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An Engineering Guide to
Soft Starters

CONTROL
TECHNIQUES

Contents

1. Introduction

1.1 General

Studies have shown that approximately 90% of the motors employed in industrial applications use no form of control other than simple electromechanical switching. This results in increased machine wear as rapid acceleration causes damaging torque transients and high peak currents. Soft starters solve this problem through controlling the application of current during acceleration and deceleration.

In applications where motor speed can be varied, significant energy savings can be realised by using variable speed drives. However in fixed speed applications soft starters are still the most economic solution.

The purpose of this guide is to outline the principle benefits of using soft starters compared to other electro-mechanical start methods, and to discuss the advantages and disadvantages of the various soft start methods. This guide also covers some of the advanced functionality that can be found in today's modern soft starters as well as the considerations when choosing and sizing soft starters.

1.2 Benefits of soft starters

Soft start enhances motor start performance in many ways including:

➜ Smooth acceleration without the torque transients associated with electro-mechanical reduced voltage starters.

➜ Voltage or current is applied gradually, without the voltage and current transients associated with electro-mechanical reduced voltage starters.

➜ Lower start currents and/or shorter start times because constant current control gives higher torque as motor speed increases.

➜ Easy adjustment of start performance to suit the specific motor and load.

➜ Precise control over the current limit.

➜ Consistent performance even with frequent starts.

➜ Reliable performance even if load characteristics vary between starts (eg loaded or unloaded starts).

In addition to superior starting performance, soft starters also provide a range of features not available from other reduced voltage starters. This includes areas such as:

➜ Soft stop (which helps eliminate water hammer)   ➜ Metering and monitoring

➜ Braking   ➜ Operating history and event logs

➜ Motor and system protection   ➜ Communication network integration

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1.3 Typical Applications

Soft starters can offer benefits for almost all motor starting applications. Typical advantages are highlighted in the table below.

Table 1-1 Typical soft start applications

Pumps
- ➜ Minimised hydraulic shock in pipelines during start and stop.
- ➜ Reduced starting current.
- ➜ Minimised mechanical stress on motor shaft.
- ➜ Phase rotation protection prevents damage from reverse pump rotations.

Conveyor Belts
- ➜ Controlled soft start without mechanical shocks, e.g. bottles on a belt do not fall over during starting, minimised belt stretch, reduced counterbalance stress.
- ➜ Controlled stop without mechanical shock (soft stop).
- ➜ Optimum start performance even with varying starting loads (e.g. coal conveyors start loaded or unloaded).
- ➜ Extended mechanical lifetime.
- ➜ Maintenance-free.

Centrifuges
- ➜ Smooth application of torque prevents mechanical stress.
- ➜ Reduced starting times over star/delta starting.

Ski Lifts
- ➜ Jerk-free acceleration increases skier comfort and prevents swinging T-bars etc.
- ➜ Reduced starting current allows starting of large motors on a weak power supply.
- ➜ Smooth and gradual acceleration whether the ski lift is lightly or heavily loaded.
- ➜ Phase rotation protection prevents operation in reverse direction.

Compressors
- ➜ Reduced mechanical shock extends the life of the compressor, couplings and motor.
- ➜ Limited start current enables large compressors to be started when maximum power capacity is limited.
- ➜ Phase rotation protection prevents operation in reverse direction.

Fans
- ➜ Extended coupling life though reduced mechanical shock.
- ➜ Reduced start current enables large fans to be started when maximum power capacity is limited.
- ➜ Phase rotation protection prevents operation in reverse direction.

Mixers
- ➜ Gentle rotation during start-up reduces mechanical stress.
- ➜ Reduced starting current.

1.4 Different motor starting methods

1.4.1 Star/Delta

A star/delta start configuration comprises a six terminal motor that is delta connected at the supply voltage. The star/delta starter employs three contactors to initially start the motor in a star connection, then after a period of time, to reconnect the motor to the supply in a delta connection. While in the star connection, the voltage across each winding is reduced by a factor of the square root of 3. This results in the current and torque being one third of the full DOL voltage current and torque whilst in star configuration. If there is insufficient torque available while connected in star, the motor will only accelerate to partial speed. When the timer operates (set normally from 5-10 seconds), the motor is disconnected from the supply and reconnected in delta resulting in full voltage start currents and torque.

Figure 1-1 Star/delta connection

1 Main contactor

2 Thermal overload

3 Motor (three-phase)

4 Delta contactor

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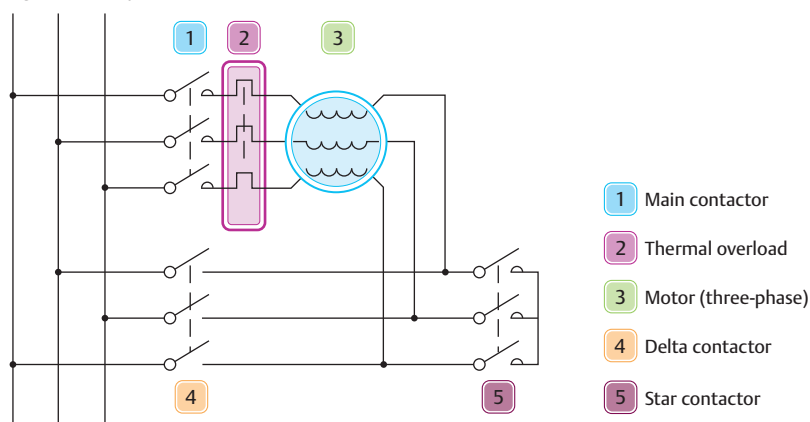
Compared with star/delta starters, soft starters are much more flexible and provide a smooth start with no risk of transients.

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 do not 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.

1.4.2 Auto-transformer

Auto-transformer starters use an auto-transformer to reduce the voltage during the start period. The transformer has a range of output voltage taps that can be used to set the start voltage. 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 start voltage is set by tap selection, and the start time is controlled by a timer. If the start voltage is too low, or the start time incorrectly set, the transition to full voltage will occur with the motor at less than full speed, resulting in a high current and torque step.

Figure 1-2 Auto-transformer connection

1	Run contactor
2	Thermal overload
3	Start contactor (A)
4	Start contactor (B)
5	Auto-transformer
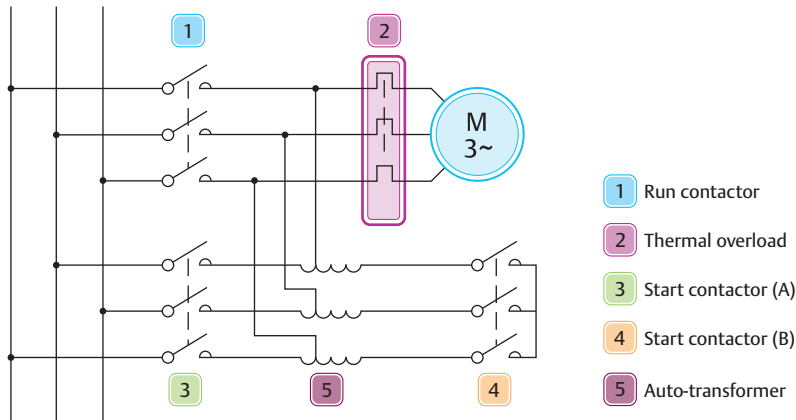
Compared with auto-transformer starters, soft starters are much more flexible and provide a much smoother start.

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.

1.4.3 Primary resistance starters

For primary resistance starting, resistors are connected in series with each phase, between the isolation contactor and the motor. The voltage drop across the resistors results in a reduced voltage applied to the motor, thus reducing start current and torque. The reduced voltage start time is controlled by a preset timer. If the time is too short, the motor will not have achieved full speed before the resistors are bridged. Start voltage is determined by the resistors used. If the resistance is too high there will be insufficient torque to accelerate the motor to full speed.

Figure 1-3 Primary resistance connection

1	Line contactor
2	Run contactor
3	Thermal overload
4	Start resistors
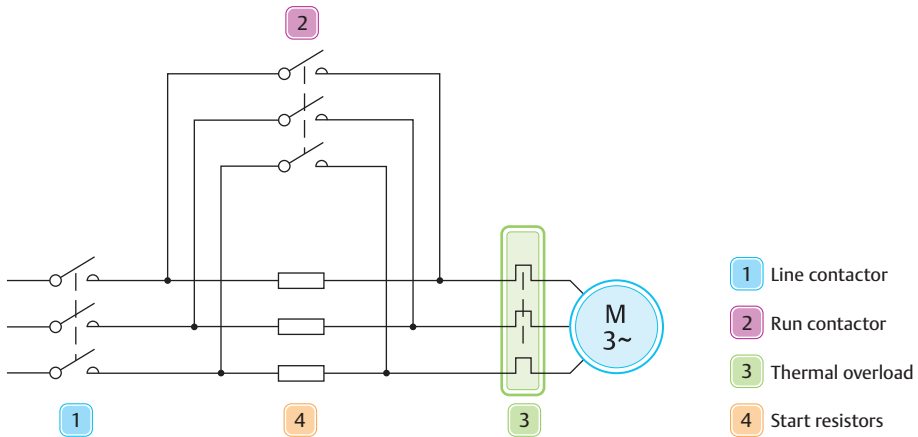
Compared with primary resistance starters, soft starters are more flexible and reliable.

