IE3-IE4 premium-efficiency motors: choosing the right motor control and protection components

White Paper

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Executive summary

Amid mushrooming global demand for energy and increasing concern for the environment, countries around the world are implementing tighter environmental restrictions. Industrial motors, a major global consumer of electricity, are one of the prime targets of the new regulations and standards.

The transition to IE3 premium efficiency motors and IE4 super premium efficiency motors is underway, raising challenges for businesses. However, these challenges also bring opportunities for businesses to reduce energy costs and increase efficiency while lightening their impact on the environment.

To make the right motor starter choices and ensure maximum energy efficiency, it is important to be aware of how IE3 premium efficiency motors behave during starting and the impact this behavior can have on protective devices. Schneider Electric TeSys motor starter products (motor circuit breakers, overload thermal relays, and contactors) have undergone extensive laboratory testing with different motor brands to confirm their compatibility with IE3 and IE4 motors

The guidelines in this white paper are designed to help you make the right choices according to your electrical installation and motor.

Glossary

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 version 2014.

DOL (direct on line) motor starter: The simplest type of motor starter, also includes protection devices, and in some cases, monitoring.

Inrush peak: A short, high-current transient occurring during the first milliseconds when the motor is started.

MEPS (Minimum Energy Performance Standard): Local regulation specifying the minimum required energy performance for enery-using products. In Europe the EU MEPS for direct on line motors is IE3.

LRA (Locked Rotor Amps), also called LRC (Locked Rotor Current): The amount of electrical current drawn at the moment the motor is started, but not yet turning.

OEM: Original Equipment Manufacturer.

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.

VSD: Variable speed drive.

Introduction

Worldwide demand for energy is expected to double by 2050. Growing concern for the environment is driving the emergence of more stringent energy-efficiency regulations around the globe. And the industrial sector is on the front lines. Electric motors account for 70% to 80% of electricity consumption in the industrial sector, making them a prime target for energy-saving measures.

Legislators are addressing energy efficiency in the industrial sector with new regulations. The EU Directive on Energy-related Products (ErP) came into force in 2009. And, since January 2015, the Directive has required most direct on line motors to be of the IE3 premium-efficiency class or higher.

Recent market research by global information company IHS revealed the continued gradual market penetration of IE3 motors. Because motor regulations are not strictly enforced, the transition is expected to remain gradual. Despite demand from customers for IE3 motors and, more generally, energy-efficient solutions, some OEMs continue to offer IE1. As customers begin to include IE3 or even IE4 motors in their requirements, the market will inevitably shift toward these motors.

The arrival of these new motors at industrial sites across Europe has created some new challenges. Most notably, these motors' electrical behavior is different than their less-efficient counterparts, with typically higher inrush peaks and locked rotor currents. Standard motor starters and related equipment could therefore be inadequate in some cases.

This paper begins with a review of the new standards for high-efficiency motors and the work currently being done by the international standards technical committees to update motor and motor starter standards. It then continues with a discussion of how the new IE3/IE4-class motors affect direct on line starting. Finally, it provides guidelines for selecting the most energy-efficient and robust motor starters for IE3/IE4 motors.

1. The drive for energy efficiency

1.1. Industrial motors: a key contributor to consumption– and potential savings

Worldwide demand for energy is expected to double by 2050. At the same time, governments are under pressure to halve their countries' CO_2 emissions to head off climate change before it is too late.[1]

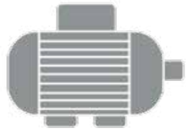
If we are to find a solution, we must look beyond measures like turning off the lights when we leave a room and target the biggest energy consumers. For example, according to the International Energy Agency, electric motors account for 40% of total global electricity consumption, coming in ahead of lighting, a far better-known culprit, which weighs in at just 19%.

Industry is also a major global energy consumer. And the electric motors used in many industrial plants typically consume 65% to 80% of total plant electricity. On a global scale, industrial motors represent 28% of total worldwide electricity consumption. This is no surprise when you consider that an estimated 300 million industrial motors worldwide are running at full speed for extended periods of time.

More efficient industrial motors can have a huge impact on energy consumption and generate substantial cost savings for plants. The German Federal Environmental Agency has estimated that increasing motor efficiency could save 135 billion kWh and 63 million tons of carbon dioxide (CO_2) by 2020 in the EU alone. In the United States, the NEMA (National Electrical Manufacturers Association) Premium® energy efficiency motor program is also expected to save 5,800 Gigawatts of electricity and 80 million tons of carbon dioxide over the next ten years.

