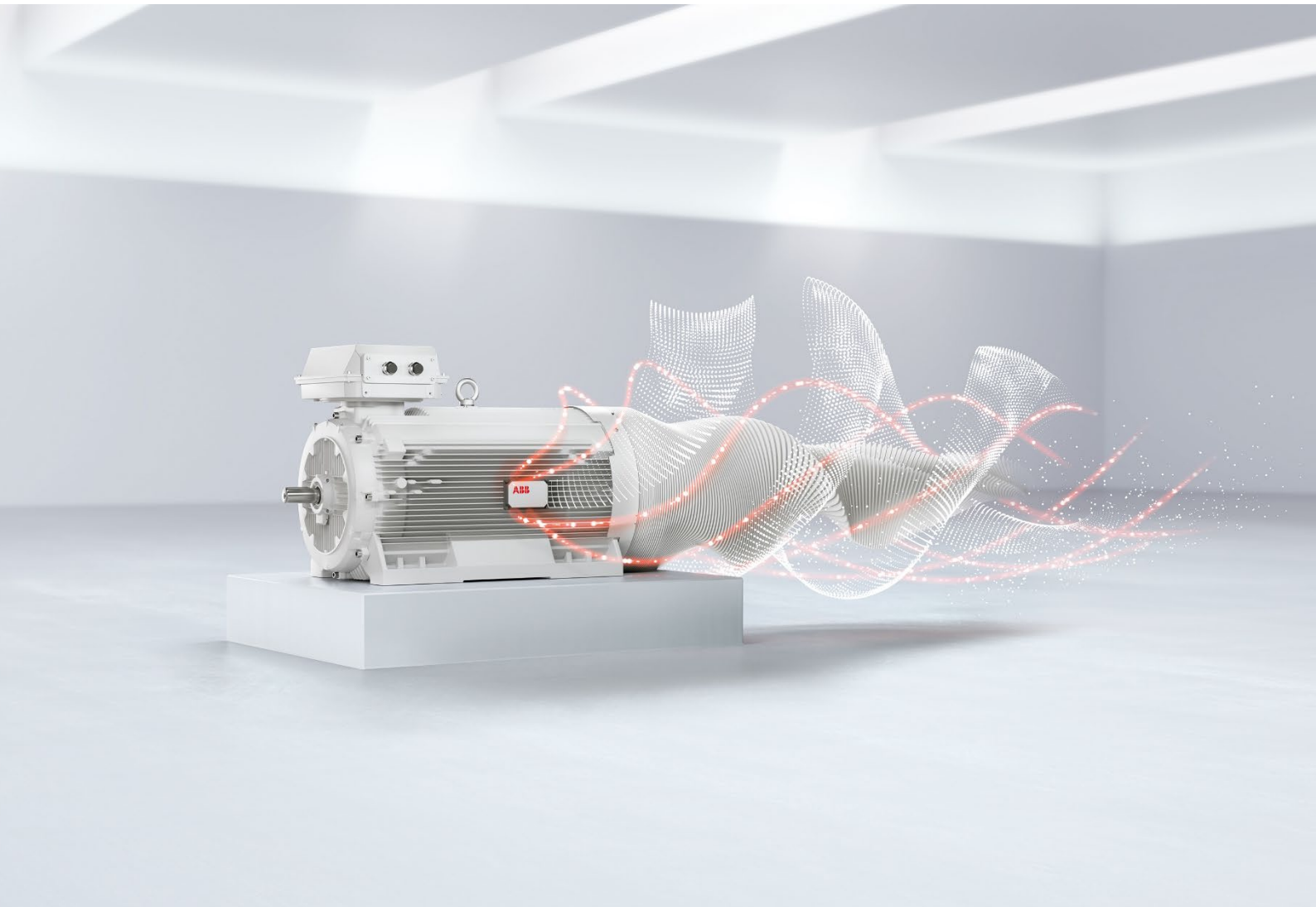
APPLICATION NOTE

Motor starting and protection for premium-efficiency motors

IE3 / IE4 ready for premium-efficiency motor starting
and the new AC-3e utilization category



International motor efficiency

World industry and commerce are facing an energy challenge. Global demand for energy is rising steadily. At the same time, pressures to reduce energy consumption and carbon dioxide (CO_2) emissions and provide secure power supplies are becoming ever stronger.

Efficient motors help cut energy costs and limit carbon dioxide emissions. It has been estimated that electric motors account for about 65 percent of the electricity consumed in industrial applications, so the energy saving potential for industries is enormous. Energy consumption depends on the motor's kW rating, the dimensioning of the application and the operating hours.
High-efficiency motors can thus play a significant role in reducing CO2 emissions.

ABB is a long-standing advocate of the need for high efficiency in motors. Its policy is to offer high-efficiency motors as standard, available directly from stock. However, instead of concentrating solely on efficiency, we take a lifecycle approach, seeking to minimize the costs associated with our products throughout their lifetime.

Foreword

ABB is a pioneering technology leader in electrification products, robotics and motion, and industrial automation, serving customers in utilities, industry, and transport and infrastructure globally. Continuing a history of innovation spanning more than 130 years, ABB today is writing the future of industrial digitalization with two clear value propositions: bringing electricity from any power plant to any plug and automating industries from natural resources to finished products.

