New soft starters for controlled electric motor start-up

From the moment the first electric motors appeared, engineers have been searching for a way to avoid their sudden, violent starts. Several 'solutions' were tried over the years, but none of them managed to overcome the problem without adding some other, intrinsic disadvantage of its own. Only with the introduction of the soft starter did a device finally become available that had none of the drawbacks of these first attempts. Now, soft starting has gone a step further. Matching modern power electronics with smart circuitry, ABB has developed a new range of new soft starters that offers superior electronic control of the current and voltage during motor start-up plus several new design attributes.

Smooth operator

Sören Kling

Skiers know the problem only too well – the sudden, abrupt jerk that signals 'you're off' as the chair lift starts its climb to the slopes. The same problem, but in another setting, costs industry millions of dollars every year: countless AC machines – used to drive fans, crushers, agitators, pumps, conveyors, etc, – are unnecessarily stressed by unwanted load peaks day in, day out, in production plants all over the world.

This sudden, violent starting of AC motors takes its toll in a variety of ways. Among them are:

- Electrical problems due to voltage and current transients arising from direct on-line or star/delta starts. Such transients may overload the local supply network and cause unacceptable voltage variations that interfere with other electrical equipment connected to the same network.
- Mechanical problems that subject the entire drive chain, from motor to driven equipment, to severe stress.
- Operational problems, such as pressure knocks in pipelines, damage to products on conveyor belts, and uncomfortable escalator rides.

The financial consequences are considerable: every technical problem, every breakdown, costs money – in the form of repairs as well as lost production. In industry it is usually the cost of the latter that dominates.

A problem with a long history

Since the problem has been around for a long time, several solutions have been put forward and tried.

Star/delta starter

An early solution to the problem was the star/delta starter. During start-up, this connects the stator windings of the motor in a star configuration between the phase and neutral conductors of the supply network, thereby reducing the motor voltage – and consequently the motor current 1 – by a factor of $1/\sqrt{3}$. As soon as the main moment of inertia has been overcome, the motor windings are connected in a delta configuration between the phase conductors of the network to obtain the full motor voltage and power. However, this starter does not eliminate the undesirable mechanical and electrical transients; it only reduces them slightly and distributes them across two points along the time axis – the original switch-on and the subsequent star/delta changeover.

The above applies under normal conditions; unfortunately, in other circumstances change-over from star to delta mode can sometimes be worse than direct on-line start-up.

Because of this, the star/delta starter is a simple but rather limited solution to the problem.

Slipring motor

Another early solution was the slipring motor. This motor is started with a starting rheostat connected to the rotor circuit by means of a slipring device. In this way, the starting current can be reduced although the motor torque remains at the level necessary to start up the load.

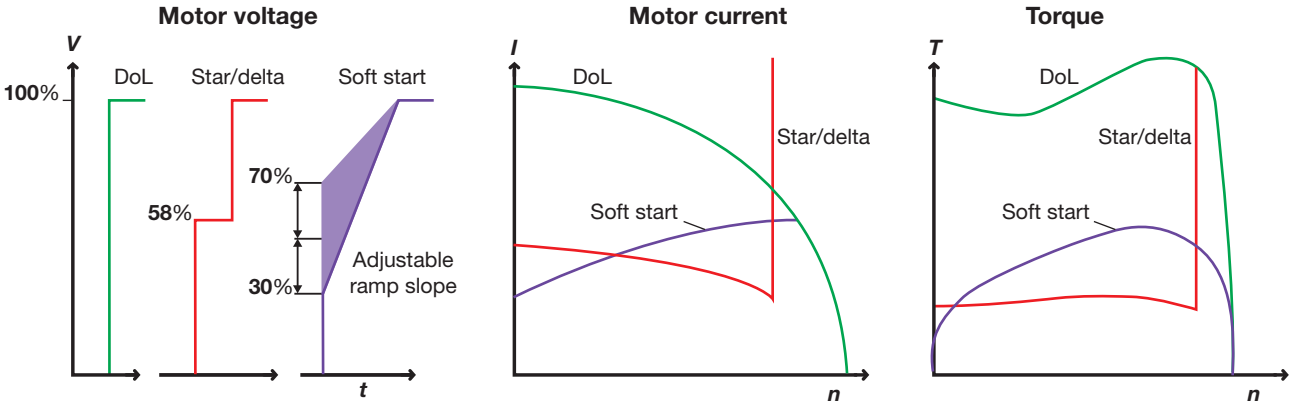
As the start-up progresses and the motor gains speed, the rotor resistance is gradually reduced. Once the starting rheostat is completely out of circuit, the motor can be run up to its full speed. At this point, the rotor windings are short-circuited, so that the motor operates from here on as an ordinary squirrel-cage motor.

