PSCAD

Transient Recovery Voltage (TRV) Studies

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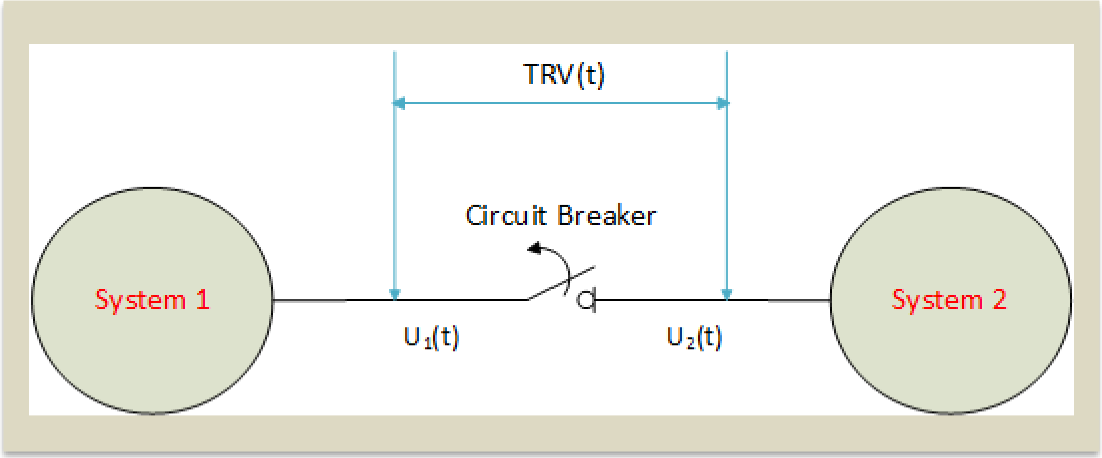
The study approach to TRV investigation, using the PSCAD/EMTDC simulation tool, is discussed in this webinar. The following topics are addressed:

- Power system modeling
- Station modeling
- IEC/IEEE TRV envelopes
- TRV simulation
- Results interpretation
- TRV mitigation methods

TRV - Definition

TRV is the voltage difference observed between the breaker terminals immediately after the current interruption of the breaker.

It is simply the difference in the power system response voltages on the source side and on the load side of the circuit breaker.



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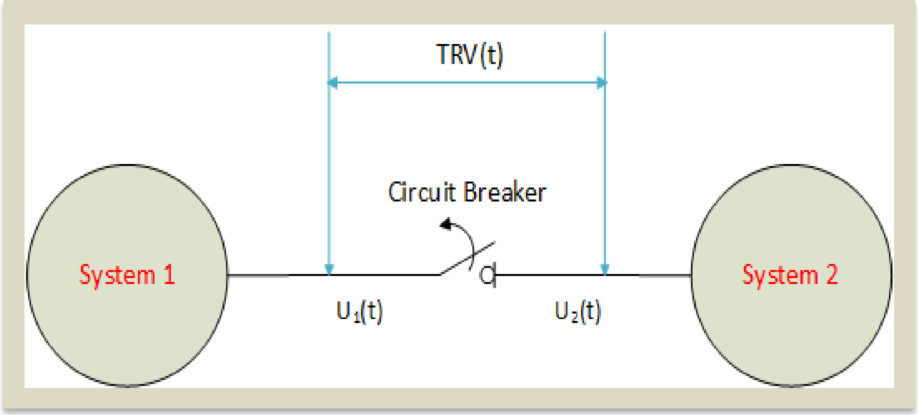
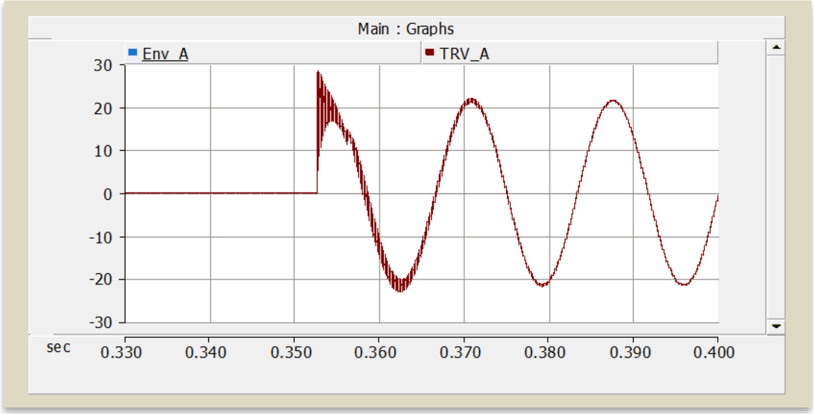
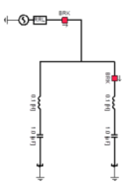




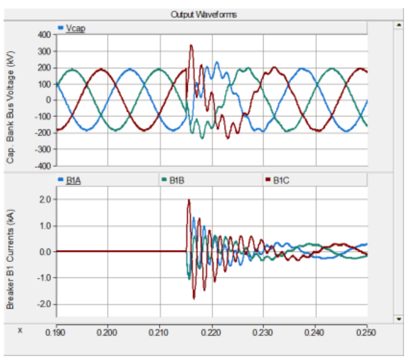
Electromagnetic Transients in Power Systems

Example: Closing/opening breakers, faults initiate electromagnetic transients.

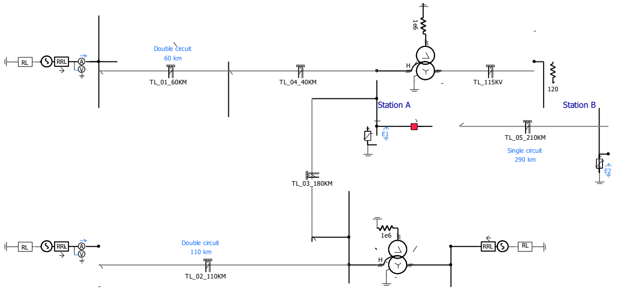
- The energy exchange between L-C causes the oscillatory transient.
- Resistance in the circuit acts to damp the transient.

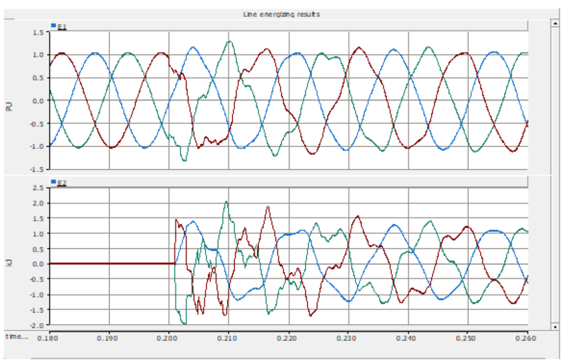


Close breaker



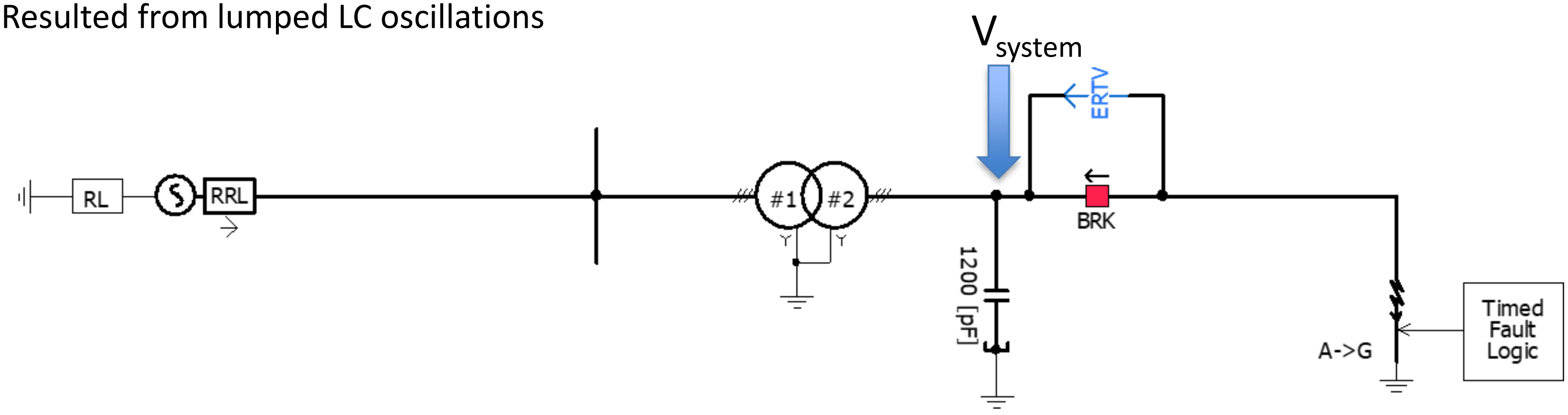
- Traveling waves on transmission lines/cables

