

High Efficiency Motors and Nuisance Starting Trips

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History

Electric motors over 1 hp consume 23% of the electricity produced in the United States. Studies have estimated that 11-18 percent of this energy valued at \$3.6–\$5.8 billion at current industrial energy prices could be saved through the use of energy efficient motors and related proven mature technologies. Despite the great potential for energy savings early (1998) studies has shown that fully 69% of motor purchasers are not aware of energy-efficient electric motors and only 17% actually purchase energy-efficient electric motors.

In an effort to promote the development, availability, and use of energy efficient motors trade organizations and government agencies have created a progression of initiatives;

1992/1997

Congress passed the Energy Policy Act (EPAAct) in 1992. (Effective October 1997). EPAAct did not create new efficiency performance levels but rather established a minimum efficiency level for motors sold in the US. Many manufacturers' energy efficient motors met these standards while most standard-efficiency motors did not. Upgrading motors from pre-EPAAct levels to EPAAct efficiency levels increases motor efficiency approximately 2.3 percent.

1994

NEMA 1994 issued definitions for “energy efficient” motors. This definition raised motor efficiency approximately 1.2 percent over EPAAct levels. Motors designated as “energy efficient” must have nominal efficiencies meeting or exceeding NEMA MG1 Table 12-10

1994

NEMA revised MG1-1993 in October 1994 to include the specifications for a Design E motor. The Design E motors were specified to satisfy the International Electrotechnical Committee (IEC) standards. The IEC standards allow motors to be designed for higher efficiency with lower restrictions on torque and starting current than Design B motors. The NEC 1999 and UL 508 standards followed with updated controller and installation requirements to accommodate the lower restrictions.

Design E motors were never manufactured. References to NEMA Design E motors were removed in the NEC 2005 edition, NEMA MG1-2003, and in later revisions of UL 508. (Note: The NEMA Design E motor was often misunderstood to be a new energy-efficient motor standard. The “E” designation had no association with “energy efficiency”; it was merely the next letter after “D”.)

1996

The Consortium for Energy Efficiency (CEE) launched its Premium Efficiency Motors Initiative. CEE worked cooperatively with manufacturers, trade organizations, and motor experts to develop efficiency standards significantly higher than those established by EPA. Motors meeting the CEE standards are designated “CEE Premium EfficiencySM”. CEE Premium EfficiencySM motors are 0.8 – 4% more efficient than EPA motors.

2001

In May of 2001 NEMA announced a new motor efficiency standard; NEMA PremiumTM efficiency. This standard was carefully designed for user-friendly motor replacement. Key performance characteristics including starting current, break down torque, and temperature considerations were retained to insure compatibility with existing applications. NEMA PremiumTM motors are required to have 20% lower losses than EPA motors.

2001

In June of 2001 NEMA and CEE agreed to align the NEMA PremiumTM and the CEE Premium EfficiencySM efficiency levels and to co-promote the standard.

These initiatives have created a myriad of confusing energy efficiency designations. Often consumers do not have a clear idea of a motor’s efficiency performance from a casual glance at its nameplate. Motor manufacturers are free to use descriptive terminology to describe their products. For example; "premium", “high”, "super", "UltraTM", "plus", "extra”, and “Super-ETM”. However only a few are governed by specific standard organizations; “Energy Efficient” (NEMA MG1 Table 12-10), “NEMA PremiumTM efficient” (NEMA MG1 Tables 12-12 and 12-13), and “CEE Premium EfficiencySM” (Aligned to NEMA MG1 Tables 12-12 and 12-13). The design of energy-efficient motors affects other operational characteristics beyond simple energy savings. Overlooking these characteristics can impact the performance and even the reliability of a system.

Energy efficient motor design

Improved energy efficiency in electric motors was achieved through various design improvements:

- 20 - 60% more copper in the windings
- 35% more electrical steel in the cores
- Thinner laminations
- Higher quality electrical steel
- More efficient rotor bar design
- Reduced windage, friction, and stray load losses
- Reduced resistance (I^2R) losses through a longer core
- Optimize air gap between the rotor and stator
- Closer machining tolerances

The motor design improvements necessary to increase motor efficiency carried with it some costs. The increased copper, lower stator resistance, and lower iron losses resulted in an increased transient inrush current.

