providing insights for today's hvac system designer
ENGINEERS NEWSLETTER
volume 51-1
March 2022

Short-Circuit Current Rating Refresher

Short-circuit current rating (SCCR) is not a new topic, but does require careful consideration, and can often result in confusion if the fundamentals are not understood. The National Electrical Code®(NEC)[1] applies to all equipment, while UL 1995[2] applies to listed equipment. Since 2005, both require that most HVAC equipment be marked with a short-circuit current rating, making it much easier for code officials to verify compliance. In 2017 the NEC requirement was expanded to include nearly all air conditioning and refrigeration equipment.

This EN provides an overview of the topic and industry terminology while offering practical solutions to common SCCR design challenges.

Defining SCCR

Short-circuit current rating (SCCR), previously known as short-circuit withstand rating (SCWR) until 1999, is an important consideration to determine if components or equipment can be safely applied in an electrical distribution system. Though SCCR has been a codified design consideration since the 1970s the requirements surrounding it have continued to evolve as understanding increases and with the availability of higher rated components.

The issues surrounding short-circuit current ratings were covered in two earlier newsletters published in 1998[3] and 2012[4]. Since the terminology can be confusing, several key terms surrounding this issue must be addressed: short-circuit, fault current, interrupt rating, short-circuit current rating, and current-limiting.

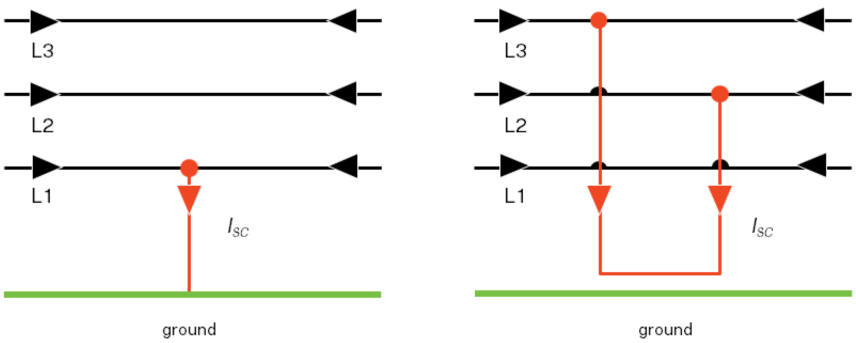
Understanding these terms and applying them correctly is fundamental to designing safe, reliable electrical distribution systems.

Terminology

SHORT-CIRCUIT

A short-circuit, or more commonly a "short," is a fault condition caused either through installation error or failure in which conductors are connected either together (phase-to-phase short) or to ground (phase-to-ground short). This creates a dangerous situation where unregulated current can flow through the shorted connection unimpeded for a brief time. During this fault condition, current levels can reach such a high magnitude that dissipation of heat and destructive magnetic fields can become an issue.

Figure 1. Three-phase power system



The left-hand image shows a three-phase power system with phase-to-ground short-circuit between the L1 conductor (phase A) and ground.

The right-hand image shows a phase-to-phase short-circuit in the three-phase power system where the L2 (phase B) conductor and the L3 (phase C) conductor are connected. In both cases the current bypasses the load (motor, compressor, etc.) and flows unimpeded.

Wiring and components in the electrical system are sized based on full load conditions. When handling full load current in typical operation the amount of heat generated by the internal resistance of the components is low enough that it can be easily dissipated into the surrounding environment. The high-fault current, even if brief, can generate such extremely high levels of heat in the conductors and components that they may melt or explode. These increased fault current levels can generate powerful magnetic forces capable of damaging conductors and components.

In this discussion, assume that any short-circuit is a “bolted” short—a zero resistance connection as though the conductors were securely bolted together—rather than wires merely touching. This will simplify the analysis, avoiding any issues of heating or resistance at the short.

