

TechTopics Topic: 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 contactor. The 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 contactor is to switch the load many times. The load is most often a motor, where the 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 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 contactor against short-circuits.

The fuses must be selected to protect the 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 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.

IEEE Std C37.46 defines the performance requirements for medium voltage current-limiting fuses. A few of the defining requirements are:

E-Rated Fuses:

Melting Time-Current Characteristics:

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

R-Rated Fuses:

- The fuse shall melt in the range of 15-35s 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 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 15-35 seconds for a current of 400A (100 times the R number). Table 10 of C37.46 requires that a 4R fuse have a continuous current capability of 130A 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 60-70A, or around 80-100A including service factor. The locked rotor current would be around 400A. Thus, the standard specifies the melting time requirement for the fuse in the approximate vicinity of the locked rotor current of the machine ($4R \times 100 =$

400A). 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 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 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 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 contactor alone.

In the discussion in the preceding paragraph, I ignore protection of the load cable, 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 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 (220-240% or 220-264% 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. A 100E fuse would probably be used for protecting a transformer with self-cooled full load current of around 70A, and with a forced-cooled full load current in the range of 85-90A (133%). The 100E fuse characteristics are set by C37.46 in the range of 220-240A (220-240% of continuous current capability). In turn, 220-240A corresponds to around 300% of the transformer self-cooled full load current or about 250% 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 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 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 2.2x the fuse E rating). The minimum interrupting current for an R-Rated fuse is available from the fuse manufacturer (or, for our equipment, published in the controller instruction manual) but is typically in the range of 1x to 3x 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 contactor.

In summary, we generally use 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 IEEE Std 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.

T. W. (Ted) Olsen
Manager, Technology