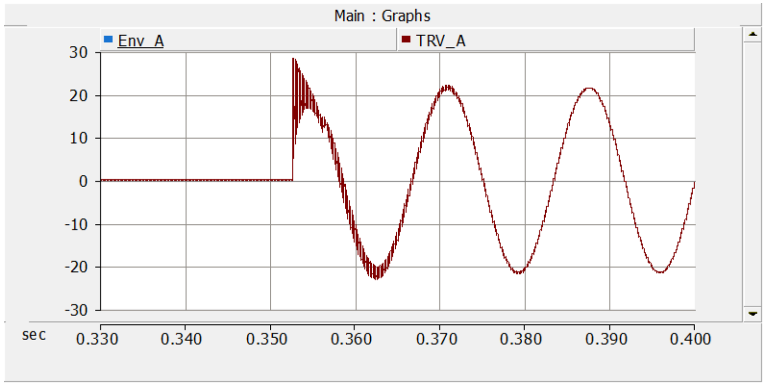


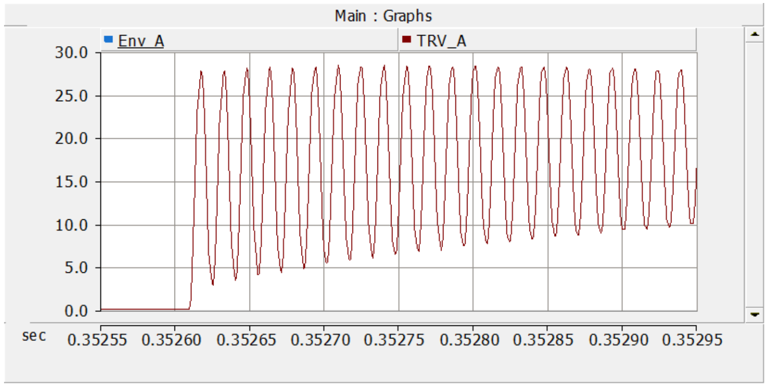


Circuit Breaker TRV - Illustration

Resulted from lumped LC oscillations

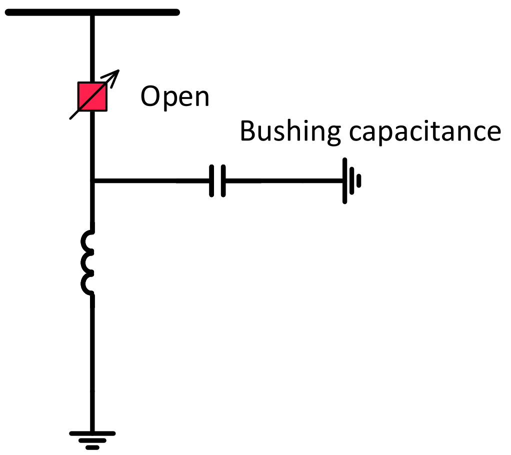




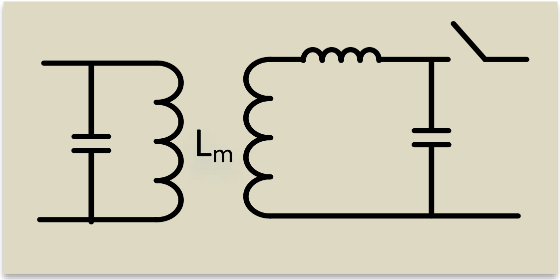


LC circuit oscillation frequency $\Rightarrow$ $f = \dfrac{1}{2\pi\sqrt{LC}}$

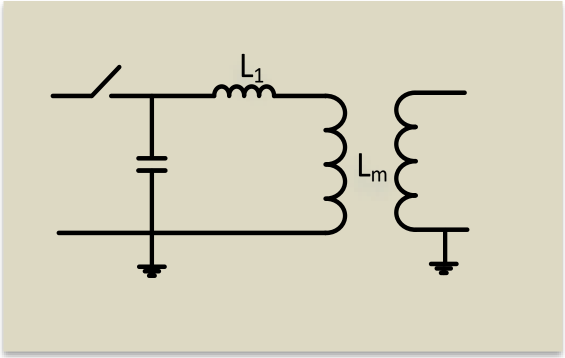
Opening a shunt reactor



Clearing a fault on transformer secondary side

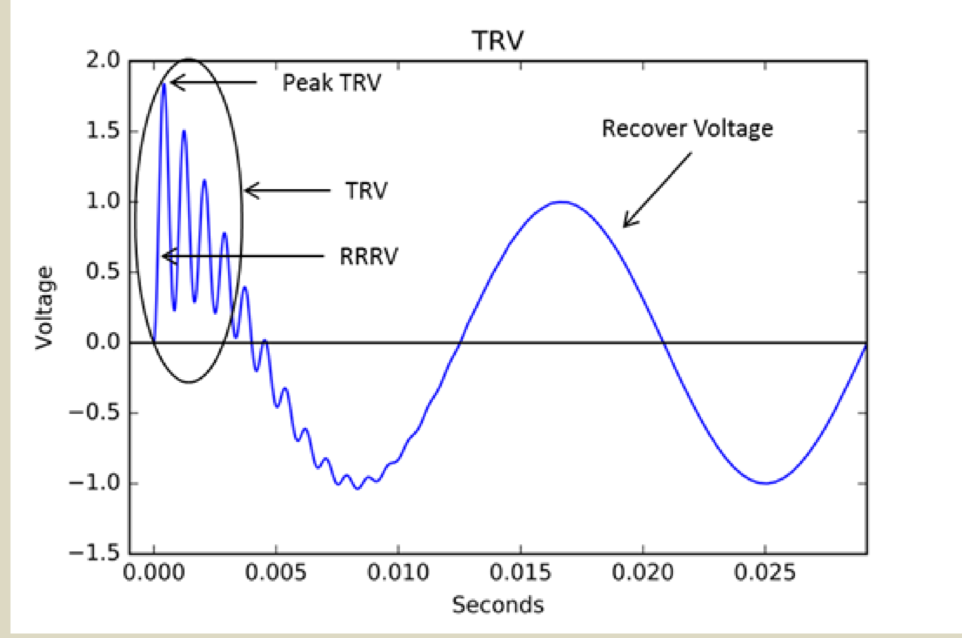


De-energizing a transformer



Circuit Breaker TRV - Definitions

The voltage across breaker the terminals upon current interruption has two successive stages; *transient recovery voltage* stage where high frequency oscillations observed followed by the *recovery voltage* stage where power frequency oscillations are observed (transient has decayed).

