Benefits of Thermal Magnetic Circuit Breakers
For Combination Starters in Low Voltage Motor Control Centers
Class 8998

Introduction

The purpose of this bulletin is to review the use of thermal magnetic circuit breakers (TMCBs) for motor starter applications. The specific case of a motor control center (MCC) is considered.

Significant changes in motors and overload protective devices have been made in the last few years. The use of solid state overload relays and energy efficient motors are now commonplace. Underwriters Laboratories® (UL) requirements and the National Electric Code® (NEC) are changing to reflect these new application realities.

The use of TMCBs addresses many of these application and standards issues. The information presented is based on Square D circuit breakers, overload relays and contactors.

Background

A combination motor controller applied in a UL 845 Listed motor control center includes a disconnect, short circuit or ground fault protective device, a controller, and thermal overload protection (see Figure 1). These functions can be provided by separate devices or combined. In fact, a new category of starter (UL 508e Listed self-protected motor starter) combines all of these functions into one component.

Component selection is based on NEC Article 430 including the following articles and tables:

- Article 430-6 (ampacity and ratings)
- Article 430-32 (overload selection)
- Article 430-52; Table 430-152 (maximum setting of branch circuit protective devices)
- Article 430-110a (disconnect rating)
- Table 430-150 (motor full load currents)
- Table 430-151 (motor locked rotor currents).

Selection and adjustment of a magnetic motor circuit protector (MMCP) and thermal magnetic circuit breaker (TMCB) are based on the motor full load currents (MFLC) from NEC Table 430-150. Overload trip element selection or setting is based on actual motor nameplate MFLC. To avoid confusion, the rest of the article usually refers to Table 430-150 current and nameplate current interchangeably.

Historically, fused switches (FSs), TMCBs, or MMCPs have served as the disconnecting device and short circuit protective element. In some cases, TMCBs and FSs have also served as the overload protective element but, because over current protection was normally provided by a separate overload relay, the MMCP with no inverse time over current protection was developed specifically for starter applications. Combination starters using MMCPs rely entirely on the overload relay to protect the contactor, conductors, and motor from inverse time overloads.

Because they provide inverse time over current protection, FSs and TMCBs can be UL Listed independently of the contactor and overload. They can then be applied together (within UL and NEC guidelines) as a combination starter.
without additional testing. MMCPs must be UL Listed as part of a combination motor controller including the overload relay.

The overload relay included thermal elements that could be tailored specifically to the motor load. Thermal elements were usually the melting alloy type. Bimetallic elements were used for applications requiring ambient compensation.

Because most motors had locked rotor currents of about 600%, overload class was defined as the maximum time that an overload would pass 600% of its rating. Class 20 overload relays became the default overload selection, although Class 10 and Class 30 overload relays were common. A Class 20 overload relay must trip eventually at 100% of its trip rating; in less than 8 minutes at 200%; and in less than 20 seconds at 600% (see Figure 2).

![Overload Trip Classes](image)

**Figure 2: Overload Trip Classes**

Interestingly, a variance is allowed. The trip time is shown as an uncertainty range. To the left of the range, the overload will not trip. In the range, the overload may trip. To the right of the range, the overload will always trip. The rating of the overload is typically 125% of motor full load current for a 1.15 service factor motor.

**Changing Application Requirements**

Since the energy conservation movement in the late 1970s improving electric motor efficiency has been a primary goal for motor manufacturers. Energy efficient motors employ design features that result in a higher X/R (impedance / resistance) ratios than older standard efficiency designs.

Although these motors have lower motor full load currents (MFLC) than their predecessors, their potentially higher motor locked rotor currents (MLRC) and inrush characteristics can result in nuisance tripping of magnetic motor circuit protectors (MMCPs) set to the 13 X MFLC maximum allowed in the
1996 (and 1999) NEC (Article 430-52). Trip tolerance on an MMCP is -20%/+30% of the circuit breaker setting. A circuit breaker with a setting equivalent to 13X MFLC may trip at 10 X MFLC and still be in tolerance.