This application note is written as a general guide for people working with low-voltage switchgear and controlgear applications for high-efficiency motor applications. All these are relevant for IEC-based European applications.

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

ABB participates in IEC working groups and IEC high-efficiency motor task forces, which are working on updating relevant product standards for motor starters.

ABB's portfolio matches the latest requirements for IE3 and IE4 motor applications, including the latest utilization categories AC-3 upgrade and AC-3e creation for contactors and motor starters. In particular, ABB has validated coordination solutions for AC-3 and AC-3e applications. The results of these tests can be found in ABB's motor coordination tables.

All the information provided in this application note is only general and each application must be handled as a specific case. Be sure to always follow all national and local installation regulations/codes for your specific application.

1. International motor efficiency standards and regulations

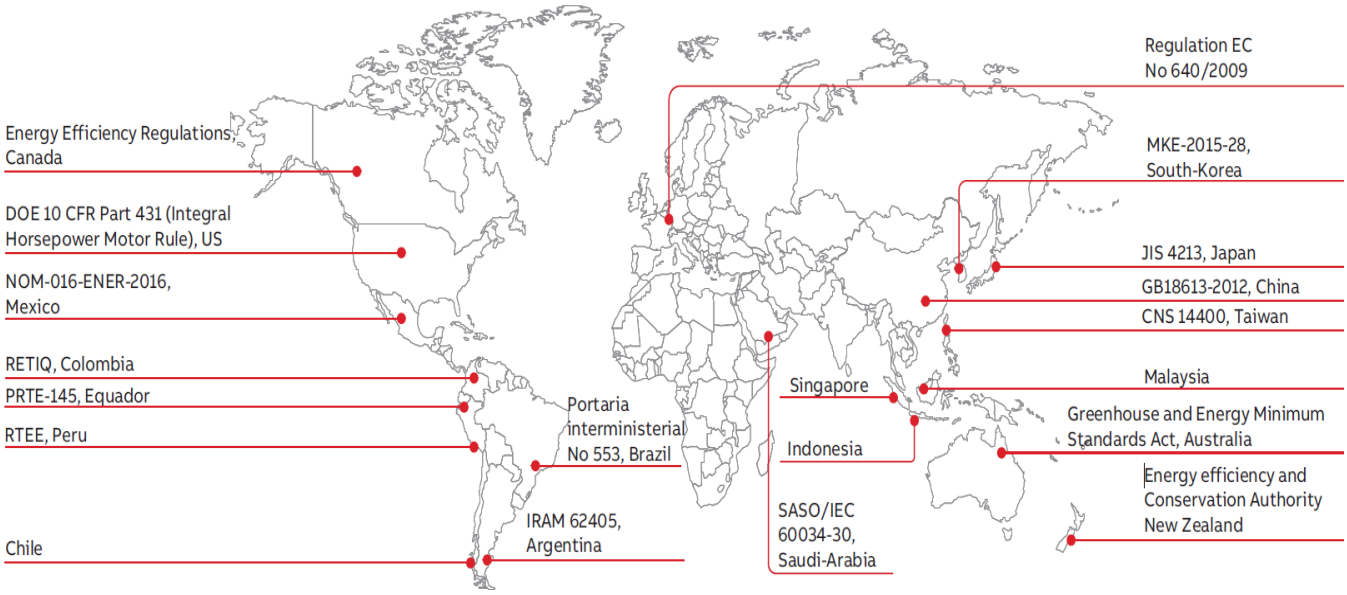


Figure 1: International motor efficiency standards and regulations.

Since the validation of IEC 60034-30:2008 and its refined IEC 60034-30-1:2014 version, a worldwide energy efficiency classification system has existed for low voltage three-phase asynchronous motors. These international standards have also been created to enable and increase the harmonization of efficiency regulations around the world.

IEC 60034-30-1:2014 defines International Efficiency (IE) classes for single-speed, three-phase, 50 Hz and 60 Hz induction motors. The efficiency levels defined in IEC 60034-30-1 are based on the test method specified in IEC 60034-2-1:2014. Both standards are part of an effort to unify motor testing procedures with Canadian and American standards, and efficiency and product labeling (IE) requirements to enable motor purchasers worldwide to easily recognize premium efficiency products.

To promote market transparency, IEC 60034-30-1 states that both the efficiency class and efficiency value must be shown on the motor rating plate and in the product documentation. The documentation must indicate the efficiency class testing method used because different methods can produce different results.

1.2 Minimum Energy Performance Standards

While IEC as an international standardization organization sets guidelines for motor testing and efficiency classes, the organization does not regulate countries' efficiency levels. The biggest drivers for mandatory Minimum Energy Performance Standard (MEPS) levels for electric motors are global climate change, government targets for curbing CO2 emissions, and growing electricity demand, especially in developing countries. The entire value chain, from the manufacturer to the end-user, must be aware of the legislation to meet local requirements, save energy and reduce the carbon footprint.

