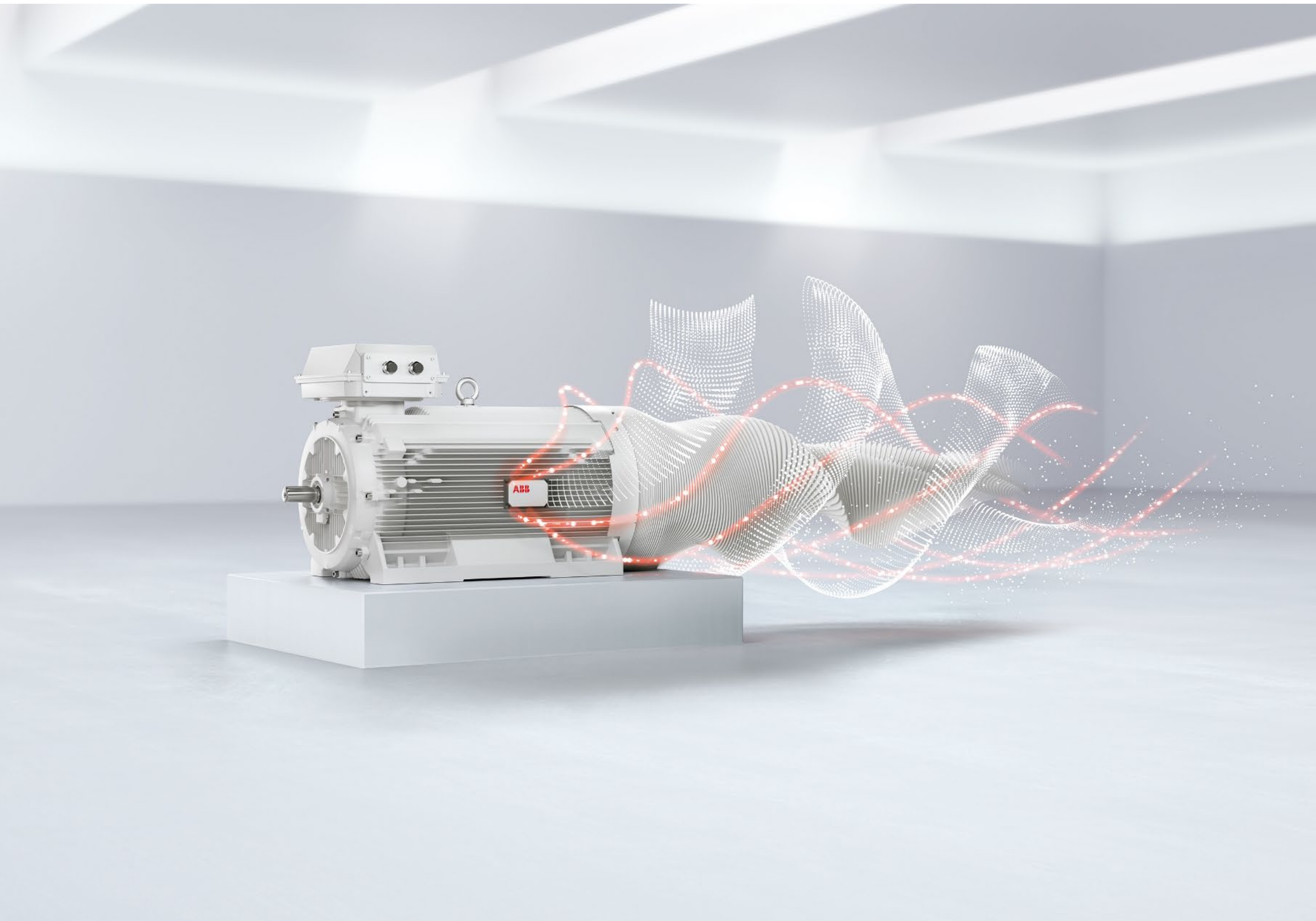
APPLICATION NOTE

Motor starting and protection for premium efficiency motors

Ready for NEMA Premium® Efficiency motor starting



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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 hp 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 Premium Efficiency motor applications.

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

ABB participates in international working groups and task forces, which are working on updating the relevant product standards for motors and motor starters.

ABB's portfolio matches the latest requirement for NEMA Premium® motor applications. In particular, ABB has validated coordinated solutions for UL/NEMA 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 the national and local installation regulations/codes for your specific application.