The advantage of the slipring motor is that a high torque can be obtained with a limited starting current. This solution is suitable mainly for applications in which there is a heavy load from the start, eg for crushers and mills. Its disadvantage is its greater electromechanical complexity, in the form of brushes, sliprings, resistors and contactors, which increases costs (including maintenance) and reduces reliability.

1 Graphs showing the basic differences between direct on-line (DoL) starting, star/delta starting and soft starting in terms of the motor voltage (*V*), motor current (*I*) and motor torque (*T*)

n Motor speed

t Time



Frequency converter

The frequency converter is technically superior to the two previous solutions since it allows precise control of all the relevant variables, ie speed, torque and power, during every phase of the operating cycle of the motor, from start through normal operation to shut-down. Another important advantage is that the control equipment is static, ie there are no moving parts. Reliability is therefore high and only little maintenance is needed.

However, the frequency converter has the disadvantage of requiring a relatively large up-front investment, and this disqualifies it for many applications, especially those where regulatory control is not actually required during normal operation.

Nevertheless, frequency converters have gained ground as the technology has been refined and prices have fallen. Today, they have practically supplanted the slipring motor.

Soft starter

The soft starter, which reached the market sometime between the end of the 1970s and the early 1980s, resembles the frequency converter in that it is also electronic and based on thyristors. It could be said that it fills the gap in functionality and price between the star/delta starters and frequency converters. With soft starters it is possible to control the motor voltage such that it increases gradually during start-up,

"Operational disturbances are down."

Andreas Allerbo, electrical and instrumentation engineer at Kemira Kemi AB, Helsingborg, Sweden

ABB soft starters have been used for several years on pumps, agitators and 160-kW fans at Kemira Kemi AB, a company producing chemicals for industry and agriculture in Helsingborg, Sweden. They were installed to reduce the forces in the couplings between the motors and the driven equipment, as well as to eliminate pressure shocks in pipelines, etc. Andreas Allerbo, electrical and instrumentation engineer at the company, which belongs to the Finnish Kemira Oy group, made this observation:

"Our experience with soft starters has been good. They do their job well, and give us hardly any trouble in the technical area. Operational disturbances are down, and that saves us money. Everywhere we use soft starters, we make use of the bypass function to relieve the thyristors and reduce heat dissipation in the devices. Should we identify other suitable applications for soft starters, we will install them there, too."

One of the two newly installed pumps at Kemira Kemi AB that were fitted with PS S soft starters from ABB, mainly to eliminate pressure shocks in the outlet pipelines of the pumps

2 Conveyors and elevators are two typical applications for which the new ABB soft starters offer considerable gains.

which naturally limits the starting current 1. This means that the motor starts smoothly and the mechanical and electrical stresses are reduced to a minimum. As a 'bonus', the device can also be used for 'soft' stopping.

Since the circuitry of the starter is electronic, it is comparatively easy to supplement its basic function with different safety and fault indications to improve motor protection and simplify fault-finding. Examples are protection against phase-loss, overcurrent and overtemperature, as well as indications of normal operation, full motor voltage and certain faults.

All settings, for example of the ramp slope and initial voltage, can easily be made on the front of the unit.

Consequently, the soft starter amply satisfies the primary requirement, which is smooth starting of electric motors, while offering further advantages, such as high reliability, a much-reduced need for maintenance, good motor protection and simple settings.