Harmonized global standards and the increasing adoption of MEPS around the world are good news for all of us. However, it is important to remember that harmonization is an ongoing process. Although MEPS are already in effect in several regions and countries, they are evolving and differ in scope and requirements. At the same time, more countries are planning to adopt their own MEPS regulations. The world map above shows the existing and future MEPS regulations.

1.3 Efficiency classes of line operated AC motors IEC 60034-30-1

It is important to know which engine types are exempt from the new efficiency regulations. IEC 60034-30-1 defines four International Efficiency (IE) classes for single speed electric motors that are rated as designed for operation on sinusoidal voltage:

- IE4 = Super premium efficiency
- IE3 = Premium efficiency
- IE2 = High efficiency
- IE1 = Standard efficiency

IEC 60034-30-1 covers the power range from 0.12 kW up to 1000 kW. Most of the different technical constructions of electric motors are covered as long as they are rated for direct on-line operation. The coverage of the standard includes the recommendation and exclusions below:

IE3/IE4 motor requirements and recommendation	IE3/IE4 motor exclusion
– Voltage range for low voltage motors up to 1000 V – Mains frequency of 50 and 60 Hz – Number of poles: 2, 4, 6, 8 – Degree of protection: all – Operating mode: S1 (continuous load), as well as electric motors designed for other operating modes, but which can still be operated continuously at rated power - Motors with two switchable rated voltages (as long as the magnetic flux is the same at both voltages) – Temperature range: -20°C to +60°C – Installation altitude: up to 4,000 m above sea level	– Motors for one speed with 10 or more poles, as well as motors designed for several speeds – Motors with mechanical commutators (e.g. DC motors) – Motors that are fully integrated into a machine and cannot be tested independently – Motors with integrated frequency inverters (compact drives) – Submersible motors that are especially designed to be operated completely immersed in liquids – Explosion-proof motors and brake motors

Note : Additional exclusions are also provided by the European MEPS (EC 640/2009).

1.4 What distinguishes an IE3/IE4 motor from less efficient motors?

IE3/IE4 motors can achieve higher efficiency thanks to innovative design and the use of better conducting material. The higher efficiency design ultimately shows a lower rated motor current for any given kW rating. However, during the motor's starting phase, there may be an increase in **inrush and starting current**. The increased inrush and starting current can in some cases affect the selection of the starter components as well as the short-circuit protection device.

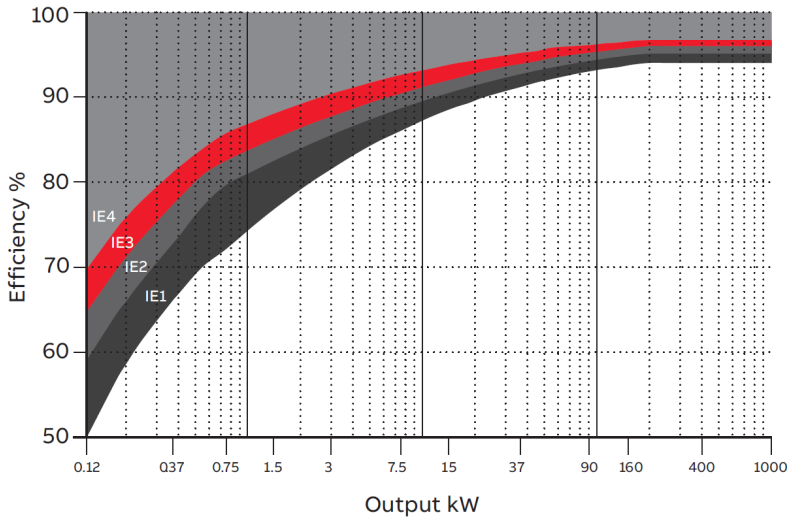


Figure 2: Overview of the nominal efficiency limits defined in IEC 60034-30-1
Note: See appendix for a detailed overview of the nominal efficiency limits defined in accordance with IEC 60034-30-1.

If a motor is directly connected to the power line, the current drawn (which is mostly reactive) will be very high during start-up. The curve in the following graph shows a typical starting RMS current curve for an IE3/IE4 motor in a direct-on-line connection. In general, the motor draws current in three steps:

- After starting, during the first 10 ms to 15 ms: 'Ipeak', an inrush current with a very high peak current. This high peak current is much higher than for IE1/IE2 motors. This is a result of the higher locked rotor apparent power and the locked rotor current reaching the higher efficiency class according to IEC 60034-30-1.
- Between the inrush and 0.5 s to 10 s, the important step starts (depending on rated power and inertia), there is a locked rotor current 'I lrc' . This current remains constant as long as the rotor starts revolving. Its' duration depends on the motor's load and design.
- Typically, after 0.5 s to 10 s, the rotor reaches its final speed. The current stabilizes to reach the motor's rated current 'In' at full load.