42%

Factories account for 42% of total worldwide electricity consumption



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Two thirds of a typical plant's electricity attributed to motors

28%

Industrial motors use 28% of all electricity worldwide

17%

Residential and non-industrial commercial motors account for 17% of electricity consumption

45%

Motors in all sectors (residential, commercial, industrial) use 45% of all electricity

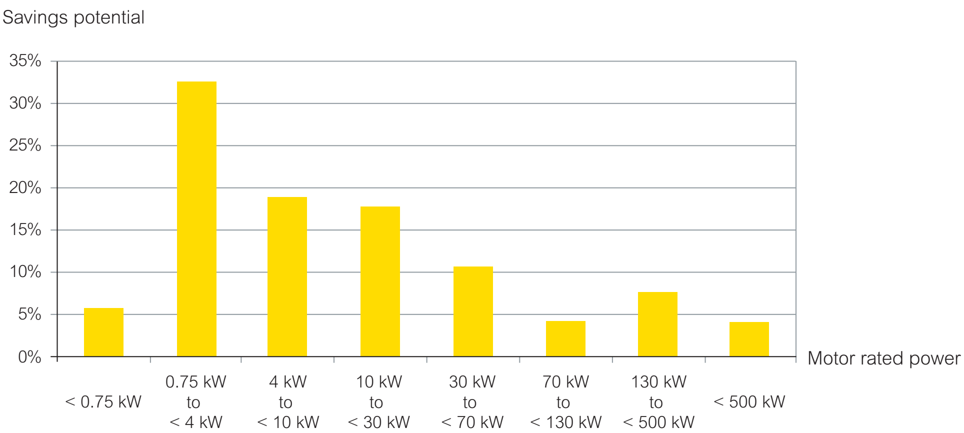


Figure 1. Energy-efficient motors have the potential to generate huge savings in the industrial sector.

[1]IEA International Energy Agency

1.2. New motor-efficiency standards

1.2.1. The European Union

The European Union's Ecodesign Directive (Directive 2009/125/EC) provides EU Member States with a framework for their energy-efficiency legislation. Most notably, the Directive requires manufacturers to design energy efficient products.

The incandescent light bulb is perhaps the best-known example: the EU outlawed the energy-hungry bulbs in 2009, spurring the emergence of eco-halogen bubble, LED, and other high-efficiency lamps.
The Directive also covers other types of products, from home appliances and electronics to building materials like windows and insulation and–crucially–industrial motors.

1.2.1.1. What the new EU regulations and standards say

Implementation in the member states will take place through instruments like laws, regulations, and standards, such as regulation EC 640/2009 on ecodesign requirements for electric motors, which came into force in January 2015, and the associated parts of IEC 60034 harmonizing standards for motor ecodesign.

IEC60034-30 sets forth new energy-efficiency classes for single-speed, three-phase, cage-induction motors with two, four, or six poles. According to this standard, motors from 0.75 kW up to 375 kW make up the vast majority of the installed motor base[2]. Therefore, the standard defines efficiency for outputs within this range.

The four energy-efficiency classes in the standard are:

- IE1 (standard efficiency),
- IE2 (high efficiency), and, of particular interest in this paper,
- IE3 (premium-efficiency).
- IE4 (super-premium-efficiency).

IE3-class, or "premium-efficiency," motors are more energy-efficient than their EFF1- and EEF 2-rated equivalents. (EFF 1, EFF 2, and EFF 3 were the three classes issued in 1998 by the European Committee of Manufacturers of Electrical Machines and Power systems, or CEMEP, and compliance with the classification was voluntary. The IEC classification replaced this older system).

The new classes will become mandatory according to the following timeline:

- All motors must be IE2 by June 16, 2011.
- All motors with output between 7.5 kW and 375 kW must be IE3 by January 1, 2015; or IE2 if a variable speed drive is used.
- All motors with output between 0.75 kW and 375 kW must be IE3 by January 1, 2017.

While IE2 motors will still be permitted when used with a variable speed drive, this is not necessarily the most energy-efficient choice. Variable speed drives create significant additional power losses and should be used only when they improve the overall energy efficiency, considering the characteristics of the whole application. Read on to learn what factors you should include in your decision to make the right motor equipment choices for your needs (http://www.capiel.eu/data/6685-Capiel-Tryptique-EN2-Version-Web.pdf).

