

## TechTopics No. 35

### Transient recovery voltage

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In reviewing specifications, misconceptions and misstatements concerning the concept of transient recovery voltage are often seen.

A typical example of a well-intended but misguided specification requirement:

**Example 1:**

Each circuit breaker shall meet the related required transient voltage withstand capabilities as described by paragraph 5.9 of IEEE C37.04. Manufacturer shall provide test data on maximum transient voltage surge created by circuit breaker.

Transient recovery voltage (TRV) is defined in the "IEEE Standards Dictionary: Glossary of Terms & Definitions" (formerly known as IEEE Std 100) as "the voltage transient that occurs across the terminals of a pole of a switching device upon interruption of the current."

Thus, transient recovery voltage is the voltage to which the circuit breaker terminals are exposed following interruption. For a vacuum circuit breaker, this is the voltage that will appear across the vacuum interrupter, and which it must withstand in order to sustain an interruption.

Figure 1 may be used to discuss the concept of TRV, and to illustrate where TRV comes from. The circuit shows the elements of a power system that are relevant to TRV.

On the source side of the circuit breaker, there is a source of system voltage, producing a sinusoidal voltage at system frequency. Also on the source side are the system inductance  $L$  and the capacitance in the vicinity of the circuit breaker. This capacitance  $C$  is shown as a line-to-ground value, as this is most relevant to TRV discussions. Capacitances remote from the circuit breaker are not of great significance relative to TRV.

The fault being interrupted is located close to the circuit breaker terminals. A close-in fault is used for this discussion, as this is considered to produce the most severe TRV condition.

With a fault located immediately adjacent to the circuit breaker load-side terminals, we observe that the voltage across the circuit breaker contacts following interruption will be the voltage across the capacitor. Since the fault has essentially zero impedance, the capacitance is effectively in parallel with the circuit breaker.

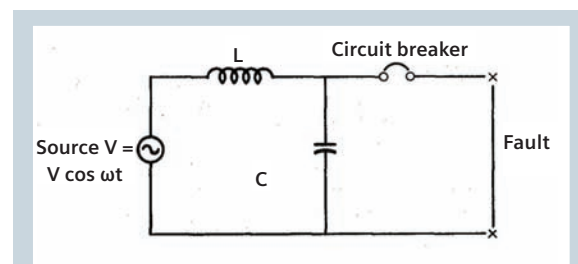


Figure 1: TRV equivalent circuit

A short-circuit current is limited by the source-side inductance  $L$ . Since the fault is essentially entirely inductive, the system voltage will be 90 degrees out of phase with the fault current. Thus, when the fault current approaches a natural current zero, the system voltage will be approaching a maximum. This is shown in Figure 2.

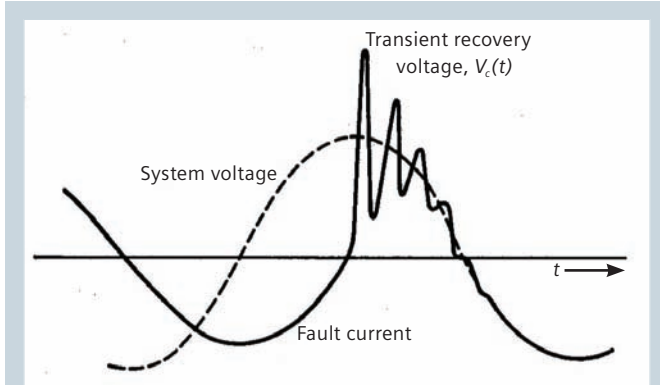


Figure 2: TRV vs. system voltage and current

After the circuit breaker contacts have parted, but prior to interruption, the voltage across the circuit breaker contacts will be equal to the arc voltage. For a vacuum circuit breaker, the arc voltage is very low, of the order of 20 to 150 volts. In turn, the arc voltage will be essentially equal to the voltage across the source-side capacitance, since the impedance of the fault is nearly zero. Thus, at the instant of interruption of current, the voltage across the vacuum interrupter and the voltage across the source-side capacitance are very low. Compared to the system voltage at this instant, the source-side capacitance voltage can be thought of as being zero.

When the fault current is interrupted by the circuit breaker, the source voltage supply will supply current to the capacitance to bring the capacitor voltage to the system voltage. The time frame of interest in discussions of TRV is very short – a few tens of microseconds. Accordingly, in this time frame, the system voltage can be thought of as a constant value at the peak of the system 60 Hz voltage. Thus, there is a very significant driving voltage to charge the capacitor.

The circuit now is a basic LC circuit, and the current in the capacitor will have a natural frequency determined by the values of  $L$  and  $C$ . For most practical applications, the natural frequency of the LC circuit will be considerably higher than the system frequency. For illustration purposes, the natural frequency of the voltage waveform for charging of the capacitor is shown in Figure 2 at a lower frequency than would exist in reality.

The system would be underdamped, meaning that the capacitor voltage will not approach system voltage asymptotically, but rather, will overshoot and oscillate around the system voltage value. Due to the small amount of damping in the system, the capacitor voltage will gradually settle down and follow the system voltage waveform.