1. Motor efficiency standards and regulations

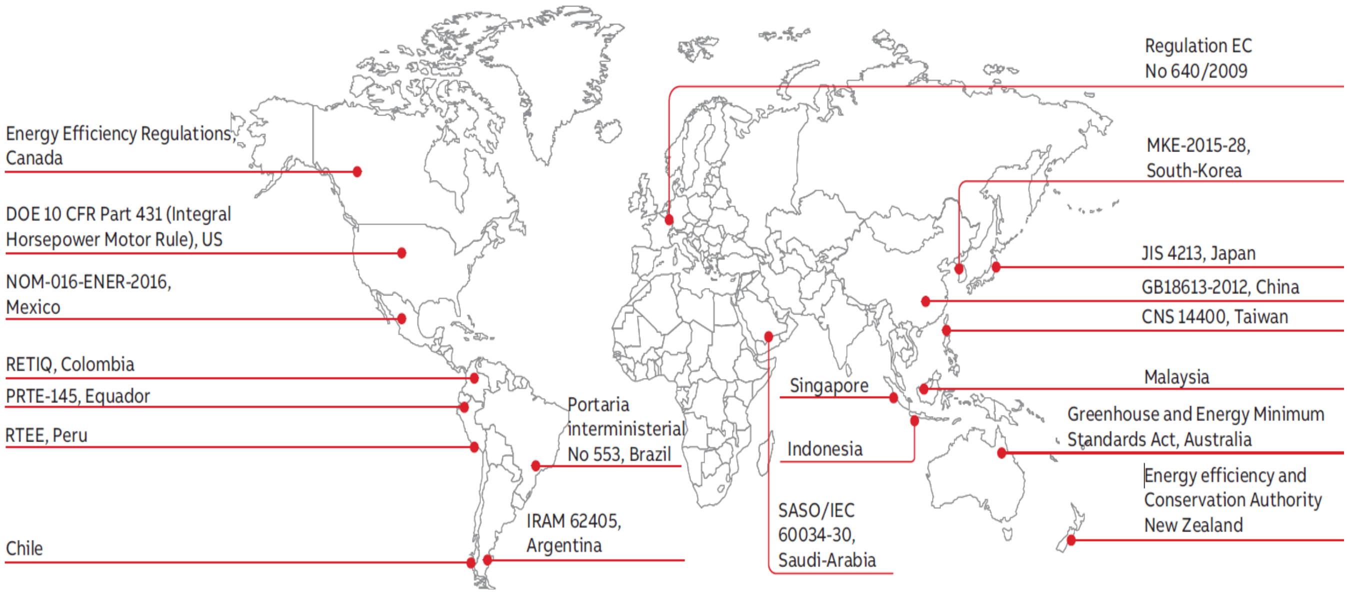

Figure 1: International motor efficiency standards and regulations.

Since 1926, the National Electrical Manufacturers Association (NEMA) has set standards for motors used in North America. NEMA regularly updates and publishes MG 1, a book that assists users in the proper selection and application of motors and generators. It contains practical information concerning performance, efficiency, safety, testing, construction, and the manufacture of alternating current (AC) and direct current (DC) motors and generators. The International Electrotechnical Commission (IEC) defines the standard for electric motors for the rest of the world. Like NEMA, IEC publishes Standards, the motors guide for the global market.

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

IEC 60034-30-1:2014 (similar to NEMA MG 1) 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. An overview of IE vs. NEMA efficiency classes can be found in the following section.

1.2 US Motor Minimum Efficiency Performance Standards

In 2014 the United States Department of Energy (DOE) established a final rule that covers 3-phase electric motors from 1-500 hp (0.75 – 370 KW). This final rule became effective on June 1, 2016. It supersedes the Energy Independence & Security Act (EISA) of 2007. For detailed information please refer to:
https://www.regulations.gov/document?D=EERE-2010-BT-STD-0027-0117

According to this legislation, additional motor types are covered and most exceptions that were possible in both EPAct 1992 and EISA 2007 legislation have been eliminated. As a consequence, the vast majority of 3-phase industrial motors are required to meet the efficiencies listed in ANSI/NEMA MG-1, table 12-1x (NEMA Premium® efficiency).