FAULT CURRENT

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 wiring, and the supplying transformer limit 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 proper size and type of circuit breakers and fuses helps to ensure 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 the fault current is prerequisite to selecting appropriate breakers, fuses, and equipment. Since the transformer is the source of the fault current, and directly effects the maximum value, the calculation begins with the service transformer supplying the equipment. Using the transformer details, such as rated capacity and internal impedance, the maximum fault current can be determined using Equation 1 below.

$$I_{sc} = \frac{Transformer\ Rating\ (in\ VA)}{\sqrt{3}\ \times\ Voltage\ \times\ Percent\ Impedance}$$

As transformers trend toward higher energy efficiency, their impedance must naturally be reduced to minimize internal losses. As seen in Equation 1, a lower impedance results in a higher potential fault current. Additionally, larger transformers deliver higher fault currents—which can result in high available fault current—even for small equipment. This reinforces the importance of carefully evaluating the SCCR requirements for equipment of all sizes.

The amount of fault current that is possible in any part of the electrical system is affected by the impedance of wiring and other components as well as any current limiting devices between the service transformer and the location of the short. The “available fault current” is the highest fault current that is possible at a point on the system during a short.

The available fault current at each equipment location varies drastically as installation sites change. It can be advantageous to leverage the reduced available fault current at these locations to more accurately specify the equipment SCCR requirements. However, the details needed to calculate the reduced fault current can be daunting when many locations must be considered.

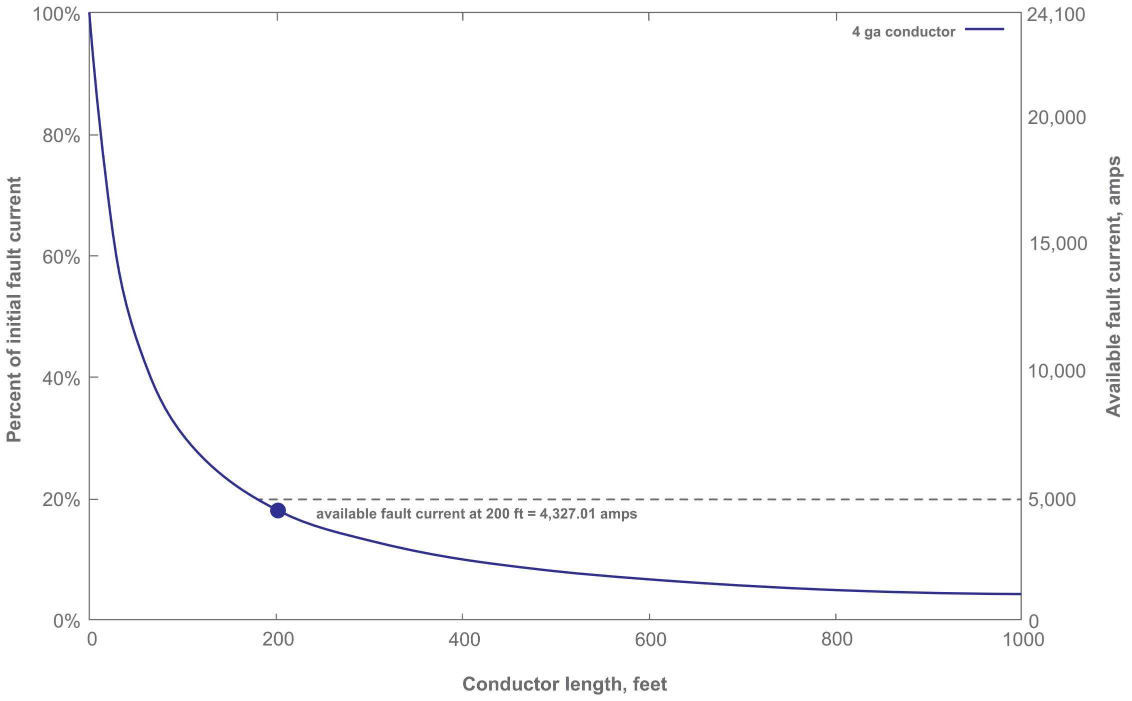
The most common simplified approach assumes negligible wire length between the transformer and the equipment. It can then be assumed the full fault current of the transformer is available to the equipment. This conservative simplification errs on the side of safety and is acceptable in most cases, but can lead to higher SCCR requirements than necessary for some equipment in the system.

