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TRV OVERVIEW FOR REACTANCE LIMITED FAULTS

1.0 INDUCTIVE REACTANCE LIMITED FAULT

One of the most severe conditions for a medium voltage circuit breaker to clear is an inductive reactance-limited fault. For this condition, the rate-of-rise of the transient recovery voltage (TRV) on the circuit breaker after the fault current has been interrupted is often quite high. If the voltage recovers too quickly after the fault current has been interrupted, the circuit breaker may reignite, resulting in the resumption of the fault current, which may cause the failure of the breaker. This fast-recovering voltage across the breaker contacts often occurs because the capacitance of the circuit is generally quite low if there is no significant cable or a surge capacitor between the operating breaker and the reactance. This type of fault condition is discussed in detail in this section.

Circuit breakers are built to standards that define the rated TRV capability of the breaker. The two circuits, which are illustrated in Figures 1 and 2, often result in TRVs that exceed the limits defined by standards. When the limits are exceeded, the circuit breakers may fail to clear the fault current, possibly resulting in a catastrophic failure. The two cases illustrated here are transformer-limited faults and reactor-limited faults.

In Figure 1, the fault current is fed predominantly by a transformer. C_1 represents the capacitance of the circuit between the transformer and the circuit breaker. C_1 includes the capacitance of the transformer and the capacitance of the bus or cable that connects the transformer to the circuit breaker. If there is no significant cable length and if the circuit breaker is physically close to the transformer, this capacitance is often quite small.

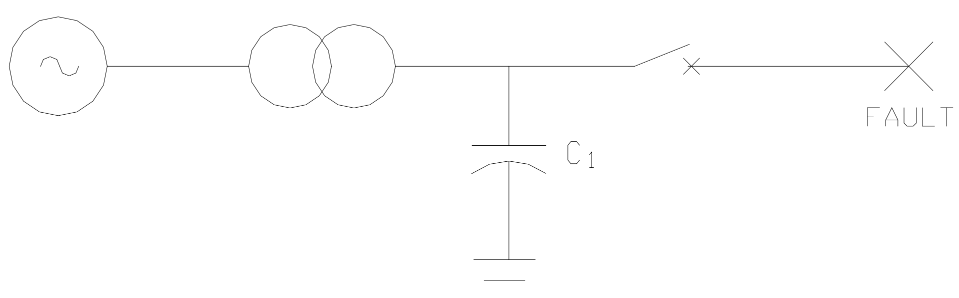


Figure 1

Figure 2 represents the condition of a fault limited by a current-limiting reactor. C_1 represents the capacitance of the circuit between the transformer and the circuit breaker. C_2 represents the capacitance between the circuit breaker and the reactor. In this circuit, C_1 is often fairly large due to cable capacitances of other circuits that are connected to the bus behind the breaker. C_2 is often quite small if there is no significant cable between the breaker and the reactor. (Another example of a similar circuit would be where the reactor is replaced by a transformer.)

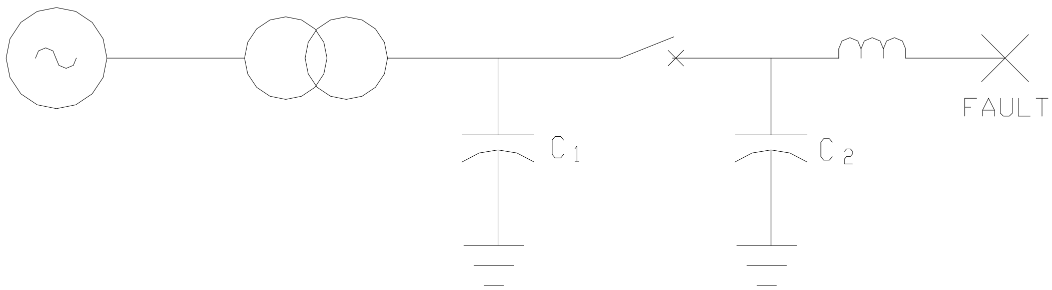


Figure 2

The worst-case fault condition for the TRV occurs for the first pole of a three-pole circuit breaker to clear a three-phase unearthed fault. (This applies to systems that are earthed or unearthed.) Also, the clearing of a symmetrical fault current causes a higher TRV than the clearing of an unsymmetrical fault current. Consequently, in this analysis, the TRV is calculated in each case for the first pole to clear the symmetrical fault current due to a three-phase unearthed fault.