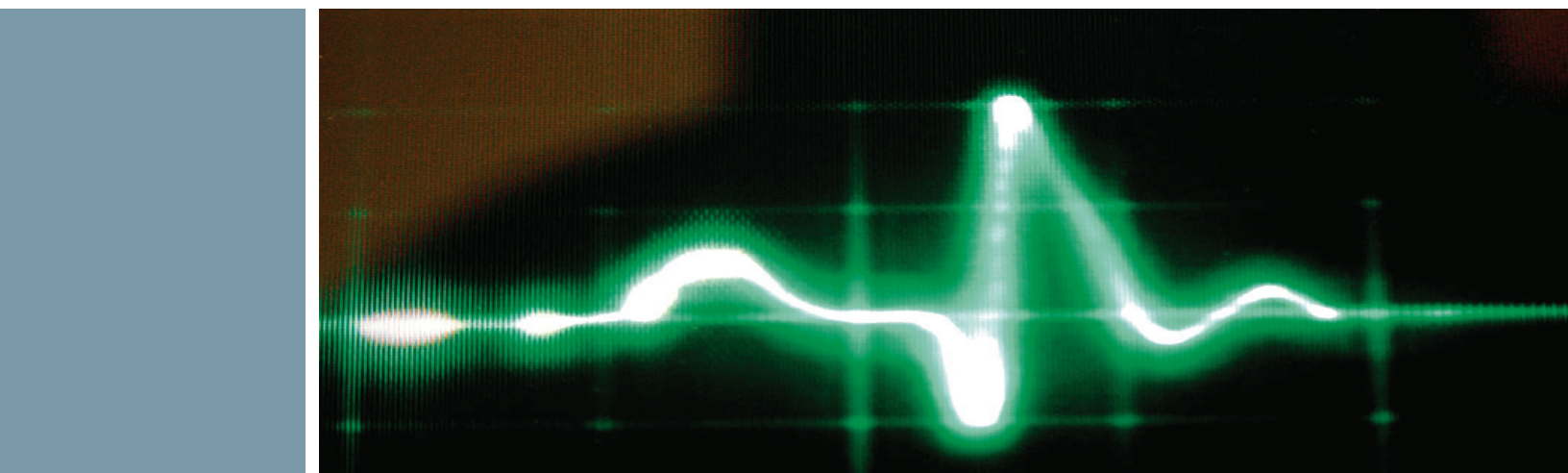
From this discussion, we can see that TRV is a function of the system parameters, primarily the source-side inductance, as well as the capacitance to ground in the near vicinity of the circuit breaker. The circuit breaker itself plays little or no role in “making” the TRV. Rather, the circuit breaker has to be able to withstand the TRV in order to sustain a successful interruption.

In this discussion, a short-circuit fault has been assumed. Moreover, while not apparent from the discussion, we have assumed a symmetrical fault interruption. The literature on TRV substantiates that the TRV associated with asymmetrical fault interruptions is less severe.

Further, we have assumed a close-in fault. In ANSI/IEEE C37.04 (refer to Figure 4 in the standard), the required TRV that a circuit breaker must be able to withstand is presented. As discussed in ANSI/IEEE C37.04 and ANSI/IEEE C37.011 (Table 1), the worst case TRV for the circuit breaker occurs at reduced fault magnitudes. The maximum TRV value that the circuit breaker must withstand is 117 percent of the TRV withstand requirement at 100 percent of rated short-circuit current. This 117 percent TRV withstand value applies at reduced fault current values of 10 percent of rated short-circuit current, as shown in ANSI/IEEE C37.06-2009, Table 3 (circuit breakers in metal-clad switchgear) or Table 7 (outdoor circuit breakers).

Interruption of load currents has not been discussed, as the resulting TRV is much lower than the TRV for fault currents. The reason for this is that switching of load currents involves relatively high power factors, typically 75 percent or higher. In the limiting case, with unity power factor, the system voltage and the current to be interrupted are in phase.

Thus, when interruption occurs, the driving voltage for charging of the parallel capacitance is near zero, and voltage transients are insignificant.



What are the typical values for medium-voltage circuit breakers? Let us consider a common 15 kV class circuit breaker for metal-clad switchgear (e.g., type GMSG) and a 15.5 kV outdoor circuit breaker (e.g., type SDV7):

		Type	
		Circuit breaker for metal-clad switchgear (ANSI/IEEE C37.06-2009, Table 3)	Outdoor circuit breaker (ANSI/IEEE C37.06-2009, Table 7)
Maximum design voltage (V)		15.0 kV	15.5 kV
At 100% interrupting current	TRV peak value $u_c$	25.7 kV	29.2 kV
	Time to peak $t_3$	66 $\mu$ s	32 $\mu$ s
At 10% interrupting current	TRV peak value $u_c$	31.2 kV	34.2 kV
	Time to peak $t_3$	15 $\mu$ s	13 $\mu$ s

When short-circuit interrupting design tests are conducted to document the performance of the circuit breaker, the test circuit in the short-circuit laboratory must be configured to produce an "inherent TRV" that is at least as severe as the values above. The "inherent TRV" of the test circuit must be at least as severe as these values in order to have a valid test. The actual TRV during the test will almost always differ, as the circuit breaker modifies the TRV (reduces it, because of the resistance in the arc).

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