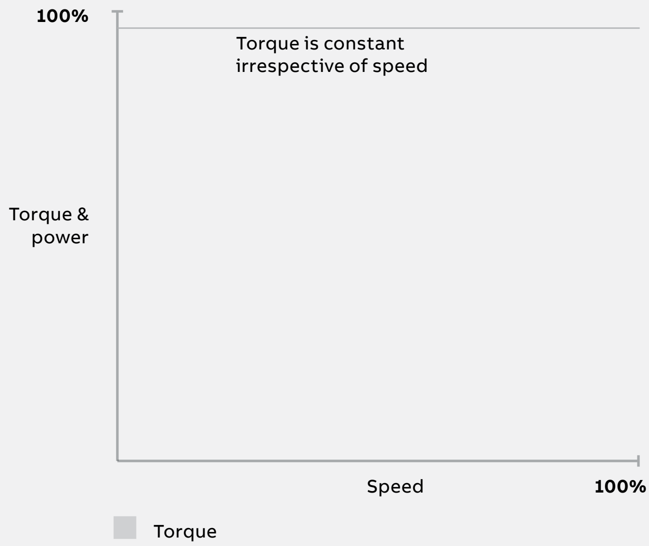
The main characteristics that describe a load type are listed below:
- Power (electrical/mechanical)
- Torque (constant/variable)
- Inertia (acceleration/braking)
- Starting requirements
- Full/adjustable speed
- Operating cycles (starts/stops)
- Environmental conditions

The type of load determines the torque-speed characteristics. The two main types are quadratic and constant.

Quadratic load type (e.g. pumps, fans)



Constant load type (e.g. conveyors, elevators)



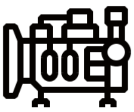
The majority of industrial applications that use electric motors to generate specific types of motion can be classified into one of the following standard categories.

Fans and blowers

Fans often have a large moment of inertia due to the heavy flywheel, which can result in a slow start (heavy–duty starting). Some fans and blowers can be started unloaded, for example, with a closed damper, which helps reduce the starting torque requirement and makes the startup easier. However, this is not always the case, and many fans and blowers still experience heavy-duty starting conditions. This should be considered when selecting the type of motor starter.

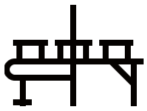
Pumps

There are many different types of pumps, such as piston pumps, centrifugal pumps, and hydraulic pumps. Both starting and stopping are crucial, as the moving fluid may either break the pump during startup or drive the pump forward during shutdown. This can create pressure surges and water hammering. In addition to the need to control starting and stopping, problems can also arise during operation that may damage the installation. This is especially true if the pump runs dry due to a lack of liquid supply or if dirt prevents smooth operation.



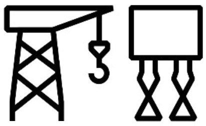
Compressors

There are various types of compressors, including piston, scroll, and screw compressors. Smaller devices are typically piston types, with load torque increasing linearly with speed, while screw compressors are preferred for higher airflow demands, exhibiting load torque that increases with the square of the speed. Compressors are designed as open or closed systems based on the application. Open systems use pressure vessels with fixed-speed solutions and two-state controllers for pressure regulation, while closed systems utilize fast-acting actuators and VFDs.



Conveyors

Conveyors can have various characteristics. The length can vary from just a few meters to several kilometres, and the belt can be horizontal or inclined. Typically, conveyors have a constant load torque with low to high braking torque, depending on the load. Especially when the conveyed goods need to be prevented from tipping or falling off the conveyor, soft starting and stopping may be required, necessitating the use of a soft starter or VFD.