[2] International Electrotechnical Commission, 2014

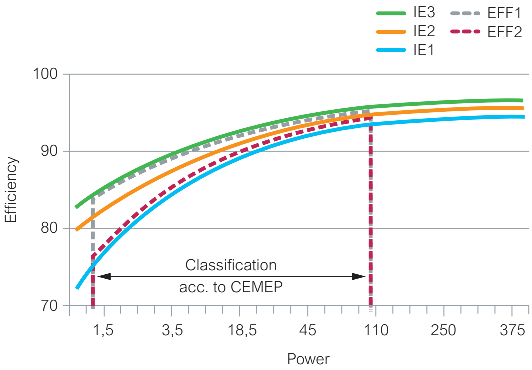


Figure 2. Comparison of IE1, IE2, and IE3 motors to their EFF1 and EFF2 predecessors.

1.2.1.2. Exceptions to the European MEPS

When making your choice, it is important to know which types of motors are exempt from the new efficiency regulations. Transport of goods and persons are excluded from the ErP Directives. Therefore specific motors used for lifting, hoisting, etc. are not in the scope of regulation EC 640/2009.

The IEC60034 standard includes only motors rated either duty-type S1 or S3, with a rated cyclic duration factor (CDF) of 80% or higher.

Continuous duty	Intermittent periodic duty with CDF >80%
The motor works at a constant load for enough time to reach temperature equilibrium.	Ratio between the period of loading and the duration of the duty cycle. $$Cdf = \frac{\text{total on-times } (t1+t2+t3\ldots)}{(\text{cycle duration } (T))} \cdot 100[\%]$$

Table 1. Determining whether a motor is continuous or intermittent duty.

Motors that do not meet these specifications do not need to be IE3 (premium-efficiency). In fact, premium-efficiency motors are not recommended for intermittent or periodic duty. This is due to the fact that any efficiency gains are very much decreased when the motor is stopped frequently. Motor utilization categories AC-4 are not appropriate with IE3 motors, which would not be efficient (and which are not required by the standard) for this type of use.

IE3 motor required/recommended	IE3 motor not required/ recommended
• have a rated voltage U_N up to 1 000 V NOTE: the standard also applies to motors rated for two or more voltages and/or frequencies. • have a rated output P_N between 0,75 kW and 375 kW • have either 2, 4 or 6 poles • are rated on the bases of either duty type S1 (continuous duty) or S3 (intermittent periodic duty) with a rated cyclic duration factor of 80 % or higher • are capable of operating direct on-line • are rated for operating conditions in accordance with IEC 60034-1, Clause 6	• Motors immersed in liquid • Brake motors or motors integrated into a machine (e.g. pump, fan, compressor) and that cannot be tested separately from the machine • Motors made solely for converter operation • Motors used to transport people or goods (lifts, elevators, hoists, conveyors) • Intermittent-duty motors with rated CDF of under 80%

Table 2. In some instances, IE3 motors are not required or even recommended.

1.2.2. Regulations and standards in other parts of the world

United States

In the United States, NEMA, the National Electrical Manufacturers Association, has rolled out an initiative similar to what is being seen in Europe with the NEMA Premium® Motors program, a label equivalent to IE3 premium-efficiency. NEMA Premium® motors account for an estimated 20% of market share in the US (2015). High prices and low ROI are slowing the widespread adoption of these motors. Their design disruption is lower than in Europe due to their de facto savings of 20% thanks to the frequency of 60 Hz in addition to their longer frame (NEMA size). Consequently, they have a lower rise of the inrush current in comparison with the European 50Hz asynchronous motors.

India

The Bureau of Indian Standards (BIS) has released updated energy-efficient motor standards (IS12615:2011) that align with EU regulations: "The efficiency performance values of motors under the scope shall be IE3 only and shall be effective from 31 January 2014. However, when these motors are used with variable frequency drives, they shall conform to IE2 values of efficiency."

China

The Chinese government published standard GB18613 setting the energy-efficiency requirements for general-purpose motors. It was updated in 2012 to more closely align with IEC 60034-30-1.

Other countries

Australia, Korea, Brazil, Mexico, Taiwan, Costa Rica, Israel, and New Zealand are among the other countries that have taken steps to improve motor efficiency through more stringent regulations.