Consider an example of a packaged rooftop unit with a minimum circuit ampacity (MCA) of 80 amps being supplied by a 500kVA, 480V transformer with an impedance of 2.5 percent. Using Equation 1 and the transformer details, determine the maximum fault current from the transformer. Note the necessary conversions.

$$I_{sc} = \frac{1000 \times 500kVA}{\sqrt{3} \times 480V \times (2.5\% \div 100)} \approx 24{,}100\ amps$$

For a more detailed analysis, consider the impedance of the wiring to the equipment. Figure 2 shows how a particular conductor can reduce the available fault current over its length. Ignoring other factors, this conductor length alone has a dramatic effect. In the example, 200 feet is enough to reduce the available fault current from 24,100 amps to less than 5,000 amps (4,327 amps). The reduction in available fault current varies with the installation details, type, and size of the conductors used, which requires it be calculated for each situation. Despite the large reduction in available fault current to consider, collecting the parameters for this detailed level of analysis can be an unwieldy amount of work for a large building, so it may be best reserved for cases where the available fault current limits equipment selection or availability.

Figure 2. Available fault current over line length (24,100 amp source fault current, 4 gauge THHN stranded copper conductors installed in metallic conduit)



The example above shows a reduction in available fault current with 4 ga conductor length with a 24,100 amp source fault current. Reduction in fault current is specific to conductor and installation details and can not be used as a generalization.

INTERRUPT RATING

Determined under standard conditions, the "interrupt rating" (also known as "ampere interrupt capacity" or AIC rating) specifies the maximum amount of current a protective device can safely cut off - i.e., without harm to personnel, 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. For the rooftop example, the interrupt rating of the circuit breaker or selected fuses must be 24,100 amps or greater to safely stop the fault.

A common misconception. Before leaving this topic, a common misconception must be dispelled: "Using an overcurrent protection device with an interrupt rating greater than the fault current is all that is required to satisfy the short-circuit code requirements." **Not so** - not unless it's also a true current-limiting device as described in the "Current Limiting" section of this newsletter (page 5). Even though the device successfully breaks the circuit, all components in the circuit will be exposed to the full magnitude of the fault current—thermal and magnetic stresses—for the time it takes the device to interrupt the fault current.

SHORT-CIRCUIT CURRENT RATING

Though often used as such, "interrupt rating" and "short-circuit current 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 "short-circuit current rating" identifies the maximum short-circuit amperage (fault current) a component, control panel, or piece of equipment can experience without injuring personnel or damaging the premises. However, the rating does not require the component to be operable after enduring a fault event.

UL 508A[5] defines the methods for determining the short-circuit current rating. A standard short-circuit current rating can be determined if all the individual components in the power circuit are listed and have a certified short-circuit current rating. Essentially the component with the lowest rating sets the rating for the assembly. A higher rating can be given by testing a current-limiting short-circuit interrupt device (e.g., a current-limiting breaker or fuse) in combination with the panel components or by using pretested combinations of components. Due to the high cost of testing HVAC equipment, manufacturers commonly use pretested combinations to provide higher short-circuit current ratings.

The short-circuit current rating of equipment or components may be dependent upon specific upstream components, current-limiting fuses for example. The requirement will be clearly indicated on the nameplate when this is the case for listed equipment.

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 ensure all ‘at risk’ components can withstand a fault condition without causing injury or damaging the surroundings. The 2020 NEC[6] states this requirement in Section 110-10, “Circuit Impedance, Short-Circuit Current Ratings, and Other Characteristics”:

> *The overcurrent protective devices, the total impedance, the equipment short-circuit current 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 equipment 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 equipment grounding conductor(s) permitted in 250.118. Listed equipment applied in accordance with their listing shall be considered to meet the requirements of this section.*

Overcurrent protective devices, such as fuses and circuit breakers, should be selected to ensure the short-circuit current rating of the system components is not exceeded if a short-circuit or high-level ground fault occurs. Any component exposed to fault currents beyond its short-circuit current rating is likely to be damaged or destroyed.