Other load types

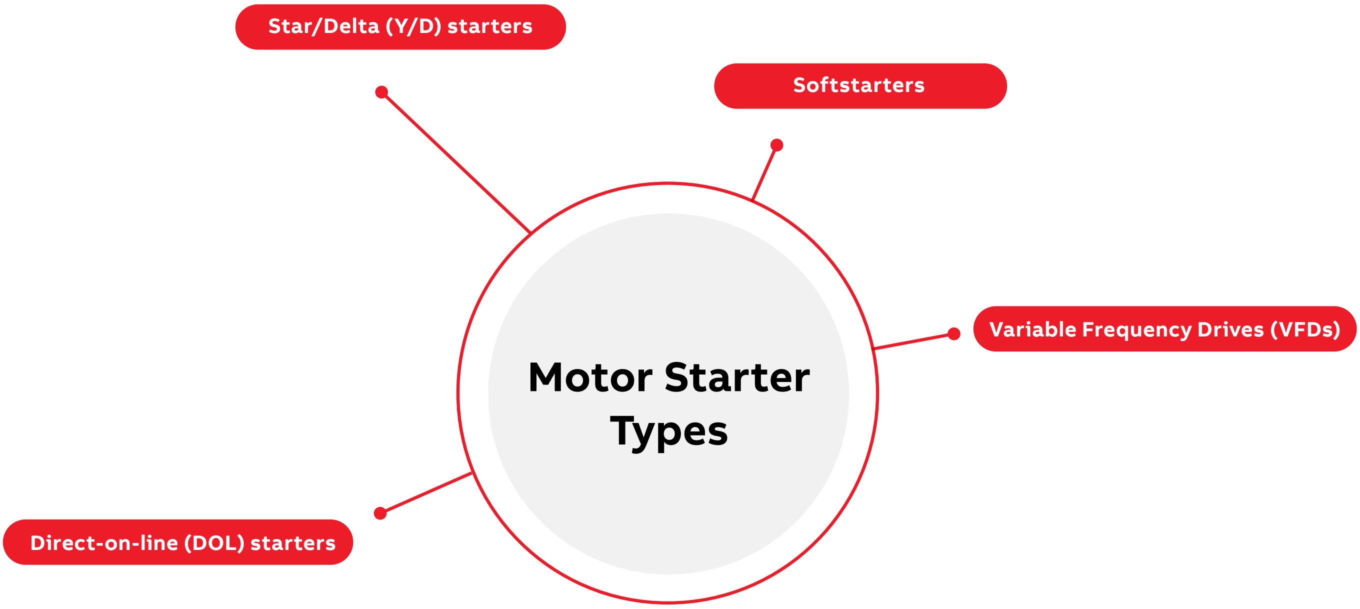
Besides the previously listed load types, several other types of loads are in use, especially in industrial applications. The requirements for the motor starters used in these applications may vary mainly based on the process requirements and the materials to be handled.

Machines like lifts and cranes typically require frequent switching operations of the motors, e.g., for inching and tipping operations. Inching focuses on small, controlled movements for positioning, while tipping involves moving a load to the point of tilting or rotation.

Mixers, choppers, portioning machines, and sorting machines are more commonly found in industries such as chemicals, pharmaceuticals, food and beverage, and water and wastewater. Other industrial processing machines, such as mills, centrifuges, grinders, and crushers, are typically used in the mining, cement, and stone industries. These machines often require large motors with high power ratings that can provide very high starting torques.

Motor starter types

In this motor starting solution guide, we will focus on the following types of motor starters, which are currently the most widely used in the market.



The history of motor starters is closely tied to the development of electric motors and the need for effective control and protection of these motors in various applications. Initially, the only equipment utilized to start and stop electric motors consisted of basic switchgear, such as electromechanical contactors and relays. These devices were employed to safely operate electric motors by connecting them directly to the mains supply **(direct-on-line)**. It was then during the mid of the last century that the need for additional protection of the motors, especially against overload conditions, led to the development of bi-metal based thermal overload relays.

Subsequently, in the 1960s, the need to reduce high inrush and starting currents - especially for large motors that were becoming more widely used in industrial applications - led to the development of **star-delta starters**. This starter type provided a way to minimize electrical stress on the motor and the power supply while also reducing mechanical stress on the load during startup.