Following motor efficiency classes are typically known:

- Super Premium Efficiency (comparable to IEC IE4)
- Premium Efficiency (comparable to IEC IE3)
- High Efficiency (comparable to IEC IE2)
- Standard Efficiency (comparable to IEC IE1)

The coverage of ANSI/NEMA MG-1 includes/excludes the following motor types:

Typical Motor Types covered:	Typical Motor Types not covered:
– Polyphase motors with a voltage that does not exceed 600 V (other than 230 or 460 V motors). This applies to 200 V and 575 Volt motor model lines – 1-500 hp – 8-pole (900 RPM) – Footless (C-face and D-flange) motors – U-frame motors – Design C motors – Motors with customer special shafts, flanges, and mountings – Brake motors (integral and add-on) – Close-coupled pump motors – Fire pump motors – Vertical solid shaft normal thrust motors (P-base)	– Single-phase motors – DC motors – Two-digit frames (48-56) – Multi-speed motors – Medium-voltage motors – Enclosed nonventilated (TENV) and enclosed air over (TEAO) enclosures – Motors with customized OEM mountings – Intermittent duty motors – Submersible motors – Encapsulated motors – Motors that are integral with gearing or brake where the motor cannot be used separately – Design D motors – Partial motors

Differences between IEC IE3 and NEMA Premium® Efficiency

IEC 60034-30 IE3 and NEMA Premium® efficiencies match for over 95% of the ratings. IEC 60034-30 IE3 provides one table with 50 Hz and 60 Hz. The ratings for the 60 Hz motors specify nearly the same values (except in a few power ratings below 3 hp). NEMA MG 1 Table 12-12 has two separate tables of slightly different numbers, this makes a full harmonization difficult. Therefore, the Department of Energy (DOE) published an alternative table for small open motors up to 3 hp that covers the same values in this range. From then on, some of the values from the alternative small engine table have been used.

1.3 What distinguishes Premium Efficiency Motors from less efficient motors?

Premium efficiency motors can achieve higher efficiency thanks to innovative design and the use of better conducting material. The higher efficiency design ultimately shows a lower motor current for any given hp 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 devices.

1: Standard Efficiency
2: High Efficiency
3: Premium Efficiency
4: Super Premium Efficiency

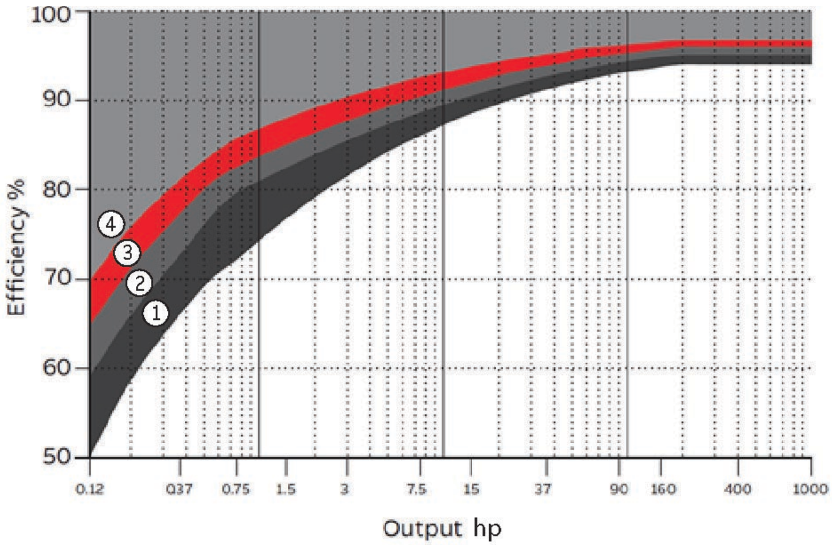

Figure 2: Overview of the nominal efficiency limits defined in ANSI/NEMA MG-1
Note: See appendix for a detailed overview of the nominal efficiency limits defined in accordance with ANSI/NEMA MG-1

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 a Premium Efficiency / Super Premium Efficiency motor in a direct-on-line connection. In general, the motor draws the 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 Standard Efficiency / High Efficiency motors. This is a result of the higher locked rotor apparent power and the locked rotor current reaching the higher efficiency class.
- 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 'LRC'. This effective current remains almost constant until the rotor starts to revolve.
- Typically when the motor starts revolving, the motor current reduced down to nominal current (full-load amperes [FLA]) until the motor has reached full speed. Its duration depends on the motor load and design.

