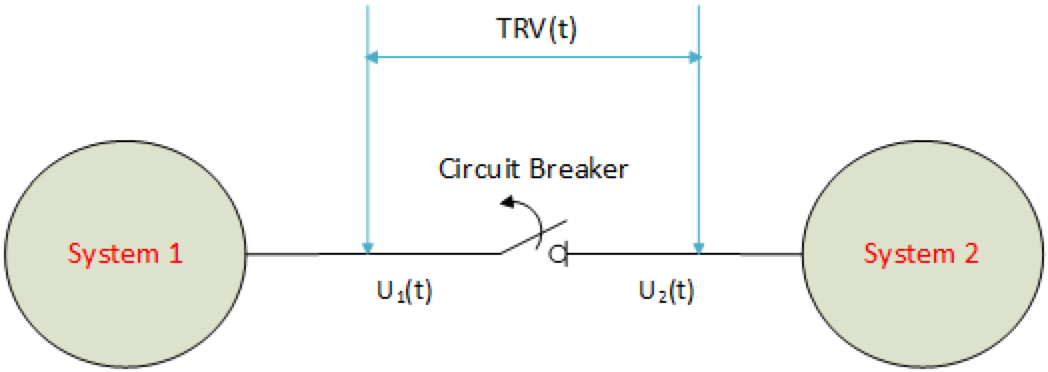
WEBINAR

Transient Recovery Voltage (TRV) Study

TRV - Definition

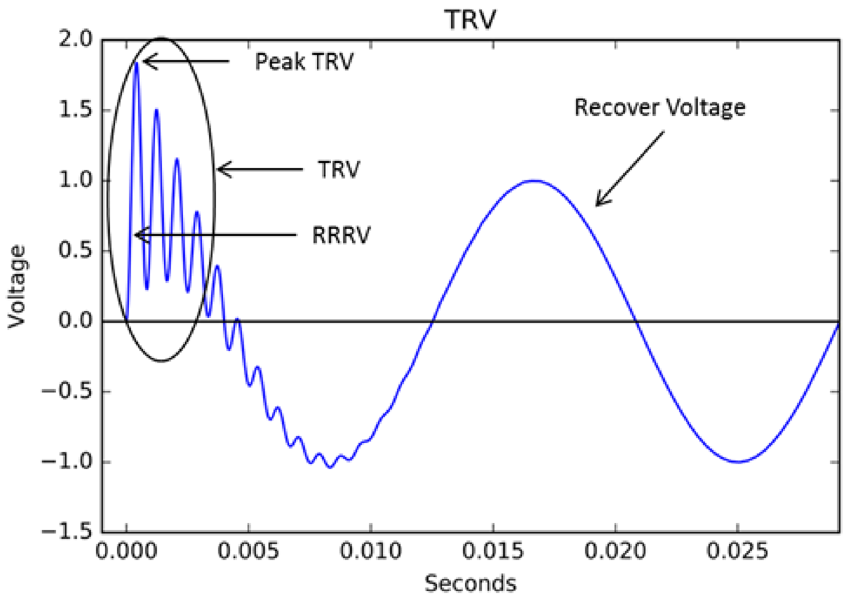
TRV is the voltage difference observed between the breaker terminals immediately after the current interruption of the breaker.

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



TRV – Definition cont....

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).



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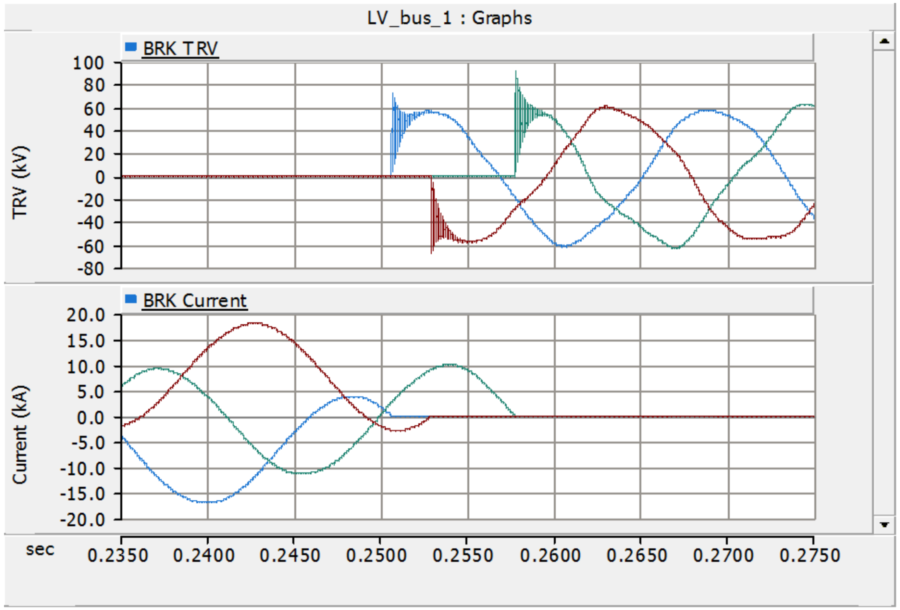
TRV Investigation

- The objective of a TRV study is to verify that the TRV experienced by the breaker during current interruption is within the capability of the breaker.
  - Under credible scenarios

- The nature of the TRV is dependent on the nature of the circuit being interrupted.
  - LRC circuit behaviour
  - Travelling waves in lines