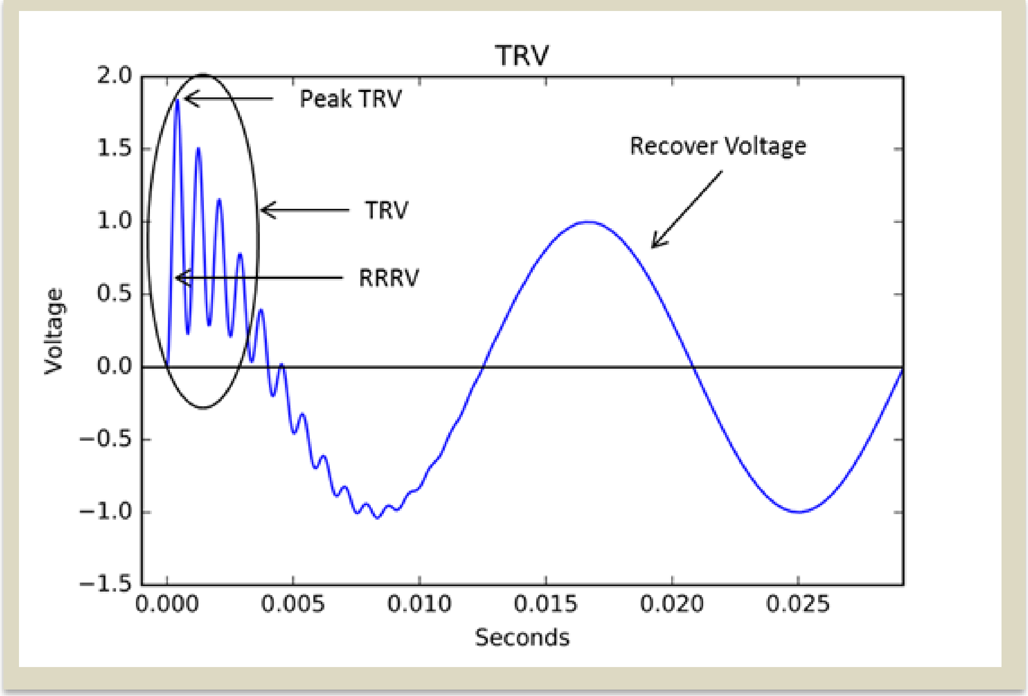


TRV Waveforms and Definitions

Key parameters:

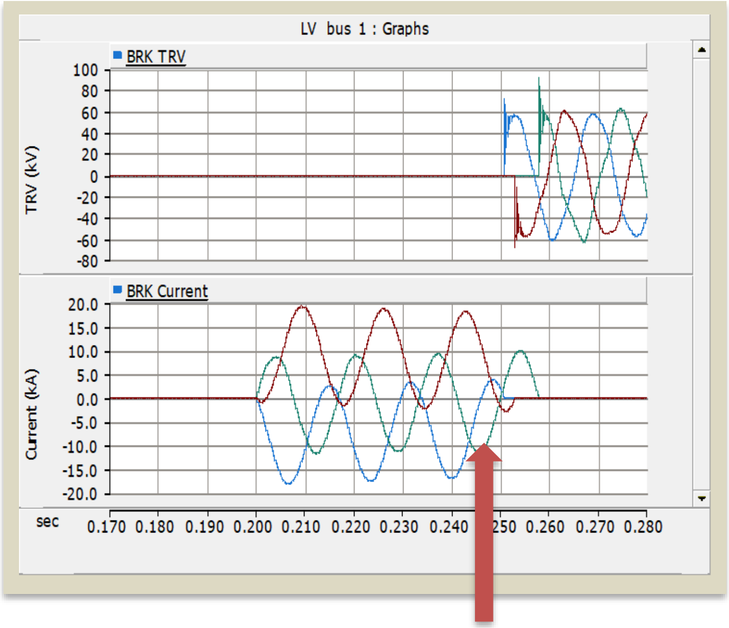
- Rate of Rise of Recovery Voltage (RRRV)
- TRV peak

Both the above quantities must be evaluated in a TRV study



Circuit Breaker Current Interruption

- Trip signal initiate the breaker pole movement (approximately 12 ms for contacts to fully open)
- The current is interrupted at a point of a natural current zero
- An electric arc (of very high temperature) sustains the current during the interval.
  - Weakened dielectric immediately following current interruption
  - If an 'excessive' voltage is applied across the breaker immediately after the current interruption, there is a risk of re-strike.



Breaker OPENING initiated

TRV withstand capability of circuit breakers

TRV capability is defined by a set of curves

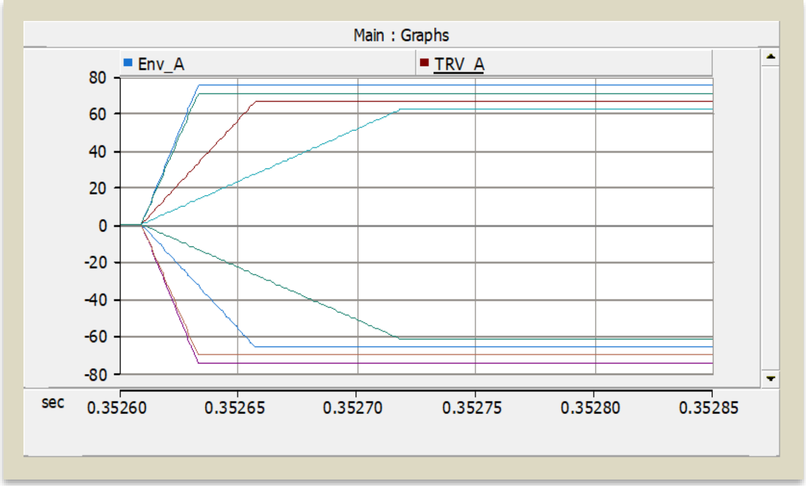
- by breaker manufacturer
- Minimum requirements as listed in IEC/IEEE

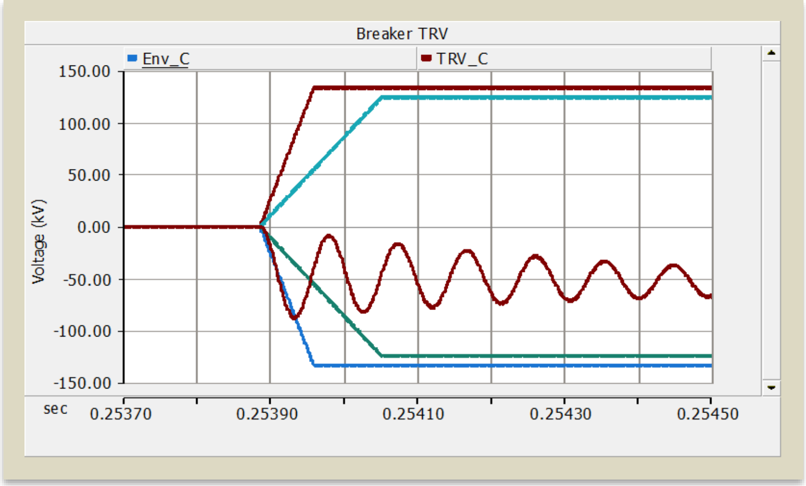
Depends on Breaker Rating (voltage and fault current rating)

- Example: 245 kV, 40 kA breaker

Depends on the actual current being interrupted

- Example: 100%, 60%, 30%, 10% of rated fault current





TRV: Modeling Considerations

TRV is a 'fast event' (10s of KHz)

- The impact of the transient is limited to a local area of the station
- The transient (TRV) itself is mainly influenced by the circuit elements (R-L-C) in close vicinity to the breaker
    - Circuit components of the station has a significant impact of TRV (bushing capacitances of equipment)
    - The 'remote system' (1-2 buses away) generally has no impact on overall TRV response.
- It is important to represent station equipment layout/capacitances for TRV studies

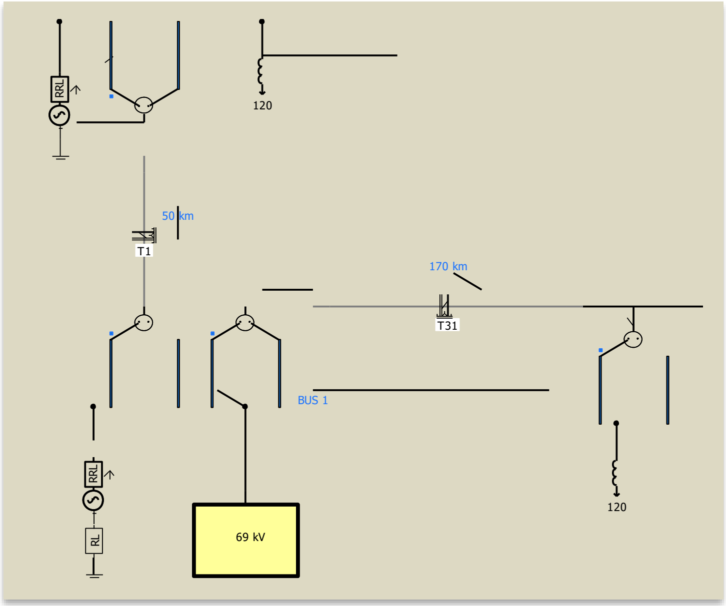
TRV: Modeling Considerations

The external network is represented in detail up to 1-2 buses away from the substation