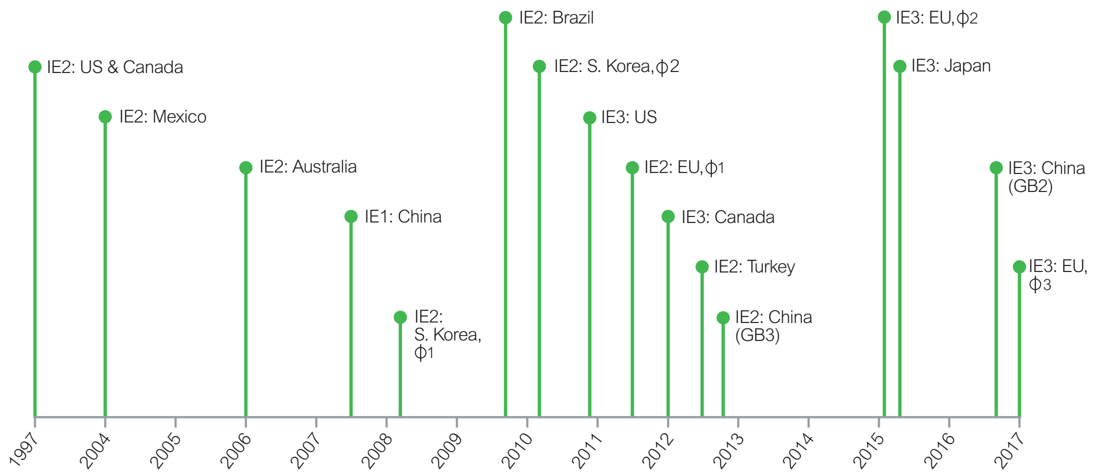


Figure 3. Worldwide, countries are tightening their motor-efficiency requirements.
Source www.eemods15.info

2. What you need to know about asynchronous motors before you choose

Robust and reliable, asynchronous (or induction) motors represent 95% of the worldwide installed motor base. Therefore, the protection of these motors is a matter of great importance in numerous applications.

2.1. Direct on line (DOL) starting of induction motors

Different starting methods can be employed for asynchronous motors, the simplest of which is direct on line (DOL) starting. Depending on the protection level and the components used, a DOL motor starter usually consists of a circuit breaker, a contactor, and an overload relay for protection.

Advantages	Disadvantages
• Simple • Low purchase price • Good starting torque	• May not be suitable for use with high-torque motors • Must be carefully selected to avoid nuisance tripping during starting

Table 3. DOL motor starter advantages and disadvantages.

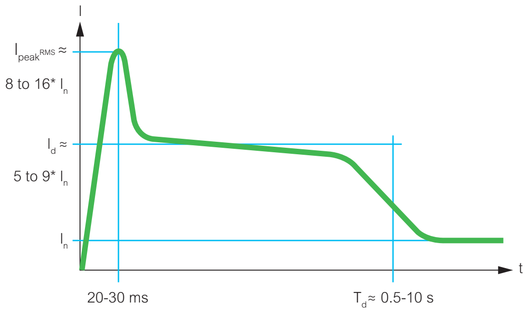


Figure 4. Direct on-line starting current for the average induction motor (super-premium IE4 motors).

You will find more information about asynchronous motors and their different protection and control methods below. To go further, please refer to Schneider Electric's Electrical Installation Wiki: http://www.electrical-installation.org/enwiki/Asynchronous_motors_(full_page).

2.1.1. Inrush current

High-power asynchronous motors directly connected to the line will draw high start-up current (see Fig. 1), which is mostly reactive. Figure 1 shows a typical starting RMS current curve for an asynchronous motor in a direct on line connection. In general the motor draws current in three steps:

- During the first 20ms to 30ms: shortly after starting, a high peak current (inrush), symbolized here as "Ipeak", is observed.
- Between inrush and 0.5s to 10s (depending on rated power and inertia), a steady-state current called LRC (here abbreviated as Id) is seen. This current remains constant as long as the rotor just starts revolving; its duration depends on the motor's load and design.
- After 0.5s to 10s: the rotor accelerates and reaches its final speed. the current stabilizes to reach the motor's nominal current (In) at full load.

2.1.2. Protection for DOL starters

The most common way of building DOL starters is by combining a circuit breaker, contactor, and overload relay (Figure 5). This system offers several advantages. Installation, operation, and maintenance are relatively simple (components are easier to replace than fuses) and high uptime is ensured thanks to immediate restarting (when Type 2 coordination is selected). The system can be controlled remotely and is compatible with mechanical and electrical interlocks. Motor manufacturers usually provide tables to facilitate the selection of these components.

