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High-voltage fuses - expulsion (power) and current-limiting types

Fuses are commonly used in medium-voltage and high-voltage distribution systems, as they offer relatively inexpensive overcurrent protection and do not require control power to operate. In utility distribution systems, these fuses are almost always of the expulsion (power) type. In industrial distribution systems, these fuses are more often of the current-limiting type. This issue of TechTopics discusses the two broad types of fuses for medium-voltage applications.

Expulsion (power) fuses

The expulsion fuse is perhaps the oldest fuse design for medium-voltage applications, with its first application in approximately 1910. A power or expulsion fuse is a fuse that vents exhaust gases during the interruption process. These fuses are often called boric-acid fuses, and the fuse uses boric acid for interruption. The short-circuit current flowing through the fuse causes the melting of a current-carrying component, and hence, the formation of an arc.

The fuse usually includes a spring to move the severed current-carrying part away from the fixed terminal, elongating the arc and exposing the arc to a greater portion of the fuse body. The arc acting on the internal materials in the fuse creates a chemical reaction in which the boric acid is converted to exhaust products, primarily water vapor, which is expelled through the fuse-venting system. The water vapor de-ionizes the arc gases, so that the arc does not reignite after the following current zero.

The arc voltage of the fuse is quite low, so the fuse does not limit peak current. The fuse interrupts, generally at the first current zero following arc initiation. For use in metal-enclosed switchgear, the fuse includes a means of exhaust gas control, which may be known as a filter, a condenser, or by other terms. The function of the filter is to reduce the amount of contaminants released, particularly, the amount of water vapor released. In effect, the filter virtually eliminates concerns about the exhaust gases.

The exhaust of gases from the fuse does not deteriorate the switch assembly, as the design tests include tests with the maximum fuse size to demonstrate that fuse operation does not cause failures (such as flashovers) in the switch enclosure.

The fuse is reusable, as the internal fuse link is replaceable, and the fuse link is a fraction of the cost of the complete fuse and fuse holder.

Expulsion fuses have higher continuous-current ratings than most current-limiting fuses. A single barrel fuse can extend to 400E at 5 kV or 15 kV, and when paralleled, can extend to 720E (2 x 400E x 90 percent = 720E) without an increase in the size of the switch enclosure.

Current-limiting fuses

A current-limiting fuse operates on a somewhat different principle. The fuse has a current-carrying element, often of copper or silver, with geometry carefully controlled so that when the current-carrying element melts, it does so at multiple spots along its length, creating a series of arcs along the length of the fuse. The current-carrying element is surrounded by silica sand. When exposed to the arc, the sand is converted to a form of glass, which has high insulating properties. Because there are multiple arcs in the fuse, the resulting arc voltage is quite high. This significantly reduces the fault-current magnitude and the high arc voltage prevents re-ignition of the arc following the current zero.

The current-limiting fuse therefore limits the peak current allowed through the fuse to a lower value than if the fuse were not present, hence, the term “current-limiting”. This has a number of advantages, the most significant being that it allows use of equipment on systems with higher short circuit than would be possible without fusing.

However, the current-limiting fuse also has limitations. First, they generally are limited in the continuous current ratings, typically to 300E for 15 kV fuses. They also generate heat during normal operation, which must be dealt with in the design of the enclosure. And, the fuse itself is relatively costly, and when it operates, the entire fuse must be replaced.

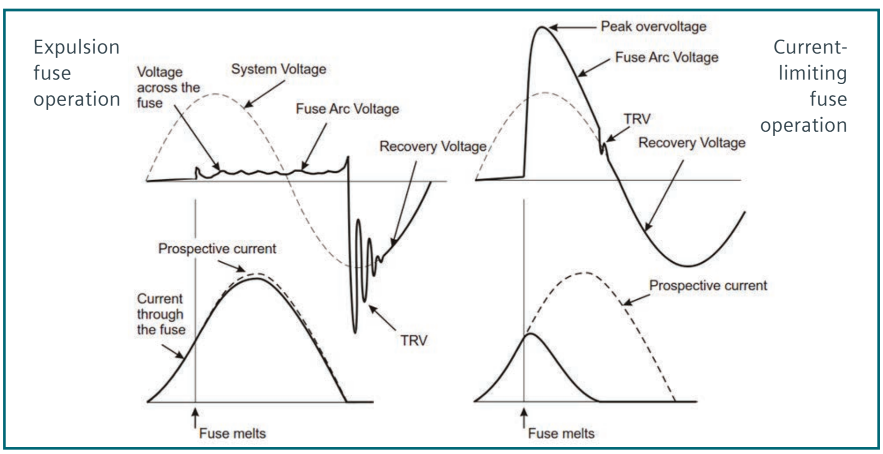
Interruption in expulsion and current-limiting fuses

The difference in the interrupting process of expulsion and current-limiting fuses is perhaps best illustrated using some information contained in IEEE Std C37.48.1, shown below:

In the illustrations, the prospective current is the current that would flow if the fuse were not present.

In the left-hand illustration, the operation of an expulsion fuse is shown. For short-circuit currents, the fuse element melts early in the cycle, but the resulting arc voltage in the fuse, as shown in the top portion of the illustration, is quite low. Because the arc voltage is very low, the arc does not affect the fault current to an appreciable degree. The fault current continues to flow up to the next current zero, at which current interruption is complete.

In the right-hand illustration, the operation of a current-limiting fuse is shown. As with the expulsion fuse, the fuse element melts early in the cycle, but the resulting arc voltage in the fuse, shown in the top portion, is large. The arc is essentially a resistive impedance, and this causes the current to be considerably reduced from the prospective current. The effect of the large arc voltage is to limit the peak current that results, and to reduce the duration of current flow.



Footnote:

1. IEEE Std C37.48.1-2011, clause 4.5, figure 2.

The current limitation action is highly significant for equipment design. The peak-withstand current of an assembly determines the required mechanical strength of the assembly, including bus supports. The force imposed between conductors is a function of the square of the first peak of a short-circuit current. In the absence of the current-limiting fuse, the peak current can be as much as 2.6 times the symmetrical current (e.g., 130 kA for an application on a 50 kA system).

However, using a 300E 15 kV fuse as an example, the peak let-through current on a 50 kA (symmetrical) system is limited to 40 kA peak. Since force is related to the square of the peak current, the force between conductors is reduced by a factor of approximately $(40^2/130^2)$, or about 10 percent of the force that would be imposed between conductors if the fuse were not present.

For fuses with higher continuous current rating, the current-limiting effect is not as great. For example, using a 5.5 kV 600E fuse, the peak let-through current on a 50 kA (symmetrical) system is about 101 kA, so the force between conductors would be reduced to $(101^2/130^2)$, or about 60 percent of the force that would be imposed between conductors if the fuse was not present.

Design tests

Regardless of fuse type, the load-interrupter switch design tests include short-circuit tests with fuse interruption at the worst-case conditions of fuse characteristics, to demonstrate that the combination of fuse and interrupter switch performs as required by the applicable standards.

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