TRANSIENT RECOVERY VOLTAGE STUDY

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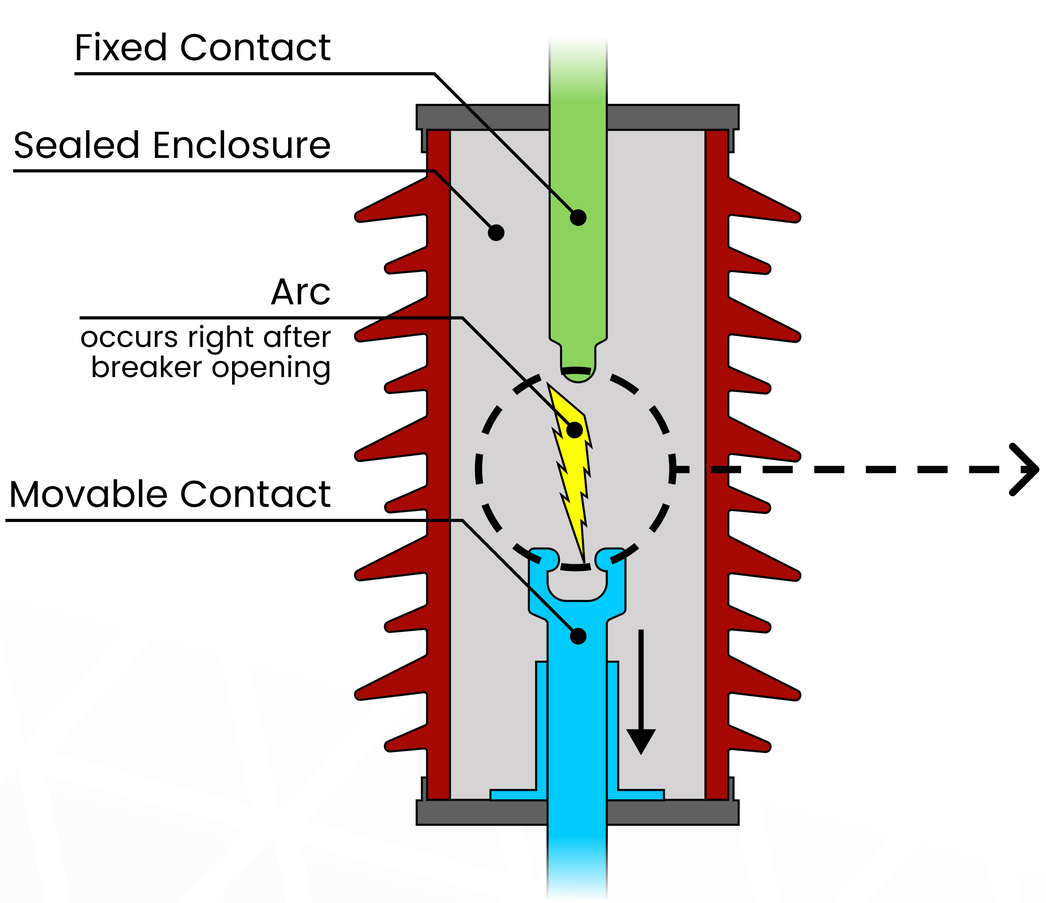
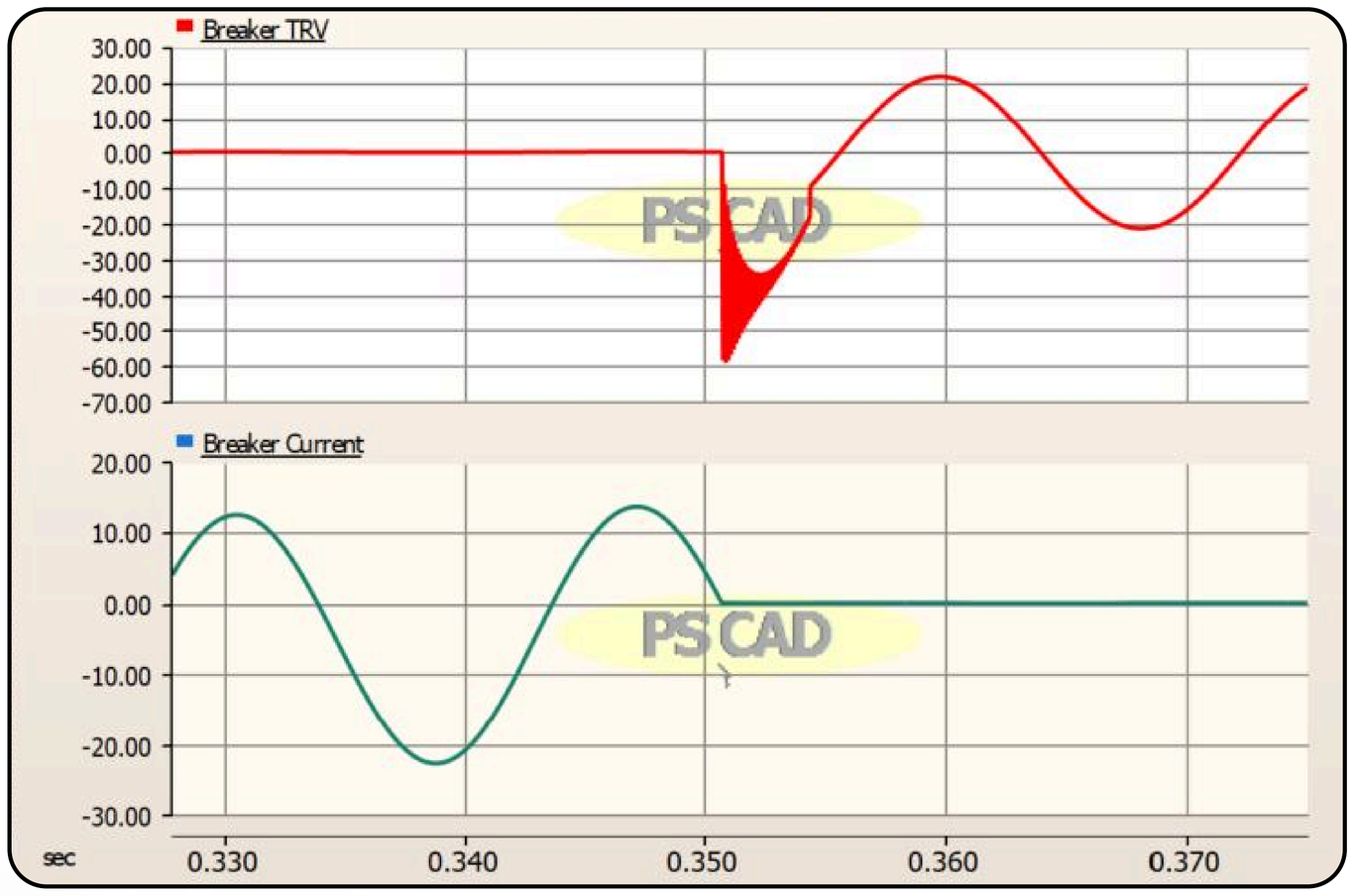
Overview