2.0 SINGLE-PHASE FAULT

The equivalent circuit for a single-phase fault is illustrated in Figure 3 for the simple circuit of Figure 3. L_1 represents the transformer impedance, and the current source represents the short circuit current that is being interrupted. The TRV that the circuit breaker would see in this case is also illustrated in Figure 3. The equations that define the TRV are summarized as follows:

$$V_{TRV} = E\ (1 - \cos\ (\ t\ /\sqrt{L_1C_1}\ )$$

where,

$E\ =\ \sqrt{2}\ I_{SC}\ \omega\ L_1$ in kV

$\omega\ =\ 2\ \pi\ f = 314$ radians/second for 50 Hz systems

I_{SC} is short circuit current in kA rms

L_1 is inductance in Henries

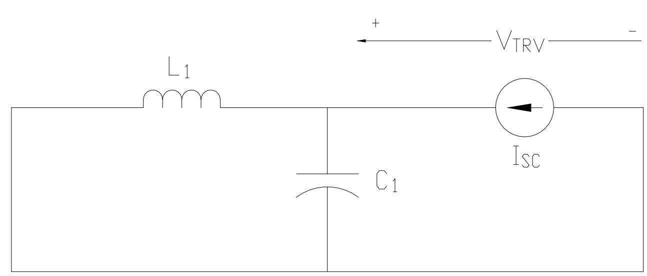
C_1 is capacitance in Farads

t is time in seconds

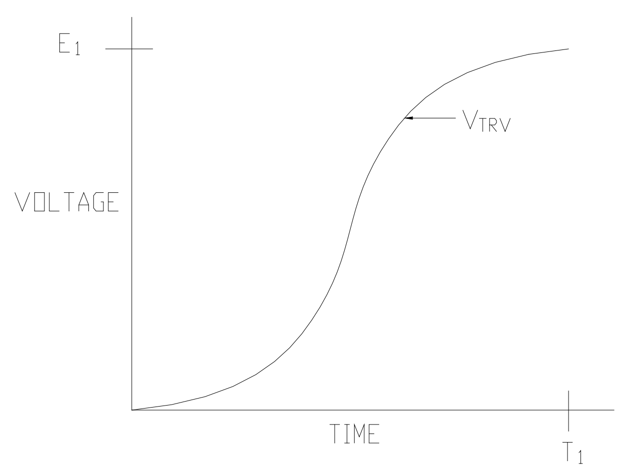
The parameters for V_{TRV} in Figure 3 are defined as follows:

$$E_1 = 2\ E$$

$$T_1 = \pi\sqrt{L_1C_1}$$



EQUIVALENT CIRCUIT FOR CALCULATING TRV



1 - COSINE TRANSIENT RECOVERY VOLTAGE

Figure 3

3.0 THREE-PHASE UNEARTHED FAULT

The equivalent circuit for a three-phase unearthed fault is illustrated in Figure 4 for the simple circuit of Figure 1. The TRV that the circuit breaker would see in this case is illustrated in Figure 5. The equations that define the TRV are summarized as follows:

$E_3 = 1.5\ E_1$

$T_3 = T_1$

where E_1 and T_1 are defined in Section 2.0.

For the case illustrated in Figure 4, there is often some significant capacitance on the load side of the circuit breaker. This is illustrated in Figure 6. In that case, the TRV is composed of two different frequencies. The TRV on the source side of the circuit breaker will be of a higher frequency and faster rate-of-rise than the TRV on the load side of the circuit breaker. If the capacitance is much higher on the load side of the TRV, then the initial TRV will approach that for a single-phase fault. (See Section 2.0)