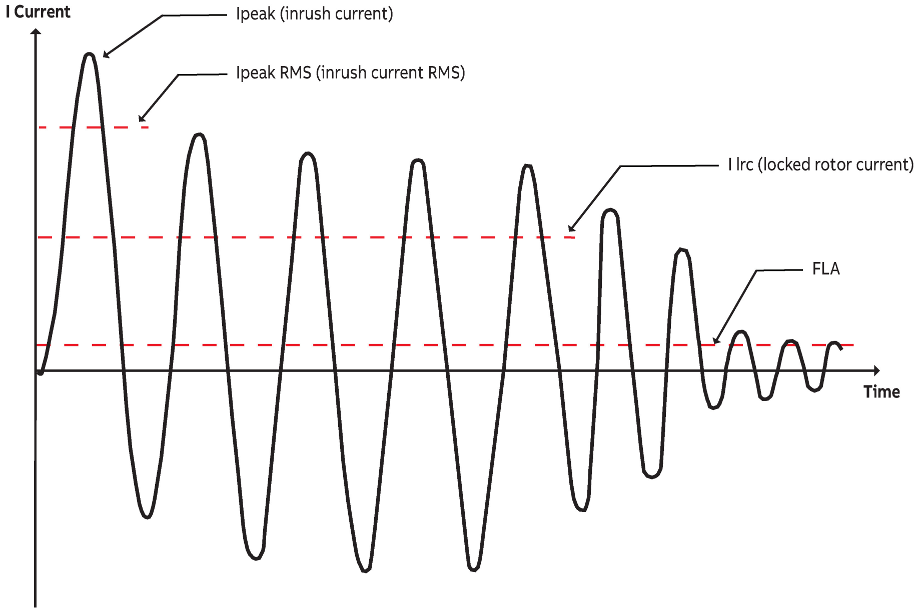

Figure 3: Diagram with the current at the start-up of a Premium Efficiency / Super Premium Efficiency motor

The tests and analyses clearly show that Premium Efficiency / Super Premium Efficiency motor, in general, may draw a higher starting current than Standard Efficiency / High Efficiency Motors (the higher the counter-torque is the higher the starting current). Once the Premium Efficiency / Super Premium Efficiency motor reaches full speed, the motor current is lower for the same load condition compared to the High Efficiency Motors, because of the higher efficiency (and therefore saving more energy).

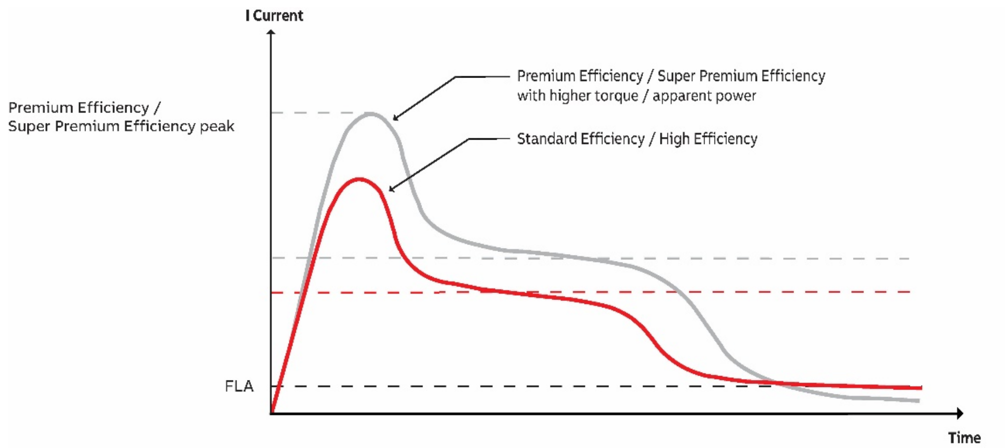

Figure 4: Diagram showing the different currents for the Premium Efficiency / Super Premium Efficiency motors.

1.4 NEMA Motor design categories

NEMA specifies the parameters for the starting performance of single-speed three-phase cage induction motor designs.
However, the standard established five different designs - A, B, C, D, and E for electrical induction motors. Different motors with the same nominal horsepower may have different starting currents, torque curves, speeds, and other variables. When selecting a motor for an intended task all engineering parameters must be considered. Typical characteristics of all NEMA Motors are shown in below table:

NEMA Motor characteristic	Basic Characteristics:	Locked Rotor Torque[1]	Pull - Up Torque[1]	Breakdown Torque[1]	Locked Rotor Current[2]	Slip	Efficiency	Typical Applications
NEMA Design A	Normal locked rotor torque High locked rotor current	70 - 275%	65 - 190%	175 - 300%	n/a	0.5 - 5%	High or Medium	These Motors are commonly used for fans, pumps, and blowers where large starting torques are not necessary and the motor does not need to support a large load.
NEMA Design B	Normal locked rotor torque Normal locked rotor current	70 - 275%	65 - 190%	175 - 300%	600 – 700 %	0.5 - 5%	High or Medium	These Motors are commonly used for fans, pumps, and blowers where large starting torques are not necessary and the motor does not need to support a large load
NEMA Design C	Higher locked rotor torque Normal locked rotor current	70 - 285%	140 - 195%	190 – 225 %	600 – 700 %	1 – 5 %	Medium	These Motors are used in machines that require the motor to start under a load such as conveyors, compressors, crushers, crushers, stirring motors, agitators, and reciprocating pumps.
NEMA Design D	High locked rotor torque Normal locked rotor current High slip	275%	n/a	275 %	600 – 700 %	5 – 8 %	Low	These motors are used for machinery with high peak loads such as elevators, hoists, oil-well pumping, wire drawing motors, and punch presses.
NEMA Design E	Normal locked rotor torque High locked rotor current Low slip	75 - 190%	60 – 140 %	160 - 200%	800 – 1000 %	0.5 – 3 %	High	These motors can be used in similar applications like A and B motor like fans, pumps, motor-generator sets, and blowers with low starting torque.

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.

(1)% of Full-load Torque

(2)% of Full-Load Current

2. ABB and efficiency standards

ABB determines efficiency values according to NEMA MG-1 (and/or 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 controllers. It has always advocated the need for motor efficiency, and high-efficiency products have formed the core of its' portfolio for many years.

ABB offers motor protection and control equipment that has been validated for use with Premium Efficiency / Super Premium Efficiency motors.

2.1 Selecting the right combination of protection and control devices

Short-circuit detection is intended to protect electrical systems against fault currents. The value for the magnetic tripping current should be above the currents caused by a motor during start-up (inrush current peak and lock rotor current). An electrical system's design is influenced by the level of the response value (magnetic tripping current, overload release current and make/break current): the higher the response value is, the larger the cable cross-sections that need to be protected. This increases system and switchgear costs. The response values of ABB´s protection and control devices have been adapted to meet the requirements of the latest motor generations. Here is an example using a manual motor controller and a contactor in a motor application:

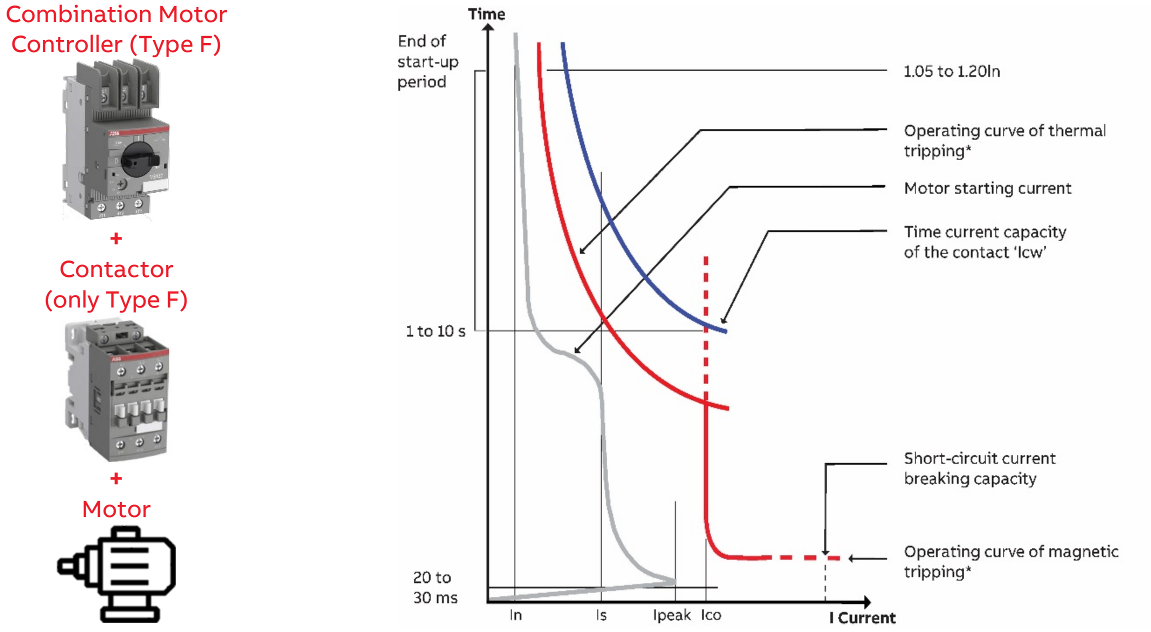

Figure 5.1: Diagram showing a typical starting current and the characteristics of the protective devices.
**The manufacturer's tolerances must also be considered.*

