Reprinted with permission from the Conference Record of the 42nd Petroleum and Chemical Industry Conference, Denver, Colorado, September 11-13, 1995, pages 227-230.

Use of inverse time, adjustable instantaneous pickup circuit breakers for short circuit and ground fault protection of energy efficient motors

By

DENNIS W. HEATH
GE Electrical Distribution & Control
Plainville, CT 06062

H. L. BRADFIELD, P.E.
Area Chairman, IEEE Industry
Applications Society
Bechtel Corporation
Houston TX 77252-2166

ABSTRACT

Many energy efficient low voltage motors exhibit first half cycle instantaneous inrush current values greater than the National Electrical Code's 13 times motor full load amperes maximum permissible setting for instantaneous trip circuit breakers. The alternate use of an inverse time circuit breaker could lead to inadequate protection if the breaker does not have adjustable instantaneous settings. Recent innovations in digital solid state trip unit technology have made available an inverse time, *adjustable* instantaneous trip circuit breaker in 15A to 150A ratings. This allows the instantaneous pickup to be adjusted to a value slightly above motor inrush so that low level faults will be cleared instantaneously while avoiding nuisance tripping at startup. Applications, settings and comparisons are discussed.

INTRODUCTION

More than 30 years ago the molded case circuit breaker industry developed a line of motor short circuit protective devices or "instantaneous trip breakers" that improved on the thermal magnetic or "inverse time breaker" in two distinct ways. First, the instantaneous only breaker (sometimes called a motor circuit protector) had no long time or "thermal trip." It was deemed redundant since the overload relay or "heater" was providing this long time thermal function.

Secondly, the instantaneous or "magnetic" pickup was made adjustable so it could be set slightly above the motor inrush. This was a significant improvement over the fixed instantaneous thermal magnetic breaker.

Many years ago the National Electrical Code[2] established a maximum setting for this instantaneous trip breaker of seven times motor FLA, the theory being that value was just above the typical 6X locked rotor current. Some years later an exception permitted increasing the setting to 1300% of FLA, but only if it could be demonstrated the motor could not be started with the 700% setting. Finally, the instantaneous inrush "phenomenon" was recognized!

In the mid-1980's energy efficient motors were introduced. While the full load current for a given horsepower rating is less than for a standard efficiency motor, the first-half cycle transient inrush and locked rotor current, as ratios to the full load current, are higher for energy efficient motors[1]. All motors exhibit this phenomenon of a transient peak current on start up. It is very similar to a short circuit on an ac system in that the only significant resistance presented to the motor circuit is the stator winding itself. At this instant there is no back EMF and no significant magnetic field to oppose current flow[6]. The inrush is higher because of the higher X/R ratio brought about by the lower resistance of energy efficient motors.

As a consequence many energy efficient motor applications require one of the following: (1) setting the instantaneous breaker higher than 13 times FLA in violation of the National Electrical Code (NEC); (2) using an inverse time circuit breaker for which the Code does not specify any limit for instantaneous operation and which may not provide adequate short circuit protection; or, (3) using an instantaneous trip breaker with a damping means. (At least one manufacturer claims to offer this and it is permitted by NEC Article 430-52(a) FPN.)

In an article in the June 1986 issue of *Electrical Apparatus*, R. L. Nailen notes, "Because the induction motor draws a starting current so high...a basic difficulty in motor circuit protection lies in selecting or adjusting the breaker or fuse to distinguish reliably between the sudden high current resulting from normal motor starting and that caused by a true short circuit." Nailen further states, "The first fact of motor life ignored by the Code is the actual magnitude of the transient or first cycle offset."[6]

In a 1986 IEEE IAS paper, Scheda notes the two most commonly encountered problems in applying high-efficiency motors are (1) replacing a standard motor with a high-efficiency motor and (2) the need to use thermal sensors on larger machines since higher settings for electronic control would violate the NEC. His paper concludes, "It is suggested that work be done in the industry and standards organiza-

tions to serve the needs arising from the use of electronic detection of instaneous [instantaneous] currents for motor protection."[3]

This paper will address some of the work done in the industry to serve these needs and, in particular, how the use of an "electronic detection" inverse time circuit breaker can be appropriately applied when an instantaneous trip breaker would nuisance trip.