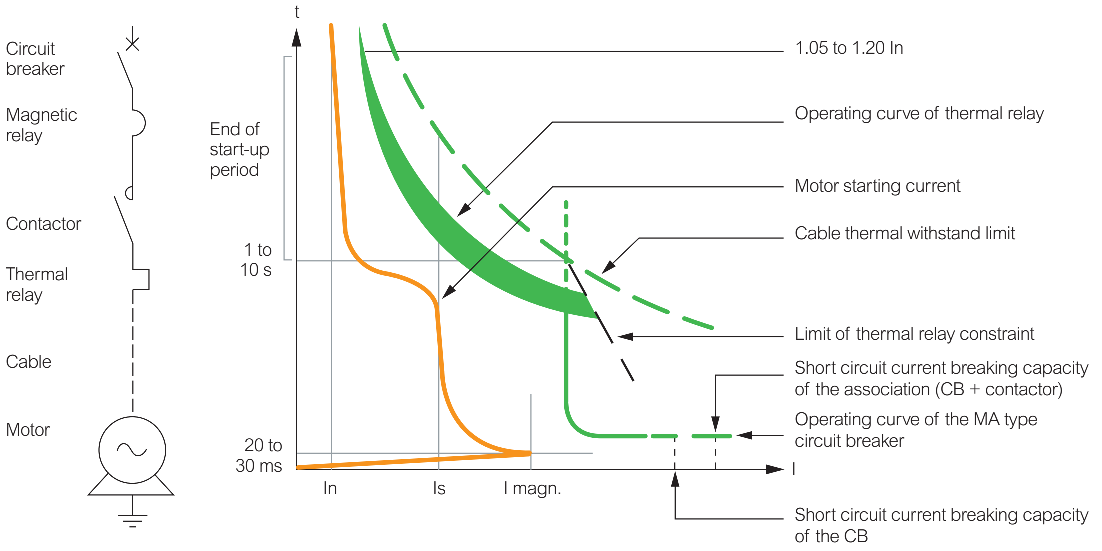


Figure 5. Tripping characteristics of a circuit-breaker, contactor, and thermal relay protection system.

However, before you choose, it is important to understand how premium-efficiency motors behave differently during starting than previous-generation motors. Most notably, improvements in motor design have resulted in changes to inrush current and locked rotor current.
The following section outlines the main changes and explains how they affect your choice of circuit-breaker, contactor, and thermal relay.

2.2. Premium-efficiency motors

2.2.1. Design characteristics

The new premium-efficiency motors have several new design characteristics with regard to previous generation motors:

- Lower stator and rotor resistances
- Longer motor length
- Improved silicon steel and lamination for better magnetization and lower eddy currents
- Reduced air gap for lower magnetic resistance
- Various improvements in rotor design, bearings, and cooling to reduce other losses

IE4 motors are coming on the market, the trend toward higher inrush peak and starting current is clear, and will continue as more efficient motors penetrate the market. The following table provides typical values. However, due to different design characteristics, there are large variations between one motor and another, even for the same rated power.

Parameter	Typical value for IE1 motors	Typical evolution from IE1 motors to IE3/IE4 motors
Rated current $I_{e,rms}$	Depends on rated power	5 to 10%
Locked rotor current ratio + I_d / I_n	Motors < 15kW: 6 or less times I_d/I_n	+10 to +30%
	Motors 15–55kW: 6 or less times I_d/I_n	+10%
	Motors >55kW: ~7	+ 4%
Starting time tstart	Depends on torque	Expected to decrease, but marginal effect in practice
Inrush current factor $\kappa = I_{peak} / I_d$	1.2 to 1.4	+30 to +50%
Steady-state temperature	Depends on class	Temperature rise decrease and fan size reduced

Table 4. Differences in motor behavior from IE1 to IE3/IE4 motors.

2.2.2. Premium-efficiency motor current load

IE3 premium motors are more energy efficient than IE2 motors. In Figure 6, IE3 motors have an higher inrush current and an higher starting current but in full run will have a lower current consumption than IE2. Figure 6 is a simplified version of Figure 7 made after some measurement on physical motors in our laboratory.