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

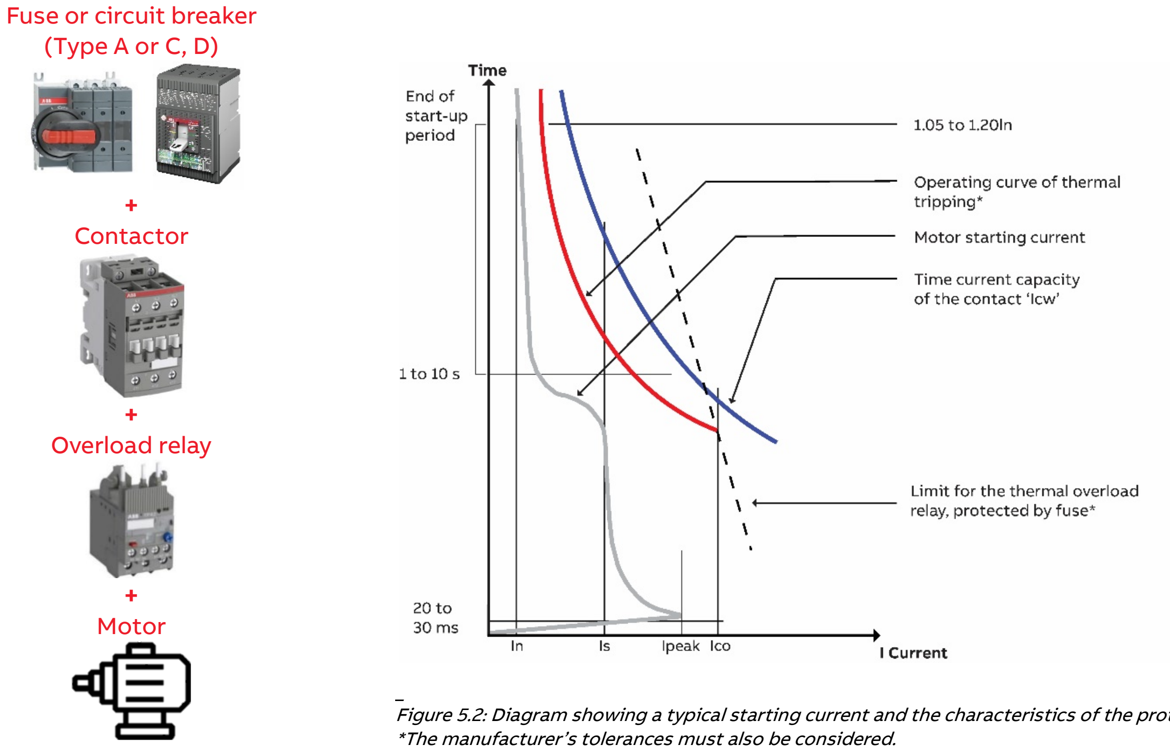

Figure 5.2: Diagram showing a typical starting current and the characteristics of the protective devices.
**The manufacturer's tolerances must also be considered.*

Note : Regarding the correct coordination of your application, you will find more information in chapter 7 of the MMS Guide : 2CDC131060M0202

2.1.1 Manual Motor Controllers and Overload Relays

The advantage of the new, more efficient motors (Premium Efficiency / Super Premium Efficiency motors) 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, starting current to nominal current, is increased. Motors with high starting currents can thus cause the manual motor controller to trip (magnetic tripping). This is also referred to as 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 controller's settings range, and a motor with a high in-rush current is used.
The risk of unwanted tripping increases with the ratio LRC / FLA. The theoretical case of a manual motor controller and thermal overload relay is shown in the figure below. The grey curve shows the start-up current of a High Efficiency motor, the red curve the one of a Premium Efficiency motor. If the values between the motor starting current and the device's threshold black curve are too close, (when using the High Efficiency configuration for a Premium Efficiency application) it can lead to unwanted tripping.