The next evolution of motor starters was taking place when **softstarters** were widely introduced in the 1980s. They allowed a gradually ramping up of voltage and consequently current to the motor during startup, enabling a further reduction of electrical and mechanical stress.

The most recent advancement in motor starters was the commercialization of **variable frequency drives (VFDs)**. Although these devices have been available since the 1960s, it was the integration of microprocessors in the 1980s that paved the way for the modern VFDs that are used today. Current VFDs enable a significant advancement in motor control, allowing for precise adjustment of motor speed and torque by varying the frequency and voltage supplied to the motor.

Today, the combination of all the means intended to start and accelerate motors, to ensure continuous operation of motors, to switch off the supply from the motor and to provide means for the protection of motors and associated circuits against operating overloads, is what is referred to as motor starter. Especially, overload protection can now be provided by more advanced electronic based devices, such as electronic overload relays.

To complete the picture, it is important to note that modern motor starters often incorporate mechanisms to protect the motor branch from short-circuits. These starters are commonly referred to as **protected motor starters**. Depending on various technical, economic, and operational factors, short-circuit protection may be implemented for either an individual motor branch or a group of motor branches. The most common method for providing short-circuit protection is by integrating circuit breakers (such as manual motor starters, MCCBs, or MCBs) or fuses into the motor branch.

Direct-on-line (DOL), also know as across-the -line or Full Voltage Non-Reversing (FVNR) / Full Voltage Reversing (FVR) is the simplest, most compact and most cost-effective method for starting squirrel cage asynchronous motors. Hence DOL is the most used starter type, especially for small to medium sized motors. For applications that require to reverse the direction of the motor (e. g. conveyor systems that require to change the direction of material flow) a second contactor must be added to the DOL starter.

DOL starters connect the motor directly to the mains supply, thus carrying out starting at full voltage. The inrush and starting current can become very high in this case, which can cause disturbances like voltage dips to the supply system and high electro-dynamical stresses on the motor connection cables or even in the windings of the motor itself. While the high starting torque allows for shorter acceleration times, it can also create substantial mechanical stress on the system, which may shorten the lifespan of its components.

DOL starters typically allow to control the motor with a hand-operated switching device (e.g. manual motor starter) or a contactor. Manual switching is usually only used for small motors that don't need to be started or stopped often (e.g less than 10 starts per day). The other motors normally use contactors in combination with short-circuit protection and overload protection. This solution can also be controlled with a control system or PLC.

The permissible motor size for a direct-on-line start is dependent on the area of use. Some utilities restrict DOL starting for motors rated at 5.5 kW / 7.5 hp or higher. However, in industrial facilities with independent supply systems, much larger motors - up to 250 kW / 350 hp or more - are operated with direct-on-line starting method.

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Current regardless of load

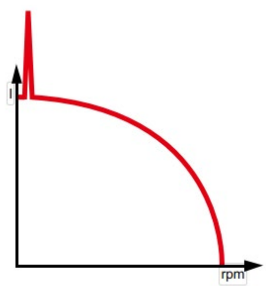

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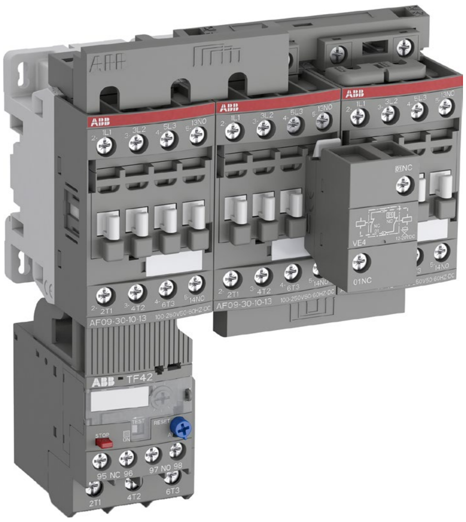
Figure 1
Current curve DOL

When to use a direct-on-line starter
- When the motor is small (typically < 15 kW / 20 hp)
- When the motors will be started and stopped not too frequently
- When space is critical
- When price is essential
- When a high torque is required to overcome the load inertia
- When the application requires the motor to be at full speed fast



Star-delta starters consist of three contactors: one star, one delta, and one line contactor. Additionally, a motor protection device (like overload relay or manual motor starter) and a timer are required. The three phases of a star-delta start are decribed below.