A limitation of the soft starter, however, is that it cannot always be used in motor drive applications which require a high torque from the beginning. This limitation is due to the fact that the device does its job by ramping up the motor voltage to its maximum (and during shut-down ramping it down to the set switch-off level). As the torque is proportional to the square of the voltage, the connected motor will not be able to reach full torque from the beginning. Because of this, the soft starter is more suitable for lighter, more easily started motor drives, eg for pumps, fans, conveyors and elevators 2.

The new ABB range of soft starters

ABB has been making soft starters since the beginning of the 1980s, and the valuable experience gained in the meantime has gone into the design of today's product range. The latest series, named PS S, has been significantly

3 ABB's latest series of solid-state soft starters, named PS S, is for motor currents in the range of 3 to 515 A and for supply voltages from 208 to 690 V.

improved in many respects 3. It covers motor currents from 3 to 515 A and supply voltages from 208 to 690 V.

The new product range has several important attributes:

■ *Compact:* As a result, there is room for more soft starters on a given mounting surface.

■ *Easy to install:* The device can be screwed onto a mounting plate (only four holes are needed) or, alternatively, snapped onto a mounting rail; the cables are easy to connect in either case. Clear instructions are provided on the front.

■ *Easy to set up:* With just three settings – slope of the start-up ramp, slope of the shut-down ramp and initial voltage – it is possible to adjust the soft starter for a wide range of applications. These settings are easily made with the clearly labeled rotary switches on the front of the unit.

■ *Solid-state electrical circuit:* This ensures the highest reliability and reduces maintenance to a minimum, even in applications with frequent starts and stops.

'Inside-delta' connection

The larger units in the family can be connected into the delta circuit of the motor just like a star/delta starter 4. This means that the current loading of the soft starter is reduced by a factor of $1/\sqrt{3}$, which extends the current handling range as far as 515 A. The inside-delta connection makes it possible to satisfy the requirements of any given application with a smaller device than would otherwise be possible, saving users both space and money.

Safe and rugged design

The units have sturdy enclosures and feature good insulation of all live parts. Thus, they are able to withstand rough

Soft starters and Industrial^{IT}

Integrating information from a large variety of applications is a recognized problem in computer science. It has long been acknowledged that a single, integrated architecture is needed – one that hides from the user all the differences between the various applications.

ABB has been addressing this very problem over the past few years. As the world's largest provider of automation technologies, we help industry leaders worldwide achieve integrated, real-time solutions for automation and information across their enterprises through our Industrial^{IT} initiative. In a nutshell, Industrial^{IT} is an information architecture for seamless linking of multiple applications and systems in real time.

From now on, all new ABB products, whether they are software or hardware, will carry the ABB Industrial^{IT} enabled symbol. This tells customers that the product has the ability to be combined with other Industrial^{IT} products in a 'plug and produce' manner.

Before they can carry this symbol, all new products have to be assessed (and all existing products reviewed). There are four levels of certification:

Level 0 – Information
Level 1 – Connectivity
Level 2 – Integration
Level 3 – Optimization

Level 0: Information

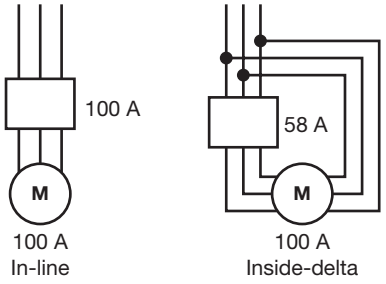
Products featuring a low level of integration (ie, products that do not exchange information with other products) – like the soft starters described in this article – are said to be Level 0: Information enabled.

To become Industrial^{IT} Level 0: Information enabled, a product must have the following aspects:

Product identification: To reference the product, a unique product identification must have:

1. An ABB identity number
2. An EAN article numbering code
3. A product name
4. A product type designator

4 The largest members of the PS S family can also be connected into the delta circuit of the motor, just like a star/delta starter. This reduces costs by allowing a smaller and less expensive starter to be used.



handling without exposing personnel to danger. And the electrical circuit is largely fail-safe; in the unlikely event of an internal fault, the unit shuts down to protect the connected equipment.