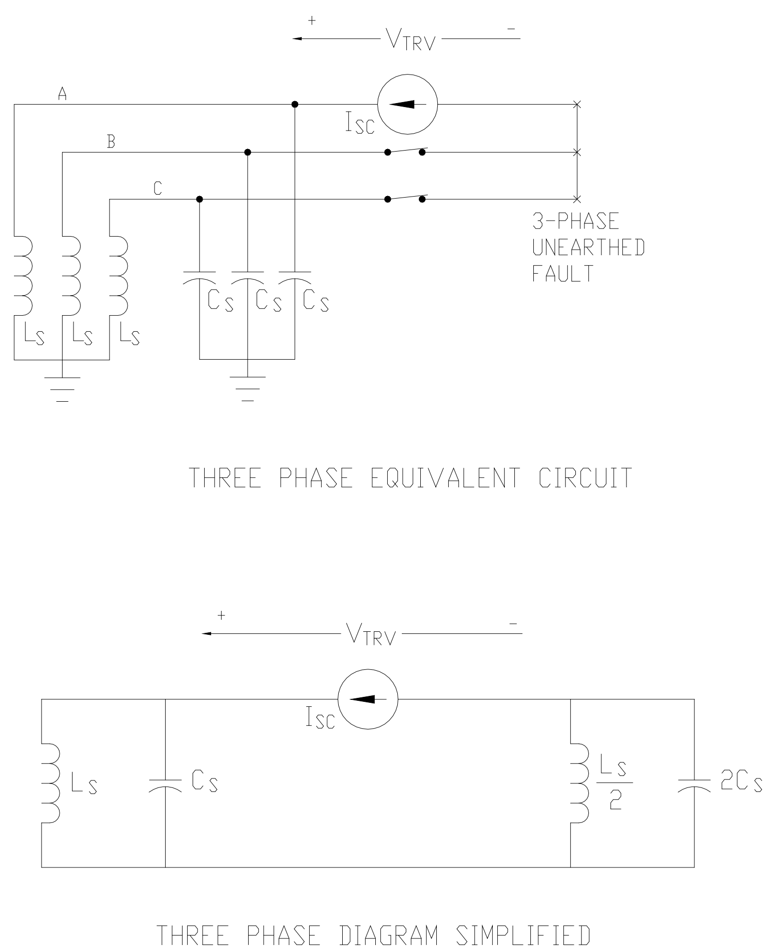


Figure 4

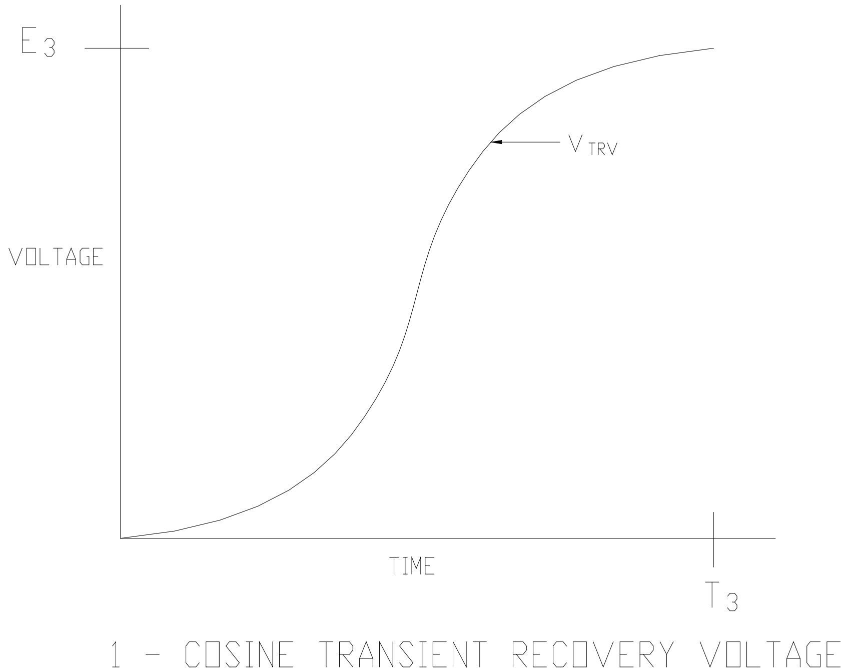


Figure 5

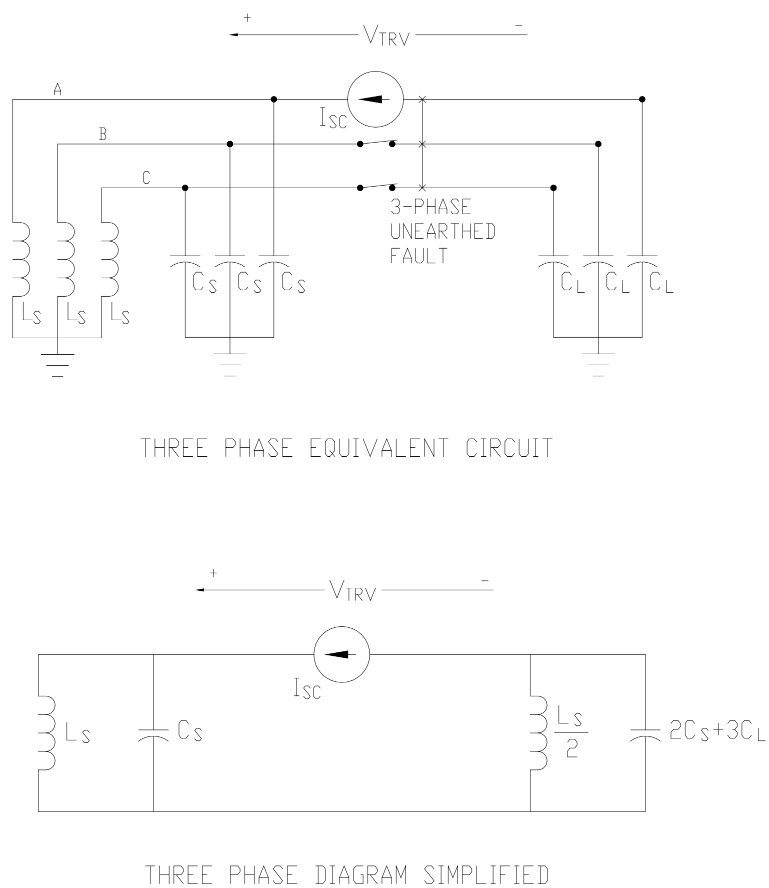


Figure 6

4.0 EQUIPMENT CAPACITANCE VALUES

In doing a transient recovery voltage (TRV) study, one of the key parameters is the capacitance characteristic of each system component. However, the capacitance is not typically provided with other nameplate information. A good source of capacitance values is given in Annex B of IEEE Standard C37.011-2011 – Application Guide for Transient Recovery Voltage for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

