TRANE

ENGINEERS NEWSLETTER

providing insights for today's HVAC system designer

Protecting The Electrical Distribution System…

Short-Circuit Withstand Ratings Demystified

"Normal" and "overload" conditions … "fault current"…"interrupt" versus "withstand" ratings…"current-limiting." Knowing what these terms mean and applying them correctly is fundamental to designing safe, reliable electrical distribution systems. This is especially true in light of more stringent code enforcement and the current design trend to deliver energy savings by selecting low-impedance transformers. Why? **Lower transformer impedances mean higher short-circuit currents.**

Simply choosing a circuit breaker with a high interrupt rating won't assure adequate protection under short-circuit conditions. With an "ounce of prevention," you can avoid the code official's "red tag" at your next system start-up. Let's review the meaning of the terms that opened this article, define some of the issues related specifically to HVAC motor starter applications and identify practical, effective solutions.

Normal Operation, *n.*

"Normal operation" describes the full (or rated) load conditions of each system component. For motors, it includes the amps intially drawn at start-up, i.e. **inrush current**, as well as the full- or rated-load amps drawn while running. The magnitude of inrush current for a particular application depends on the type of starter used (e.g. wye-delta).

Normal operating conditions determine wire and transformer sizing. They're also used in conjunction with "fault conditions" to select overcurrent protection devices such as circuit breakers and fuses. Rating factors are applied, based on the type and number of connected loads, to assure that the devices selected adequately protect the motor as it starts and while it's running.

Let's look at an example. Suppose a 500-ton chiller has a 480-volt motor that draws 400 amps at rated load conditions. The electrical distribution system includes a wye-delta starter powered by a 1,500-kVA transformer. Operating "normally," the chiller motor draws about 800 amps during the 4 seconds it takes to start; then 400 amps or less at running speed.

The size of the interconnecting wires between the transformer and starter reflects the type and rated amperage draw of the load, i.e. the chiller motor. Sizing the wires on this basis assures that they can carry the inrush current at start-up without overheating.

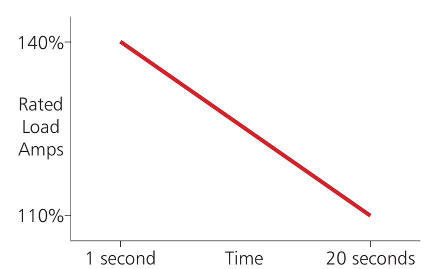
Overload Operation, *n.*

Inductive loads, like the chiller motor in our example, behave differently than resistive loads such as electric heaters. Their current draw is greatest at start-up and corresponds to the existing load when running. In other words, a motor operating normally draws rated amps (RLA) at rated load, fewer amps at less-than-rated load and more amps at greater-than-rated load. It's the latter condition that necessitates overload protection.

Adding an overload protection device prevents the motor from drawing more than its rated amperage for an extended period. Basic overload devices simply open the circuit when current draw reaches the "trip" point. More sophisticated devices attempt to restore normal motor operating conditions by reducing the load, but will disconnect the motor if overloading persists.

For most overload protection devices, "trip" time is determined by the magnitude of the overload. Figure 1 illustrates a straight-line, time/current "trip" curve that shows response times for current draws greater than 110 percent of RLA. A device with these characteristics would allow our example chiller motor to draw 480 amps for 8 seconds before disconnecting it.

Figure 1



Fault Current, *n.*

Imagine a wrench inadvertently left in a starter following service. Touching two terminals, it completes the circuit between them when the panel is energized. What results is a potentially dangerous situation or "fault condition" caused by the low-impedance, phase-to-phase or phase-to-ground connection … a "short circuit."

Fault current, also called "short-circuit current" (I_{sc}), describes current flow during a short. It passes through all components in the affected circuit. Fault current is generally very large and, therefore, hazardous. Only the combined impedance of the object responsible for the short, the wire, and the transformer limits its magnitude.

One objective of electrical distribution system design is to minimize the effect of a fault, i.e. its extent and duration, on the uninterrupted part of the system. Coordinating the sizes of circuit breakers and fuses assures that these devices isolate only the affected circuits. Put simply, it prevents a short at an outlet from shutting down power to the entire building!

Calculating the magnitude of short-circuit current is prerequisite to selecting appropriate breakers and fuses. If the distance between transformer and starter is brief, the calculation can be simplified by ignoring the impedance of the interconnecting wiring … a simplification that errs on the side of safety. We can also assume that the source of the fault has zero impedance, i.e. a "bolted" short. Given these assumptions, the only impedance left to consider is that of the transformer. (Impedance upstream of the transformer is usually negligible.)

Suppose the 1,500-kVA transformer in our example has impedance of 5.75 percent. With this value and the equation below, we can determine how much fault current a short circuit will produce. As you can see, a short would force our wiring to carry more than 30,000 amps when it was designed to handle only 400 amps!

$$I_{sc} = \frac{1500\ kVA \cdot 1000}{480\ V \cdot 1.73 \cdot 0.0575}$$

$$= 31{,}400\ amps$$

Short-circuit current is often two orders of magnitude greater than normal operating current. Unless a circuit breaker or fuse successfully interrupts the fault, this enormous amperage rapidly heats components to very high temperatures that destroy insulation, melt metal, start fires … even cause an explosion if arcing occurs. The inherent likelihood of severe equipment and property damage, as well as the risk of personal injury or death, underscores the importance of sufficient electrical distribution system protection.