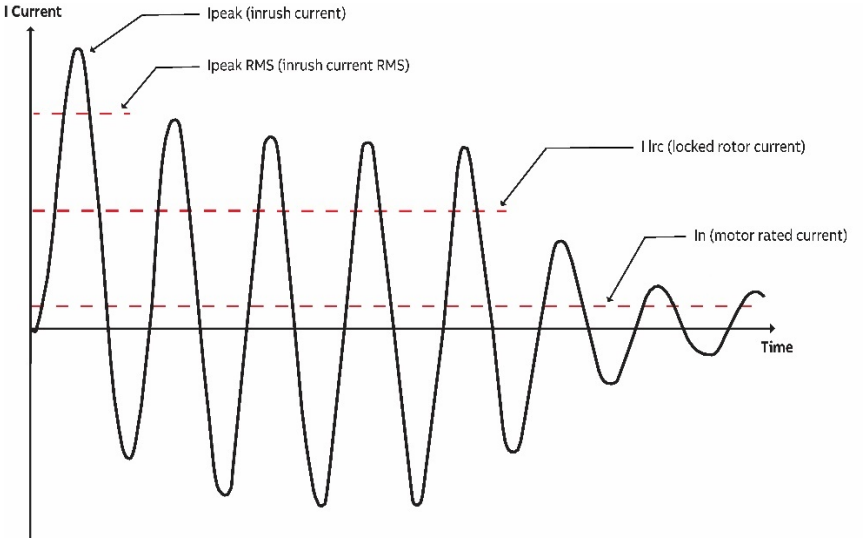


Figure 3: Diagram with the current at the start-up of an IE3/IE4 motor.

The tests and analyzes clearly show that high-efficiency motors IE3/IE4 NE/HE, in general, may draw a higher starting current than IE3/IE4 N/H motors.
Once the IE3/IE4 motor reaches full speed, the rated motor current is lower compared to IE2 motors for the same load conditions, because of the higher efficiency (and therefore saving more energy).

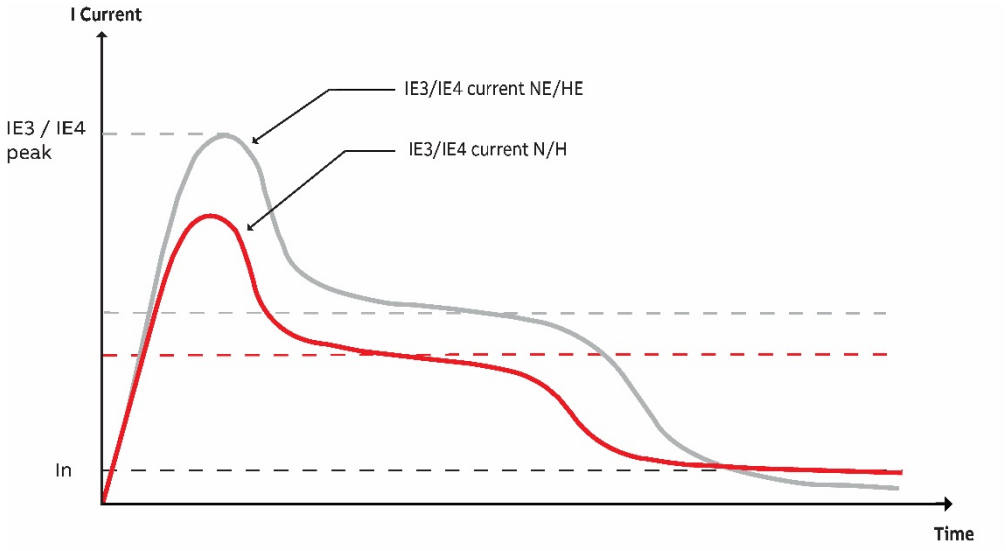


Figure 4: Diagram showing the different currents for the IE4/IE3 motors.

1.5 N/H and NE/HE motor design categories

IEC 60034-12 specifies parameters for the starting performance of single-speed three-phase 50 Hz or 60 Hz cage induction motor designs; the rated voltage is up to 1000 V. The application is direct-on-line or star-delta starting and a S1 duty type.
However the important part of IEC 60034-12 specifies the design letter **E** for extended efficiency motors, and additionally describes the new NE and HE designs. The design categories are N/H and NE/HE motor designs, and a description of what this means is shown in the below table:

Motor Design	Specification of the different designs	Specification details	Maximum values of locked rotor apparent power	
			P_N Range of rated output (kW)	S_l/P_N
Design N	**N**ormal starting torque	Normal starting torque three-phase cage induction motors, intended for direct-on-line starting, having 2, 4, 6, or 8 poles, rated from 0.12 kW to 1600 kW.	$P_N \leq 0,4$	22
			$0.4 < P_N \leq 0,63$	19
			$0.63 < P_N \leq 1,0$	17
			$1.0 < P_N \leq 1,8$	15
			$1.8 < P_N \leq 4,0$	14
Design H	**H**igh starting torque	High starting torque three-phase cage induction motors with 4, 6 or 8 poles, intended for direct-on-line starting, rated from 0.12 kW to 160 kW.	$4.0 < P_N \leq 6,3$	13
			$6.3 < P_N \leq 25$	12
			$25 < P_N \leq 63$	11
			$63 < P_N \leq 630$	10
			$630 < P_N \leq 1\,600$	9
Design NE	**N**ormal starting torque + Motors utilizing extended / higher locked rotor apparent power and current to achieve a **higher E**fficiency class according to IEC 60034-30-1	Normal starting torque three-phase cage induction motors having higher locked rotor apparent power than design N, intended for direct-on-line starting, having 2, 4, 6 or 8 poles, rated from 0.12 kW to 1600 kW.	$P_N \leq 0,4$	22
			$0.4 < P_N \leq 0,63$	19
			$0.63 < P_N \leq 1,0$	17
			$1.0 < P_N \leq 6,3$	15
			$6.3 < P_N \leq 25$	14
Design HE	**H**igh starting torque + Motors utilizing extended / higher locked rotor apparent power and current to achieve a **higher E**fficiency class according to IEC 60034-30-1	High starting torque three-phase cage induction motors having higher locked rotor apparent power than design H, with 4, 6 or 8 poles, intended for direct-online starting, rated from 0.12 kW to 160 kW.	$25 < P_N \leq 63$	13
			$63 < P_N \leq 630$	12
			$630 < P_N \leq 1\,600$	11

Note: The locked rotor apparent power shall not be greater than the appropriate value given in the table. The values given in the table are independent of the number of poles and are maximum values at rated voltage.

2. ABB and efficiency standards

ABB determines efficiency values according to IEC 60034-2-1 using the low uncertainty method with additional load losses determined by the method of residual loss.

It is good to mention and emphasize that the IEC 60034-2-1 test method, which is known as an indirect method, is technically equivalent to the test methods in the CSA 390-10 standards and IEEE 112 Method B leading to equivalent losses and therefore efficiency values.

ABB offers a large range of motors, contactors, and manual motor starters. It has long advocated the need for motor efficiency, and high-efficiency products have formed the core of its' portfolio for many years.

ABB supplies high-efficiency motors for additional energy savings when using utilization categories AC-3 and AC-3e defined according to IEC 60947-4-1. IEC 60947-4-1 Ed.4 introduces a new AC-3e utilization category for AC current switching, keeping the use and definition of the existing AC-3 utilization category unchanged.

Squirrel-cage motors starting, switching off motors during running, reversing

AC-3	AC-3e
Refers to the **asynchronous motors of designs N and H** according to IEC 60034-12:2016.	Refers to **asynchronous motors of designs NE and HE**, according to IEC 60034-12, with extended / higher locked rotor apparent power and current than designs N and H respectively, to achieve a higher efficiency class according to IEC 60034-30-1.
The AC-3 category remains with unchanged characteristics for the complete control and motor protection product scope defined for motor starting and protection solutions.	Manual motor starters, 3-pole AF contactors and B mini-contactors are suitable for AC-3e applications. The manual motor starters MS116, MS132, MS165, and the contactors AF09...AF96, B6/B7 have an AC-3e rating (same as AC-3 rating): - listed on their respective technical data pages. - certified on CB certificates delivered by third-party laboratories. - marked on their type label. For AF116...AF1650 contactors, please consult your ABB local sales organization
AC-3 making and breaking capacities unchanged	**New AC-3e making and breaking capacities**

2.1 Selecting the right combination of protection and control devices

Short-circuit detection is intended for unusually high currents in the electrical system. The value for the magnetic tripping current should be above the currents caused by a motor during start-up. A system's dimension is influenced by the level of the response value: the higher the response value is, the larger the cable cross-sections that need to be protected must be. This increases system and switchgear costs. The response values of protection and control devices have therefore been adapted to the motor starting currents previously used.

Here is an example using a manual motor starter and a contactor in a motor application:



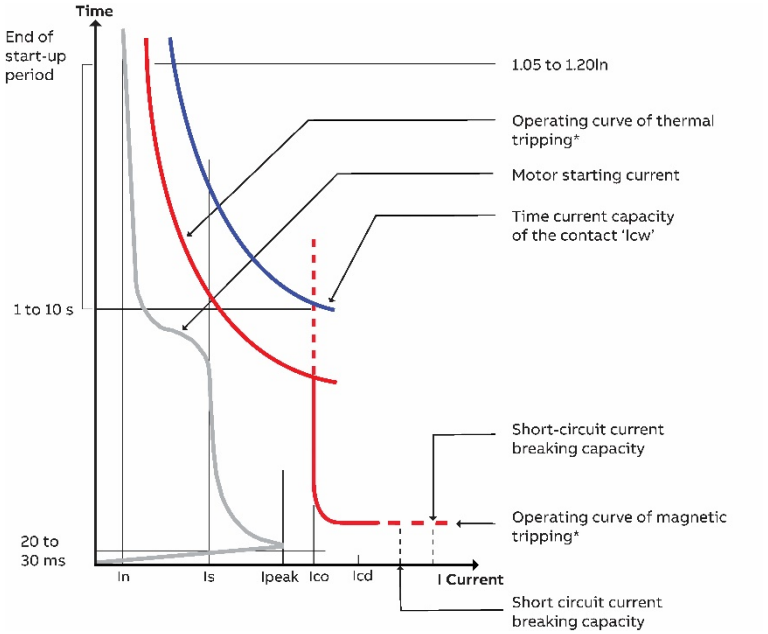


*Figure 5.1: Diagram showing a typical starting current and the characteristics of the protective devices. *The manufacturer's tolerances must also be considered.*