5.0 TRV STANDARD

For reactor-limited faults, the two-parameter reference line, as defined in IEEE Standard C37.06-2009, is generally applicable. This capability is illustrated in Figure 7. The prospective TRV of the system is not to exceed the reference line, defined by u_c and t_3; it should cross the specified delay line, defined by t_d, u', and t', close to zero voltage but should not recross it later. The standard values that define the TRV rating are given at 10%, 30%, 60%, and 100% of rated current.

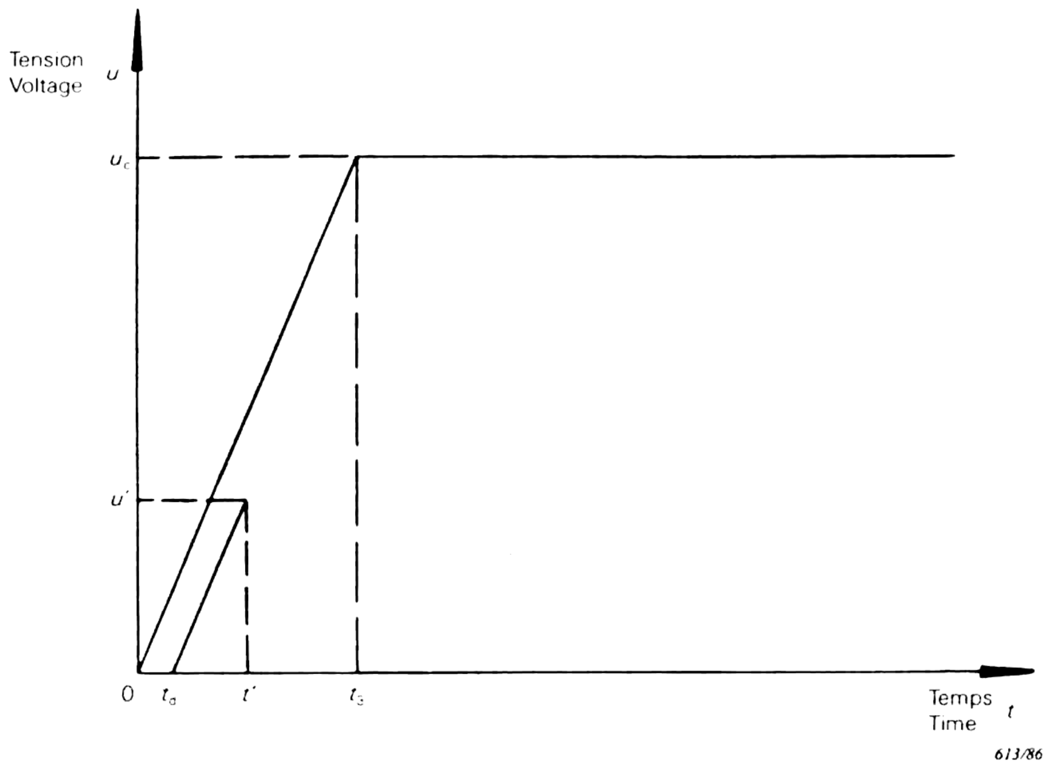
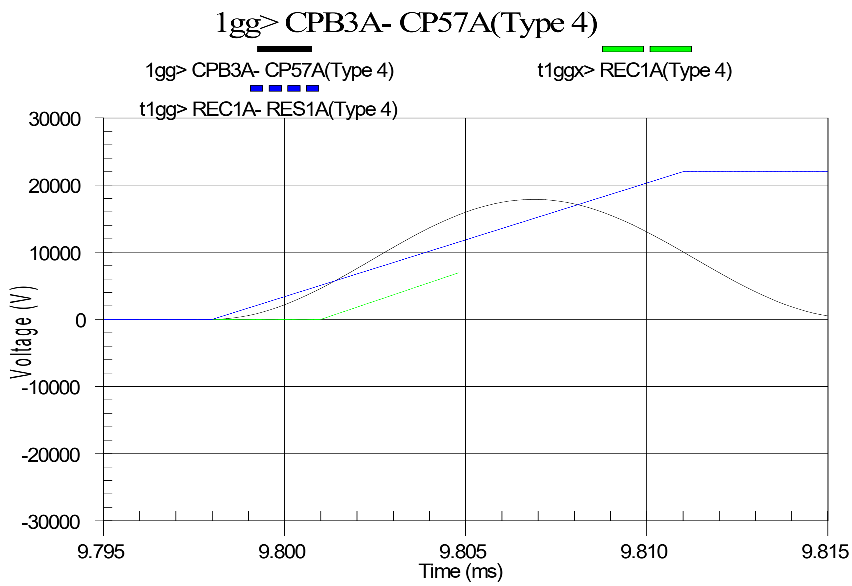