Star phase (start-up)
During the starting phase, the motor windings are connected in a star configuration, reducing the voltage to 1/√3 (~ 58%) of the full line voltage. This lower voltage decreases inrush and starting currents, allowing the motor to accelerate with minimal current draw and mechanical stress. Once the motor approaches its rated torque, the star connection switches to delta. This phase must last long enough for the motor to nearly reach steady-state speed; if too short, it may not effectively reduce stresses.

Transition phase (switching from star to delta)
In this phase a timer controls the opening and closing of the dedicated contactors to switch from the star to the delta configuration. The transition may briefly interrupt the power supply, causing a current spike that is typically lower than in a DOL start. The timing of the changeover is crucial to ensure the electric arc on the star contactor is extinguished while the delta contactor is not closing too early, as this could cause a short-circuit. On the other hand, delaying the switch from star to delta may lead to motor deceleration and current peaks in the delta phase.

Delta phase (steady-state running)
After the transition, the final phase is reached, where the motor windings are delta-connected, and the motor receives the full line voltage. The motor now produces its full torque and power, operating at its rated efficiency.

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Current with peaks regardless of load

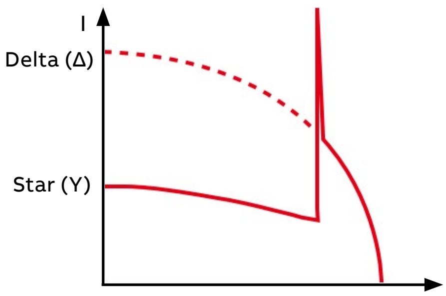

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Figure 2
Current curve star-delta

When to use a star-delta starter

- When the load has a low to moderate inertia
- When only a gradual acceleration is required during start-up
- When DOL starting is not permitted by the utility
- When current peaks are still acceptable
- When a simple, reliable, and cost-effective starting method is needed
- When the use of a softstarter or VFD is not desired

Softstarters limit the starting current of electrical motors by gradually increasing (ramping up) the voltage – and consequently the motor acceleration and torque – from an initial level to full voltage. Technically, this is accomplished by employing semiconductors (ABB softstarters use thyristors) in the main circuit, which significantly reduce current spikes.

This helps to prevent voltage drops in the network and reduces torque impulses, thereby minimizing mechanical stress on the equipment during the soft start, compared to direct-on-line or star-delta starting methods. Another advantage of this starting method is the ability to adjust the torque to meet the precise application requirements, regardless of whether a loaded or unloaded start is required.

Advanced softstarters are typically equipped with a built-in electronic overload relay -which eliminates the need for an external protection relay - and a PTC input that allows for measuring the temperature of the motor windings.

In addition, modern softstarters also include electromechanical bridging contacts, such as built-in bypass relays or bypass contactors. Once the motor is close to reaching its operating speed, it is common to bypass the semiconductors to avoid high power losses during continuous operation. Furthermore, certain softstarters are equipped with extra integrated features and functionalities, including a soft stop function that mitigates water hammering and pressure surges in pumping systems. This feature also helps protecting sensitive materials on conveyor belts. Other available features may include DC braking, dry-running protection, and pump cleaning capabilities.

In an in-line configuration, a softstarter requires only three motor cables for operation. However, when set up in an inside-delta configuration—allowing a larger motor to be started with a smaller softstarter—six supply wires are needed. This arrangement necessitates a three-phase controlled softstarter, while more economical versions usually use only two-phase control.