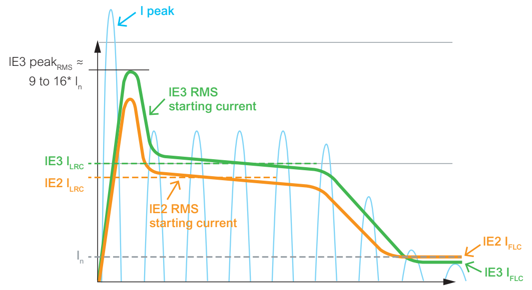


Figure 6

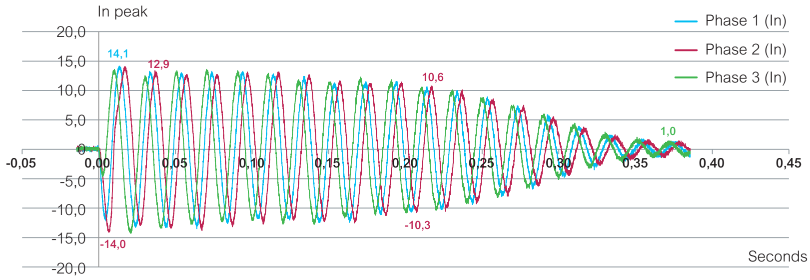


Figure 7

This higher inrush current has a potential impact on the performance of protection and control products due to the fact that the locked rotor current increases the thermal stress on all devices, risking untimely thermal tripping of circuit breakers and relays. The high peak of the inrush may also lead to circuit breaker nuisance tripping.

Motor manufacturers usually state the locked rotor current as an Id/In ratio. However, it is hard to know in advance how high the initial peak of the inrush–important information when selecting the right circuit breakers–will be.

The ratio between the highest inrush peak and the locked rotor current is commonly called the kappa ratio (κ) and its order of magnitude is on average between 1.4 and 1.6 for IE3 motors; it can be as high as 2.0 for very high torque according to IEC 60034-12. The kappa ratio is calculated as follows:

$$\kappa = \frac{\text{Ipeak}}{\text{Locked Rotor Current}} \cong 1.4 \rightarrow 2.0$$

2.2.3. The influence of efficiency on locked rotor current

Some manufacturers do offer super-premium-efficiency (IE4) motors following standard IEC 60034-30-1. IE2 motors on the market that have LRCs superior to 8In, similar to the performance achieved by IE3 motors. Depending on the motor manufacturer, it is possible to purchase an IE2 motor that has a LRC superior to 8*In.

Figure 7 shows the statistical distribution of 50 Hz motors available on the market by stated efficiency (according to manufacturers' catalogue information). As efficiency improves, LRC increases. Therefore, all of the components in a motor protection system will need to be assessed to align with the move towards higher motor efficiency standards. In all cases, it is highly recommended to follow the manufacturer's instructions and recommendations to avoid nuisance tripping–and downtime–due to higher starting currents.

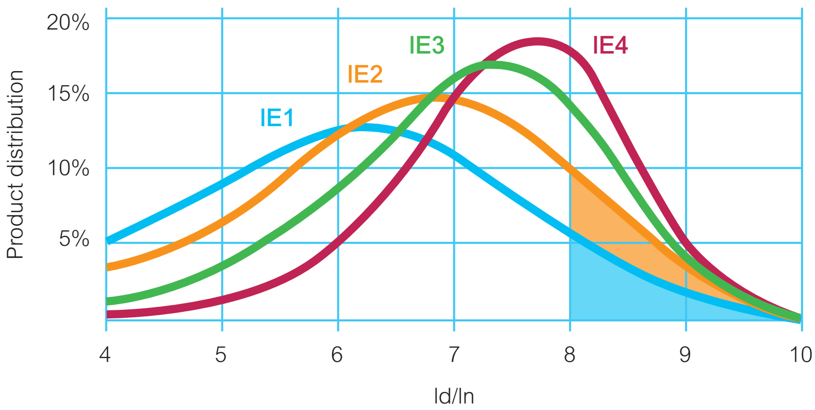


Figure 7. Statistical distribution of locked rotor current according to manufacturer catalog specifications.

Expected LRC will also depend on the motor's rated power. Figure 8 shows the average LRC of motors for ratings from 0.2 kW to 400 kW depending on motor efficiency. For IE3 and IE4 motors the increase in starting current ranges from 16% to 32% for motors rated between 0.75 kW and 100 kW, currently the most common motor ratings on the market.