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.

1.4.4 Variable speed drives

A variable speed drive (VSD) is a device that can control the speed of an electric motor by controlling the frequency and voltage of the electrical power supplied to it. When a drive starts a motor, it initially applies a low frequency and voltage to the motor thus allowing high inrush currents to be avoided.

As drives can be used to control the speed of the motor substantial energy savings are possible when the motor can be run at a reduced speed.

If the application cannot be run at part speed then a soft starter will be a more energy efficient solution compared to a drive, at least where a contactor is used to bypass the starter once the motor is at full speed. In such applications a soft starter will require less capital outlay compared to a drive.

1.5 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.

Figure 1-4 Successful soft start
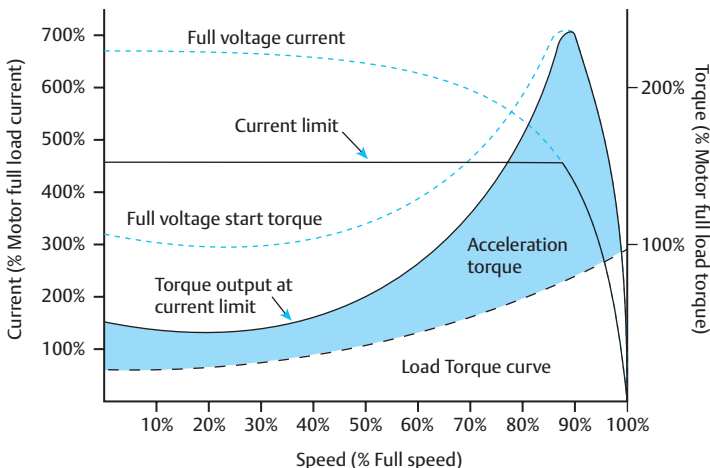
Figure 1-5 Unsuccessful soft start
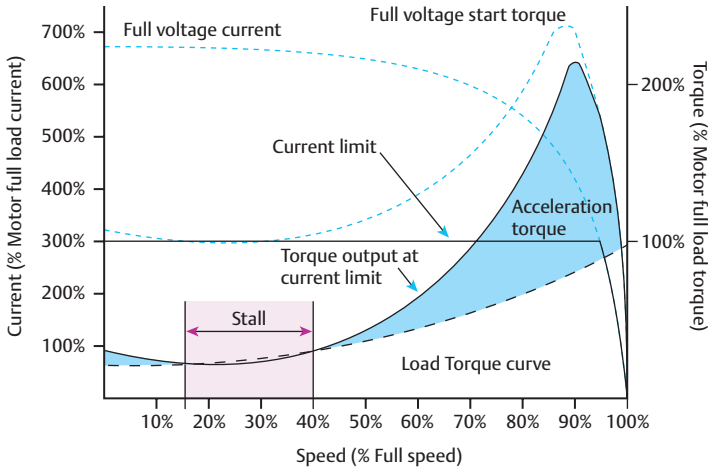
1.6 Are all three phase soft starters the same?

No. There are different styles of soft starter which control the motor in different ways and offer different features.
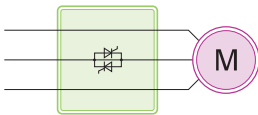
Single phase control

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.
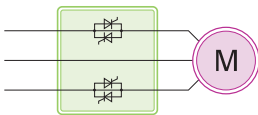
Two phase control

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.
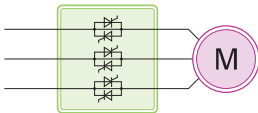
Three phase control

These devices control all three phases, providing the optimum in soft start control. Three phase control should be used for severe starting situations.

2. Soft Start and Soft Stop Methods

2.1 Soft Start Methods

Soft starters offer a variety of methods to control motor starting. Each soft start method uses a different primary control parameter.

Table 2-1 Soft start methods

Soft Start Method	Parameter Controlled	Performance Parameters Influenced
Timed Voltage Ramp	Voltage	Start current, start torque, acceleration
Constant Current	Current	Start torque, acceleration
Torque Control	Torque	Start current, acceleration
Adaptive Acceleration Control	Acceleration	Start current, start torque

Best results are obtained by selecting the soft start method that directly controls the parameter of most importance for the application. Typically soft starters are used to limit motor start current or control load acceleration and/or deceleration.

2.1.1 Timed Voltage Ramp (TVR) Starting

Timed voltage ramp (TVR) was the earliest form of soft starting. TVR slows the application of voltage, which reduces the start current. This reduces start torque and slows the motor's rate of acceleration.

The main benefits of voltage control are:

➜ reduced start current and start torque

➜ elimination of mechanical and electrical transients

TVR soft starting is not suitable for high inertia loads (such as fans), which require a high level of voltage to accelerate the load.

TVR soft starting is widely used in open loop (voltage controlling) soft starters. TVR soft starting is not commonly found in closed loop soft starters, which monitor and control current.

Figure 2-1 TVR soft start

1 Initial start voltage

2 Full voltage

3 Initial start time
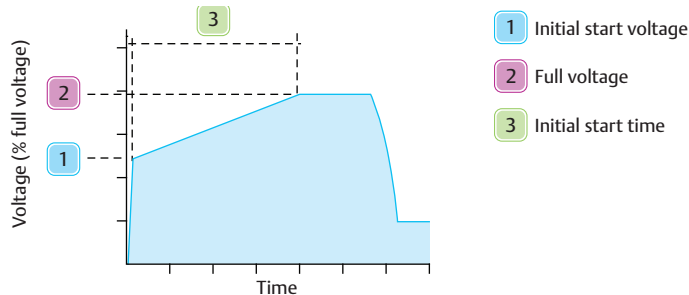
2.1.2 Current limit starting

With current limit starting, the soft starter delivers voltage to the motor until it reaches a specified current level, then pauses the voltage ramp. When the current drops, the voltage ramp continues. This keeps start current within the required limit, although the motor's actual current level varies throughout the start.

This can be useful for generator set applications where the supply is limited.

2.1.3 Constant current

With constant current starting, the current is raised from zero to a specified level and keeps the current stable at that level until the motor has accelerated.

Constant current starting is ideal for applications where the start current must be kept below a particular level.

Figure 2-2 Constant current soft start
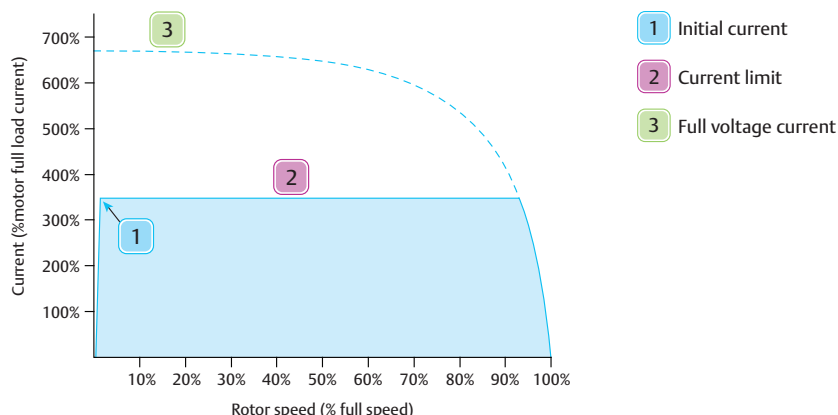
2.1.4 Current Ramp

Current ramp soft starting raises the current from a specified starting level (1) to a maximum limit (3), over an extended period of time (2).

Current ramp starting can be useful for applications where:

→ the load can vary between starts (for example a conveyor which may start loaded or unloaded). Set the initial current to a level that will start the motor with a light load, and the current limit to a level that will start the motor with a heavy load.

→ the load breaks away easily, but starting time needs to be extended (for example a centrifugal pump where pipeline pressure needs to build up slowly).

→ the electricity supply is limited (for example a generator set), and a slower application of load will allow greater time for the supply to respond.

Figure 2-3 Current ramp soft start

Current (% motor full load current)

700% 600% 500% 400% 300% 200% 100%

| 4 | Full voltage current

| 2 | Start ramp time

| 3 | Current limit

| 1 | Initial current

10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Rotor speed (% full speed)

| 1 | Initial current
| 2 | Start ramp time
| 3 | Current limit
| 4 | Full voltage current
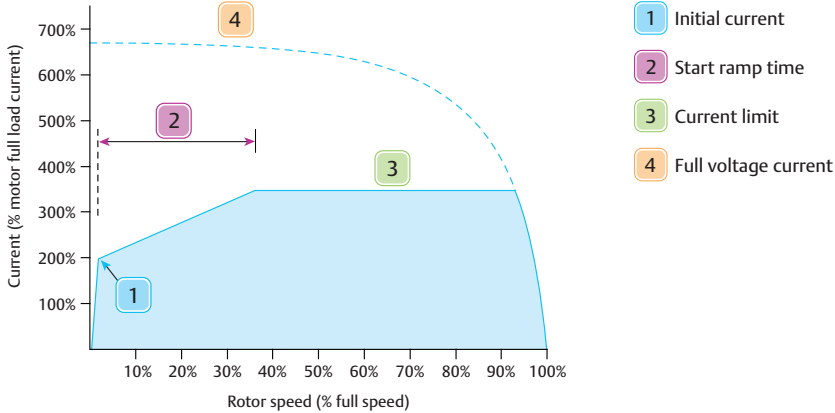
2.1.5 Torque Control

Torque control is promoted as a method of providing a more linear speed ramp in soft starters. By providing a constant acceleration torque, torque control will allow the motor to speed up or slow down in a linear fashion.