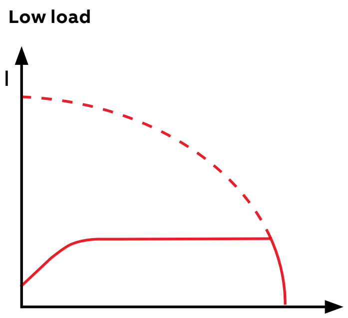

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Figure 3
Current curve softstarter - low load

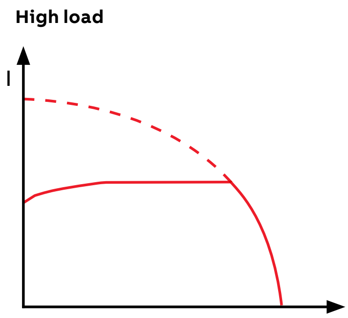

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Figure 4
Current curve softstarter - high load

When to use a softstarter
- When the motor is continuously running at full speed
- When reduced inrush and starting currents are required to protect the network
- When reduced starting torque is required to reduce maintenance costs
- When a star-delta starter should be replaced with a more sophisticated starter
- When advanced features to protect pumps and pipes are required (protection against water hammering, pump dry-run, etc)
- When a complete starting solution is required that incorporates motor control and protection in a single device

Variable frequency drives - sometimes also called frequency converters – control the speed of alternating current motors (primarily three-phase induction motors) by varying the frequency and voltage supplied to the motor. VFDs use semiconductors (IGBTs = Insulated Gate Bipolar Transistors) to control the output waveform.

They typically consist of three main parts:
- A **rectifier** (AC to DC) that converts incoming AC power to DC power.
- A DC bus (intermediate circuit) that stores and smooths the DC power using capacitors and inductors.
- An **inverter** (DC to variable AC output) that converts DC back to AC with a variable frequency and voltage.

The drive can supply the motor with nominal torque and current throughout the entire startup process. The rated motor torque is available even at low speeds, while the starting current remains low – typically between 0.5 and 1 times the rated motor current, with a maximum of 1.5 times the nominal current.

Another useful feature of drives is the soft stop, which ensures a smooth stop, just as a softs-tarter does. This is particularly beneficial in appli-cations such as water pumps and conveyor belts, where controlled deceleration is important.

While VFDs offer advantages in regulating motor speed and reducing energy consumption, they also have significant disadvantages that make their utilization costly and complex.

For instance, drives can cause substantial electro-magnetic interference that negatively affects nearby equipment, necessitating the use of double-shielded cables. Additionally, harmonics generated by the power electronics must be mitigated using filters and inductors.

Due to high power losses and heat dissipation, VFDs require more space in the control cabinet. In applications where speed control is needed for only about 20 percent of the operating time, while the motor runs at full speed the rest of the time, adding a bypass contactor to the motor branch may help reduce overall power losses.

In conclusion, a variable frequency drive is ideal for applications that require continuous speed adjustments and advanced torque control. However, if speed control is not needed during normal operation or only for a minor time, using a VFD solely for starting and stopping the motor is inefficient. In such cases, a softstarter is usually a more compact and cost-effective alternative.