With the advent of the Energy Policy Act of 1992, and its 1997 target implementation date, efficiency is now a concern for the majority of industrial applications. A new type of motor (Design E) has been defined with better-than-normal efficiency, but even higher inrush characteristics than previous designs. In recognition of the new design, the 1996 NEC provided for settings of up to 17X MFLC for Design E motors.

Design E motors have not yet become common in the marketplace. Application problems with existing energy efficient designs, however, continue to be an issue. The 1999 NEC allows the higher 17 X MFLC setting for current Design B energy efficient motors where lower settings are not sufficient to start the load. In the last few years NEMA, NEC and UL standards have all been modified to reflect higher locked rotor currents.

While the application of motor starting was changing, the technology used for motor overload protection was evolving also. Widespread use of solid state overload relays in the 1990s has revolutionized motor protection. Features such as current unbalance and phase loss protection are standard with products such as the MOTOR LOGIC solid state overload relay manufactured by Square D. Application advantages include the elimination of thermal units (“heaters”) and ambient insensitivity. Because the impedance of the overload thermal elements has been removed, units may operate at lower temperatures or in smaller enclosures.

Along with these new features have come new requirements. The trip characteristic of these overload relays may differ from the original melting alloy class equivalent.

These overload relays do not have elements in the current path and use internal current transformers (CTs) for current sensing. Figure 3 compares a solid state overload with the melting alloy equivalent. The variability bands have been removed for clarity. Note the current transformer saturation point (indicated with a black dot) on the solid state trip curve.

In addition, solid state overload relays may require looping for small horsepower motors or the use of separate CTs for larger loads.

The reduction of overall impedance can reduce the SCCR rating of the MCC combination starter. High interrupting MMCPs or TMCBs may be required to maintain the SCCR rating. Current limiting modules may also be available to extend the SCCR range. This may be an important consideration in retrofits to existing installations.

The use of thermal magnetic circuit breakers to improve the short circuit rating or eliminate nuisance tripping associated with energy efficient motors raises several application questions.
The Coordination Question

TMCBs with a continuous current rating (CCR) of 100 A or below typically have a non-adjustable magnetic trip point. A properly adjusted MMCP may clear specific low-level short circuit conditions faster than the non-adjustable TMCB. The crossover between the overload relay trip curve and the branch protective trip curve is also affected. These issues are often misunderstood and some misconceptions exist about the effectiveness of MMCPs versus TMCBs.

The following scenario appears to be a poor application for a TMCB: a 460 V, 1 hp motor with a full load current of about 2.1 A. From NEC Article 430-110a and Article 430-52 / Table 430-152, a TMCB must have a CCR at least 1.15 X MFLC up to a maximum of 2.5 X MFLC. If this requirement does not match a standard breaker rating, selection of the next available standard breaker ratings is acceptable.

This is particularly significant for low horsepower applications. A 15 A TMCB is the lowest standard rating and, therefore, may be used for a load of less than 1 A. This range would require two to three MMCPs (3, 7 and 15 A ratings) based on the maximum allowable adjustment of between 8 X and 13 X MFLC (13 X for high efficiency).

For MMCP breakers below 100 A, the magnetic trip point is usually fixed at about 10 X CCR. The 15 A rating has a higher setting than most at about 30 X CCR (450 A). This implies that our 460 V 1 hp motor with a MFLC of 2.1 A would have a magnetic trip point of more than 200 X MFLC. This may seem to be an area of concern until you evaluate the equivalent branch circuit. Keep in mind the branch protective device only provides short circuit protection. Motor protection is provided by the overload relay.

The protected circuit has a NEMA Size 1 contactor and a #12 AWG conductor (the smallest devices used in an MCC and the smallest recommended power conductor). The #12 AWG conductor is rated for approximately 25 A depending on insulation type and installation method (20 A according to UL 508 Table 40.2).