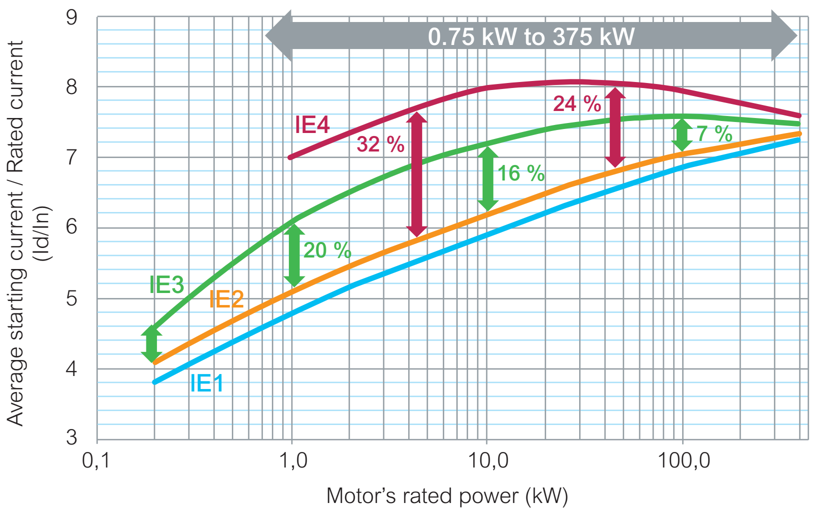


Figure 8. LRC and rated power.

2.2.4. The influence of the electrical installation on starting current and inrush peak current

Certain characteristics of the electrical installation can influence the current consumed by the motor during the starting phase. The following are the most relevant ones to take into account when using premium-efficiency motors:

- Cable length and cross section: a limited cross section (a cable not over-dimensioned for the motor's In) would limit the peak that can run through the cable; this is also true of longer wire lengths.
- Rotor position: when starting the motor, the physical position of the rotor with regards to the stator can influence the magnitude of the inrush peak.
- Power factor: a low power factor is caused by any inductive/reactive load and will have a negative impact on the whole electrical installation; this problem can be diminished by the use of capacitors.
- Electrical angle.
- Motor brand.
- Rating, oversizing motor rating can lead to higher inrush at startup.

2.3. Selecting the right protective devices

As stated above, the most common way of protecting DOL starters is by combining a circuit breaker, contactor, and thermal relay. A magnetic or thermal-magnetic circuit breaker provides short-circuit protection and breaking to avoid damage to the installation. A thermal relay detects overload currents and shuts the motor down before overheating has a chance to damage the insulation. A contactor is used to control the motor, providing on/off switching. Choosing the right devices and knowing which devices to use in combination is crucial.

2.3.1. Circuit breaker and thermal relay

As described above, as starting current increases, so does the risk of nuisance tripping. Figure 9 shows the hypothetical case of a suboptimal circuit breaker and thermal relay. The green curve shows the starting current of an IE2 motor, and the red curve, its IE3 version. If the values between the motor's starting current and the equipment's threshold are too close to each other, using the IE2 configuration for the IE3 motor may result in nuisance tripping and downtime. This depends on the motor technology, the electrical equipment brand, and correct installation of all electrical wiring, devices, and equipment.

To select the right circuit breaker and overload relay, you should:

- Follow the recommendations of your motor protection manufacturer.
- Avoid over-dimensioning cable sections.
- Verify that the electrical characteristics stated by the motor manufacturer are in accordance with the motor starters used.
- Verify the coordination of the motor starter components if there are selected separately, without using a recommended coordination tables.

Schneider Electric TeSys circuit breakers and thermal relays have undergone magnetic, electrical, and thermal endurance testing in laboratory conditions to ensure their compatibility with IE3 motors. After further tests, the compatibility with IE4 motors has been also verified.

