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# TechTopics No. 58

## What is the difference between E-rated and R-rated current-limiting fuses?

In medium-voltage motor control equipment with NEMA Class E2 controllers, current-limiting fuses are used in series with the main vacuum contactor. The vacuum contactor is intended to switch only load-or low-level fault currents, and cannot withstand the full short-circuit current of the system without protection. The function of the vacuum contactor is to switch the load many times. The load is most often a motor, where the vacuum contactor is intended to switch the normal, full-load current as well as the locked-rotor current of the machine. The load is also frequently a power transformer, where the vacuum contactor must withstand magnetizing inrush current, switch the normal continuous current of the transformer, and switch moderate overload and low-level fault currents. The major function of the current-limiting fuses is to protect the vacuum contactor against short circuits.

The fuses must be selected to protect the vacuum contactor, coordinate with the overload relay, and must also have appropriate characteristics to protect the connected load for currents higher than those handled by the vacuum contactor. The characteristics needed to properly protect a rotating machine are different from those required to protect a power transformer, so fuses tailored to the protection needs have been developed.

ANSI/IEEE C37.46 defines the performance requirements for medium-voltage current-limiting fuses. A few of the defining requirements follow.

### E-rated fuses

Melting time-current characteristics:

- For fuses rated  $\leq 100$  A, melting time shall be 300 s for a current in the range of 200 percent to 240 percent of the continuous current rating of the fuse.
- For fuses rated  $> 100$  A, melting time shall be 600 s for a current in the range of 200 percent to 264 percent of the continuous current rating of the fuse.

### R-rated fuses

- The fuse shall melt in the range of 15 s to 35 s at a current of 100 times the R number.

The standard adds that R-rated current-limiting type fuses are backup type fuses for use in high-voltage motor starters to increase the interrupting rating of the combined package (series rating).

It is apparent that the requirements for the time-current characteristics for E-rated and R-rated fuses are totally different from each other. Why is this, and what does it mean from the point of view of application? It goes back to the applications for which the fuses are intended.

R-rated fuses are backup type fuses (not full range) intended for motor applications. These fuses are designed with "R" numbers defined in ANSI/IEEE C37.46, which seem to bear no relation to their use. However, the key factor is their use. Let us use a typical 4R fuse for purposes of illustration. A 4R fuse must melt in 15 to 35 seconds for a current of 400 A (100 times the R number). Table 10 of ANSI/IEEE C37.46 requires that a 4R fuse have a continuous current capability of 130 A in an ambient of 40 °C. The typical application for a 4R fuse would be for a motor with a full-load current of the order of 60 A to 70 A, or around 80 A to 100 A including service factor. The locked-rotor current would be around 400 A. Thus, the standard specifies the melting time requirement for the fuse in the approximate vicinity of the locked-rotor current of the machine ( $4R \times 100 = 400$  A and  $60$  A FLA  $\times 6 = 360$  A locked-rotor current).

The sizing of the fuse may seem a bit undersized, but the fuse application must consider the effect of two consecutive starts from ambient temperature to have the same capability as the machine.

The motor overload-relay protective settings must be selected such that the vacuum contactor will perform normal switching, including switching of the full-load current and switching of the locked-rotor current. The R-rated fuse must be selected to provide some margin between time-current characteristics of the fuse and those of the motor-overload relay. Thus, the specification of the time-current characteristics of the R-rated fuse by ANSI/IEEE C37.46 is intentionally oriented to current values that are in the range of the locked-rotor current of the rotating machinery. The protection must assure that the vacuum contactor operates for load and locked-rotor currents, and the fuse operates above the locked-rotor current and for currents above the interrupting capacity of the vacuum contactor alone.

In the discussion in the preceding paragraph, the protection of the load cable is ignored, as the motor is the limiting factor in protection of the load circuit for a motor load.