Although the voltage level is different, this could be compared to your home window fan. The fan motor is usually less than 1 hp. The “overload” is internal to the motor. The controller is the switch on the fan. The circuit is a #12 AWG conductor or smaller and the short circuit protection is provided by a 15 or 20 A branch breaker.
Figure 4 shows the coordination curves for this application.

In a 460 V scenario, high-level short circuit fault currents (above 600 A) should be cleared instantaneously by both a non-adjustable TMCB and MMCP. Fault currents between 28–600 A would be cleared instantaneously by an MMCP (set to the 13 X NEC standard efficiency limit) but could be inverse time related for a non-adjustable TMCB. (A fault of 250 A would have a maximum delay of two seconds.)

In the narrow fault current range between 28–600 A, the MMCP limits thermal and mechanical stress better than a non-adjustable TMCB. However, the contactor is protected in either case because the overload relay should not open the contactor above its interrupting rating. Note that although the crossover may be shifted slightly upward (from 28 to a maximum of 40 A) the TMCB does not interfere with the normal inverse time protection of the overload relay.

The short time current carrying and interrupting capacity of a NEMA contactor is proven during combination starter UL 508 and 845 testing and NEMA ICS2 qualification. They must interrupt for 10 operations and conduct for 10 seconds at 10 X the maximum FLC for any starter horsepower or voltage rating covered by that size contactor.

The maximum current for a NEMA Size 1 contactor occurs in a 7.5 hp, 200 V starter. (MFLC of 25 A, 10 X 25=250 A). The standards require testing at 250 A and 200 V only; Square D, however, usually tests at 600 V for convenience. In general, TYPE $^*$ contactors manufactured by Square D interrupt at least 10 X their maximum continuous current at 600 V (in this case 270 A). Generically, continuous current rating does not relate to interrupting ability. Other vendors may elect to test at the minimum voltage and current levels.
The “Properly Adjusted” Key

Selection and adjustment of both MMCPs and TMCBs are based on NEC Table 430-150 full load currents. Some branch protective devices are set in multiples of the device CCR. This value must be calculated by dividing the Table 430-150 MFLC by the CCR to determine the proper setting.

Proper overload trip setting is based on actual motor nameplate MFLC and service factor. Looping for small horsepower motors or the use of separate CTs for larger loads may require conversion to provide the correct value. Given the large tolerance band for both the overload (+12.5%) and circuit breaker (-20%/+30%) these settings are “Ball Park” at best.

Circuit breaker current ratings are usually the same regardless of voltage. Motor full load currents, on the other hand, vary significantly with voltage. At some voltages, the allowable NEC adjustment range for a given motor full load current may not align well with the range of standard circuit breakers. This is true especially if the allowable range is extended to 17X MFLC. In these cases, more than one circuit breaker may be required to cover the full NEC allowable range.

De-rating, which is sometimes necessary as a result of ambient temperature or altitude, will affect the overload, circuit breaker, and conductors differently. Proper adjustment of devices in these conditions can be difficult. When equipment is shipped from the factory, the settings are usually at the minimum level, as the actual full load currents are not known.

Sub-contractors are not always precise in their commissioning adjustments. It may fall to the end user to check all protection settings. Only a detailed review by a qualified electrician, electrical inspector, or engineer can identify improperly adjusted applications.

In the worst case scenario, the MMCP may be set to the maximum value to complete subsystem check-out during commissioning. If the protective device is not subsequently adjusted correctly, a significant gap in protection may go undetected until a problem results. Many MMCP and MFLC combinations would allow settings of 25X MFLC and higher if set to their maximum trip point.

The NEMA Size 1 contactor mentioned on page 5 is a good example of this. This time, the contactor is applied in a 10 hp, 480 V, NEMA Size 1 starter with a full load current of 14 A. An MMCP rated at 30 A is used typically (a 15 A MMCP does not meet the 1.15X MFLC criteria in NEC 430-110a). As determined previously, the maximum tested contactor interrupting and withstand current is 250 A.