Here is an example using a fuse, a contactor and an overload relay in a motor application:



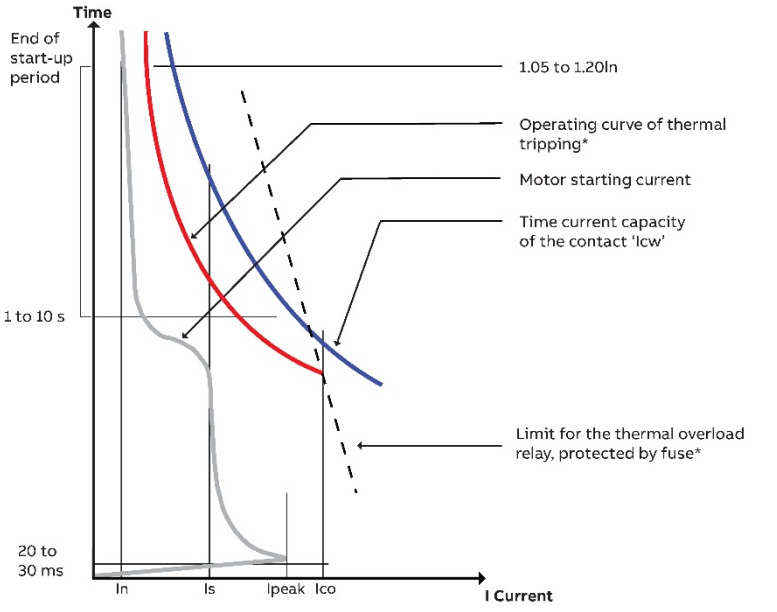


*Figure 5.2: Diagram showing a typical starting current and the characteristics of the protective devices. *The manufacturer's tolerances must also be considered.*

2.1.1 Manual motor starters and overload relays

The advantage of the new, more efficient motors (IE3/IE4) is that the current at the end speed is reduced, resulting in lower energy consumption. The disadvantage is that start-up and inrush currents are significantly higher on average than with previous motor generations.
The ratio, Is/In starting current to nominal current, is increased. Motors with high starting currents can thus trigger the manual motor starters (magnetic tripping). This leads to unintentional tripping ("nuisance tripping") during motor start-up.
For example, nuisance tripping can occur if the motor current is in the upper range of the manual motor starter's settings range, and a motor with a high in-rush current is used.
As already described, the risk of unwanted tripping increases with the ratio Is/In. The theoretical case of a manual motor starter and thermal overload relays is shown in the figure below. The grey curve shows the start-up current of an IE2 motor, the red curve of an IE3 motor. If the values between the motor starting current and the device threshold black curve are too close (when using the IE2 configuration for an IE3 application) it can lead to unwanted tripping.

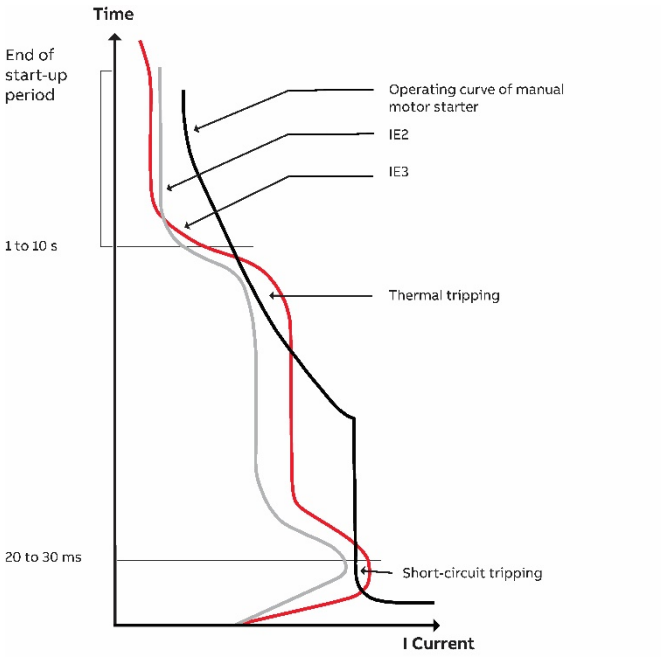


Figure 6: Diagram showing possibilities for an unexpected tripping

Unwanted tripping can depend on motor technology, correct installation, electrical wiring, equipment, and devices. However, to select the correct manual motor starter and the correct overload relay, you should:

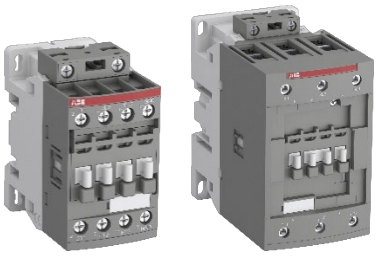
- Ensure that the electrical characteristics specified by the motor manufacturer match those of the motor starters used.
- First, check the motor classification (N/E or NE/HE) or the Is/In ratio. Then select the starter components using the ABB Selected Optimized Coordination tool (SOC, see Chapter 3) providing the relevent motor data (power, voltage, type of short-circuit protection, type of overload protection).
- Follow the motor protection manufacturer's recommendations.
- Note that for NE/HE motors AC-3e rated components must be used.
- Check the max. cable length to the motor and be sure to consider the increased starting currents when selecting the cables.
- Check the switching frequency (operations per hour), as this may increase the component's temperature incorrectly.