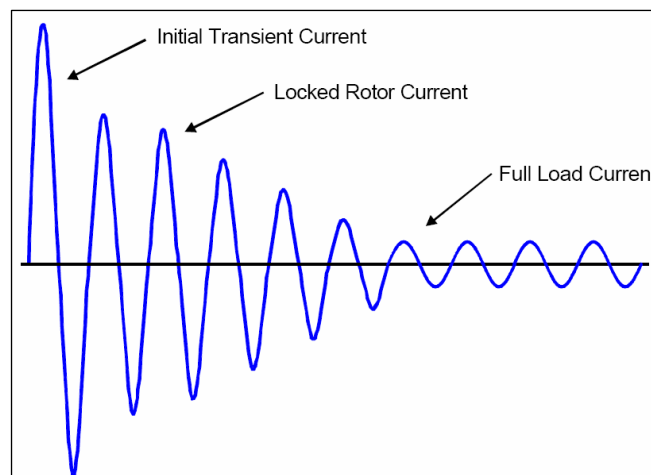
Energy-efficient motor starting current

There are two often misunderstood components of a motor’s starting current. The most recognized component is the locked rotor current (LRC). The LRC is the root-mean-square (RMS) value of the current drawn by an induction motor after full voltage is applied and which tapers off as the motor accelerates. The maximum value of the LRC is roughly 4 - 8 times the motor’s full load ampere (FLA) rating. The maximum level of LRC is determined by the NEMA MG1 Table 430.7B and is marked on the motor’s nameplate at the NEMA Code Letter;

Code Letter	Kilovolt-Amperes per Horsepower with Locked Rotor
A	0–3.14
B	3.15–3.54
C	3.55–3.99
D	4.0–4.49
E	4.5–4.99
F	5.0–5.59
G	5.6–6.29
H	6.3–7.09
J	7.1–7.99
K	8.0–8.99
L	9.0–9.99
M	10.0–11.19

The LRC of energy-efficient motors is limited to the same NEMA standard as older standard-efficiency motors. However, the second component of a motor’s starting current is not.

The second and least recognized component of a motor’s starting current is the initial transient inrush current. This current flows for less than one half line cycle but can exceed the motor’s full load current rating by 13 to more than 20 times FLA, well beyond the typical LRC of 6 times FLA.



All motors draw a transient inrush current on startup. At the moment AC line power is applied to a motor there is no back EMF and no significant magnetic field to oppose the current flow. The only resistance to current flow is the stator resistance itself. The lower resistance and the higher X/R ratios found in high-efficiency motors causes this surge current to be significantly higher than in the older standard-efficiency motors.

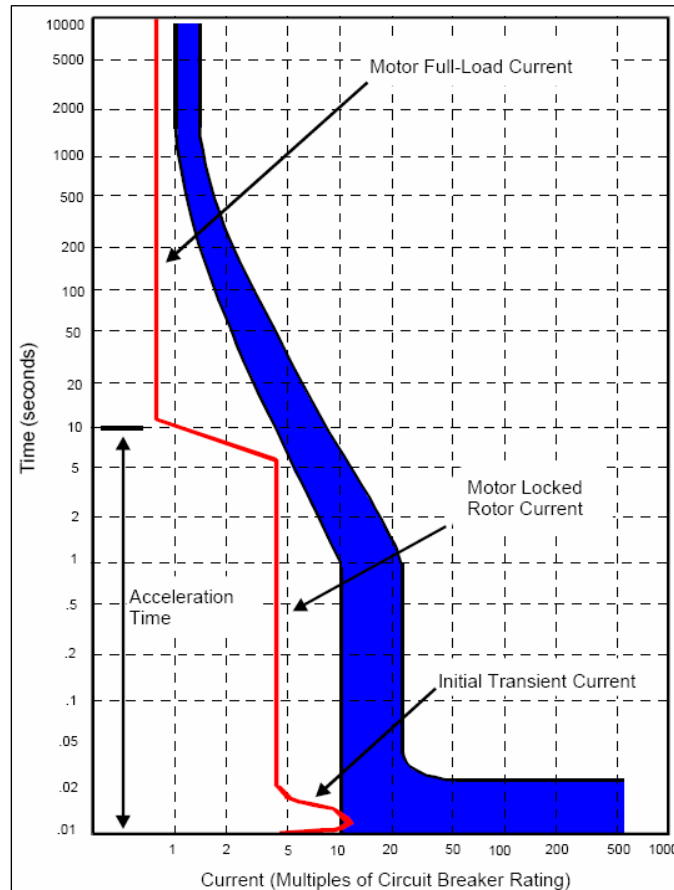
Motor Starting Current and Short Circuit Protection