The 30 A MMCP maximum setting is about 350 A (25X MFLC), but includes the +30% allowable UL tolerance. If the +30% allowable UL tolerance is provided, the MMCP breaker might not trip until 455 A (32X MFLC) (see Figure 5 on page 7). In this case, an incorrectly adjusted MMCP could allow the contactor to open above its tested rating in the low-level fault band between 250 and 455 A.
A 25 A TMCB would be selected for this application. The TMCB provides a nominal fixed instantaneous trip point of 438 A (600 A at the +20% tolerance). The inverse time trip characteristic of a TMCB provides protection between the instantaneous trip point and the overload relay trip curve. In this case, the TMCB inverse time protection would clear low level faults before the overload relay attempted to open the contactor (At 250 A the TMCB would open in less than 3 seconds) (see Figure 5).

Similar results occur for 20 and 30 hp ratings. For these ratings the TMCB provides some back-up protection for an improperly adjusted overload relay without interfering with the normal inverse time protection of the properly adjusted one. Contactor protection is not dependent on TMCB adjustment as is the case with an MMCP.

Conclusion

In general TMCBs have distinct advantages in the range under 100 A:

- NEC code compliance is not dependent on circuit breaker setting or adjustment (<100 A).
- Significant reduction in nuisance tripping associated with high in-rush applications
- Wide application range under 15 A
- Possible back-up overload protections against improper adjustment, contact weld or control circuit failure
- Common spares with general branch circuits
- High short circuit current rating (SCCR)
Because most MCC applications are under 100 A, the majority of starter units using TMCBs will not require adjustment of the magnetic trip point for short circuit protection. In many of these applications a TMCB will provide some degree of backup protection for improperly adjusted overload relays or control system faults.

Although the protection crossover is shifted, TMCBs will not usually interfere with the normal inverse time protection of a properly adjusted overload relay.

The advantages of TMCBs are particularly valuable in the following high-inrush applications:

- Where a transformer is switched as part of the motor circuit such as an autotransformer starter
- Where high efficiency motors are likely to be used and motor data is not available
- For use with Design E motors
- Where unusual application conditions are expected such as voltage fluctuations or extremely low power factor
- With CT rated overload relays and high available fault current

TMCBs above 100 A (used in NEMA Size 4 starters and larger) usually have an adjustable magnetic trip point similar to MMCPs. The setting is typically adjustable from 5 to 10 X the TMCB continuous current rating (CCR). In general, the adjustment range corresponds to values from 8 X to 14 X MFLC. Because the instantaneous trip point is dependent on the magnetic setting, the coordination of a TMCB and an MMCP in this range is similar.

References and Recommended Reading

The following is a list of references and recommended reading. These will help you gain a wider perspective of the industry standards and technological advances that have driven the evolution of thermal magnetic circuit breakers for combination motor starters.

References

- ANSI/UL 508-1993; American National Standards Institute; Underwriters Laboratories; “Industrial Control Equipment”
- ANSI/UL 845-1997; American National Standards Institute; Underwriters Laboratories; “Motor Control Centers”
- ANSI/NEC 70, 1999; American National Standards Institute; National Fire Protection Association, National Electric Code; Quincy, MA
- ANSI/NEC ICS2, 1993; American National Standards Institute; National Electric Manufacturers Association, Industrial Control Standards; Washington DC
- Square D Digest 171, 1997; Square D Company, Palatine, IL

Recommended Reading

- IAS Meeting Article, 1998; “Application Guidelines for Instantaneous Trip Circuit Breakers in Combination Motor Starters”; George Gregory and Lorraine K. Padden
- IEEE Applications Magazine, Institute of Electrical and Electronics Engineers, January/February 1997; “Short Circuit Protection of Energy Efficient Motors”; by Dennis Heath and H.L Bradfield
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