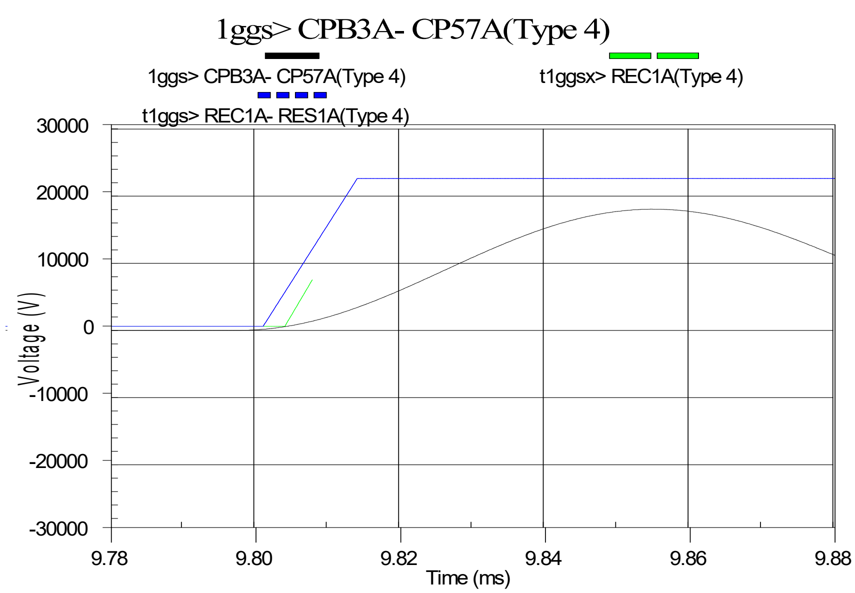
FIG. 11. — Représentation d'une TTR spécifiée par un tracé de référence à deux paramètres et par un segment de droite définissant un retard.
Representation of a specified TRV by a two-parameter reference line and a delay line.

Two-Parameter Reference Line
Figure 7

An example of a TRV that exceeds the TRV rating is illustrated in Figure 8. The TRV standard is illustrated by the dashed lines. An example of a TRV that is within the TRV rating is illustrated in Figure 9.



Example TRV That Exceeds the TRV Rating
Figure 8



Example TRV That Is Within the TRV Rating
Figure 9

The two-parameter reference line of Figure 7 has two key characteristics: the initial rate-of-rise of the TRV and the peak of the TRV. The initial rate-of-rise is governed by the capacitance of the circuit between the circuit breaker and the reactance, which is limiting the fault current. Consequently, if the TRV duty is too severe, the rate-of-rise can be reduced by adding adequate capacitance from line to earth at that location. If the peak of the transient is too severe, the remedy for that is generally to use a circuit breaker with a higher voltage rating.

Referring back to Section 3.0, the theoretical maximum peak value of the TRV for the conditions being evaluated here would be

$$1.5 \times 2 \times \sqrt{2} \times V_{LL} / \sqrt{3} = 2.45 \times V_{LL}$$

where V_{LL} is the system operating voltage.