- Accurate representation of the fault current level at the station is important
- Accurate representation of the external system using Thevanin's voltage sources

Detailed representation of substation equipment

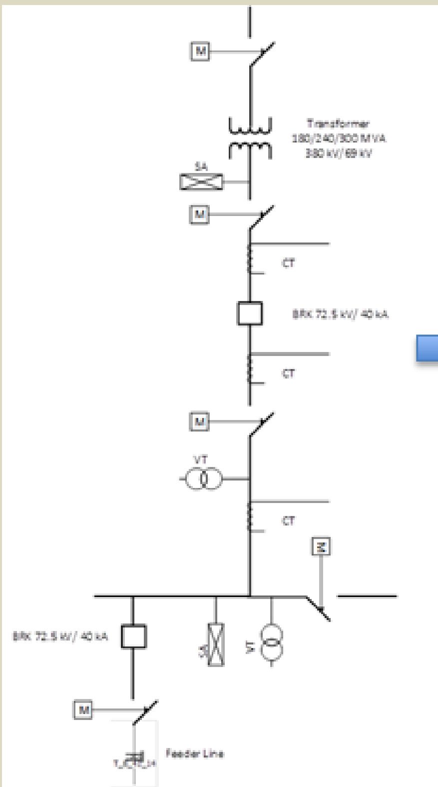
- Bushing capacitances of equipment



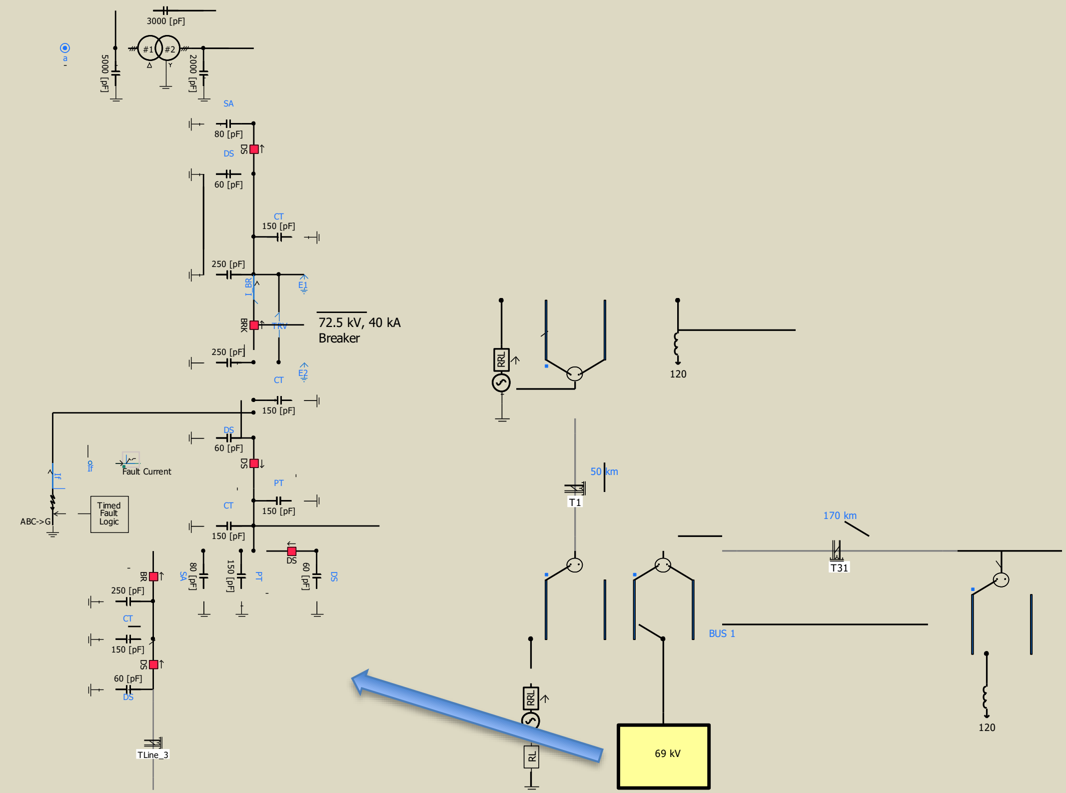
TRV: Modeling Considerations

Detailed representation of substation equipment

- Bushing capacitances of equipment



Single line Diagram



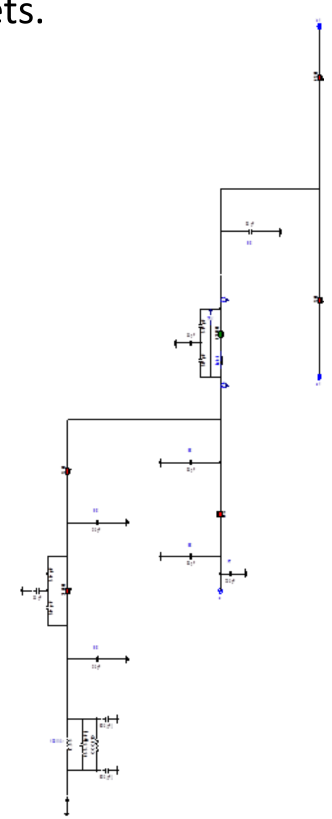
PSCAD Model

Typical busing capacitance values

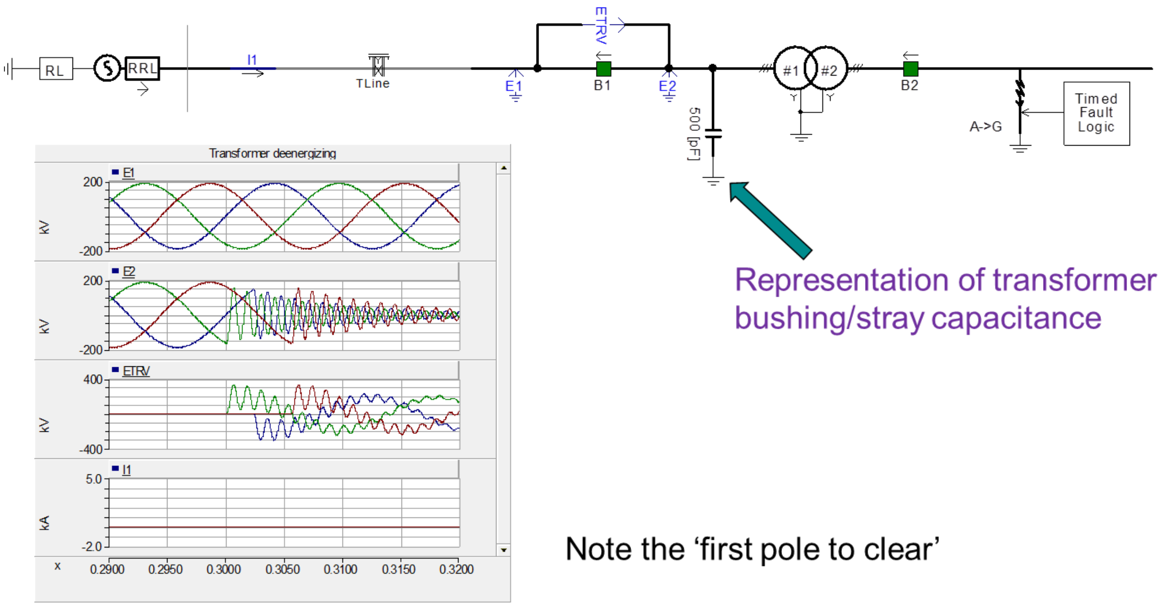
The specific bushing capacitance values may not be available from data sheets.