NEC PROTECTION PARAMETERS REVIEW

Inverse Time Circuit Breaker: The NEC sets the guidelines for motor and motor circuit protection in Article 430 Part D, "Motor Branch-Circuit Short-Circuit and Ground-Fault Protection." Article 430-52(a) deals with the permissible setting and/or rating of the motor branch-circuit short-circuit and ground-fault protective device. Without exception these settings or ratings are in multiples of the motor full load current taken from Table 430-150.

NEC Article 430-52(a) Exception No. 2c permits an increase from 250% (Table 430-152) to 400% for motor full load currents of 100A or less for determining the ampere rating of an inverse time circuit breaker. Again it must be stressed there is no mention of the breaker's instantaneous response.

Instantaneous Trip Circuit Breaker: Article 430-52 also covers the use of an instantaneous trip circuit breaker and states, in part, "an instantaneous trip circuit breaker shall be used *only if adjustable*, and if *part of a listed combination controller* having coordinated motor overload and short-circuit and ground-fault protection in each conductor, and if it *will operate at not more than 1300 percent of motor full-load current*." (Italics are the authors')

Which Provides The Better Protection? For a standard efficiency motor an instantaneous trip breaker will generally provide better short-circuit protection than a fixed instantaneous, inverse time breaker. If, however, the transient first cycle inrush of an energy efficient motor exceeds the 13 times FLA value, an inverse time breaker is the better choice, *but only if the instantaneous is adjustable.*

Several circuit breaker manufacturers do recommend the use of a "thermal magnetic" breaker sized to approximately 200-300% FLA when it is known the motor instantaneous inrush will exceed 1300% of FLA. They do not mention the fixed instantaneous, which is the only offering in the 100, 125 or 150 frame sizes of all but one manufacturer, may be too high to provide adequate protection. For example, consider a 460Vac, 40 horsepower energy efficient motor which the Code Table 430-150 claims 52 FLA. A thermal magnetic breaker sized to 250% FLA is selected. Since a 130A (2.5 x 52 = 130A) rating is not a standard ampere rating, a 150A fixed instantaneous breaker is selected. The actual instantaneous pick up is 2250 symmetrical rms amperes or 15 times the breaker ampere rating. This breaker will not respond instantaneously until a current of 2250 symmetrical rms amperes or 3181 peak amperes flows. The 40 horsepower motor's first half cycle inrush is found from the manufacturer to be 629 peak amperes (12.1 FLA).

There will be no problem starting the motor, but a short circuit current of, for example, 1900 amperes will not be cleared until the thermal portion of the trip unit responds in, typically, several seconds. (While not acceptable by the NEC, an instantaneous trip breaker set at, for example, 16 times FLA will provide tighter short circuit protection than an inverse time breaker who's fixed instantaneous will not operate until a fault escalates to 30 or 40 times FLA. Note the latter is an NEC acceptable solution!)

ADJUSTABLE INSTANTANEOUS, INVERSE TIME BREAKER FOR ENERGY-EFFICIENT MOTORS

There have been many articles and technical papers written in the last few years discussing nuisance tripping of protective devices serving energy efficient motors [1],[3],[4]. Most present the dilemma of the "NEC 1300% maximum operating value" with little help for solving it. Some suggest changing to a thermal magnetic molded case circuit breaker without the caution noted above.

This paper will present a Code-acceptable solution for this nuisance tripping problem. And it is a solution that does not sacrifice on protection.