To enable premium efficiency motors to start, ABB has increased the magnetic tripping level for some manual motor starters to ensure a start without tripping. The implementation became effective in August 2014 with IE3 motors.
ABB manual motor starters and thermal overload relays have been subjected to magnetic, electrical, and thermal endurance tests under laboratory conditions to ensure compatibility with IE3 and IE4 motors.

2.1.2 Contactors

A contactor is an electromechanical device intended to control motors with ON / OFF switching. The rated nominal current of a contactor is specified as In.
ABB's AF contactors have been designed from the outset to handle premium and super premium efficiency motors. When designing contactors to match the new efficient motors, there is a balance between being able to close the contacts during a high inrush current peak and not causing an increased mechanical tear in the contact system at the same time.
ABB has been able to solve this using the AF platform technology. This allows the performance of the magnet system to be fine-tuned, resulting in an optimized function for the job. it can be used independent of the motor's efficiency class.



For higher locked rotor amp applications such as an IE3 or IE4 motor with a NE or HE design, ABB has successfully tested and CB certified the 3-pole AF09…AF96 contactors and B6/B7 mini contactors for the AC-3e utilization category.

2.1.3 Contactor life cycle durability

Behavior of contactors conducting AC-3 operations in terms of life cycle durability.
For AC-3 or AC-3e utilization categories, the electrical durability curves, as available in the catalog, can also be used in IE3/IE4 motors usages. When stating the age of an AC-3 application, the breaking of the rated motor current will have a major influence on the contactor. Since the rated current is lower using an IE3 motor, the life cycle will have a close to the previous durability.

The durability test condition as defined by the IEC60947-4-1 standard remains the same whatever the AC-3 and AC-3e utilization categories.

2.2 Softstarters with premium-efficiency motors

The utilization category that applies to softstarters is AC-53, and due to the switching technology of the softstarter the same category applies regardless of the motor efficiency level. However, when designing a motor control circuit it's important to understand the effects of a premium-efficiency motor.

The softstarter enables a motor to be accelerated smoothly within the desired time, thereby reducing the starting current. After the starting process and reaching the rated speed, the softstarter is usually bypassed, the motor is then directly connected to the grid. Likewise, the motor can be stopped for a preset time. Softstarter is thus ideal for starting and stopping applications, where the inrush current is disproportionately high, as required in some IE3/IE4 motor applications.

The mentioned problems can easily be resolved with a standard softstarter from ABB. The control algorithm and the thyristor technology reduce the inrush and locked rotor current to significantly lower levels and allow for a fully controlled start without issues. The softstarter also makes the whole operation smoother without jerks or shocks during the ramp, extending the lifetime of the mechanical parts and the load that the motor is controlling.

To avoid issues with IE3/IE4 motors, the softstarter power components need to be designed for these types of higher starting currents. ABB's softstarters are designed and built with one of the highest-rated components making all motor starting easy and effective.