Torque control monitors current and power factor, and adjusts the output power of the motor to make the torque difference between the motor and load as constant as possible.

Torque control is suitable for applications where:

→ load torque is constant (linear) throughout the start

→ load torque is constant between starts.

2.1.6 Adaptive Control for Starting

Adaptive Acceleration Control is a new intelligent motor control technique. In an adaptive control soft start, the soft starter adjusts the current in order to start the motor within a specified time and using a selected acceleration profile.

Every application has a particular starting profile, based on characteristics of the load and the motor. Adaptive Acceleration Control offers three different starting profiles, to suit the requirements of different applications. Selecting a profile that matches the inherent profile of the application can help smooth out acceleration across the full start time. Selecting a dramatically different Adaptive Control profile can somewhat neutralise the inherent profile.

The soft starter monitors the motor's performance during each start, to improve control for future soft starts.

Note

Adaptive Control controls the motor's speed profile, within the programmed time limit. This may result in a higher level of current than traditional control methods.

Figure 2-4 Adaptive Control soft start

1 Early acceleration
2 Constant acceleration
3 Late acceleration
4 Start time
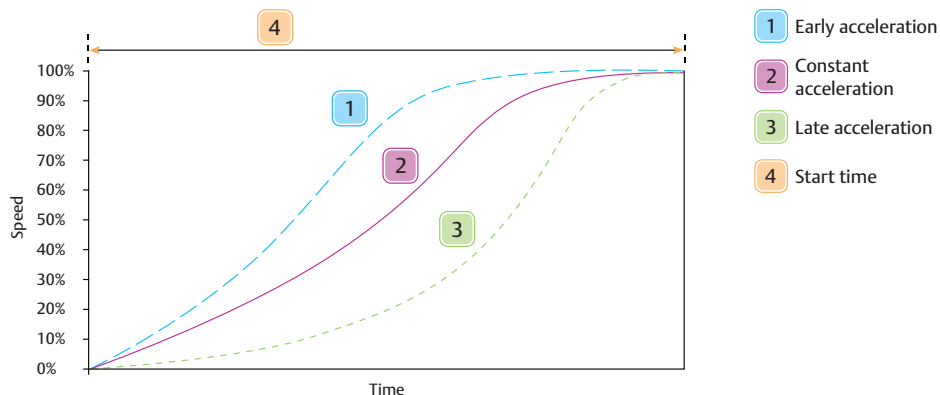
How to Select the Adaptive Acceleration Control Start Profile

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.

Some loads, such as submersible pumps, should not be run at slow speeds. An early acceleration profile will raise the speed quickly, then control acceleration through the rest of the start.

Table 2-2 Adaptive Control profiles for common applications

Application	Parameter	Suggested value
Pump Centrifugal	*Adaptive Start Profile* *Adaptive Stop Profile*	Early Acceleration Late Deceleration
Pump Submersible	*Adaptive Start Profile* *Adaptive Stop Profile*	Early Acceleration Late Deceleration
Fan Damped	*Start Mode* *Current Limit*	Constant Current 350%
Fan Undamped	*Adaptive Start Profile*	Constant Acceleration
Compressor Screw	*Start Mode* *Current Limit*	Constant Current 400%
Reciprocating Compressor	*Start Mode* *Current Limit*	Constant Current 450%
Conveyor	*Start Mode* *Current Limit* *Adaptive Stop Profile*	Constant Current 400% Constant Deceleration
Crusher Rotary	*Start Mode* *Current Limit*	Constant Current 400%
Crusher Jaw	*Start Mode* *Current Limit*	Constant Current 450%

2.1.7 Kickstart

Kickstart provides a short boost of extra torque at the beginning of a start, and can be used in conjunction with current ramp or constant current starting.

Kickstart can be useful to help start loads that require high breakaway torque but then accelerate easily (for example flywheel loads such as presses).

Figure 2-5 Current ramp soft start with kickstart

1	Kickstart level
2	Kickstart time
3	Initial current
4	Start ramp time
5	Current limit
6	Full voltage current
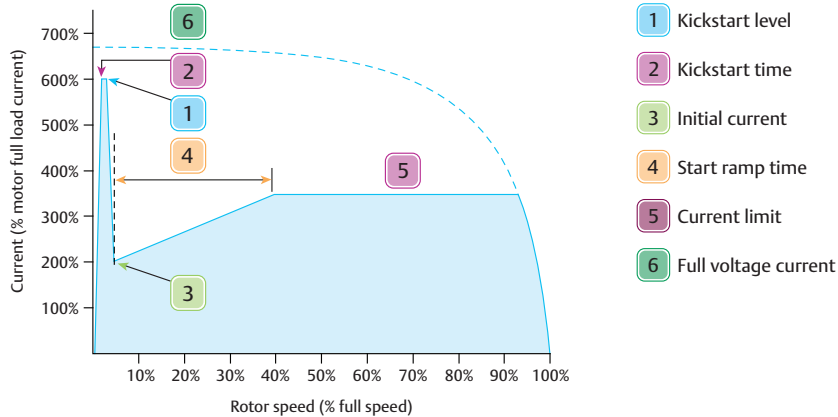
2.2 Stop Methods

Soft starters offer a variety of methods for the control of motor stopping.

Table 2-3 Soft stop methods

Stop Method	Performance Result
Coast To Stop	Natural load run down
TVR Soft Stop	Extended run down time
Adaptive Control	Extended run down time according to selected deceleration profile
STV Stop	Extended run down time
Brake	Reduced run down time

Soft starters are often used in pumping applications to eliminate the damaging effects of fluid hammer. Adaptive Control should be the preferred stop method for these applications.

2.2.1 Coast to Stop

Coast to stop lets the motor slow at its natural rate, with no control from the soft starter. The time required to stop will depend on the type of load.

2.2.2 Timed Voltage Ramp (TVR) Soft Stop

Timed voltage ramp reduces the voltage to the motor gradually over a defined time. The load may continue to run after the stop ramp is complete.

Timed voltage ramp stopping can be useful for applications where the stop time needs to be extended, or to avoid transients on generator set supplies.

Figure 2-6 TVR soft stop
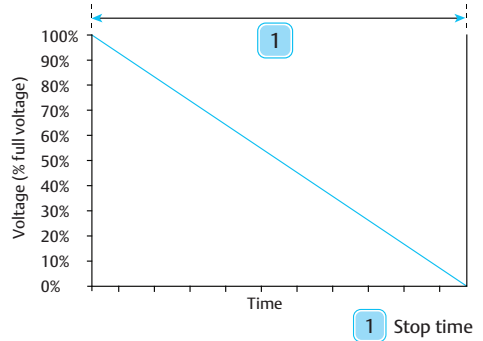
2.2.3 Adaptive Control for Stopping

In an adaptive control soft stop, the soft starter controls the current in order to stop the motor within a specified time and using a selected deceleration profile. Adaptive Deceleration Control can be useful in extending the stopping time of low inertia loads.

Note

Adaptive control does not actively slow the motor down and will not stop the motor faster than a coast to stop. To shorten the stopping time of high inertia loads, use brake.

Every application has a particular stopping profile, based on characteristics of the load and the motor. Adaptive Deceleration Control offers three different stopping profiles. Choose the adaptive control profile that best matches your application requirements.

Figure 2-7 Adaptive Deceleration Control soft stop
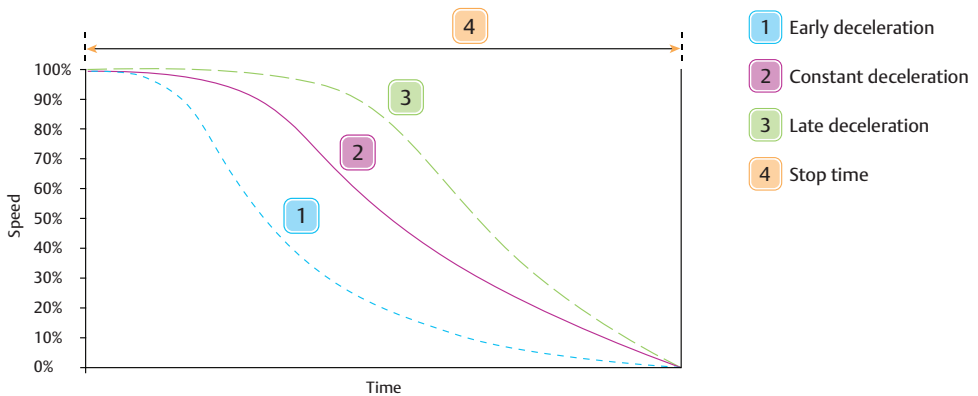
The advent of Adaptive Control has made solving the problem of fluid hammer easier as the most appropriate deceleration profile can be selected for the application.