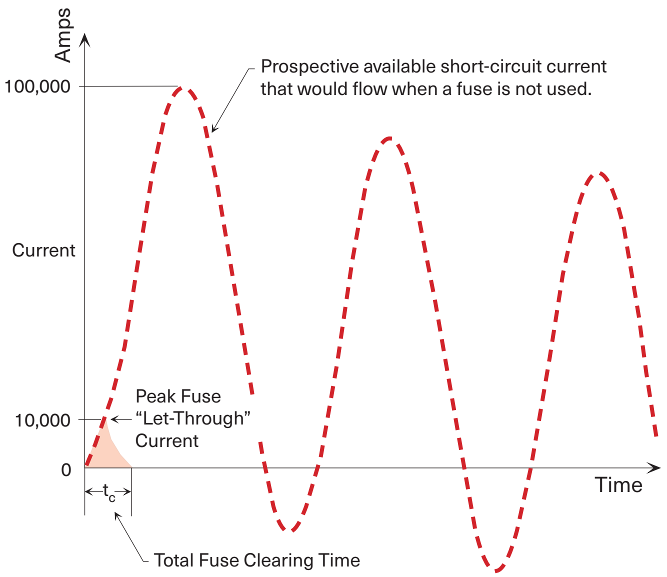
To comply with this section of the NEC, the example unit nameplate must have a short-circuit current rating of at least 24,100 amps indicating the rooftop power circuit would be able to safely withstand the fault current.

Labeling Requirements

Since 2005, NEC has required most air conditioning and refrigeration equipment to be marked with a short-circuit current rating to ensure the equipment rating meets or exceeds the available fault current. The 2017 NEC added the requirement that the available fault current be documented for air conditioning and refrigeration equipment to further improve this coordination.

The 2005 NEC included an exception to the short-circuit current rating marking requirement for all equipment with an MCA less than 60 amps. The exception caused significant confusion, leading some to believe short-circuit current rating need not be considered for equipment below 60 amps. This was never the intention of the exception. Instead, it allowed equipment with an MCA below 60 amps to use an assumed minimum short-circuit current rating (5kA) unless it was otherwise marked. To help alleviate confusion this exception was removed in the 2017 version of NEC.

Figure 3. Potential current during a fault event and let-through current of current-limiting fuse during the fault condition



CURRENT LIMITING

All components and wiring in an electrical distribution system offer some degree of resistance to current flow. Under normal conditions, the heat produced due to current flow 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 dissipated. Interrupting the current stops the addition of heat to the system.

Figure 3 shows that time is a critical determinant of the amount of energy added. Starting at time zero, the addition of current, therefore resulting energy as heat, increases quickly during a fault condition. An electrical short that lasts three cycles, for example, adds six times the energy of one lasting just one-half of a cycle. Figure 3 also shows the effect of a current-limiting device. A breaker or fuse will stop the current flow, but to be classified as current-limiting, the interrupting device must open the circuit within one-quarter cycle (1/240 second for 60 Hz, or 1/200 second for 50 Hz)[7]. Tripping quickly during a fault stops the current flow before the fault current peaks. The largest current allowed to pass through a current-limiting device before interrupting the fault is called the "let-through" current. It is a function of the devices and the available fault current and must be determined through testing.

Current-limiting devices can provide important advantages. Returning to the rooftop example, if there isn't a unit available with a short-circuit current rating greater than 24,100 amps, compliance with NEC Section 110-10 requires one of the following:

- Add a current limiting device, usually a fuse or circuit breaker, that can restrict the fault current to a value less than the unit's short-circuit current rating.
- Redesign the electrical distribution system to reduce the fault current. Typically, this is done by selecting a different service transformer, changing the service entrance equipment, or adding an isolation transformer. Choosing this approach warrants a more detailed fault current analysis.
- The more detailed available fault current calculation, including conductor impedance, would be warranted here. As shown in Figure 2 including this additional impedance can greatly reduce the available fault current and thus the required short-circuit current rating of the equipment. This calculation must be documented to ensure proper coordination can be confirmed by the electrical inspector.