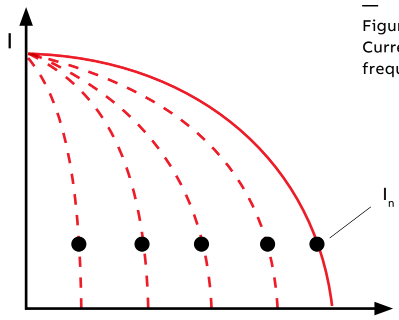

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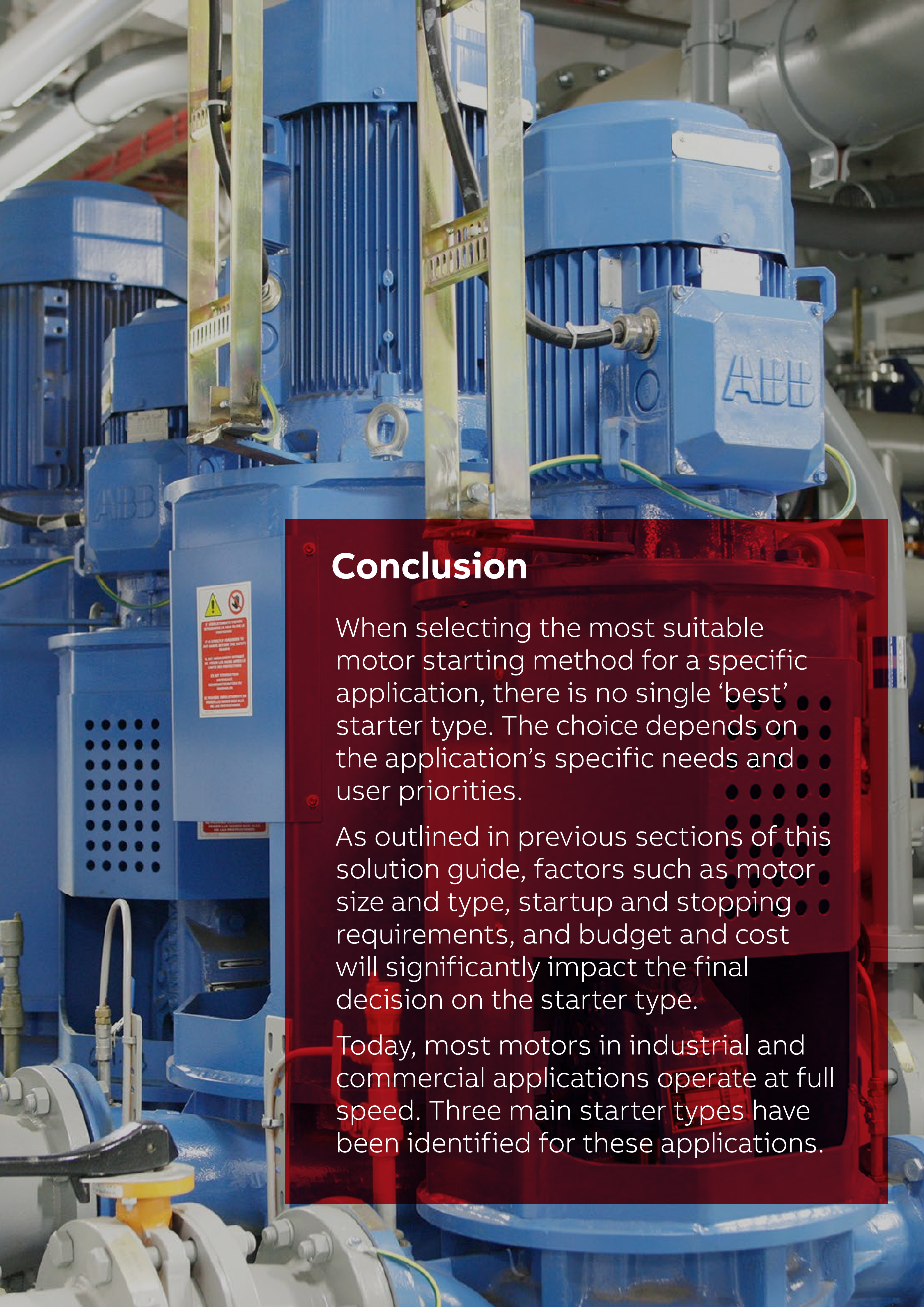
Figure 5
Current curve variable frequency drive

When to use a variable frequency drive
- When the motor type requires a VFD to be started
- When the process demands speed control
- When the process requires advanced torque control
- When price and space is of limited importance
- When the application has varying loads, and running the motor at full speed is unnecessary
- When regulations / laws require the use of a VFD to improve overall energy efficiency



Conclusion

When selecting the most suitable motor starting method for a specific application, there is no single 'best' starter type. The choice depends on the application's specific needs and user priorities.