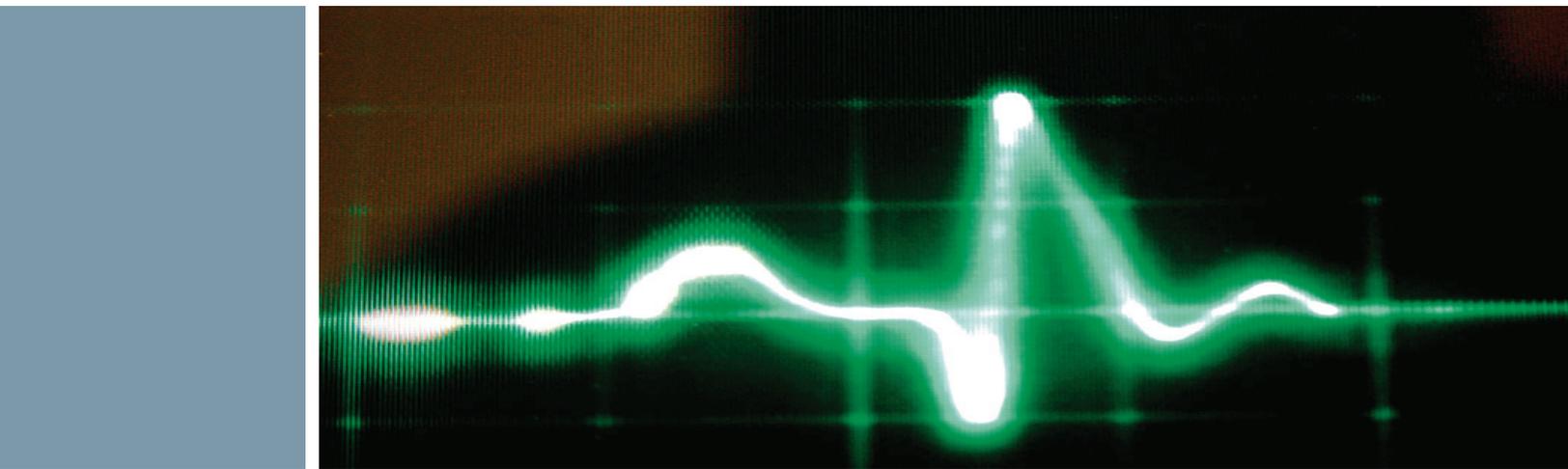
E-rated fuses, on the other hand, are not intended to provide motor protection. Instead, they are general purpose (not full range) type fuses intended primarily for transformer and load-cable protection. The limiting conditions for the load cable and for the transformer are somewhat similar, since the heating of both is a function of  $I^2t$ . The transformer is the significant element from the protection perspective, because the magnetizing current of the transformer is a fairly consistent characteristic, as is the thermal damage curve of the transformer.

The melting characteristics of medium-voltage fuses (including E-rated fuses) are a function of the particular manufacturer's design, and ANSI/IEEE C37.46 specifically recognizes that the melting time at current values above those specified in the standard will vary by manufacturer. Therefore, the standard does not attempt to specify melting times for E-rated fuses for currents that approximate the transformer inrush current/duration, nor for short-circuits. Instead, the standard focuses on moderate overload currents (220 percent to 240 percent or 220 percent to 264 percent of continuous capability, depending on the fuse size). By doing so, the standard provides a benchmark for moderate overload protection of the transformer.

Let us consider an example. An 100E fuse would probably be used for protecting a transformer with self-cooled, full-load current of around 70 A, and with a forced-cooled, full-load current in the range of 85 A to 90 A (133 percent). The 100E fuse characteristics are set by ANSI/IEEE C37.46 in the range of 220 A to 240 A (220 percent to 240 percent of continuous current capability). In turn, 220 A to 240 A corresponds to around 300 percent of the transformer self-cooled, full-load current, or about 250 percent of the forced-cooled, full-load current. Hence, the standard sets a benchmark for the E-rated fuse melting time-current characteristics in the range of small overloads of the transformer.

The standard is not really concerned with "good" overload protection of the transformer, since it recognizes implicitly that any fuse does not provide protection in the overload range that is as good as can be provided by a protective relay.

The E-rated fuse is a "general purpose" fuse, while the R-rated fuse is a "backup" fuse, as defined in ANSI/IEEE C37.40. When used on a vacuum contactor, both types of fuses are used in a backup "role," meaning that the fuse must be selected to interrupt currents that are above the interrupting rating of the vacuum contactor alone. The overload relay (for motor applications) or overcurrent relay (for transformer and mixed-load applications) must be selected and set to protect the load device, and to protect the fuse from overheating due to overload currents between the continuous current rating of the fuse and the minimum interrupting current of the fuse. The minimum interrupting current for an E-rated fuse is that current that causes the fuse elements to melt in one hour (up to 2.2 times the fuse E rating). The minimum interrupting current for an R-rated fuse is available from the fuse manufacturer (or, for Siemens equipment, published in the controller instruction manual), but is typically in the range of one time to three times the fuse continuous current rating. It should be noted that minimum interrupting current will vary by fuse type, rating and manufacturer, and the reader is advised to check the specifics of each situation.



Comparison of a particular fuse manufacturer's melting time-current curves confirms this discussion. For low currents, the melting time curves are relatively close to each other for E-rated and R-rated fuses. However, for very high currents, the melting time curve of the R-rated fuse is nearly vertical, whereas that of the E-rated fuse is much more sloped. Thus, for very high currents, the E-rated fuse more closely approximates an  $I^2t$  heating curve (applicable to cables and transformers), whereas the R-rated fuse interrupts more quickly to protect the associated vacuum contactor.

In summary, Siemens generally uses R-rated fuses for motor applications, and E-rated fuses for transformer (or combination load) applications. The characteristics of the fuses are determined in major part by ANSI/IEEE C37.46, and the standard defines fuse melting time-current characteristic requirements in terms that ultimately relate to the needs of the loads that the fuses are intended to protect.

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