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 current rating listed on the nameplate of the equipment. Such cases require adding an appropriate current limiting device or redesigning the electrical system to reduce available fault current.

The fault current analysis in the rooftop unit scenario consisted of a simplified, worst-case calculation. While this is often sufficient to select system components, a more detailed analysis including additional circuit impedance may be justified.

To learn more, refer to The IEEE® Buff Book: *Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems*[8] published by The Institute of Electrical and Electronics Engineers, Inc.

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References

[1] National Fire Protection Association. 2020. NFPA 70. *National Electrical Code Handbook*. 2020 ed. Quincy, MA: NFPA.

[2] Underwriters Laboratories Inc. 2015. UL 1995. *Standard for Safety: Heating and Cooling Equipment*. 5th ed. Northbrook, IL: UL.

[3] Guckelberger, D. and Bradley, B. 1998. "Protecting the Electrical Distribution System… Short-Circuit Withstand Ratings Demystified." Trane Engineers Newsletter, 27-3.

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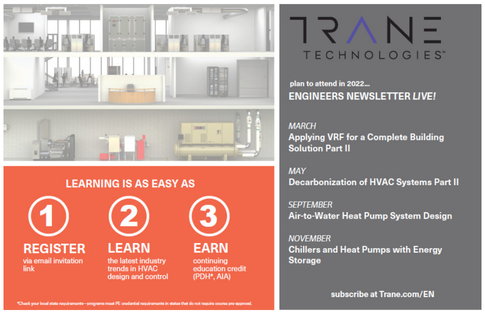
[8] The Institute of Electrical and Electronics Engineers. 2001. IEEE Standard 242-2001. *The IEEE Buff Book: IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems.* New York, NY: IEEE.



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MARCH

Applying VRF for a Complete Building Solution Part II. This program builds on the December 2020 ENL that covered variable refrigerant flow systems. This program will dive deeper into the topic of integrated controls and will review energy modeling software tips and tricks unique to VRF. We will also discuss the concept of applied VRF systems which combine traditional system concepts while using refrigerant in lieu of water as well as a brief review of several applicable requirements from ASHRAE® Standards 62.1-2019 and 90.1-2019.

MAY

Decarbonization of HVAC Systems Part II. In this program we will look at potential electrification solutions for three different applications; small office, K-12 school, and a healthcare facility. We will model these electrification solutions for locations across the country, provide outputs related to energy and emission reductions, and compare different electrified designs against traditional gas heating solutions.

SEPTEMBER

Air-to-Water Heat Pump System Design. Building on the previous two Decarbonization of HVAC Systems ENLs, this program will cover electrified building heating systems utilizing air-to-water heat pumps. Topics covered will include operating characteristics of air-to-water heat pump equipment, system load and unit sizing considerations, system hot water design temperature considerations, system configurations and options including heat recovery, storage and auxiliary heat, as well as system control considerations.

NOVEMBER

Chillers and Heat Pumps with Energy Storage. Adding energy storage to buildings not only saves energy, energy costs and water, but it also saves carbon. In this program we will revisit the benefits and techniques for incorporating thermal energy storage for cooling. In addition, we will explore ways to use storage to minimize the impact that decarbonization of buildings and electrifying heat are expected to have on energy costs.

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2022 Marks the 50-Year Anniversary of the Trane *Engineers Newsletter*!

We have launched a monthly blog series celebrating the 50th Anniversary of the Trane Engineers Newsletter. Each month, the blog features a different systems topic, authored by our outstanding Applications Engineering team members.

The second week of each month, the latest article will be shared on the Trane blog and by the brand's social media channels. Below you'll find the complete list of topics you can expect in 2022!

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