PS S 03...25

Compact units for 3 to 25 A

Soft starters in this series are designed for smaller motors with rated currents in the range of 3 to 25 A and mains voltages of 230, 400, 500 and 600 V. They are intended for installation side by side on DIN rails. The units are equipped with bypass contacts in the main circuit, which relieve the thyristors during normal operation and reduce heat generation. Thus, very compact starter solutions can by built.

Every unit can be wired for control voltages in the ranges 24–110 V AC/DC or 110–480 V AC, which simplifies their incorporation in existing control systems and reduces the number of different versions required.

PS S 18/30...300/515

Flexible units for 18 to 515 A

Units in this series are intended for larger motors and offer greater flexibility with regard to installation and use. The series covers rated motor currents in the range 18 to 300 A, but as they can be connected into the delta circuit of the motor like a star/delta starter 4, 5, they

Product documentation: The product document format must be in a non-editable format, this means that the information is viewed using Adobe Acrobat Reader (*.pdf). The following documentation must be provided:
1. Product data sheet or technical reference manual
2. Installation and commissioning manual
3. Application manual
4. Operating manual
5. Maintenance and service manual
6. Declaration of conformity regarding CE marking
7. Environmental product declaration
8. Environmental information

CAD data: For easy integration of the products into electrical and/or mechanical CAD systems, electrical and mechanical CAD models must be provided. These include:
1. Electrical engineering data
2. Mechanical CAD data

Technical data and product classification: A 'product class' identifies a group of products with the same set of attributes. This aspect contains those attributes that distinguish one product class from another.

Other points that must be taken into consideration when certifying a product as Level 0 include:
1. The product must fit naturally into the ABB Industrial^{IT} Architecture.
2. The product must be developed and produced with adequate quality control.
3. Product support must be available.

Depending on the certification required, products aiming for a higher degree of integration and interoperability with other products will be assessed for Level 1, 2 or 3 enabled certification at an ABB Industrial^{IT} certification assessment center in Västerås (Sweden), Minden (Germany) or Wickliffe (USA).

“Soft starters have eliminated some troublesome operational problems.”

Sven-Åke Mårtensson at the Köpingebro Sugar Mill in southern Sweden, here in front of a soft starter for one of the sugar centrifuges

At Köpingebro Sugar Mill[1] in southern Sweden, electrical department manager Sven-Åke Mårtensson recalls a whole series of problems that soft starters have solved:

“We installed soft starters for our sugar centrifuges, sugar elevators and belt conveyors in the early 1990s. Before that, we had been using direct-on-line or star/delta starters.

The problem with the sugar centrifuges, which the soft starters have since solved, was caused by their high moment of inertia. The star/delta starters tended to trip when changing from star to delta mode, which made the entire upstream transport chain trip due to interlocks. The delayed re-start caused the hot sugar solution to cool down so much that it wasn’t possible to centrifuge it anymore. We simply had to solve the trip problem!

