

CASE STUDY

# Current-limiting fuse arc voltage and its role in reducing voltage dips



Industry: Electrical utility  
 Challenge: Reduce voltage dips  
 Product: Hi-Tech® current-limiting fuses

**Abstract:**

When a fault occurs on a power system, all customers in an affected area will experience a drop in voltage for the duration of the fault. Faults occurring on the primary side of step-down transformers produce the largest effect, although transformer secondary faults (through faults) will also have an effect. For the purposes of this discussion, only primary faults will be considered. For a line-to-ground fault, the line voltage at the site of the fault will drop to ground voltage (for a fully grounded system, essentially zero), with any slight voltage produced by the fault impedance. For a line-to-line fault, the voltage change could be even more significant. At the instant the fault occurs, increased current begins to flow through the fault circuit impedance. This impedance is distributed through the system and includes line inductance and resistance, as well as substation transformer impedance. The circuit is predominantly inductive, and so the rate of change of current through the inductance provides the voltage to oppose the system voltage in limiting the fault current rate of rise. System voltage is, therefore, distributed through the system from normal voltage to lower voltage, and a tap-line situated at a point where half the fault circuit impedance was on the source side and half on the load (fault) side would experience a 50 percent reduction in voltage for the duration of the fault.

If the fault has to be cleared by a circuit breaker, all customers connected to the substation transformer feeding the fault will experience a voltage drop until it clears, possibly for as long as six cycles. If an expulsion fuse clears the fault, shorter operation is possible; at relatively high currents, clearing in as little as one loop can occur (typically 8–14 ms). Because expulsion fuses produce little voltage while they arc, they do not significantly affect the magnitude of the voltage dip, only its duration (just as they do not limit the magnitude of the fault, only its duration).

**Solution:**

The use of current-limiting fuses has a much greater effect on reducing voltage dips. To see why this is so, the interrupting performance of a current-limiting fuse must be examined. Figure 1 shows a current-limiting fuse and an expulsion fuse operating on a moderately high fault current (about 5000 A for a 100 A fuse). When an expulsion fuse melts (Figure 1b), an arc is produced. However, because the arc is relatively short and unconfined, little voltage appears across the fuse (“arc voltage”) until a natural current zero occurs when the circuit TRV appears across the “gap” in the fuse. If the gap is sufficiently de-ionized, the arc will not re-ignite, the current flow is interrupted, and system voltage returns to normal (for the fuse, called “recovery voltage”). The low arc

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01 Figure 1  
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02 Figure 2

voltage does not significantly reduce the value of the first peak of fault current; hence, this type of fuse is also called “non-current-limiting.”

When a current-limiting fuse melts (Figure 1a), multiple arcs are produced in a long element confined in quartz sand. This introduces a significant resistance in the circuit, and voltage quickly rises across the fuse. When this arc voltage equals the system voltage, the  $di/dt$  in the fault circuit (which has been providing the opposing voltage-to-system voltage during the fuse melting time) is zero; that is, the current has stopped rising and is, momentarily, at a constant value (peak current).

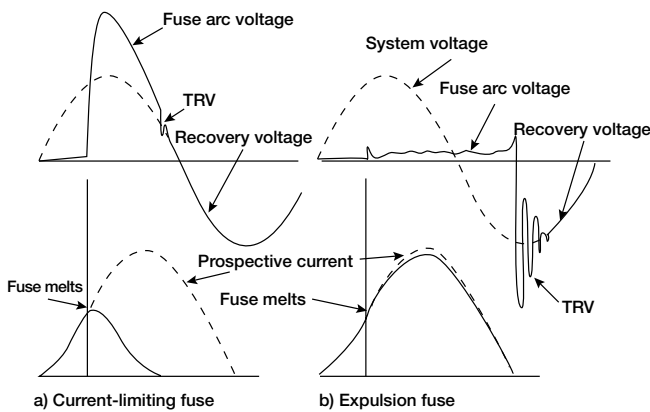
The voltage across the fuse continues to rise as the arcs continue to get longer and the fuse resistance continues to increase; peak arc voltage is limited to about 2.2 times the system peak by standards. During the time the arc voltage exceeds the system voltage, the current decreases with a  $di/dt$ , such that the excess of arc voltage over system voltage is matched by voltage developed in the fault circuit inductance (which now opposes the decrease in current). This is illustrated in Figure 2. The fuse quickly forces the current to zero, well before the natural current zero. The fuse resistance has changed a predominantly inductive circuit into a predominantly resistive circuit. From the perspective of voltage dips, the instant that the fuse arc voltage equals the system voltage

(very shortly after melting occurs), the fault has no effect on dragging down system voltage. In fact, for the remaining few milliseconds of arcing, system voltage is elevated due to the fuse arc voltage, which is distributed around the fault circuit inductance.

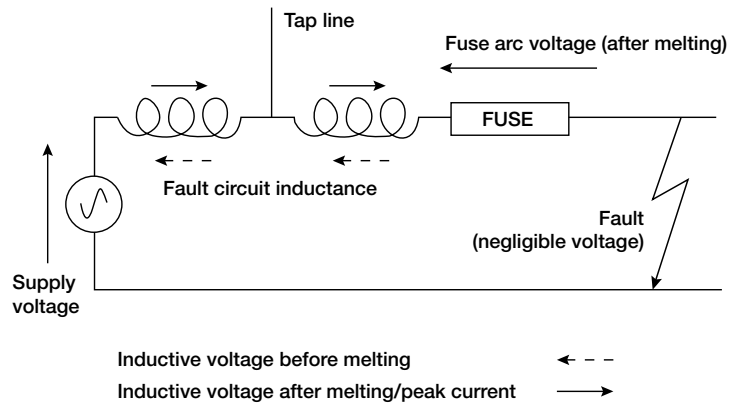
**Conclusion:**

A current-limiting fuse reduces the duration of a voltage dip on the system to its melting time, plus the fraction of a millisecond it takes for the fuse arc voltage to equal the system voltage. One feature of a fuse is that the higher the current, the faster it melts, as there are virtually no mechanical aspects involved in its melting process. The higher the fault current (and, therefore, likely the greater the number of customers affected), the shorter the dip duration will be.

Contact your local agent for more details about this application or on how your system protection can reach the next level with Hi-Tech expertise and current-limiting fuse products.



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