Table 2-4 Adaptive Deceleration Control soft stop profiles

Adaptive Stop Profile	Application
Late Deceleration	High head systems where even a small decrease in motor/pump speed results in a rapid transition between forward flow and reverse flow.
Constant Deceleration	Low to medium head, high flow applications where the fluid has high momentum.
Early Deceleration	Open pump systems where fluid must drain back through the pump without driving the pump in reverse.

Note

Pump stopping: The hydraulic characteristics of pump systems vary considerably. This variation means the ideal deceleration profile and stop time will vary from application to application. The table provides guidelines on selecting between Adaptive Control deceleration profiles, but we recommend testing the three profiles to identify the best profile for the application.

How to Select the Adaptive Deceleration Control Stop Profile

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.

Note

Adaptive Control controls the motor's speed profile, within the programmed time limit. This may result in a higher level of current than traditional control methods.

2.3 Jog

Jog runs the motor at reduced speed, to allow alignment of the load or to assist servicing. The motor can be jogged in either forward or reverse direction.

The maximum available torque depends on the soft starter. Check the soft starter User Guide for details.

Figure 2-8 Jog operation
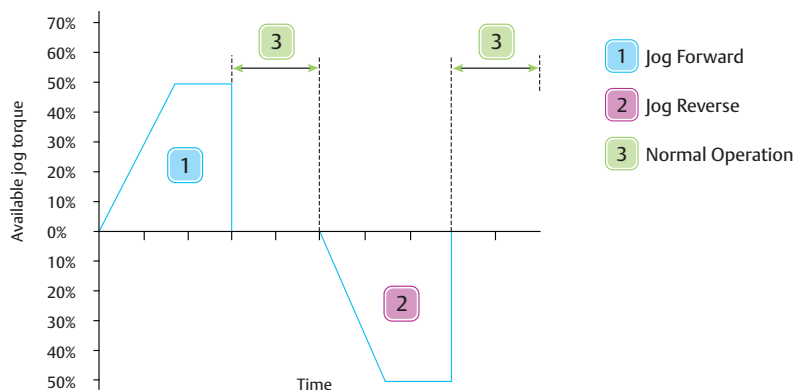
3. Choosing Soft Starters

3.1 Three step process

1. Identify the features required. This will help you choose the best starter to suit your application.

2. Identify your application. This will tell you the start current required.

3. Calculate which starter model matches your requirement.

3.2 Step 1 - Starter selection

You need to select a starter that offers the features you require for the application. This may include:

➡ the best start method for the application

➡ input and output options to interface with external equipment

➡ serial communication control

➡ specific protections

3.3 Step 2 - Application selection

Different applications typically require different levels of start current.

The level of start current affects how many starts the soft starter can complete per hour. Some soft starters may not offer high enough start current for extreme applications.

3.3.1 Typical Start Current Requirements

Table 3-1 Typical start current requirements

Application	300%	350%	400%	450%	Application	300%	350%	400%	450%
Agitator			✔		Fan - High Pressure				✔
Atomiser			✔		Grinder		✔		
Bottle Washer	✔				Hydraulic Power Pack		✔		
Centrifuge				✔	Mill				✔
Chipper				✔	Mill - Ball				✔
Compressor - Reciprocal (loaded)				✔	Mill - Hammer				✔
Compressor - Reciprocal (unloaded)			✔		Mill - Roller				✔
Compressor - Screw (loaded)			✔		Mixer				✔
Compressor - Screw (unloaded)		✔			Pelletiser				✔
Conveyor - Belt				✔	Planer		✔		
Conveyor - Roller		✔			Press		✔		
Conveyor - Screw			✔		Pump - Bore	✔			
Crusher - Cone		✔			Pump - Centrifugal		✔		
Crusher - Jaw				✔	Pump - Positive Displacement			✔	
Crusher - Rotary		✔			Pump - Slurry				✔
Crusher - Vertical Impact		✔			Re-pulper				✔
Debarker		✔			Rotary Table			✔	
Dryer				✔	Sander		✔		
Dust Collector		✔			Saw - Bandsaw				✔
Edger		✔			Saw - Circular		✔		
Fan - Axial (damped)		✔			Separator				✔
Fan - Axial (un-damped)				✔	Shredder				✔
Fan - Centrifugal (damped)		✔			Slicer	✔			
Fan - Centrifugal (un-damped)				✔	Tumbler			✔	

3.4 Step 3 - Starter sizing

The soft starter must be the correct size for the motor and the application. Select a soft starter that has a current rating at least equal to the motor's full load current (nameplate) rating, at the start duty.

For example:

➜ application: centrifugal pump

➜ full load current: 213 A

➜ starts and stops: required to start and stop twice daily (evenly through the day)

➜ other features required: water hammer control is required

Typical start current for a centrifugal pump is 350%. You need to select a soft starter model which is rated >213A at 350% FLC. The best soft stop method to control water hammer is Adaptive Control

Other factors that may affect the sizing are:

➜ environmental conditions (altitude or ambient temperature)

➜ is the installation bypassed or non-bypassed

➜ is the connection in-line or inside delta

3.5 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.

Figure 3-1 AC53a utilisation code
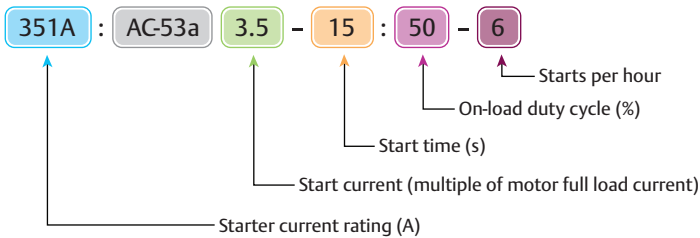
Starter current rating:	The full load current rating of the soft starter given the parameters detailed in the remaining sections of the utilisation code.
Start current:	The maximum available start current.
Start time:	The maximum allowable start time.
On-load duty cycle:	The maximum percentage of each operating cycle that the soft starter can operate.
Starts per hour:	The maximum allowable number of starts per hour.
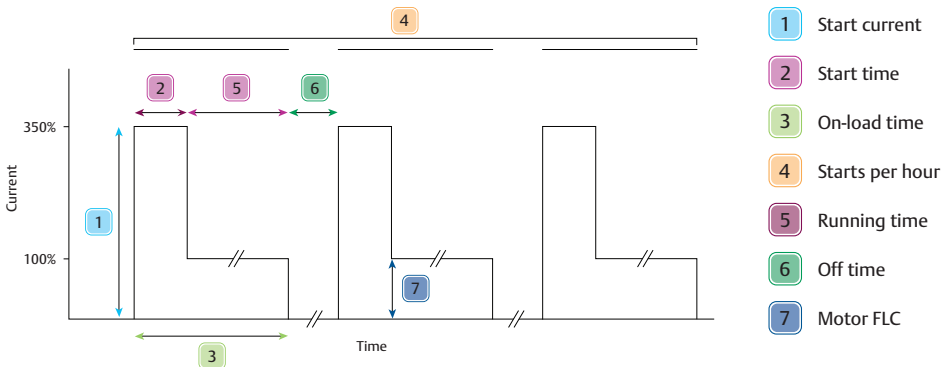
$$\text{Operating cycle} = \frac{\text{Start time} + \text{Running time}}{\text{Start time} + \text{Running time} + \text{Off time}}$$

3.6 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, the length and current level of the start, and the amount of time the soft starter will be off (not passing current) between starts.

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.

Figure 3-2 AC53b utilisation code
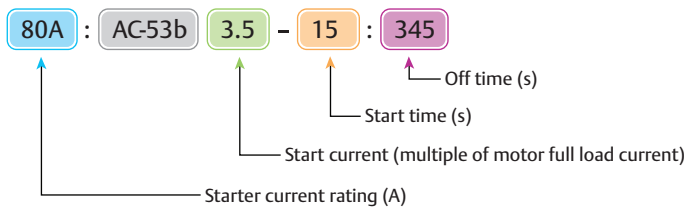
Starter current rating:	The full load current rating of the soft starter given the parameters detailed in the remaining sections of the utilisation code.
Start current:	The maximum available start current.
Start time:	The maximum allowable start time.
Off time:	The minimum allowable time between the end of one start and the beginning of the next start.
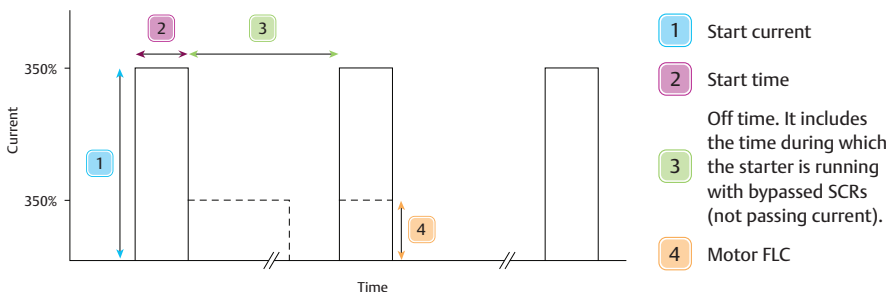
3.7 Typical Motor FLCs

If you don't have accurate information on your motor's start current characteristics, the table below can help you estimate the likely full load current for a particular motor size. This information can help when choosing a soft starter, but will not provide an optimised solution because the characteristics of different motors can vary considerably.