As outlined in previous sections of this solution guide, factors such as motor size and type, startup and stopping requirements, and budget and cost will significantly impact the final decision on the starter type.

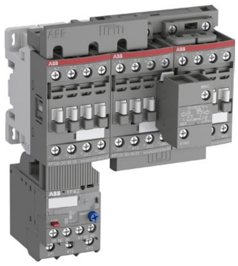
Today, most motors in industrial and commercial applications operate at full speed. Three main starter types have been identified for these applications.

DOL starters

DOL starters remain the most widely used type in the market, proven effective for decades, particularly for smaller motors (< 15 kW / 20 hp).

Key strengths:
- Cost-efficient and space-saving
- Easy to install and commission

Considerations:
- Stress on the electrical network and mechanical equipment
- Nuisance tripping of protection devices due to high inrush currents



Star-delta starters

Star-delta starters have been used for decades, primarily to mitigate the issues associated with DOL starting. Depending on factors such as region or industry, users still frequently utilize star-delta starters, especially for mid-sized motors (15 kW / 20 hp to 500 kW / 750 hp).

Key strengths:
- Reduced inrush / starting currents
- More cost efficient than softstarters and VFDs

Considerations:
- Complex wiring and higher space requirements compared to DOL
- Not suitable for loads that require high starting torque

Softstarters

Softstarters are the preferred solution for addressing issues associated with both previously listed starter types. They are especially suitable for replacing star-delta starters and can even be used for much larger motors (up to ~ 1200 kW).

Key strengths:
- Limited inrush/starting currents and reduced mechanical stress
- More cost-efficient and space-saving than VFDs

Considerations:
- More expensive compared to DOL and star-delta starters
- No speed control during continuous operation

Variable frequency drives

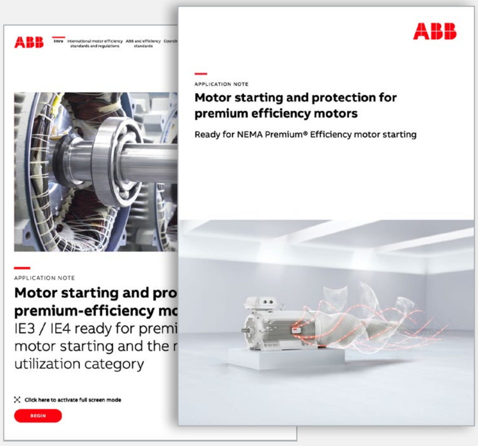
VFDs have become more popular in recent years, primarily because they are the only option when motor speed control is required. Additionally, some specially designed and very large motors (>1200 kW) can only be operated with a drive.

Key strengths:
- Full control of speed and torque
- Enables potential energy savings

Considerations:
- Very costly and high space requirements
- Complex to install and commission

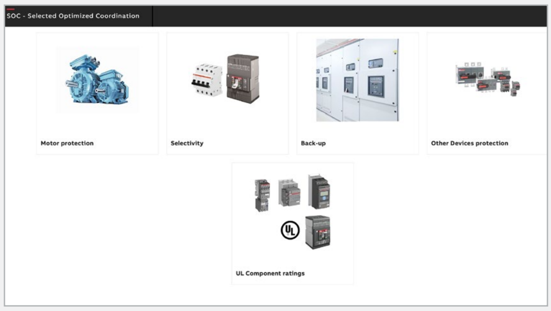
Additional information

Application Notes



- Motor starting and protection for premium-efficiency motors (IEC) — WEBSITE
- Motor starting and protection for NEMA premium-efficiency motors (NEMA) — WEBSITE