- Typical values as per IEC/IEEE (IEEE C37.011)

Description	Capacitance (pF)
Earthing Switch	50
Current Transformer	200
Capacitive Voltage transformer – outdoor	5500
Surge Arrester	80
SF6 to Air Bushing	100
Voltage Transformer	200



Importance of Bushing/Stray Capacitance: Example: de-energizing a unloaded transformer



Note the 'first pole to clear'

TRV in this case is due to an oscillatory transient. The frequency and magnitude of the transient is thus determined by the L and C of the circuit involved.

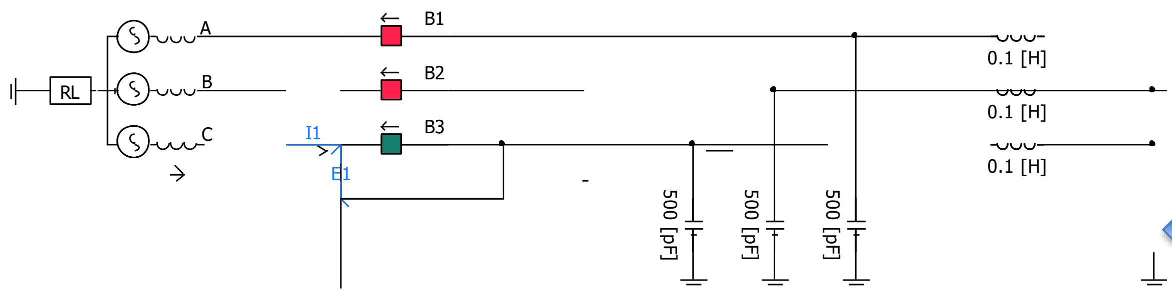
- Here, the TRV is mainly due to oscillations on transformer side of the breaker (E2)
- Oscillation frequency : $1/(2\pi \cdot \sqrt{(LC)})$
- The rate of rise of TRV can be limited by adding capacitance

Illustration of a simple yet important points

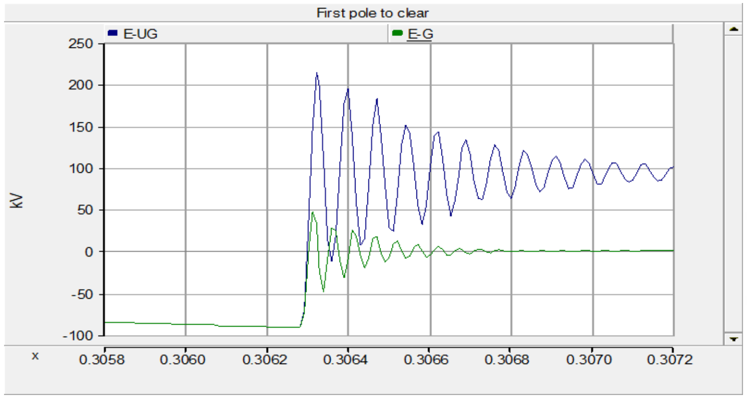
First Pole to Clear

The three poles (of breaker) do not break the current at the same instant due to 120 degree phase shift on the 3 phases

- First pole to clear typically has the worst TRV
- Grounding conditions have an impact



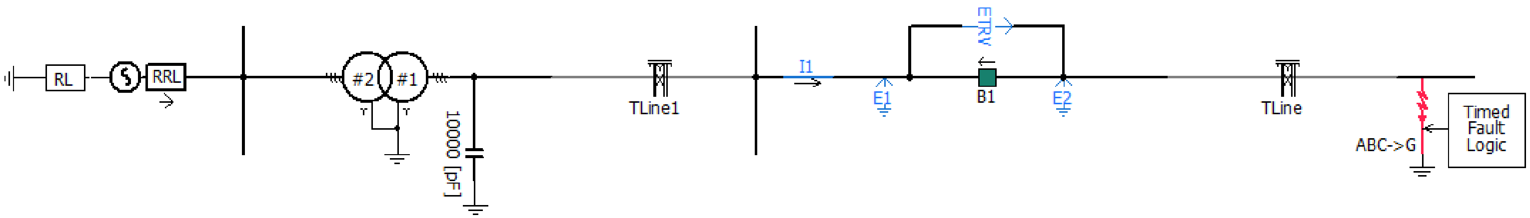
Neutral Grounding

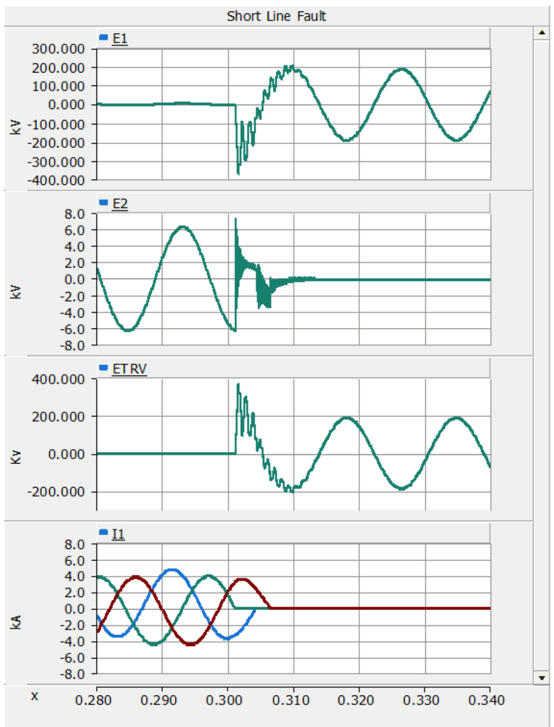


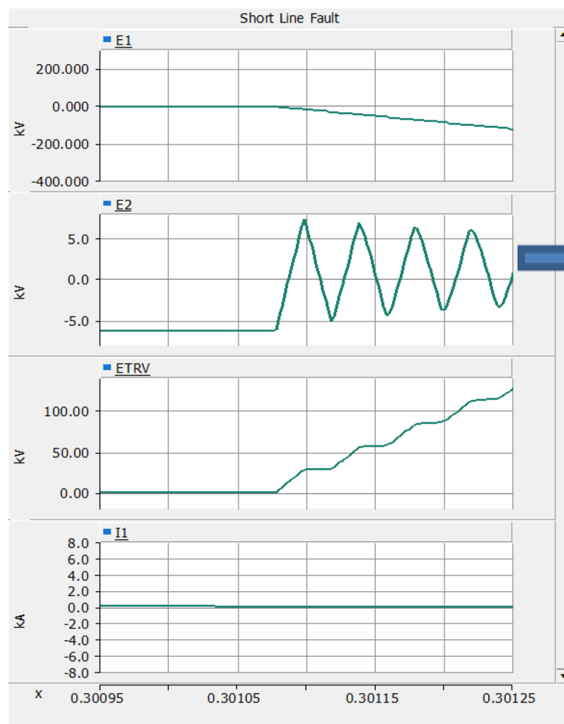
With neutral not grounded

With neutral grounded

Triangular TRV (Short Line Fault)- Travelling waves in lines impact TRV







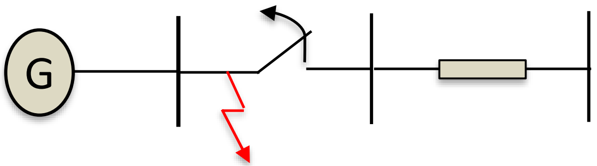
The more severe contribution to TRV is imposed from line side. Note that the voltage magnitude is very low.