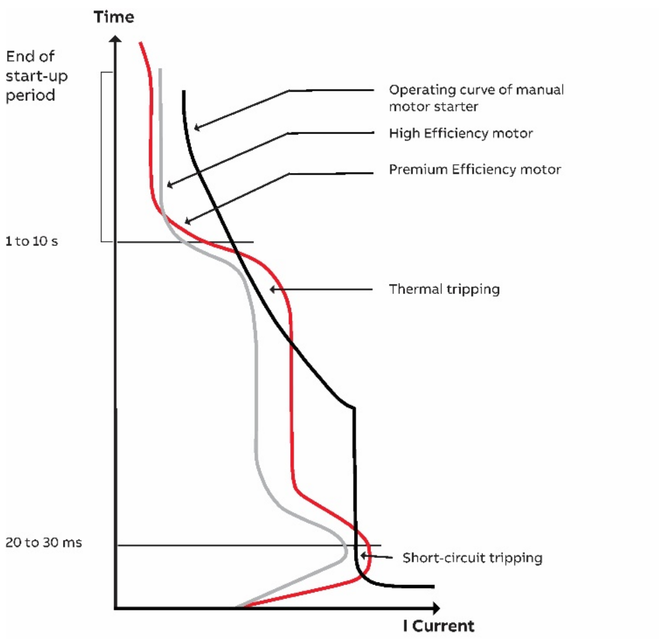

Figure 6: Diagram showing possibilities for an unexpected tripping

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

- Ensure that the electrical characteristics specified by the motor manufacturer match those of the motor starter equipment used.
- First, check the motor type or the LRC / FLA ratio. Then select the starter components using ABB's Selected Optimized Coordination tool (SOC, see Chapter 3) providing the relevant motor data (power, voltage, type of short-circuit protection, type of overload protection).
- Follow the recommendations of the motor protection equipment manufacturer.
- 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), increase the component's temperature.

To enable Premium Efficiency / Super Premium Efficiency motors to start, ABB has increased the magnetic tripping level for some manual motor controllers to ensure a start without tripping.
ABB manual motor controllers and thermal overload relays have been subjected to magnetic, electrical, and thermal endurance tests under laboratory conditions to ensure compatibility with Premium Efficiency / Super Premium Efficiency motors.

2.1.2 Contactors – Magnetic Motor Controllers

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 Efficiency motors 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 increased mechanical wear or chatter 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. AF contactors can be used independently of the motor's efficiency class.

For higher locked rotor amp applications such as Premium and Super Premium Efficiency motor with high starting torque, ABB has successfully tested the 3-pole AF09...AF96 contactors and B6/B7 mini contactors.

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2.2 Softstarters with premium-efficiency motors

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 Premium Efficiency motor applications.