Table 3-2 Typical motor FLCs

| Motor Power		Current rating at different voltages				
kW	HP	220-230 V	380-400 V	440 V	500 V	660-690 V
7.5	10	27	15.5	13.7	12	8.9
11	15	39	22	20.1	18.4	14
15	20	52	30	26.5	23	17.3
18.5	25	64	37	32.8	28.5	21.3
22	30	75	44	39	33	25.4
25	35	85	52	45.3	39.4	30.3
30	40	103	60	51.5	45	34.6
37	50	126	72	64	55	42
45	60	150	85	76	65	49
55	75	182	105	90	80	61
75	100	240	138	125	105	82
90	125	295	170	146	129	98
110	150	356	205	178	156	118
132	180	425	245	215	187	140
140	190	450	260	227	200	145
147	200	472	273	236	207	152
150	205	483	280	246	210	159
160	220	520	300	256	220	170
185	250	595	342	295	263	200
200	270	626	370	321	281	215
220	300	700	408	353	310	235
250	340	800	460	401	360	274
257	350	826	475	412	365	280
280	380	900	510	450	400	305
295	400	948	546	473	416	320
300	410	980	565	481	420	325
315	430	990	584	505	445	337
335	450	1100	620	518	472	355
355	480	1150	636	549	500	370
375	500	1180	670	575	527	395
400	545	1250	710	611	540	410
425	580	1330	760	650	574	445
445	600	1400	790	680	595	455
450	610	1410	800	690	608	460
475	645	1490	850	730	645	485
500	680	1570	900	780	680	515
560	760	1750	1000	860	760	570
600	800	1875	1085	937	825	625
650	870	2031	1176	1015	894	677
700	940	2187	1266	1093	962	729
750	1000	2343	1357	1172	1031	781
800	1070	2499	1447	1250	1100	833
850	1140	2656	1537	1328	1168	885
900	1250	2812	1628	1406	1237	937
950	1275	2968	1718	1484	1306	989
1000	1340	3124	1809	1562	1375	1041

3.7.1 Using soft starters with large motors

There are several factors to consider when planning to use a soft starter with a large motor (> 300 kW).

→ Larger motors have copper rotor bars, not aluminium. This reduces effective starting torque and can increase rotor inertia.

→ Increased rotor inertia may require a longer start time.

→ The start current may need to be greater than for a smaller motor, by 50% to 100% of motor FLC.

→ Starts per hours are generally limited by the motor's duty cycle rating.

4. Applying Soft Starters/System Design

4.1 Do I need to use a main contactor?

While soft starters can be installed with or without a main contactor, Control Techniques recommend their use for the following reasons:

→ May be required to meet local electrical regulations.

→ Provides physical isolation when the starter is not in use and in the event of a soft starter trip.

→ Even in the off state SCRs do not offer a high degree of isolation due to leakage through the SCR and protection networks.

Main contactors should be AC3 rated for the motor FLC.

Figure 4-1 Installation with main contactor

KM1 — Main contactor

F1 — Semiconductor fuses (optional)
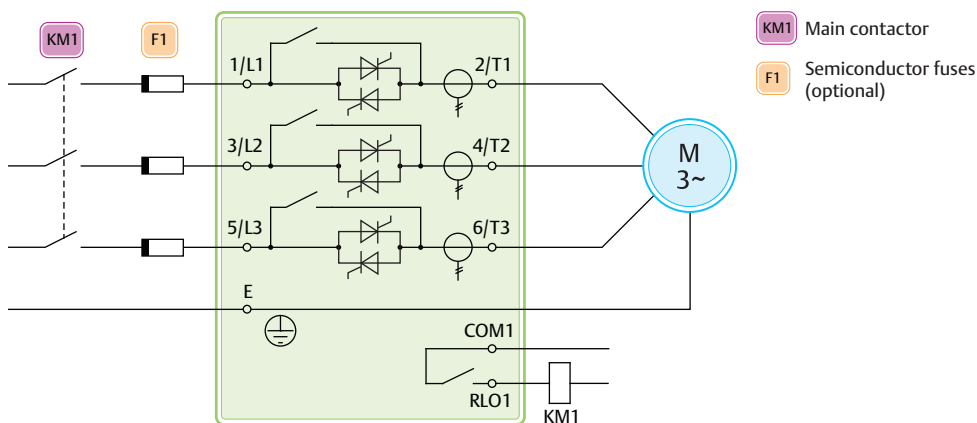
4.2 What are bypass contactors?

Bypass contactors bridge out a soft starter's SCRs when the motor is running at full speed. This eliminates heat dissipation from the SCRs during run state. SCRs dissipate approximately 4.5 watts per running ampere if not bypassed.

Some soft starters include built-in bypass contactors, others require an external bypass contactor.

Bypass contactors:

➜ Allow soft starters to be installed in sealed enclosures

➜ Eliminate the cost of forced-air cabinet ventilation

➜ Save energy by eliminating SCR losses during run

Bypass contactors should be AC1 rated for the motor FLC. The AC1 rating is adequate because the bypass contactor does not carry start current or switch fault current.

Digistart IS: Non-bypassed models have dedicated bypass terminals, which allow the soft starter to continue providing protection and monitoring functions even when bypassed via an external bypass contactor. The bypass contactor must be connected to the bypass terminals and controlled by the soft starter's run output (terminals COM2, RLO2).

Figure 4-2 Installation with external bypass contactor

www.controltechniques.com
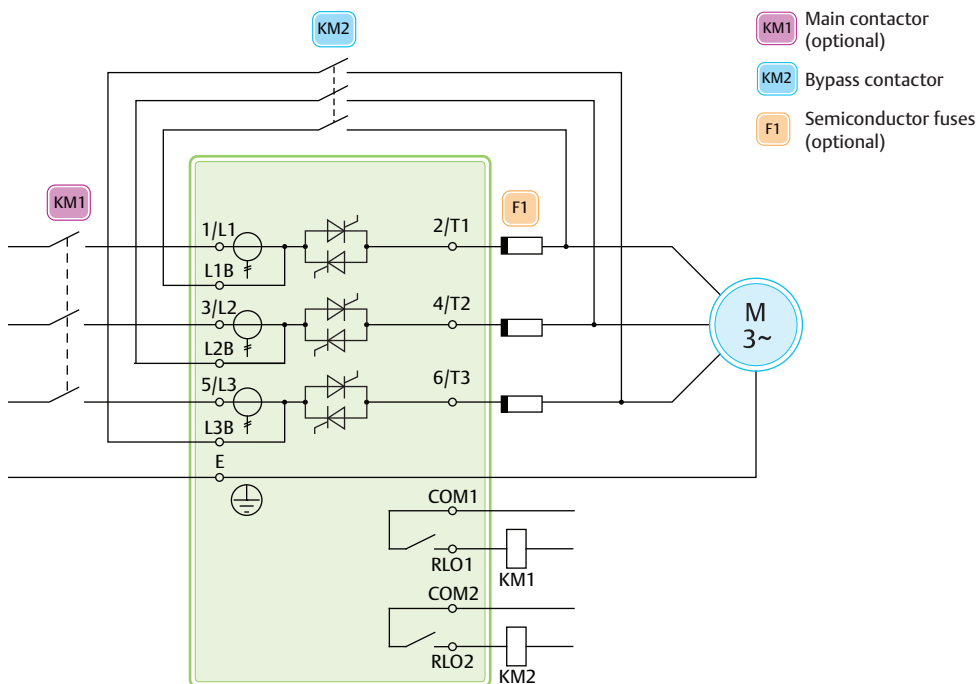
4.3 What is an inside delta connection?

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 wiring 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.