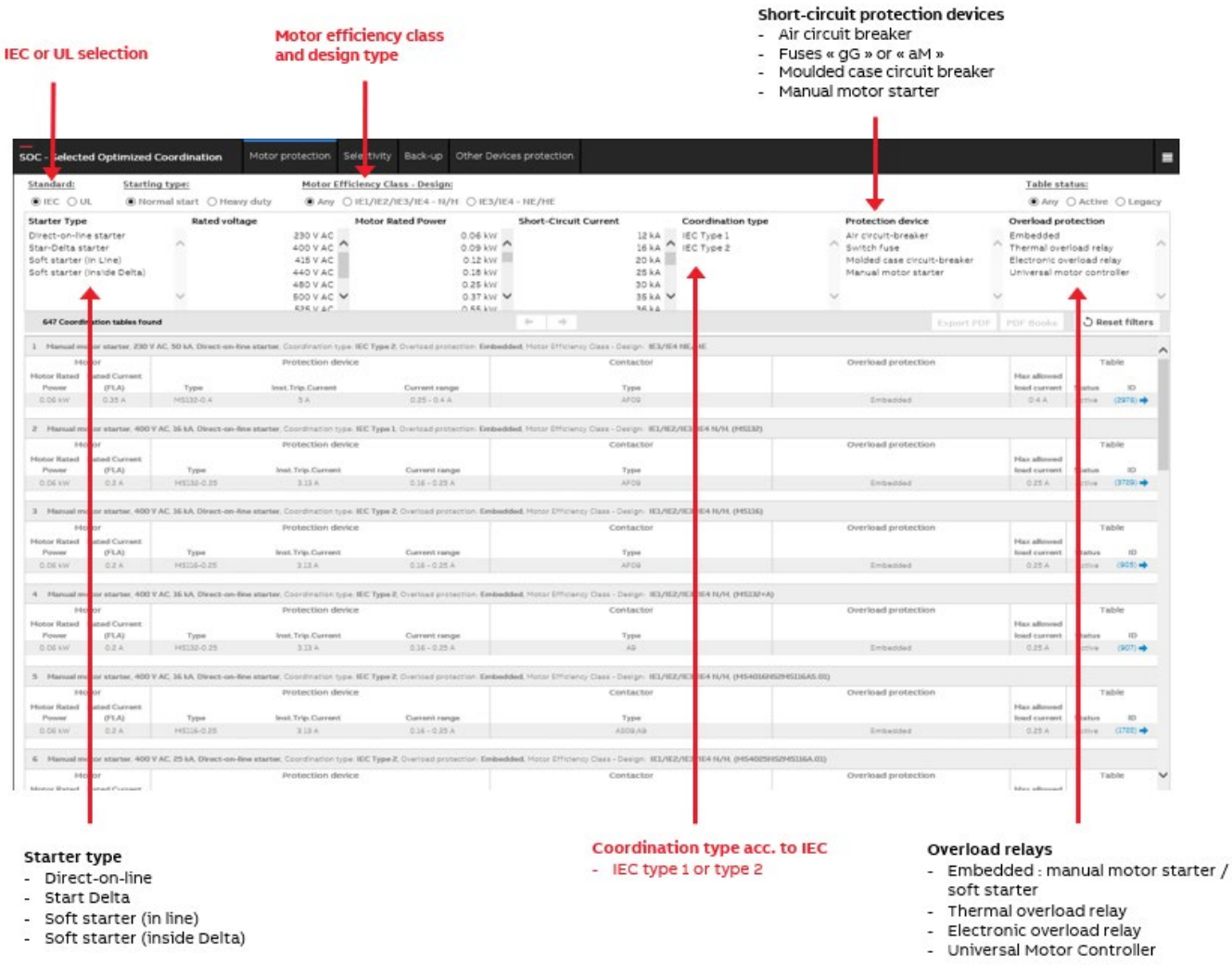


3. Coordination

In compliance with IEC standards, ABB defines the coordination between Short-Circuit Protection Devices (SCPD) and control products.
ABB's Selected Optimized Coordination tool (SOC) allows the required protection against short-circuits and overloads to be selected. SOC includes many possible selection choices such as starter type, short-circuit level and overload characteristics, rated power and voltage, motor efficiency class and so on.
For IEC, the motor efficiency class now includes how the motor design type use is distinguished.

- **IE1/IE2/IE3/IE4 N/H** : The asynchronous IE1/IE2/IE3/IE4 motor may be of design N or H, according to standard IEC60034-12:2016.
  The selection of a recommended coordinated starter combination according to the AC-3 utilization category does not change when upgrading from an IE1/IE2 motor to an IE3 or IE4 motor.

- **IE3/IE4 NE/HE:** The asynchronous IE3/IE4 motor may be of design NE or HE, according to standard IEC60034-12:2016 with extended/locked rotor apparent power and current than design N and H motors.
  The selection of a recommended coordinated starter combination according to the AC-3e utilization category was updated to match the requirements as stated in IEC 60947-4-1 Ed. 4



To find the coordination tables for motor protection, please see :
https://www.lowvoltage-tools.abb.com/soc/

Stay updated on manual motor starters, contactors and motor protection and control solution.

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

http://new.abb.com/low-voltage

Glossary

Ico	Crossover current: current corresponding to the crossover point of the mean or published curves representing the time-current characteristics of the overload relay and the SCPD respectively
Icd	Current representing a fault current equal to or higher than the current corresponding to the crossover point of the mean value of the published curves representing the time-current characteristics of the overload relay and the SCPD respectively
Ie	Rated operational current according to IEC 60947-1
IE3	Premium-efficiency class for single-speed motors according to IEC 60034-30.
IE4	Super premium-efficiency class for single-speed motors according to IEC 60034-30
I lrc	Locked rotor current, steady-state current with the motor held at rest at rated voltage and frequency
In	Rated current (rating defined in relevant product standard)
Is	Selectivity limit current, current co-ordinate of the intersection between the total time-current characteristic of the protective device on the load side and the pre-arcing (for fuses) or tripping (for circuit-breakers) time-current characteristic of the other protective device
Is/In	Starting current ratio
MEPS (Minimum Energy Performance Standard)	Local regulation specifying the minimum required energy performance for energy-using products. In Europe the EU MEPS for direct on-line motors is IE3
Pn	Rated output, the value of the output included in the rating according to IEC 60947-1
RMS	Root Mean Square: The RMS value of an AC supply is the steady DC equivalent, which would convert electrical energy to thermal energy at the same rate in a given resistance
Si	Locked rotor apparent power, apparent power input with the motor held at rest at rated voltage and frequency
SOC	Selected Optimized Coordination tool
SCPD	Short-circuit protective device
Ue	Rated operational voltage according to IEC 60947-4-1

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