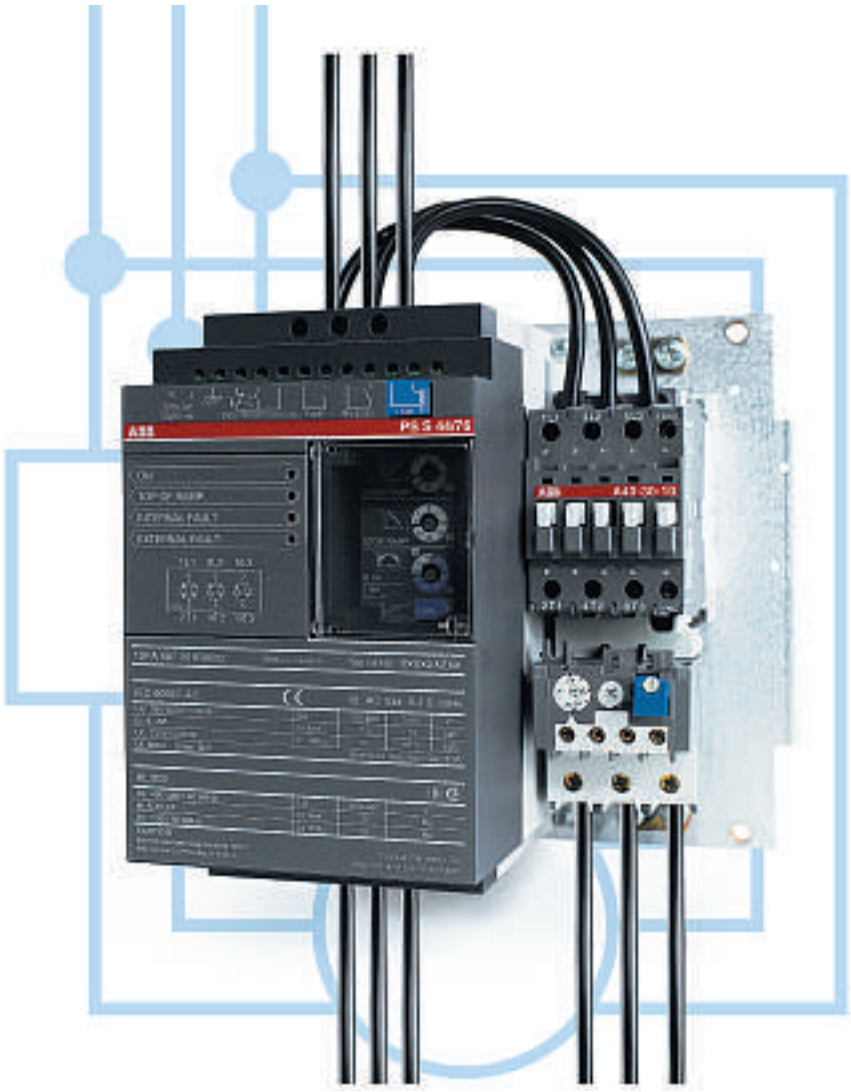
Since the centrifuges play such a vital role in the process chain, we have gone one step further with our larger units and equipped them with frequency converters. These give us more control of the variables we are interested in. However, on our smaller centrifuges the soft starters have proved every bit as valuable. Our start-up problems with the centrifuges are gone now, thanks to a large extent to the soft starters.

Another problem involved the sugar elevators: due to a problem in the transport chain from the centrifuges to the silos – and as a result of interlocks in that chain tripping – some elevators occasionally stopped when fully loaded. There was usually no alternative but to clear the elevator by hand and then restart it empty, costing us hours of expensive production time.

This problem, too, could be solved by the soft starters. Now, our elevators start up smoothly, without slipping.

[1] Köpingebro Sugar Mill belongs to Danisco Sugar, which is part of the Danisco group.

5 A typical inside-delta configuration, replacing a star/delta starter



can manage currents as high as 515 A. This capability makes it easier than ever to replace existing star/delta starters to achieve smoother starts (and stops).

The solid-state circuit design (there are no electro-mechanical contacts in the main circuit) makes the devices particularly well-suited for motor drives which have to be started and stopped frequently.

All the units in this series can be equipped with a separate current limitation circuit, making it possible to set a maximum starting current that will be adhered to whatever ramp time is set. This function simplifies set-up, especially of drives with high moments of inertia, which often need long start-up times.

The devices are equipped with four LEDs indicating 'On', 'At full voltage', 'External fault' and 'General fault', as well as a built-in master fault indication relay. These diagnostics functions simplify supervision and failure identification.

The units in the series are designed for a utilization factor of 110 to 115%, which means that they are able to handle the corresponding overcurrent of the connected motors.

The built-in bypass signal relay can be used to operate an external contactor that bypasses the thyristors during continuous operation or when starting several motors sequentially using one soft starter.

The problem solved

The benefits of soft starting are felt right across industry. Hardly a production area exists that does not depend to some extent on motor drives, and which therefore would not profit from having ABB soft starters installed. Comments by numerous plant operators testify to this (see pages 58 and 62). Their functionality and design attributes put soft starters among the essential 'must have' devices for a whole range of applications in modern industrial plants.

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