Interrupt Rating, *n.*

Determined under standard conditions, the "interrupt rating" specifies the maximum amount of current a protective device can cut off **safely** … i.e. without harm to personnel or resulting damage to equipment, the premises or the device itself. For example, a circuit breaker that trips "safely" successfully interrupts the fault, can be reset and will function properly afterward. To safely stop the fault current calculated for our chiller-motor scenario, the interrupt rating of the circuit breaker or fuses selected must be at least 31,400 amps.

Before leaving this topic, let's dispel a common misconception: "An overcurrent protection device with a comparatively high interrupt rating limits current to other components." **Not so** —not unless it's also a true current-limiting device as described on page 3. Even though the device successfully breaks the circuit, all components in the circuit will be exposed to the full magnitude of fault current (as well as the severe thermal and magnetic stresses that accompany it) for the time it takes the device to respond.

Withstand Rating, *n.*

Though often confused, "interrupt rating" and "withstand rating" are **not** interchangeable terms. Unlike the interrupt rating, which defines the performance limit of an overcurrent protection device (e.g. circuit breaker or fuse), the "withstand rating" is a performance limit for an **enclosure**. In other words, it identifies the maximum short-circuit amperage an enclosure can contain without injuring personnel or damaging the premises.

Underwriters Laboratories Inc. (UL) defines the short-circuit test methods and parameters for HVAC equipment. Essentially, the test subjects an enclosure to the recommended current, i.e. 4,000 amps if the unit RLA exceeds 40 amps and 3,500 amps if it's less. If the doors blow open or if it emits flames or sparks, the enclosure fails the test. For those that pass, it's "acceptable"—even probable—that the internal components will be damaged beyond repair. Given the destructiveness and expense of this test, it's not surprising that most manufacturers prefer not to pursue higher-than-normal short-circuit withstand ratings for their equipment unless there's a documented need.

Recall that when a fault occurs, all components in the circuit experience the brunt of the short circuit until it's stopped. Therefore, it's important to assure that all components "at risk" can withstand a fault condition without causing injury or damaging the surroundings. The National Electric Code (NEC) states this requirement in Section 110-10, "Circuit Impedance and Other Characteristics":

The overcurrent protective devices, the total impedance, the component short-circuit withstand ratings, and other characteristics of the circuit to be protected shall be selected and coordinated to permit the circuit protective devices used to clear a fault to do so without extensive damage to the electrical components of the circuit. This fault shall be assumed to be either between two or more of the circuit conductors, or between any circuit conductor and the grounding conductor or enclosing metal raceway.

Commentary in the *1996 National Electrical Code® Handbook* further explains Section 110-10:

Overcurrent protective devices (such as fuses and circuit breakers) should be selected to ensure that the short-circuit withstand rating of the system components will not be exceeded should a short circuit or high-level ground fault occur.

System components include wire, bus structures, switching, protection and disconnect devices, distribution equipment, etc., all of which have limited short-circuit ratings and would be damaged or destroyed if these short-circuit ratings are exceeded. Merely providing overcurrent protective devices with sufficient interrupting ratings will not ensure adequate short-circuit protection for the system components. When the available short-circuit current exceeds the withstand rating of an electrical component, the overcurrent protective device must limit the let-through energy to within the rating of that electrical component.

To comply with this section of the NEC, all of the component selections in our chiller-motor scenario must be based on a minimum short-circuit withstand rating of 31,400 amps … a requirement well above UL's standard ratings.

Current Limiting, *n.*

All components and wiring in an electrical distribution system offer some degree of resistance. Under normal conditions, the heat produced when current flows against this resistance readily dissipates to the surroundings. However, the enormous current generated during a short circuit produces damaging heat at a much faster rate than can be safely dispersed. Interrupt the current and you stop adding heat to the system.

As Figure 2 suggests, time is a critical determinant of the amount of heat (energy) added. An electrical short that lasts three cycles, for example, adds six times the energy of one lasting just one-half cycle. It's in this sense that all circuit breakers and fuses "limit" current.

Figure 2 also shows the effect of a current-limiting device. To be truly **current-limiting**, the interrupting device must open the circuit within one-quarter cycle (1/240 second), i.e. before the fault current peaks.

Remember our chiller-motor scenario? If there's no starter available with a short-circuit withstand rating greater than 31,400 amps, compliance with NEC Section 110-10 requires that we either:

- Add a current limiting device, i.e. usually a fuse, but sometimes a circuit breaker and fuse in series, that restricts the fault current to a value less than the starter's short-circuit withstand rating. Or …
- Redesign the electrical distribution system to reduce the fault current. Choosing this approach warrants a more detailed fault-current analysis.