Tools



- Selected Optimized Coordinations — WEBSITE
- Application Configurator — WEBSITE
- eConfigure Devices Product Selection — WEBSITE
- ABB Drives and Motor Selector — WEBSITE
- proSoft Softstarer Selection — WEBSITE

Guides / Handbooks

- Contactor Guide (incl. Overload Relays) — WEBSITE
- Manual Motor Starter Guide — WEBSITE

  Softstarter Handbook — WEBSITE
- Drives Guide / Handbook — WEBSITE
- ABB Motor Guide — WEBSITE

Catalogs

- Main catalog Motor protection and control — WEBSITE
- Softstarter Catalog — WEBSITE
- Drives Catalog — WEBSITE

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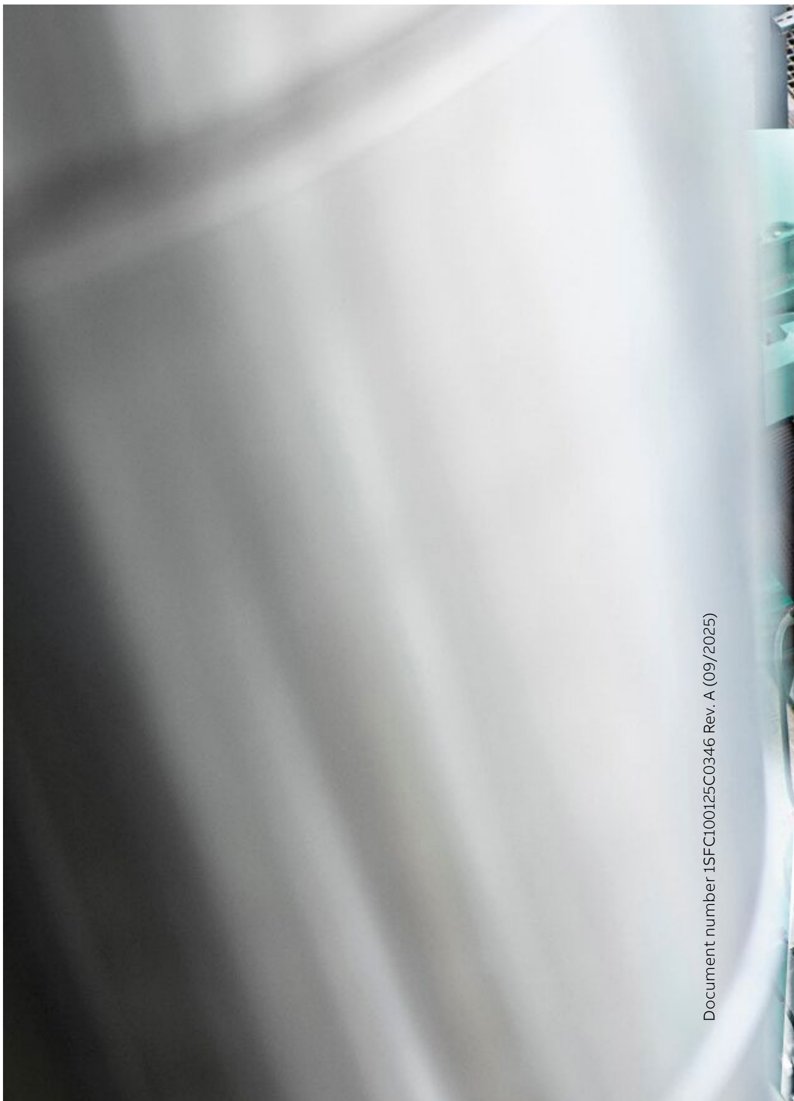
721 61 Västerås
Sweden

You can find the address of your local sales organization on the ABB homepage

https://new.abb.com/low-voltage/products/motor-protection

https://abb.com/lowvoltage



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