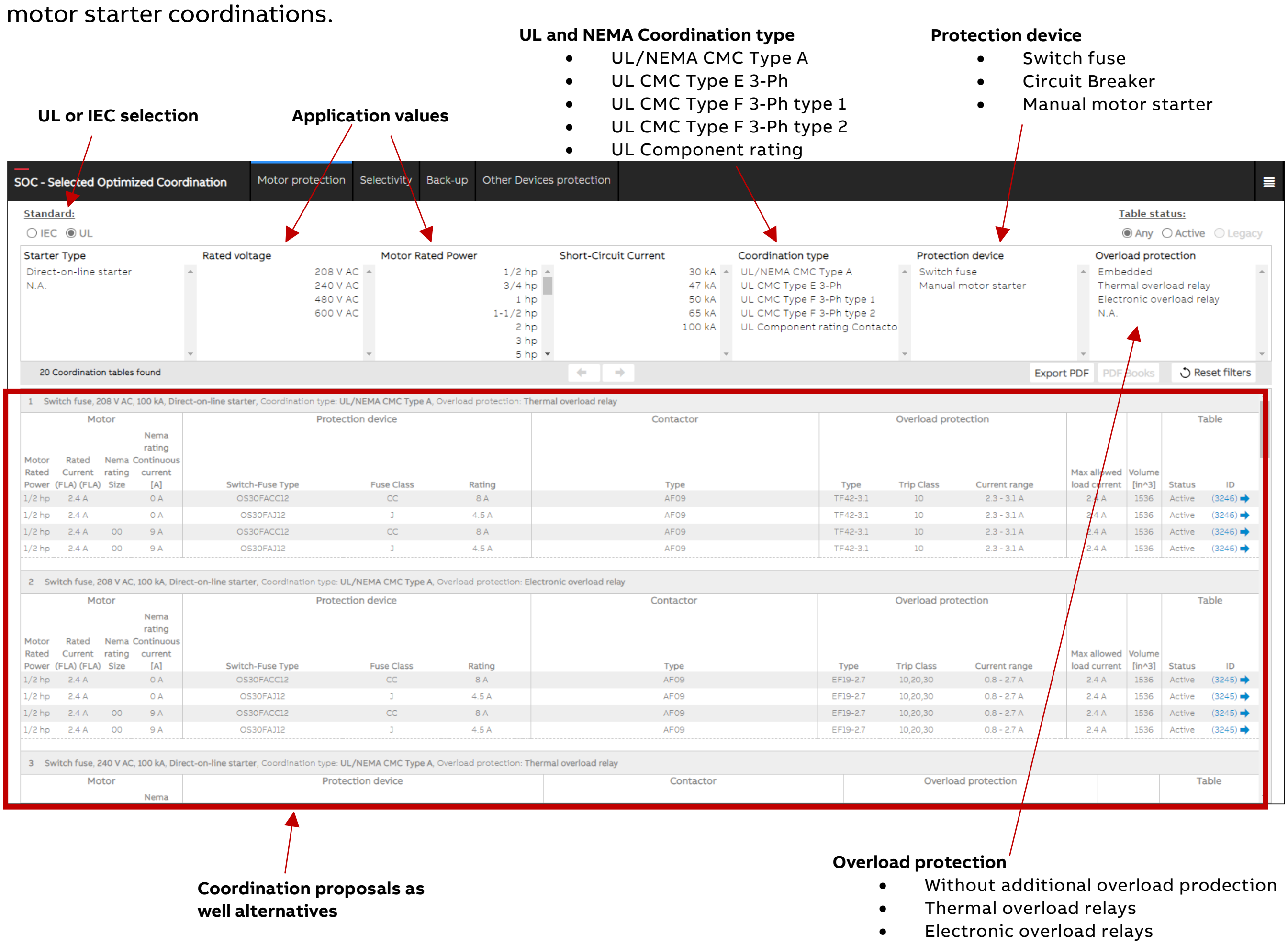
The mentioned problems can easily be resolved with a standard softstarter from ABB. The control algorithm and the thyristor technology reduce the inrush and locked rotor current to significantly lower levels and allow for a fully controlled start without issues. The softstarter also makes the whole operation 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 Premium Efficiency 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

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.
The coordination among devices cannot be determined directly. Tests in power laboratories shall be carried out to qualify the coordination type at low fault and high fault currents, according to UL or IEC standards.
ABB's coordination tables are the results of such tests and represent ABB's offerings in terms of motor starting and protection, selectivity, back-up, and switch-disconnector protection.
Determining the Short-Circuit Current Rating of a complete electrical panel can be very challenging, especially if proper considerations are not made during the initial stages of the component selection process.
ABB's tested SCCRs can be accessed online through SOC selection tool for Combination Motor Controller and UL component ratings, providing comprehensive coordination tables to quickly select motor starter components over a wide range of HP ratings based on common global motor voltages (50/60 Hz) and SCCR fault levels.

Please be aware that SOC is currently being enhanced to fully reflect all relevant aspects for the selection of UL motor starter coordinations.



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

Stay updated on Manual Motor Controller, contactors, and motor protection and control solution.

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

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

Glossary

FLA	Full Load Amps is the actual current drawn by the motor depends upon the driven load and on the operating voltage at the motor terminals. If the load increases, the current also increases.
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
v	Rated current (rating defined in relevant product standard)
LRC	Locked rotor current is the current drawn by the motor at its rated voltage when its rotor is kept stationary or in other words rotor is not spinning or rotating. So when starting a motor, its rotor is already at rest. This means, starting current and locked rotor current should be the same.
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
MMC	Manual Motor Controller (Manual Motor Starter)
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
SOC	Selected Optimized Coordination tool
Slip	The difference between the synchronous speed of the electric motor magnetic field, and the shaft rotating speed is slip - measured in RPM or frequency
SCPD	Short-circuit protective device
Torque	Torque is the turning force through a radius - with the units Nm in the SI-system and the units lb ft in the imperial system. The torque developed by an asynchronous induction motor varies when the motor accelerates from zero to maximum operating speed.

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