Transient Recovery Voltage (TRV) is the rapidly rising voltage that appears across a circuit breaker's contacts immediately after fault current interruption. The main characteristics of TRV are the magnitude and rate of rise.

If the TRV magnitude or rate of rise exceeds the breaker's dielectric recovery capability, restrike or breaker failure may occur—potentially leading to equipment damage or system outages.





Study Scope & Scenarios

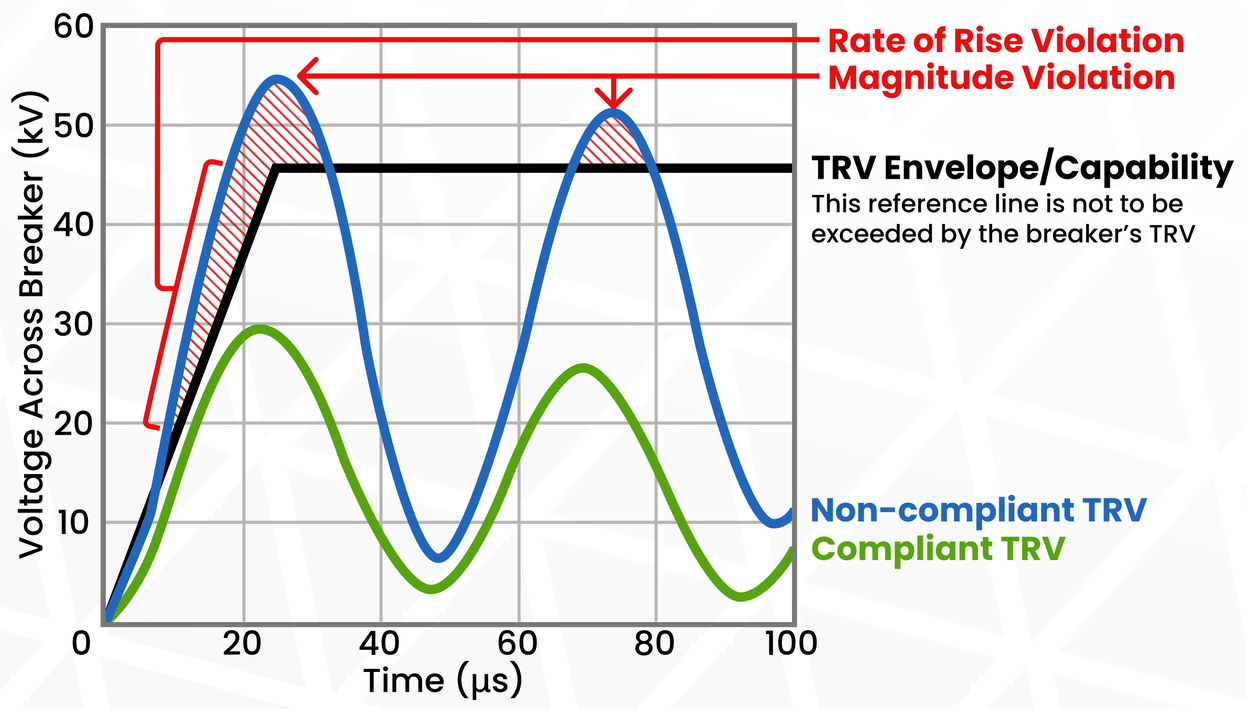
TRV simulation scenarios are developed to capture worst-case breaker stress.

CAUSES OF BREAKER STRESS

1. System Characteristics
   - X/R Ratio
   - Short-Circuit Ratio
2. Events
   - Capacitor Bank Switching
   - Fault
     - → Fault Location
     - → Fault Magnitude
     - → Fault Type

Each parameter is simulated to maximize TRV severity, not only to simply represent normal system operation.

The simulation results are compared against relevant standards or project-specific requirements.



Applicable Standards and Criteria

Pterra provides **independent, physics-based TRV** assessments to confirm breaker suitability under worst-case operating conditions in accordance with **internationally recognized standards and utility practices**.

- **IEEE Std. C37.011** Application Guide for AC High-Voltage Circuit Breakers
- **IEC Std. 62271-100** High-Voltage AC Circuit Breakers
- **IEEE Std. C37.04/ IEEE Std. C37.09** Breaker Ratings and Testing Requirements
- IEEE/IEC/Utility-specific TRV Envelopes and Procurement Specification

www.pterra.com
info@pterra.us

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Methodology Considerations

TRV requires Electromagnetic Transient (EMT) approach focused on dielectric recovery during the first microseconds after current interruption. Analysis is performed directly across breaker contacts, using worst-case current zero interruption, and an accurate, frequency-dependent representation of the surrounding network.

1 NETWORK MODELLING

Network is modelled accordingly by request, starting with the major power components, including transmission lines, generators/inverters, transformers, cables, loads, capacitor banks, reactors, breakers, etc.

2 COMPONENTS MODELLING

Components affecting TRV magnitude and rate of rise are explicitly modeled, including transmission lines, CTs, PTs, surge arresters, source impedance, and transformer interwinding and winding-to-ground capacitances.

3 SCENARIOS DETERMINATION

Events are determined accordingly by request or IEEE standards to capture the most severe TRV waveforms; three-phase fault, single line fault, short line fault. Fault locations are also determined.

4 TRV ANALYSIS

Breaker TRV waveform is measured based on the events and scenarios and will be evaluated against TRV envelope, which is calculated in accordance with IEEE/IEC standards[1].

[1] Pterra provides accurate and automated TRV envelope generator module in the industry-grade software PSCAD/EMTDC to compare against the TRV waveform.