Illustration of a simple yet important points

Generator Breaker TRV Studies - IEEE Std. C37.013

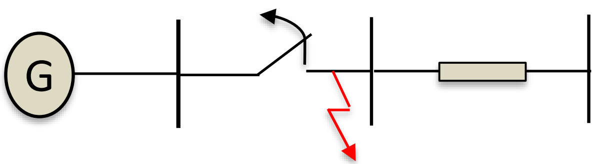
System-Source Faults

- Fault Current through the breaker from system side
- Single envelop based on MVA rating and kV rating of the machine (No fault duty)
- Relaxed envelope compared to Generator-Source faults



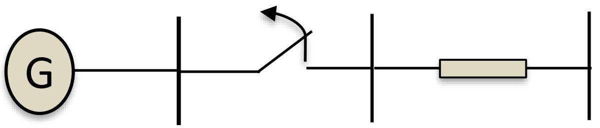
Generator-Source Faults

- Fault Current through the breaker from generator side
- Single envelop based on MVA rating and kV rating of the machine (No fault duty)
- Tight envelope compared to System-Source faults



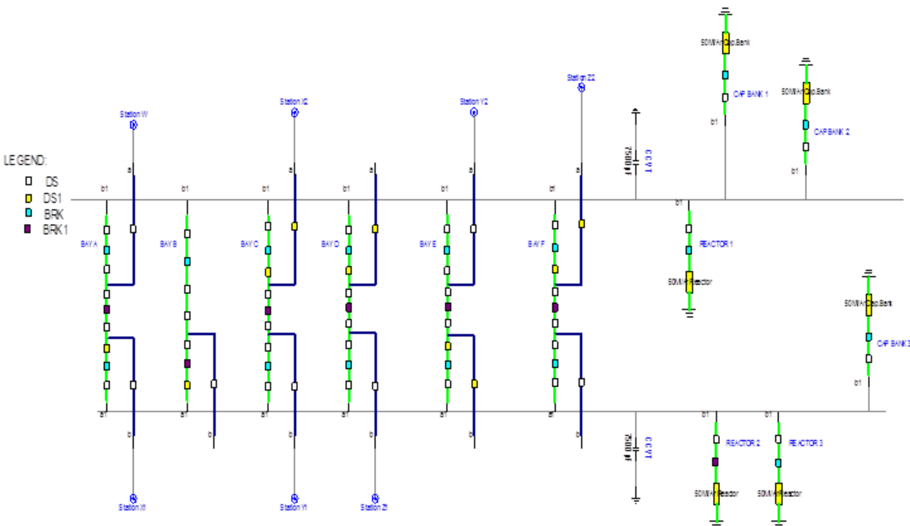
Out-of-Phase TRV

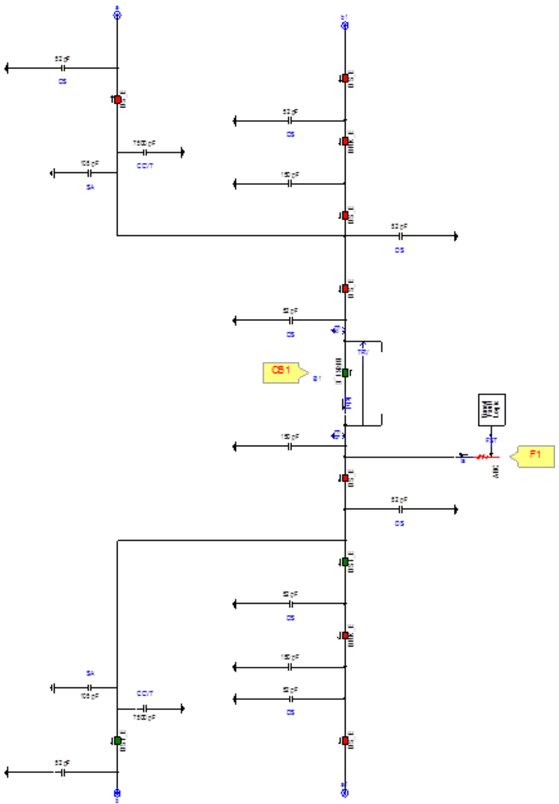
- Single envelop based on MVA rating and kV rating of the machine



TRV study scenarios

Study scenarios should be carefully selected after reviewing the breaker arrangements.





- Amount of detail in the model is significant
- Study should consider different breaker ON/OFF status

TRV study scenarios

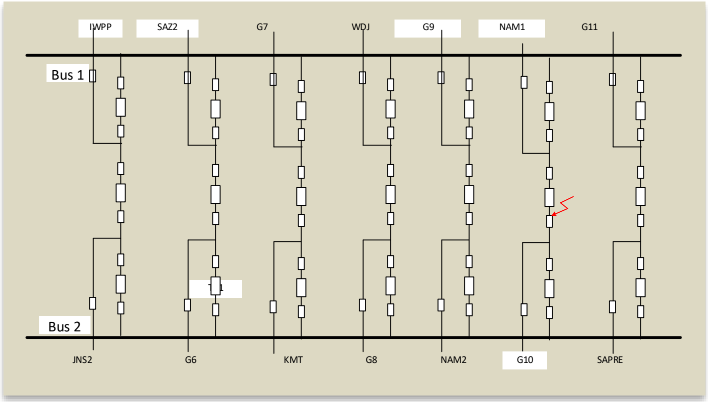
Typical study Scenarios

- Station faults (breaker terminal faults)
- Short line faults (2-3 km from the station)
- Remote faults (Ex. mid line faults)
- Faults on Series compensated lines
- Reactor and transformer de-energization

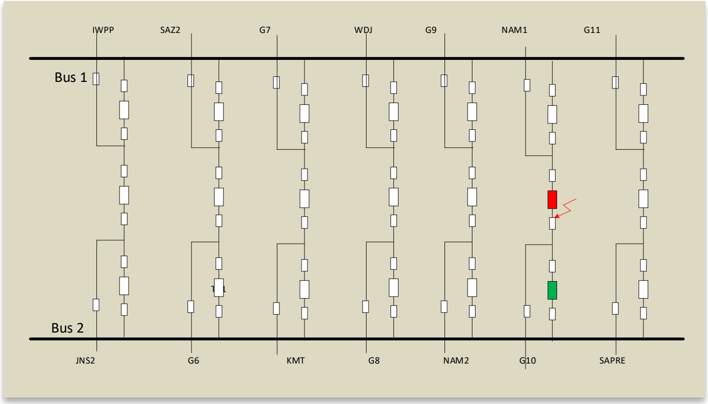
Fault Types

- 3 phase unground fault
  - Typically gives the worst TRV
  - Not always a credible case
- Three phase faults
- Phase -G faults

TRV study scenarios



(a)



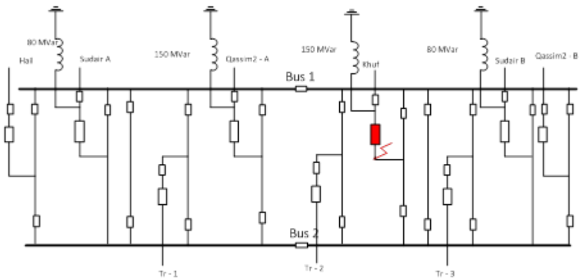
(b)

TRV should be studied under credible conditions: Study scenarios should be carefully selected.

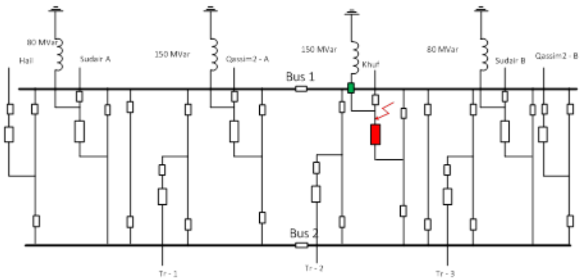
- Studying the opening of the breaker under condition (a) is meaningless
- Study scenario (b) instead.