Figure 4-3 Inside delta installation, internally bypassed
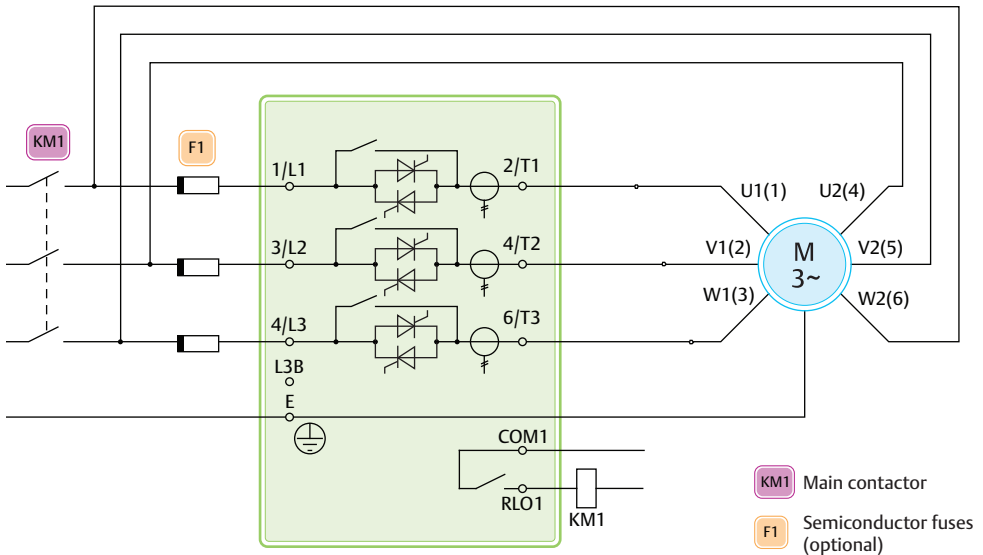
Figure 4-4 Inside delta installation, externally bypassed
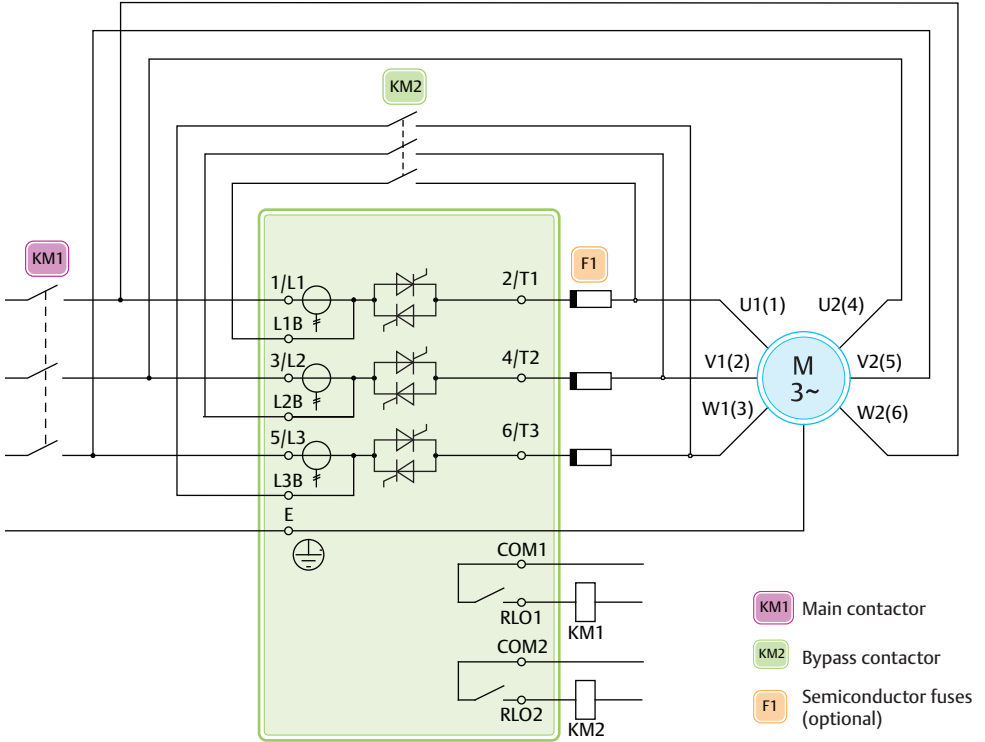
4.4 How do I replace a star/delta starter with a soft starter?

If the soft starter supports inside delta connection, simply connect it in place of the star/delta starter.

If the soft starter does not support inside delta connection, connect the delta connection to the output side of the soft starter.

4.5 How do I use power factor correction with soft starters?

Individual power factor correction capacitors can be used with soft starters, provided they are installed on the input side of the soft starter and switched in using a dedicated contactor when the motor is running at full speed. The contactor should be AC6 rated for the motor full load current.

Connecting power factor correction capacitors to the output of a soft starter will cause equipment failure due to severe overvoltage. This overvoltage is created by resonance between the inductance of the motor and the power factor capacitance.

PFC capacitors can be sized using the following formula:

kVA (Cap) = √3 x Vline x 0.8 x motor no load current

4.6 How do I ensure Type 1 circuit protection?

Type 1 protection requires that, in the event of a short circuit on the output of a soft starter, the fault must be cleared without risk of injury to personnel. There is no requirement that the soft starter must remain operational after the fault.

Type 1 protection is provided by HRC fuses or a MCCB that form part of the motor branch circuit.

As a minimum, the protection method must be able to sustain the required motor start current. Typical selection criteria are listed below.

Table 4-1 Type 1 circuit protection

Starter type	Protection Type	Fuse Rating (% Motor FLC)	
		< 350% FLC 15 seconds	> 350% FLC 15 seconds
Compact soft starter	Fuse (non time delayed)	175%	200%
	Fuse (time delayed)	150%	175%
	MCCB*	150- 200%	
Advanced soft starter	Fuse (non time delayed)	150%	
	Fuse (time delayed)	125%	
	MCCB*	150- 200%	

* Consult the manufacturer's specifications

Maximum fuse ratings for Type 1 motor protection are specified in UL and IEC standards.

Fuse	Rating (% Motor FLC)
Fuse (non time delayed)	300%
Fuse (time delayed)	175%

4.7 How do I ensure Type 2 circuit protection?

Type 2 protection requires that in the event of a short circuit on the output of a soft starter the fault must be cleared without risk of injury to personnel or damage to the soft starter.

Type 2 protection is achieved by using semiconductor fuses. These fuses must be able to carry motor start current and have a total clearing $I^2t <$ the I^2t of the soft starter SCRs.

Semiconductor fuses for Type 2 circuit protection are additional to HRC fuses or MCCBs that form part of the motor branch circuit protection.

Refer to the soft starter's Product Guide for semiconductor fuse recommendations.

4.8 How do I select cable when installing a soft starter?

Cable selection criteria vary according to the nature of the circuit and the location of the soft starter within the circuit. Typically:

➡ Supply cable rating
> nominal fuse/MCCB rating
> motor FLC x 1.2

➡ Inside delta motor circuit cable rating
> motor FLC x 0.7

Note

Cable current ratings may need to be derated to account for installation factors (including grouping, ambient temperature and single or parallel cabling). Always follow the manufacturer's instructions.

4.9 What is the maximum length of cable run between a soft starter and the motor?

The maximum distance between the starter and motor is determined by the voltage drop and the cable capacitance.

Voltage drop at the motor terminals must not exceed the limit specified in local electrical regulations when the motor is running fully loaded. Cabling should be sized accordingly.

Cable capacitance can be a factor for cable runs that are longer than 500 metres. Consult the soft starter manufacturer for advice - you will need to provide details about mains voltage, mains frequency and the soft starter model.

4.10 How do two-speed motors work and can I use a soft starter to control them?

Soft starters can be applied to the two most common types of two-speed motor. In both cases, separate motor protection must be provided for low and high speed operation.

Dahlander motors are special purpose motors often applied to two-speed compressor or fan applications. The motor windings are externally configured using contactors for high speed (dual star) and low speed (delta) operation.

Dual-winding motors have two separate pole configurations (eg 4 pole / 8 pole) on a common shaft. Each pole configuration (speed) is selected using an external AC3 rated contactor.

PAM (Pole Amplitude Modulated) motors alter the speed by effectively changing the stator frequency using external winding configuration. Soft starters are not suitable for use with this type of two-speed motor.

Figure 4-5 Two-speed motor

1	Control voltage	
2	Remote control inputs	
3	Motor thermistor input	
4	RTD/PT100 input	
5	Relay outputs	
6	Three-phase supply	
7	Motor terminals	
8	Remote low speed start input	
9	Remote high speed start input	
F1	Semiconductor fuses (optional)	
KA1	Remote start relay (low speed)	
KA2	Remote start relay (high speed)	
KM1	Line contactor (high speed)	
KM2	Line contactor (low speed)	
KM3	Star contactor (high speed)	
S1	Reset contact	
COM4, RLC4, RLO4	Relay output C	

Note

Contactors KM2 and KM3 must be mechanically interlocked.

4.11 Can one soft starter control multiple motors separately for sequential starting?

Yes, one soft starter can control two motors in sequence. However, the control and wiring is complex and expensive and any saving in soft starter cost is often outweighed by additional component and labour costs.

In order to use a soft starter in a sequential starting situation, Each motor must have a separate main contactor, bypass contactor and overload protection

The soft starter must be suitably rated for the total start duty.

4.12 Can one soft starter control multiple motors for parallel starting?

Yes. The circuit configuration and soft starter selection depends on the application.

Each motor must have its own overload protection.

If the motors are the same size and are mechanically coupled, a constant current soft starter can be used.

If the motors are different sizes and/or the loads are not mechanically interlocked, a soft starter with a timed voltage ramp (TVR) start profile should be used.

The combined motor FLCs must not exceed the soft starter FLC.

4.13 Can slip-ring motors be started with a soft starter?

Yes, provided that the torque available from the motor under the new configuration is sufficient to accelerate the load. This may be difficult to determine and a trial may be required.

Soft starting is not suitable for applications where:

- ➜ the slip-ring motor was installed to deliver speed control.

- ➜ the load requires extreme start torque.