UL 508a and NEC specify the ratings of devices for motor branch circuit short circuit protection. These rating can be found in NEC 2005 Table 430.52.

Type of Motor	Percentage of Full-Load Current			
	Nontime Delay Fuse ¹	Dual Element (Time-Delay) Fuse ¹	Instantaneous Trip Breaker	Inverse Time Breaker ²
Single-phase motors	300	175	800	250
AC polyphase motors other than wound-rotor Squirrel cage — other than Design B energy-efficient	300	175	800	250
Design B energy-efficient	300	175	1100	250
Synchronous ³	300	175	800	250
Wound rotor	150	150	800	150
Direct current (constant voltage)	150	150	250	150

The NEC table does not address a motor’s transient inrush current. Exceptions accompanying this table have been developed as the starting requirements of energy-efficient motors have become known. For example, the rating of dual element fuses can be increased from 175% to 225% FLA and the rating of instantaneous circuit breakers can be increased from 1100% to 1700% FLA for energy-efficient Design B motors. NEC does not allow the rating of the protective devices to be automatically increased. Code permits a change only if it can be demonstrated the recommended fuse is not sufficient to start the motor.

A nuisance starting trip will occur when a motor's transient inrush current exceeds the rating of an instantaneous circuit breaker or even a dual element fuse. The typical motor starting current curve below shows a high locked rotor current (4 - 8 times the motor's FLA) followed by the motor's steady state load.