TRV study scenarios

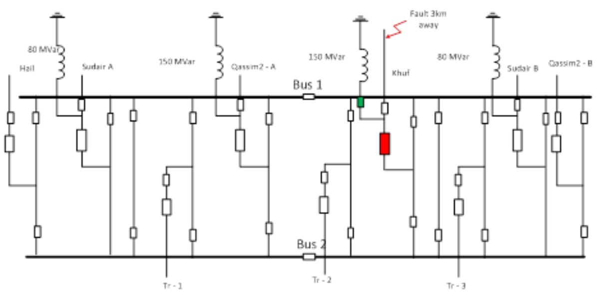
Example: 380 kV substation TRV study - 22 scenarios were studied for TRV compliance (3 selected scenarios illustrated below)



Terminal fault on Line 1



Terminal fault– reactor out of service



Short line fault on Line 1 (3km away from the Station)

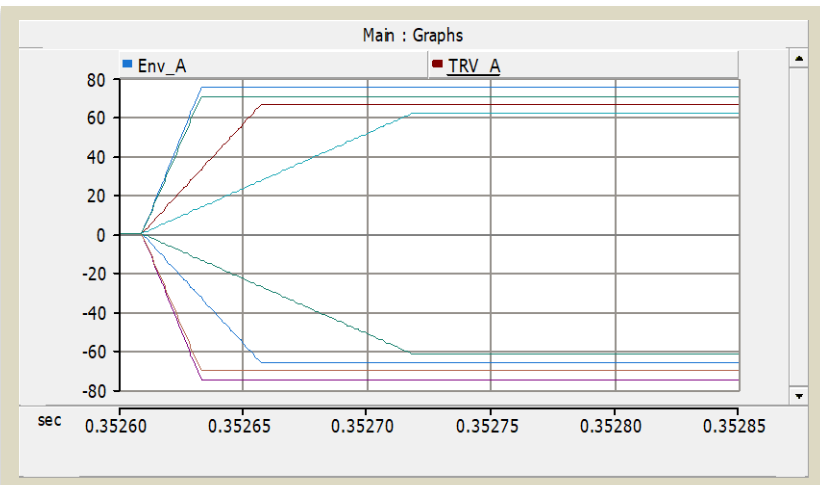
TRV withstand capability of circuit breakers

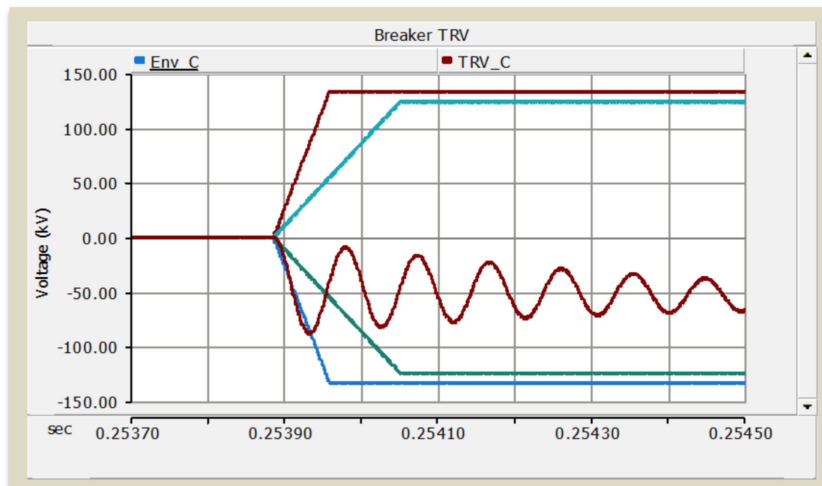
TRV capability is defined by a set of curves

- TRV capability is provided by the vendor in the form of family of curves.
- If specific capability curves are not available, information in IEC Std. 62271-100 is used for the study

Pick relevant curve (to compare system TRV waveform)based on actual % current being interrupted.

- Example: if the fault current is 24 kA and the breaker is rated for 40 kA, use the 60% curve.

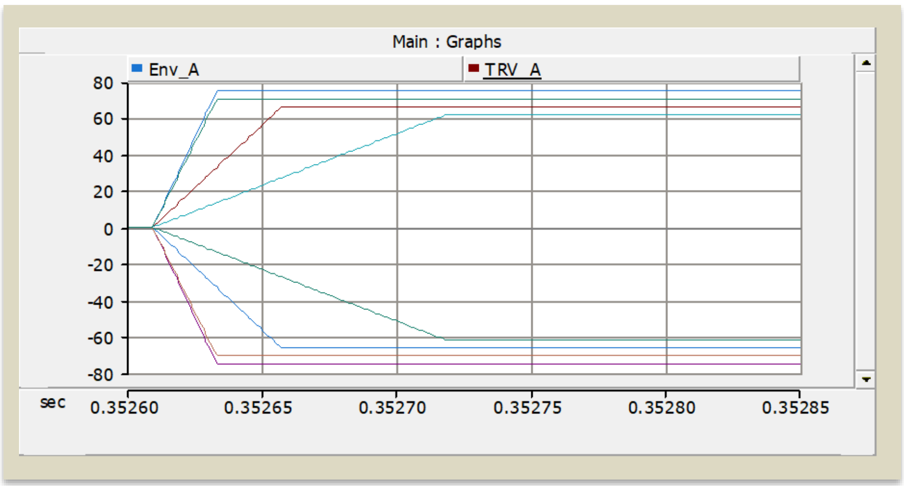




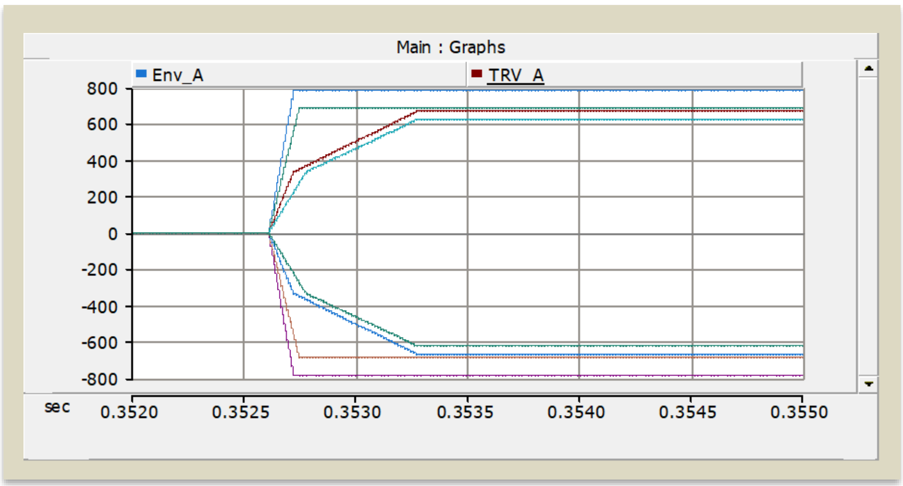
TRV withstand capability of circuit breakers

Breaker TRV Capability Curves

- 2 and 4 parameter curves
- Adjustments for Short Line Faults (SLF) (Breakers have higher TRV withstand capability than for station faults)



Two Parameter

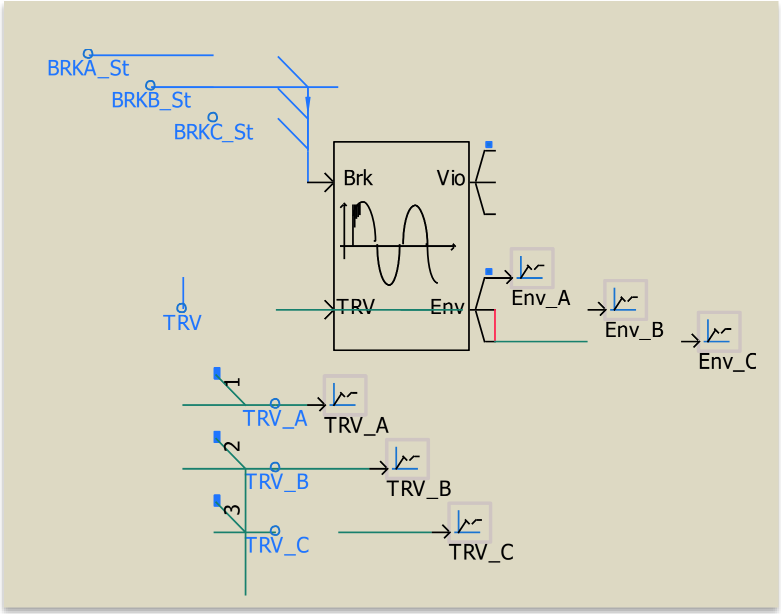


Four Parameter

PSCAD TRV Envelop Module

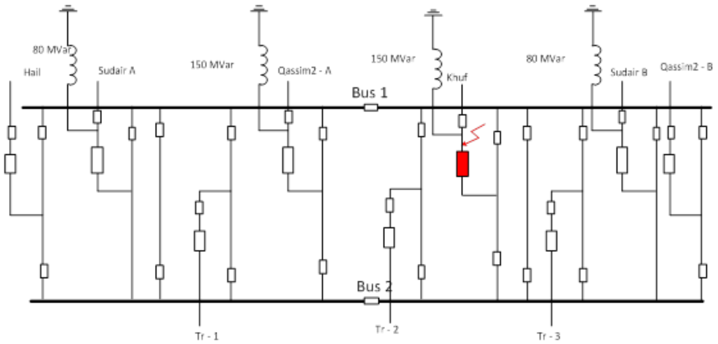
Appropriate set of capability curves can be selected based on application:

- Breaker connected to cables
- Breaker connected to overhead lines
- Effectively grounded system
- Non-effectively grounded system
- Generator fed faults



TRV – Typical responses

Station fault

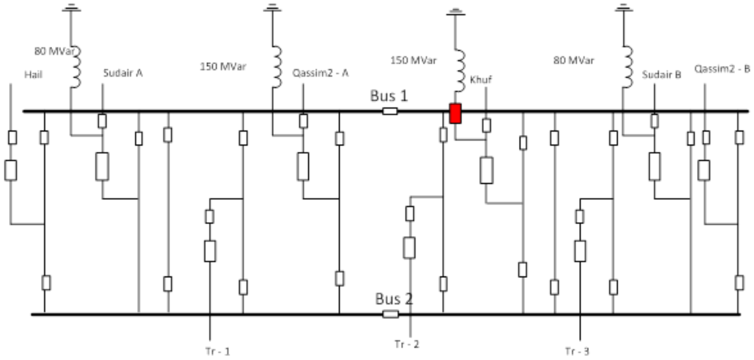


Scenario 1

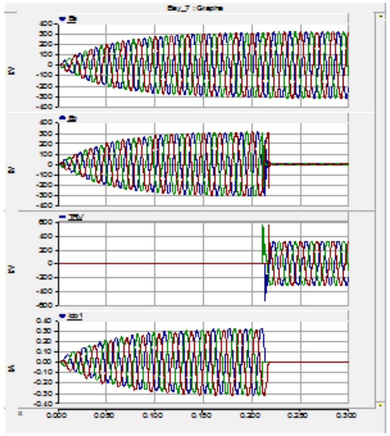
- Fault current through the breaker = 11.3 (18%)
- No violations to any TRV envelopes

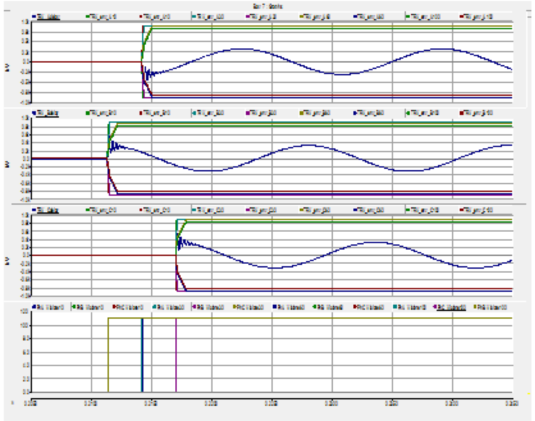
TRV – Typical responses

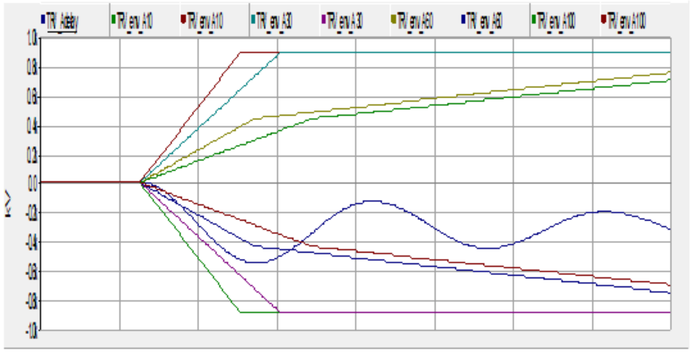
Reactor switching (opening)



Reactor opening







Breaker TRV Example

- 69 kV transforemr breaker has severe TRV violation
- 50 nF surge capacitor installed between transformer and breaker will solve the problem

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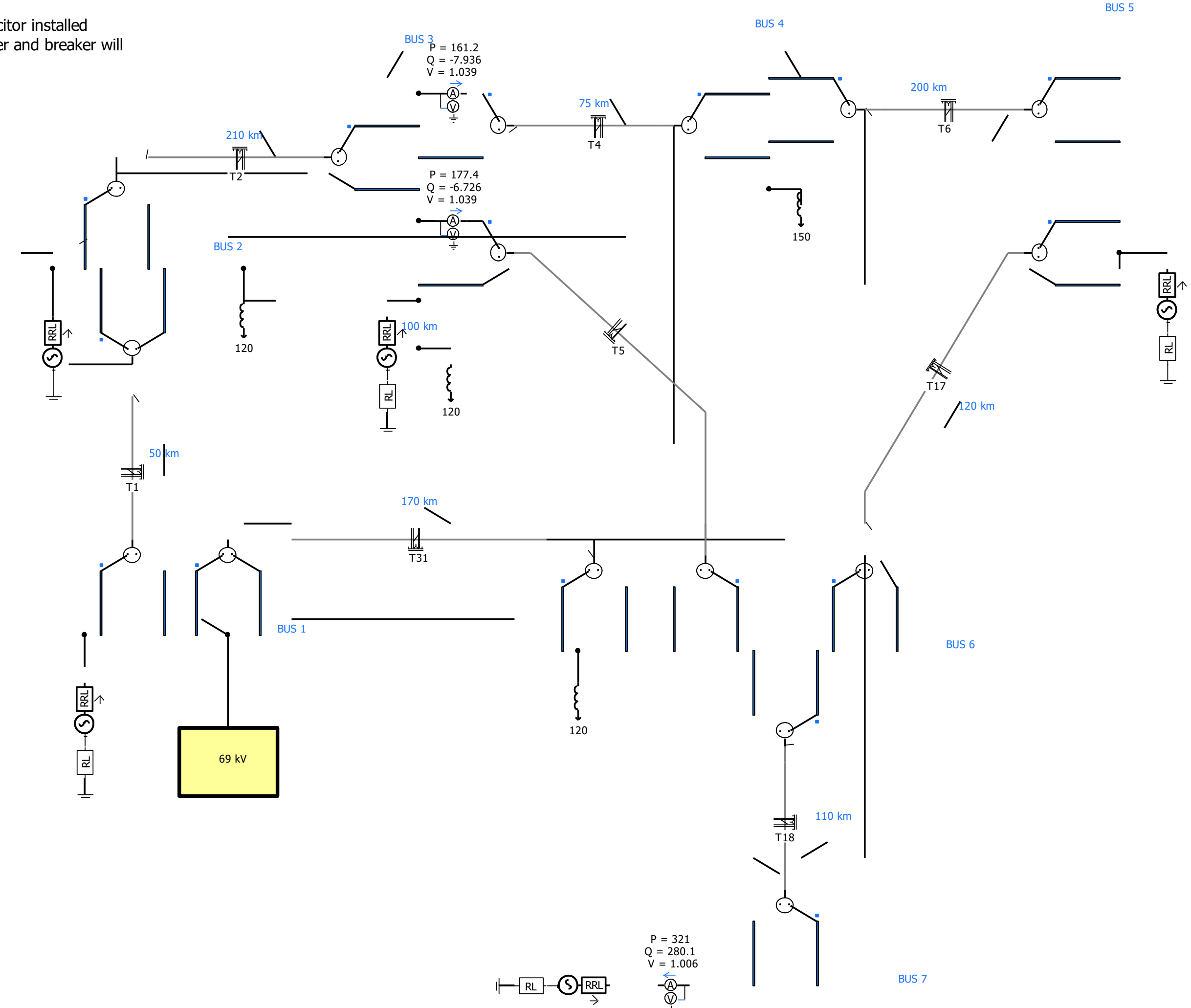

Thank you