TRV vs. Switching Transient

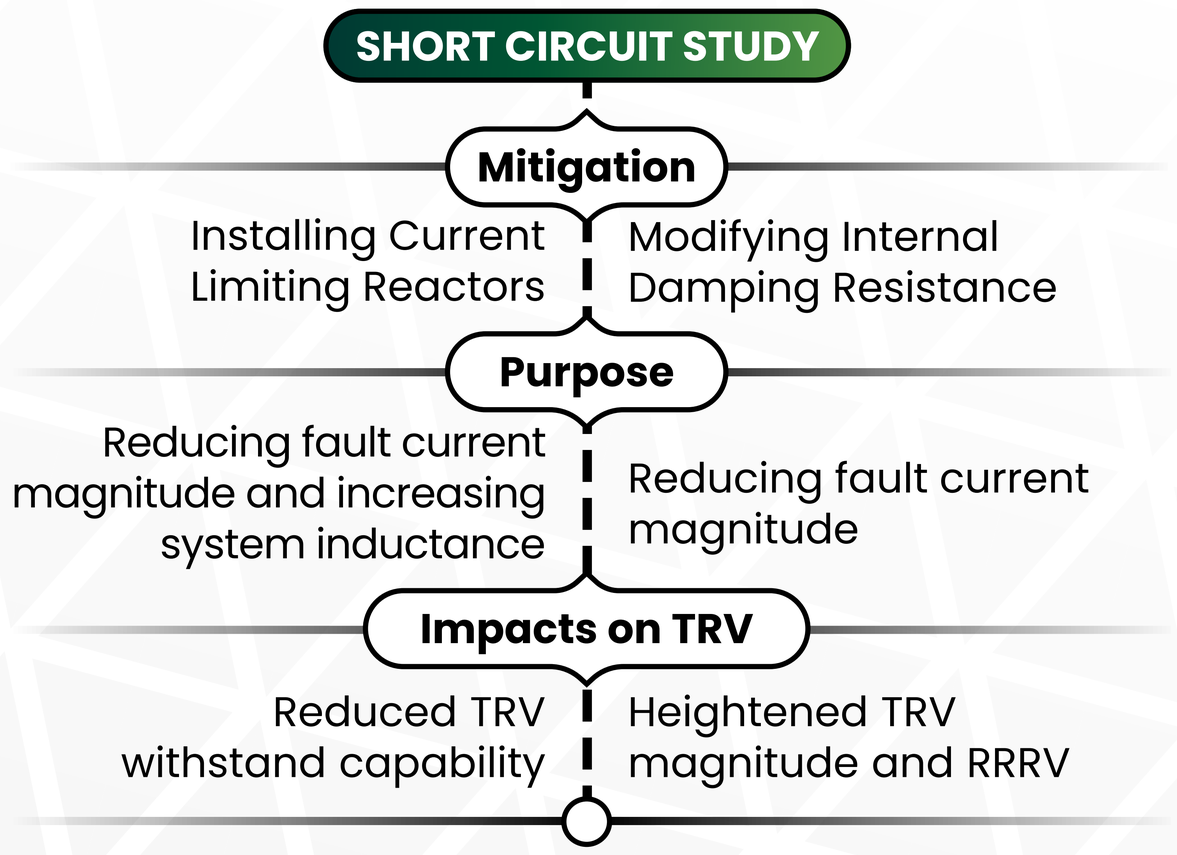
TRV assessments are often confused with switching transient studies; however, their objectives and modeling approaches are fundamentally different.

	TRV Assessment	Switching Studies
Primary Focus	Voltage across breaker contacts	Voltage at system nodes
Time Scale	First tens of microseconds	Microseconds to miliseconds
Governing Metric	Peak TRV and RRRV[2]	Overvoltage magnitude
Breaker Representation	Dielectric recovery at current zero	Ideal open/close operation
Acceptance Basis	TRV envelope compliance	Insulation coordination limits

[2] Rate of Rise of Recovery Voltage

When Short-Circuit Solutions Create TRV Challenges

Short-circuit mitigation solutions can unintentionally introduce TRV limitations if not properly evaluated. Thus, short-circuit studies should be done in coordination with TRV assessment.



Typical Solutions

SIMPLE

- Special / Definite Purpose VS. General Purpose Circuit Breaker
- Contact CB manufacturer.
- Is it possible to have 3-phase ungrounded fault?

POTENTIAL COST-SAVING

- Refine the TRV model: capacitance of all circuit elements (bus duct, transformers, reactors).
- Circuit re-configuration: consider to relocate reactor from a substation to near the PVCS or load etc.

COSTLY

- Adding capacitance near the CB ~ RRRV.
- Use of ZnO disks across CB terminals.
- Use CB with higher voltage or higher Interrupting Rating.

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