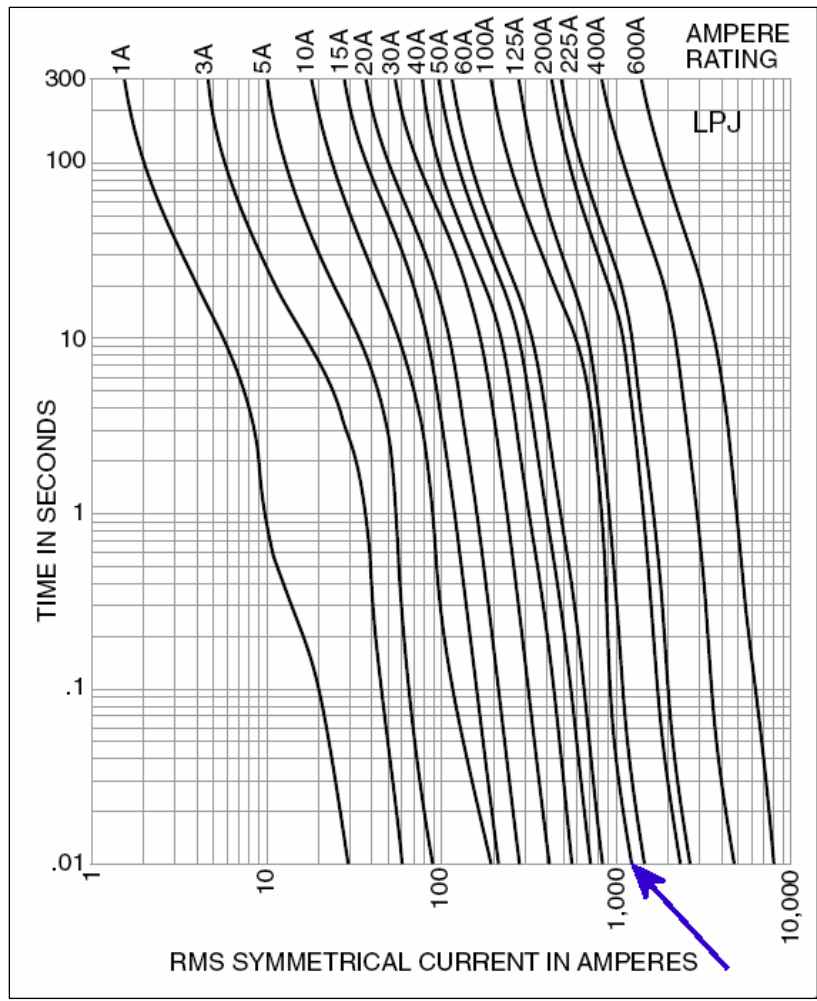


Most representations of this curve omit the initial transient inrush current shown here. The following example will illustrate why this omission can result in unexplainable nuisance starting trips;

A panel designer specifies the short circuit protection for a 60 hp, 460 VAC, 3 phase induction motor. The motor specifications are unknown so the designer uses the UL and NEC recommendations for the FLA rating (NEC Table 430.250). He selects a 100 amp Bussmann LPJ fuse which will provide the correct short circuit protection, fault current limiting, and will carry the starting current of a typical 60 hp motor.

The installer provides a 60 hp NEMA Premium™ motor. The installer is puzzled why the fuse clears once every 5 starts of the motor. The motor's horsepower rating matches the panel's rating. The fuse rating falls with the typical range for this size motor. His clamp-on current meter reads normal starting current and running current. What's wrong?

Neither the panel designer nor the installer erred. In this example the panel designer followed good engineering practice when selecting the short circuit protection. The installer in turn provided a high quality motor. Unfortunately this energy-efficient motor has a transient inrush current 22 times the nameplate's 71.2 FLA rating. The transient inrush current is too fast to be read with the installer's clamp-on current meter. The peak current is actually 1571 amps. If we examine the fuse's time-current curve we'll see the initial transient inrush current will likely clear the fuse rated at 1100 amps RMS (1555 amps peak).



Solutions

It often is sufficient to simply increase the rating of the short circuit protection device to eliminate nuisance tripping. However UL and NEC requirements may impose some restrictions. In the simplest case a larger fuse block may be needed. In more complex cases a larger fuse may not adequately protect a panel's disconnect switch, contactors, and wiring. The panel's Short Circuit Current Rating (SCCR) may also be affected. Any modifications to the equipment's short circuit protection must meet NEC and UL requirements. The equipment's manufacturer should be consulted for guidance.

Proper selection of the short circuit protection prior to construction requires the following information to be supplied to the panel builder;

- Motor data including make, model, and motor inertia.
- Load type (e.g. fan, pump, conveyor ...)
- Load inertia
- Acceleration/deceleration rate requirements
- Load brake horsepower

Nuisance starting trips can be eliminated through these steps;

- Increase the rating/setting of the short circuit protection device; Refer to NEC Table 430.52 including Exception No. 1.
- If the prior step is insufficient then a further increase of the rating/setting of the short circuit protection device is permissible; Refer to NEC Table 430.52 Exception No. 2.
- Review the modified short circuit protection device rating/setting with the panel manufacturer to evaluate UL and other design concerns.

Note: The installer should always refer to NEC 2005 Article 430.52 “Rating or Setting for Individual Motor Circuit” or other codes as locally adopted for guidance.

Conclusion

The importance of the often unknown and overlooked transient inrush current has become more apparent as energy-efficient motors have become more prevalent and higher performance short current protective devices have come into use. It is important that the selection of short circuit protection devices be properly coordinated with the selection of high-efficiency motors. The failure to coordinate the selection may result in reduced system reliability and unnecessary costs to modify the equipment.

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