Fig. 1. Time-current Coordination Plot

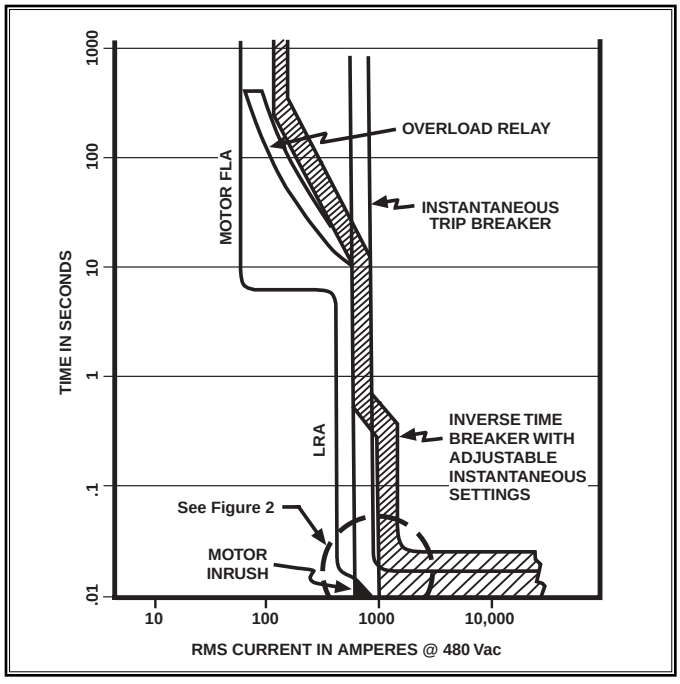

Fig. 1 is a time versus rms current plot showing a 150A frame, 125A rating, inverse time molded case circuit breaker with adjustable instantaneous trip as part of a combination controller for a 60 horsepower energy efficient motor which draws 65.3 full load amperes at 460Vac. The inverse time cir-

cuit breaker's instantaneous pick up is adjusted to a setting of 1265 symmetrical rms amperes (nominal) which is just below the maximum setting. The pick up tolerance as shown on the manufacturer's time current curve is ±20 % and this is the bandwidth shown in Fig. 1. The minimum instantaneous pick up is 0.8 x 1265A or 1012 symmetrical rms amperes or 1.414 x 1012A = 1431A peak .
An instantaneous trip breaker would be limited to a maximum setting of 13x77A (full load current from Table 430-150, as required by Article 430-6(a), not actual current) or 1001 symmetrical rms A. One manufacturer's 100A size instantaneous trip breaker has an 804A nominal setting. The next higher setting is 972A nominal with a maximum operating value of 1263A that is beyond the 13X Code limit. Again using the manufacturer's trip time curve tolerance of ±20%, the minimum operating value for the 804A setting could be as low as 0.8 x804A or 643 symmetrical rms amperes or 909 peak amperes. The instantaneous trip breaker is also shown in Fig.1.

Now let us examine the energy efficient motor's first half cycle transient inrush current. In the March 1994 EC&M Magazine *Letters* column, R. L. Smith[5] notes the locked rotor current can be seven or more times full load current. The DC offset of the locked rotor current can approach 1.73 times the symmetrical rms current, with the peak value being 1.414 times the offset [5]. The energy efficient motor could, therefore, have a first half cycle transient inrush current of 65.3 x 7 x 1.73 x 1.414 = 1118 peak amperes or higher depending on the X/R ratio between the motor and the fault. This value equates to a first half cycle inrush to FLA ratio of 17.12. Other articles support peak inrush to locked rotor ratios of 2.5 to 3.0 for locked rotor power factors of 0.25 to 0.11, respectively [5],[6].

By convention the current values plotted in Fig. 1 are in rms amperes. The 1118A peak equates to 791A rms and is shown at the .01 second horizontal axis. In addition to the motor's first half cycle inrush (791A rms), the steady state locked rotor amperes (LRA) of 457A and full load amperes (FLA) of 65.3A are plotted in Fig. 1.

Modern instantaneous trip and inverse time breakers are fast enough to respond within a half cycle if the magnitude is beyond the pickup value. Thus, the mere fact that the instantaneous motor inrush has decayed substantially after the first half cycle may not be sufficient to keep the breaker from tripping. The inverse time breaker chosen (and as set) has a minimum instantaneous pick up of 1431A peak as compared to the motor's 1118A peak inrush and will not be sensitive to the motor first half cycle inrush current.

If for some reason, the motor exhibited inrush currents higher than calculated or as stated by the motor manufacturer, there is still "room" to adjust the pick up to a higher value without fear of Code violation.
This "daylight" or space between the motor inrush and the adjustable inverse time breaker curve can be seen on the horizontal axis (0.01 second) of Fig. 1 or in Fig. 2 which is an enlarged view of the referenced portion of Fig. 1. The instantaneous breaker, on the other hand, interferes with the motor inrush at the 0.01 second time and may cause nuisance tripping unless the actual pick up value is to the extreme right side of the band width, which cannot be guaranteed.