Summary

Protecting HVAC equipment is a critical element of electrical distribution system design. Proper selection and coordination of overcurrent protection devices should occur early in the design process, and should address both normal operation and fault conditions.

Occasionally, the calculated fault current exceeds the short-circuit withstand ratings of available starters. Such cases require adding an appropriate current-limiting device or redesigning the electrical system to reduce fault current.

The fault-current analysis in the chiller-motor scenario consisted of a simplified, worst-case calculation. While this is often sufficient to select system components, a number of factors demand more detailed analysis. To learn more, refer to The IEEE Buff Book: *Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems* published by The Institute of Electrical and Electronics Engineers, Inc. ■

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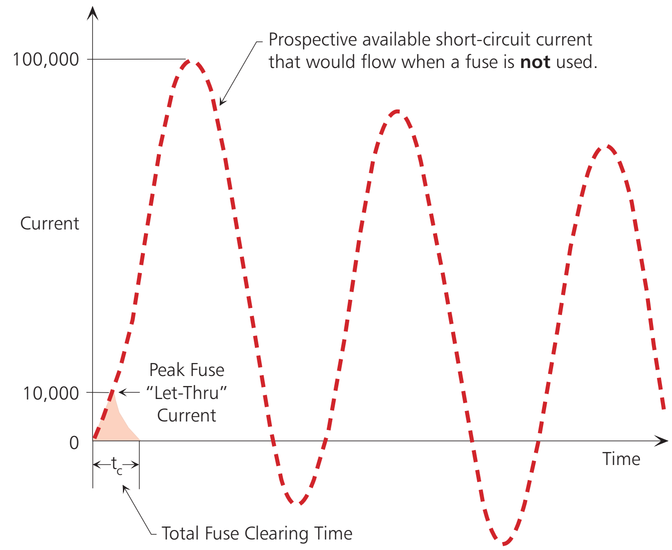
If you'd like to comment on this article, send a note to The Trane Company, Engineers Newsletter Editor, 3600 Pammel Creek Road, La Crosse WI 54601, or to www.trane.com.

Figure 2



A publication of
The Trane Company
Worldwide Applied Systems Group
La Crosse, WI 54601-7599

Sharing Insights About HVAC System Design …

The Engineers Newsletter

" … HVAC is more than a rule-of-thumb business. It requires a high level of education and knowledge for one to be effective and efficient in this business."

We received this comment from one of nearly 1,200 *Engineers Newsletter* readers who responded to the survey issued at the beginning of the year. It aptly states the logic behind the *EN's* mission **to provide HVAC system designers and engineers with reliable, technologically current information in an "easy-to-digest" form.**

The survey responses received so far (summarized below, right) provide a snapshot of how readers perceive the *Engineers Newsletter.* If these results and the comments that accompanied them represent the entire *EN* readership, then the publication is fulfilling its mission.

Looking Back …

Last year marked the silver anniversary of the *Engineers Newsletter.* If you're new to the publication, here's a bit of background.

What Is It? The *Engineers Newsletter* is a free, 4- to 8-page periodical published several times each year. Each edition tackles a specific, timely issue related to commercial HVAC system design. The "ad-free" discussion is concise and supported with illustrations and case studies. (The last page is usually reserved to promote a new product, service or system concept.)

Who Publishes It? The Trane applications engineering team oversees publication of the *Engineers Newsletter*, carefully selecting topics based on relevance and timeliness. Material is gleaned through frequent contact with customers and professionals in the HVAC industry, as well as from technical experts within and outside the Trane organization.

How's It Distributed? Most of the 40,000 recipients receive their copy of the *Engineers Newsletter* by mail, courtesy of their local Trane commercial sales office. Electronic versions are posted on the Web at **www.trane.com**, too.

Looking Ahead …

We appreciate your interest in the *Engineers Newsletter* and extend a special **thank you** to those who completed the reader survey.

If there's a topic you'd like us to tackle in a future *EN,* let us know. We value your suggestions and comments. Send them via e-mail to bbradley@trane.com or to The Trane Company, Attn: Applications Engineering, 3600 Pammel Creek Road, La Crosse, WI 54601-7599. ■

EN Readers Respond …

■ How do you usually receive this newsletter?	**93**% by mail **2**% delivered by my Trane rep **2**% from the Trane Web site **3**% other
■ How would you prefer to receive it?	**90**% by mail **6**% by e-mail **2**% delivered by my Trane rep **1**% from the Trane Web site **1**% other
■ Do you read the *Engineers Newsletter?*	**72**% yes, in detail **29**% yes, I skim it **0**% no
■ Do the topics covered interest you?	**100**% yes **0**% no
■ In general, how would you describe the level of detail that's provided?	**93**% just right **4**% too little **3**% too much
■ How do you use this publication? *(Check all that apply.)*	**87**% as a technical reference **48**% as a source for innovative design ideas **14**% to develop specifications **32**% for personal or in-house training **37**% for problem-solving
■ What is your job title?	**56**% design engineer **1**% architect **7**% contractor **12**% project manager **9**% facility manager **1**% building owner **14**% other