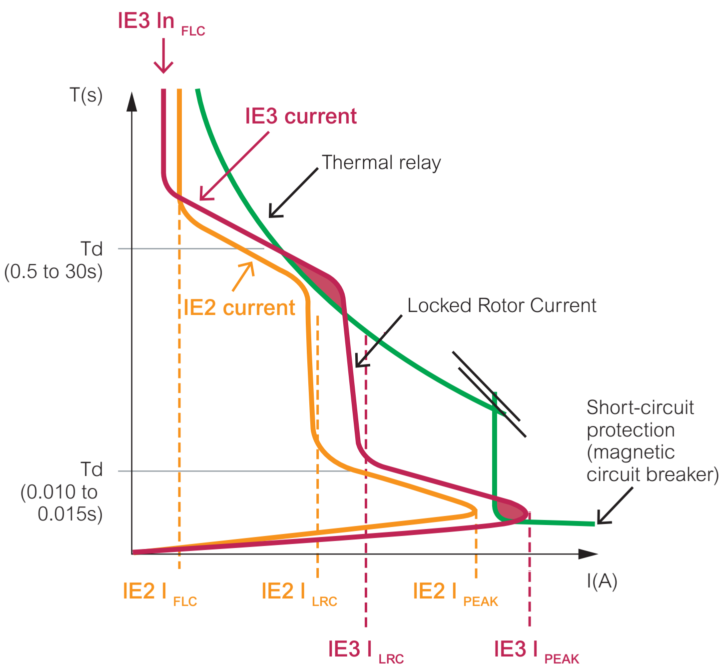


Figure 9. In the red zone: nuisance tripping with IE3 motors.

2.3.2. Contactor

A contactor is an electromechanical device designed to switch the current in an electrical circuit on and off. The maximum breaking current of a contactor is often given as a ratio of the nominal current: In. For standard applications, a contactor rated 12 In for closing and 10 In for opening is sufficient. But for IE3 or IE4 motors, the contactor should be able to break and make even during the higher inrush peak at startup to avoid harm to people or equipment.

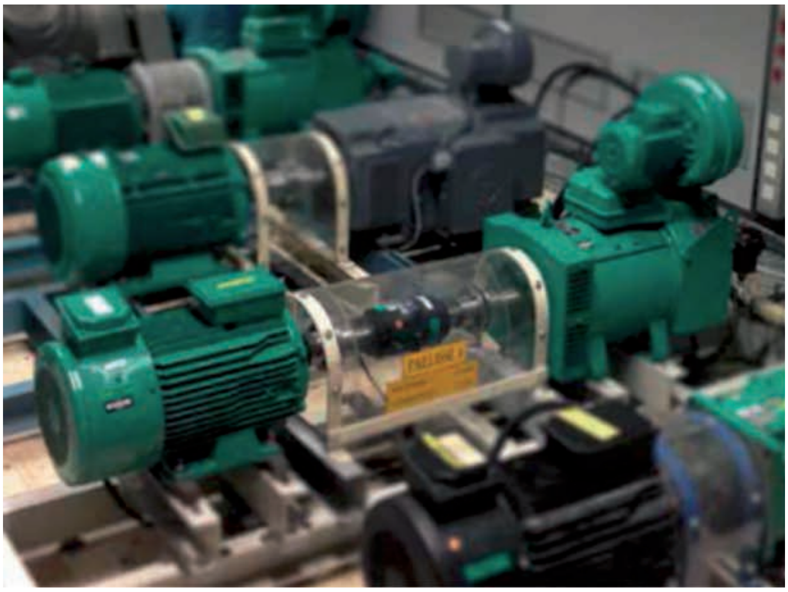
Schneider Electric TeSys D contactors can sustain up to 20 In equivalent Rms breaking and making capacity and are suitable for IE3 or IE4 motors. TeSys contactors have been successfully tested for compatibility with IE3 or IE4 motors.

2.3.3. Coordinating the circuit breaker and contactor

Schneider Electric recommends the following combinations of circuit breaker and contactor. Note that upgrading from an IE2 to an IE3 or IE4 motor does not change the recommended combination.

Motor type	IE2 motor: 5.5 kW	IE3 motor: 5.5 kW	IE4 motor: 5,5 Kw
Breaker and contactor	GV2ME16 + LC1D25	GV2ME16 + LC1D25	GV2ME16 + LC1D25

These combinations are stated in the TeSys 2017 catalogue MKTED210011EN and can be used for IE3 / IE4 motors without restriction.



3. Getting started with TeSys by Schneider Electric

Schneider Electric's TeSys motor starter range will help you make the transition to more energy efficient motors with total peace of mind. TeSys products are fully compatible with IE3 and IE4 motors as confirmed in laboratory testing for magnetic, thermal, and electrical endurance. Using TeSys circuit breakers, contactors, and thermal relays ensures optimal energy efficiency for your installation and compliance with the latest regulations.

You can also stay up to date on the latest TeSys news at www.schneider-electric.com/tesys.

TeSys Quick Selector is available to make motor starter selection fast, simple, and effective

- Quick selection of TeSys motor starter most common combinations
- Motor rated power up to 75 kw
- For Smartphone & tablet

Flash the QR code and update your app!

Available on the iPhone App Store

Android app on Google play

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