To develop starting torque, some resistance must remain in the rotor circuit during motor starting. This resistance must be bridged out using a contactor (AC2 rated for rotor current) once the motor is running close to full speed.

$$R \text{ (per phase)} = 0.2 \times \frac{V_R}{\sqrt{3} \times I_R}$$

Rotor resistance (R) can be sized using the following formula:

$$\text{Power (per phase)} = \frac{20\% \times \text{motor kW}}{3}$$

Where V_R = open circuit rotor voltage

I_R = full load rotor current

Figure 4-6 Slip-ring motor

1	Control voltage
2	Remote control inputs
3	Motor thermistor input
4	RTD/PT100 input
5	24 Vdc output
6	Relay outputs
7	Analog output
8	Three-phase supply
9	Slip-ring induction motor
KM1	Changeover contactor
F1	Semiconductor fuses (optional)
S1	Start/stop contact
S2	Reset contact
R1	Rotor resistance (external)

4.14 Can soft starters reverse the motor direction?

On their own, soft starters cannot run motors in reverse direction at full speed. However, forward and reverse operation can be achieved by using a forward and reverse contactor arrangement.

Some soft starters also provide a part speed function that runs the motor at slow speed in either forward or reverse, without a reversing contactor. However, reverse operation is limited to short periods at a fixed slow speed.

Figure 4-7 Installation with forward and reversing contactors
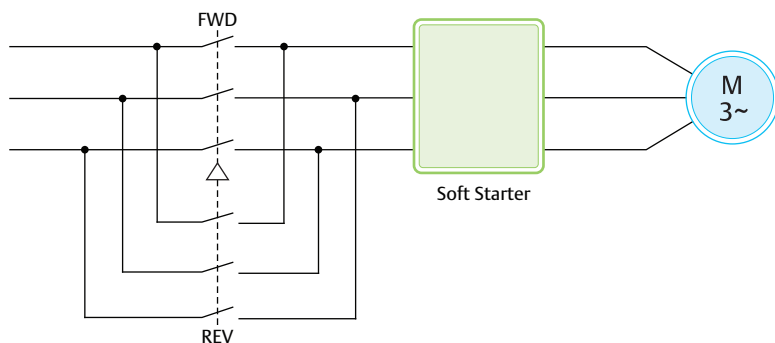
4.15 How are soft starters installed in a sealed enclosure?

Soft starters can be installed in sealed enclosures, provided the ambient temperature within the enclosure will not exceed the soft starter's rated temperature.

Heat generated within the enclosure must be dissipated, either through the enclosure's walls or by ventilation. When calculating the heat generated in the enclosure, all heat sources must be considered (eg soft starter, fuses, cabling and switchgear). The enclosure should be protected from direct sunlight to prevent external heating.

To minimise heating, soft starters are best installed in bypassed configuration.

4.16 Can soft starters control an already rotating motor (flying load)?

Yes, soft starters can start motors that are already rotating.

In general, the faster the motor is rotating in the forward direction, the shorter the start time will be.

If the motor is rotating in the reverse direction, it will be slowed to a standstill and then accelerate forwards. Allow for the extended start time when rating the soft starter.

No special wiring or soft starter setup is required.

4.17 Brake

When brake is selected, the soft starter uses DC injection to slow the motor.

Soft starter braking:

→ Does not require the use of a DC brake contactor

→ Controls all three phases so that the braking currents and associated heating are evenly distributed through the motor.

Braking has two stages:

1. Pre-brake: provides an intermediate level of braking to slow motor speed to a point where full brake can be operated successfully (approximately 70% speed).

2. Full brake: brake provides maximum braking torque but is ineffective at speeds greater than approximately 70%.

> ⚠️ **CAUTION** If the brake torque is set too high, the motor will stop before the end of the brake time and the motor will suffer unnecessary heating which could result in damage. Careful configuration is required to ensure safe operation of the starter and motor.

4.18 What is soft braking and how is it used?

Soft braking is one of two techniques used by soft starters to shorten motor stopping time. The other technique is DC braking.

Soft braking uses reversing contactors on the input or output of the soft starter. When the soft starter receives a stop command, it operates the reversing contactors and the motor is effectively soft started in the reverse direction. This applies a braking torque to the load.

Compared to DC braking, soft braking:

→ causes less motor heating

→ provides more braking torque for a given current

Soft braking is better for extremely high inertia loads.

Figure 4-8 Soft braking
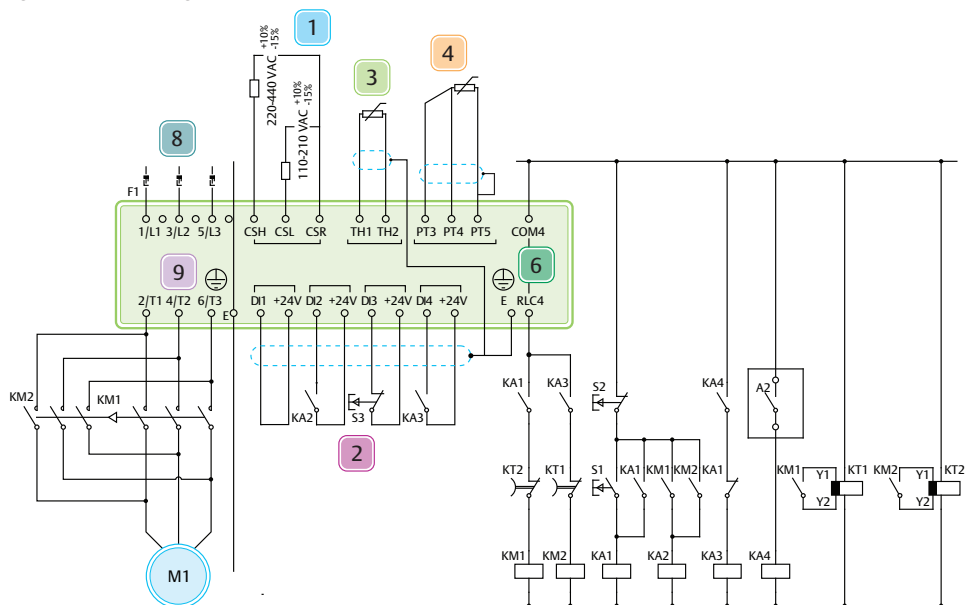
1	Control voltage	KA1	Run relay
2	Remote control inputs	KA2	Start relay
3	Motor thermistor input	KA3	Brake relay
4	RTD/PT100 input	KA4	Rotation sensing relay
6	Relay outputs	KM1	Line contactor (Run)
8	Three-phase supply	KM2	Line contactor (Brake)
9	Motor terminals	KT1	Run delay timer
A2	Shaft rotation sensor	KT2	Brake delay timer
F1	Semiconductor fuses (optional)	S1	Start contact
		S2	Stop contact
		S3	Reset contact

5. Digistart Soft Starter Selection

5.1 Three step process

To select the best soft starter for your application, you can use the tables below or use the DSSize soft starter selection software.

1. Identify the features required. This will help you choose the best starter to suit your application.

2. Identify your application. This will tell you the start current required.

3. Calculate which starter model matches your requirement.

5.2 Starter selection

You need to select a starter that offers the features you require for the application. This may include:

➜ the best start method for the application

➜ input and output options to interface with external equipment

➜ serial communication control

➜ specific protections

5.2.1 Key features

Table 5-1 Digistart features

Feature	Digistart CS	Digistart IS
Selectable soft starting profiles		
Adaptive Acceleration Control		✔
Kickstart		✔
Constant current	✔	✔
Current ramp	✔	✔
Selectable soft stopping profiles		
Adaptive Deceleration Control		✔
Timed voltage ramp soft stop	✔	✔
Brake		✔
Extensive input and output options		
Remote control inputs	2 x fixed	3 x fixed, 2 x programmable
Relay outputs	1 x fixed, 1 x programmable	1 x fixed, 3 x programmable
Analog output		1 x programmable
Built-in PT100 RTD input		1 x fixed
Easy-to-read display with comprehensive feedback		
Removable keypad	Optional Remote Keypad	✔
Multi-language feedback		✔
Date and time stamped event logging		✔
Operational counters		number of starts, hours run, kWh
Performance monitoring	current	current, voltage, power factor, kWh

Feature continued	Digistart CS	Digistart IS
Models for all connection requirements		
Current range	18 A to 200 A (nominal)	23 A to 1600 A (nominal)
Mains voltage	200 VAC to 440 VAC or 200 VAC to 575 VAC	200 VAC to 440 VAC or 380 VAC to 690 VAC
Control voltage	110 to 240 VAC 380 to 440 VAC	110 to 210 VAC 220 to 440 VAC
Internal bypassed	All models	Up to 220 A
Motor connection	In-line	In-line or inside delta
Optional features for advanced applications		
Input/output expansion	✔	✔
DeviceNet, Modbus or Profibus communication interfaces	✔	✔
RTD and Ground fault protection		✔
Fully customisable protection - See overleaf		

5.2.2 Protections

Soft starters can offer a wide range of protections for the load, motor and system. This can eliminate external motor protection devices and reduce panel space, cost and installation time.