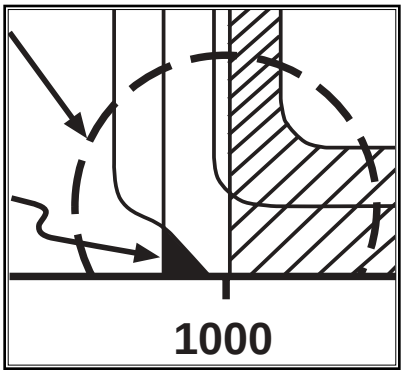

Fig. 2. Enlarged View of Motor Inrush

Referring to Fig. 2 note the minimum instantaneous operating value of the inverse time breaker is to the right of the motor transient inrush and will not be sensitive to it. The instantaneous trip breaker, however, interferes with the motor startup inrush. The next lower instantaneous setting on the inverse time breaker would provide even better protection as long as it did not operate on the -20% tolerance.

At an industrial pumping complex numerous nuisance trip problems with 30 and 40 horsepower lift station pump motors prompted an investigation. A summary of the findings follows:

a. nuisance trips occurred in about one out of five starts.
b. no faults were found in the power circuits.
c. pump shafts were free and could be turned manually.
d. when the instantaneous trip breakers were set to approximately 1800% of motor rating, no nuisance trips were experienced.
e. at one station not experiencing nuisance tripping, a thermal magnetic breaker was found rather than an instantaneous trip breaker.

In [1] it is stated that "instantaneous-trip devices set at values not exceeding 1300% of motor full-load current therefore have a high probability of developing nuisance trips." The examples above certainly support this statement. A specific NEMA proposal to revise the 1300% limitation up to 1600% has been accepted by the NFPA and will be voted on in May, 1995. If this proposal is approved, it will greatly reduce the number of nuisance trip conditions.

Even 1600% will not totally eliminate the problem, however. A case in point is plug reversing of an energy efficient 10 horsepower, 480Vac motor, data which one of the authors has seen[7]. Peak first half cycle inrush current based on numerous tests at rated voltage ranged from 250 to 415A, a ratio of 17.4 to 29 FLA. This wide range is due to the variations in residual motor voltage and to system voltage at the instant of reversal.

CONCLUSION

The problem of nuisance tripping of instantaneous trip breakers applied per the NEC limitations has been analyzed. A solution using an inverse time circuit breaker with adjustable instantaneous settings is offered. The advantages

of this solution are (1) it is in compliance with the NEC and (2) it provides excellent short circuit protection.

It is recommended those specifying or applying energy efficient motors or standard, special application motors obtain accurate instantaneous inrush values prior to selecting the device for short circuit and ground fault protection. If an instantaneous circuit breaker would have to be set above the NEC requirements, it is recommended an inverse time circuit breaker with adjustable instantaneous settings be considered.

Editor's note: at the time this paper was written, it appeared the 1996 National Electrical Code would increase the 1300% maximum instantaneous trip breaker setting to 1600%. It actually now permits a 1700% maximum *for Design E motors only.* For others, the maximum setting remains at 1300%.

REFERENCES

[1] R. G. Bartheld and S. F. Farag, "Energy efficient motor coordi nation," in *Conf. Rec. 1985 Annu. Meet. IEEE Pulp and Paper Tech. Conf.*, pp. 65-67, (85CH2129-5).

[2] *National Electrical Code*, Nat. Fire Protection Assoc., Quincy, MA, NFPA-70.

[3] Francis A. Scheda, "Transient inrush current in high-efficiency and standard motors," *IEEE Trans. Ind. Appl.*, vol. IA-22, no. 1, pp.145-147, 1986.

[4] Thomas J. Woginrich, "High-inrush currents and premium effi ciency motors," *EC&M Mag.*, p. 8, Jan. 1994.

[5] R. L. Smith, "'93 NEC change is dangerous," *EC&M Mag.*, p. 12, Mar. 1994.

[6] R. L. Nailen, "Motor inrush current: what does it really mean?" *Electrical Apparatus Mag.*, pp. 56-60, Jun. 1986.

[7] D. D. MacDonald and R. A. Morris, private communication, 1995

General Electric Company
41 Woodford Avenue, Plainville, CT 06062