Table 5-2 Digistart protection options

Trip Name	Digistart CS	Digistart IS
Excess start time	✔	✔
Motor overload (thermal model)	✔	✔
Motor thermistor	✔	✔
Current imbalance	✔	✔
Supply Frequency	✔	✔
Phase sequence	✔	✔
Instantaneous overcurrent		✔
Power circuit	✔	✔
Undercurrent		✔
Heatsink overtemperature		✔
Incorrect motor connection		✔
Input trip		✔
FLC too high (FLC out of range)		✔
Starter communication (between module and soft starter)	✔	✔
Network communication (between module and network)	✔	✔
Internal fault		✔
Overvoltage/ Undervoltage (requires Voltage Measurement card)		✔
Ground fault (requires RTD/PT100 and Ground Fault card)		✔

Trip Name continued	Digistart CS	Digistart IS
EEPROM fail		✔
Phase loss		✔
Phase shorted		✔
Motor 2 overload (thermal model)		✔
Time-overcurrent (Bypass overload)	✔	✔
RTD/PT100 overtemperature		✔
Thermistor circuit		✔
Overpower		✔
Underpower		✔

5.3 Application selection

Different applications typically require different levels of start current.

The level of start current affects how many starts the soft starter can complete per hour. Some soft starters may not offer high enough start current for extreme applications. Refer to section 3.3.1 *Typical Start Current Requirements* on page 20.

5.4 Starter sizing

The soft starter must be the correct size for the motor and the application.

Select a soft starter that has a current rating at least equal to the motor's full load current (nameplate) rating, at the start duty.

5.4.1 Digistart current ratings

Table 5-3 Digistart CS current ratings

	AC53b 4-6:354 < 1000 metres		AC53b 20:340 < 1000 metres	
	40 °C	50 °C	40 °C	50 °C
CS1x018	18 A	17 A	17 A	15 A
CS1x042	42 A	40 A	36 A	33 A
CS1x060	60 A	55 A	49 A	45 A

	AC53b 4-6:594 < 1000 metres		AC53b 4-20 580 < 1000 metres	
	40 °C	50 °C	40 °C	50 °C
CS2x085	85 A	78 A	73 A	67 A
CS3x140	140 A	133 A	120 A	110 A
CS3x170	170 A	157 A	142 A	130 A
CS3x200	200 A	186 A	165 A	152 A

Table 5-4 Digistart IS current ratings - in-line connection, bypassed operation

Model	AC53b 3.0-10:350 40°C <1000 metres	AC53b 3.5-15:345 40°C <1000 metres	AC53b 4.0-20:34 40°C <1000 metres	AC53b 4.5-30:330 40°C <1000 metres
IS1x0023B	23 A	20 A	17 A	15 A
IS1x0043B	43 A	37 A	31 A	26 A
IS1x0053B	53 A	53 A	46 A	37 A
	AC53b 3.0-10:590 40°C <1000 metres	AC53b 3.5-15:585 40°C <1000 metres	AC53b 4.0-20:580 40°C <1000 metres	AC53b 4.5-30:570 40°C <1000 metres
IS1x0076B	76 A	64 A	55 A	47 A
IS1x0097B	97 A	82 A	69 A	58 A
IS1x0105B	105 A	105 A	95 A	78 A
IS2x0145B	145 A	123 A	106 A	90 A
IS2x0170B	170 A	145 A	121 A	97 A
IS2x0200B	200 A	189 A	160 A	134 A
IS2x0220B	220 A	210 A	178 A	148 A
IS3x0255N	255 A	231 A	201 A	176 A
IS4x0360N	360 A	360 A	310 A	263 A
IS4x0430N	430 A	430 A	368 A	309 A
IS4x0650N	650 A	650 A	561 A	455 A
IS4x0790N	790 A	790 A	714 A	579 A
IS4x0930N	930 A	930 A	829 A	661 A
IS561200N	1200 A	1200 A	1200 A	1071 A
IS561410N	1410 A	1410 A	1319 A	1114 A
IS561600N	1600 A	1600 A	1600 A	1353 A

Note

Models IS3x0255N to IS561600N must be externally bypassed.

Table 5-5 Digistart IS current ratings - inside delta connection, bypassed operation

Model	AC53b 3.0-10:350 40°C <1000 metres	AC53b 3.5-15:345 40°C <1000 metres	AC53b 4.0-20:340 40°C <1000 metres	AC53b 4.5-30:330 40°C <1000 metres
IS1x0023B	35 A	30 A	26 A	22 A
IS1x0043B	65 A	59 A	51 A	44 A
IS1x0053B	80 A	80 A	69 A	55 A
	AC53b 3.0-10:590 40°C <1000 metres	AC53b 3.5-15:585 40°C <1000 metres	AC53b 4.0-20:580 40°C <1000 metres	AC53b 4.5-30:570 40°C <1000 metres
IS1x0076B	114 A	96 A	83 A	70 A
IS1x0097B	146 A	123 A	104 A	87 A
IS1x0105B	158 A	158 A	143 A	117 A
IS2x0145B	218 A	184 A	159 A	136 A
IS2x0170B	255 A	217 A	181 A	146 A
IS2x0200B	300 A	283 A	241 A	200 A
IS2x0220B	330 A	315 A	268 A	223 A
IS3x0255N	383 A	346 A	302 A	264 A
IS4x0360N	540 A	540 A	465 A	395 A
IS4x0430N	645 A	645 A	552 A	464 A
IS4x0650N	975 A	975 A	842 A	683 A
IS4x0790N	1185 A	1185 A	1071 A	868 A
IS4x0930N	1395 A	1395 A	1244 A	992 A
IS561200N	1800 A	1800 A	1800 A	1606 A
IS561410N	2115 A	2115 A	1979 A	1671 A
IS561600N	2400 A	2400 A	2400 A	2030 A

Table 5-6 Digistart IS current ratings - in-line connection, non-bypassed operation

Model	AC53a 3-10:50-6 40°C <1000 metres	AC53a 3.5-15:50-6 40°C <1000 metres	AC53a 4-20:50-6 40°C <1000 metres	AC53a 4.5-30:50-6 40°C <1000 metres
IS3x0255N	255 A	222 A	195 A	171 A
IS4x0360N	360 A	351 A	303 A	259 A
IS4x0430N	430 A	413 A	355 A	301 A
IS4x0650N	650 A	629 A	532 A	437 A
IS4x0790N	790 A	790 A	694 A	567 A
IS4x0930N	930 A	930 A	800 A	644 A
IS561200N	1200 A	1200 A	1135 A	983 A
IS561410N	1410 A	1355 A	1187 A	1023 A
IS561600N	1600 A	1600 A	1433 A	1227 A

Table 5-7 Digistart IS current ratings - inside delta connection, non-bypassed operation

Model	AC53a 3-10:50-6 40°C <1000 metres	AC53a 3.5-15:50-6 40°C <1000 metres	AC53a 4-20:50-6 40°C <1000 metres	AC53a 4.5-30:50-6 40°C <1000 metres
IS3x0255N	383 A	334 A	293 A	257 A
IS4x0360N	540 A	527 A	455 A	388 A
IS4x0430N	645 A	620 A	533 A	451 A
IS4x0650N	975 A	943 A	798 A	656 A
IS4x0790N	1185 A	1185 A	1041 A	850 A
IS4x0930N	1395 A	1395 A	1200 A	966 A
IS561200N	1800 A	1800 A	1702 A	1474 A
IS561410N	2115 A	2033 A	1780 A	1535 A
IS561600N	2400 A	2400 A	2149 A	1840 A

5.4.2 Selection example

For example:

➔ application: centrifugal pump

➔ full load current: 213 A

➔ starts and stops: required to start and stop twice daily (evenly through the day)

➔ other features required: water hammer control is required

The best soft stop method to control water hammer is Adaptive Control

Typical start current for a centrifugal pump is 350%

For 350% operation, the soft starter is rated AC53b 3.5-15:585.

The smallest model which is rated >213A is IS3x0255N.

However, with the low start frequency, it may be worth asking your supplier to check the sizing with our software tool to see if a lower rated soft starter could be used.

Other factors that may affect the sizing are:

➔ is the installation bypassed or non-bypassed

➔ is the connection in-line or inside delta

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Our simple, flexible product lines make choosing the right drive very easy. For more demanding solutions our engineers, located within our Drive Centre and Reseller network, are available to discuss your needs and provide advice. For further details, please refer to the brochures below.

Control Techniques Company Profile	Company overview		
AC & DC Drives, Servos and Drive Systems	Product Overview	100V / 200V / 400V / 575V/ 690V	0.25kW to 1.9MW
Commander SK	General purpose AC drive	100V / 200V / 400V / 575V/ 690V	0.25kW to 132kW
Unidrive SP panel mounting	High performance AC and servo drive	200V / 400V / 575V / 690V	0.37kW to 132kW
Unidrive SP Free Standing	Higher power performance AC drive	400V / 575V / 690V	90kW to 675kW
Unidrive SP Modular	High power modular AC drive	200V / 400V / 575V / 690V	45kW to 1.9MW
Mentor MP	High performance DC drive	400V / 575V / 690V	25A to 7400A
Digitax ST	Intelligent, compact and dynamic servo drive	200V / 400V	0.72Nm to 19.3Nm (57.7Nm Peak)
Affinity	Dedicated HVAC/R drive for building automation and refrigeration	200V / 400V / 575V / 690V	0.75kW to 132kW
Unimotor fm	Performance AC brushless servo motor	0.72Nm to 136Nm (408Nm Peak)	

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