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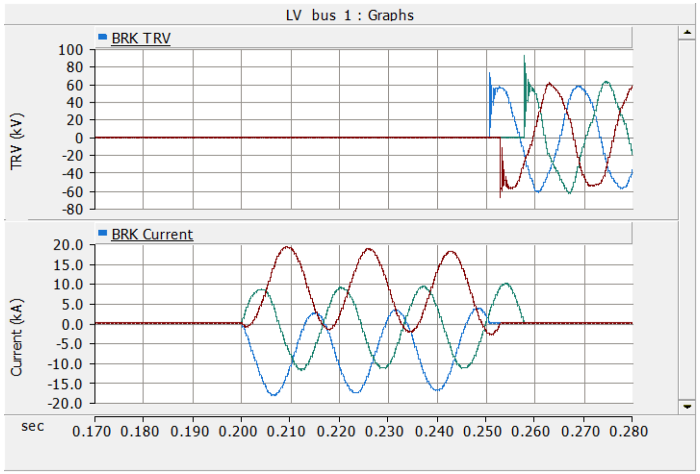
Circuit Breaker Current Interruption

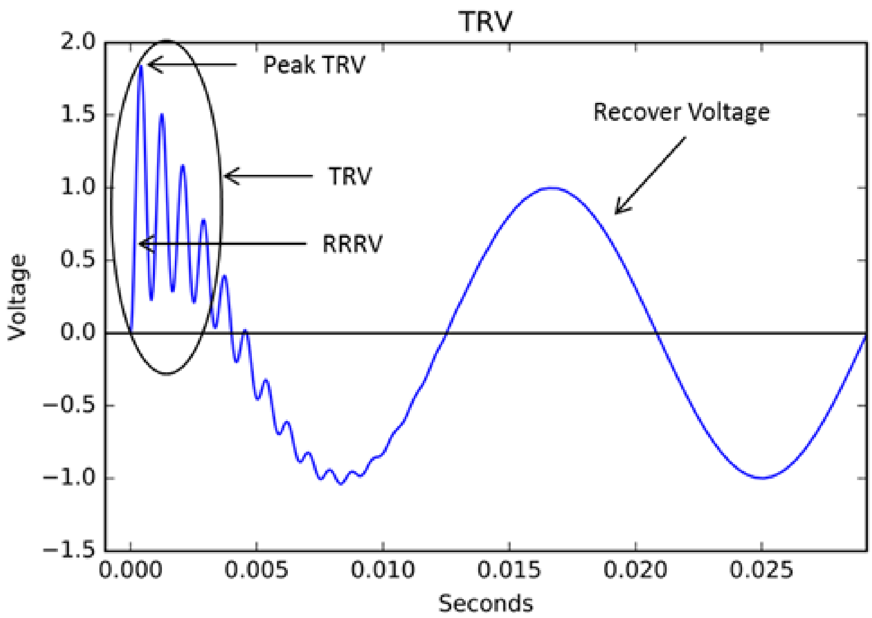
- Trip signal initiate the breaker pole movement (approximately 12 ms for contacts to fully open).
- The current is interrupted at a point of a natural current zero.
- An electric arc (of very high temperature) sustains the current during the interval.
  - Weakened dielectric immediately following current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



TRV Waveforms and Definitions

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

Both the above quantities must be evaluated in a TRV study



Modeling Considerations

- TRV is a ‘fast event’ (10s of KHz)
- The impact of a transient is limited to a local area of the station
- Circuit components of the station has a major 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

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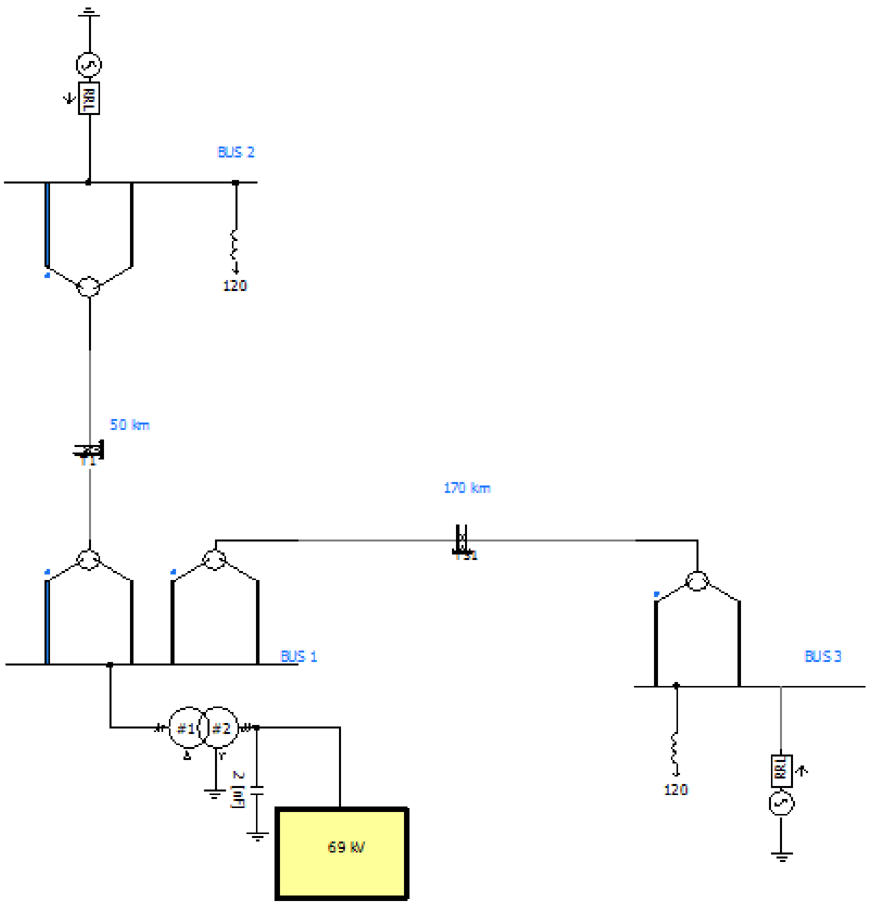
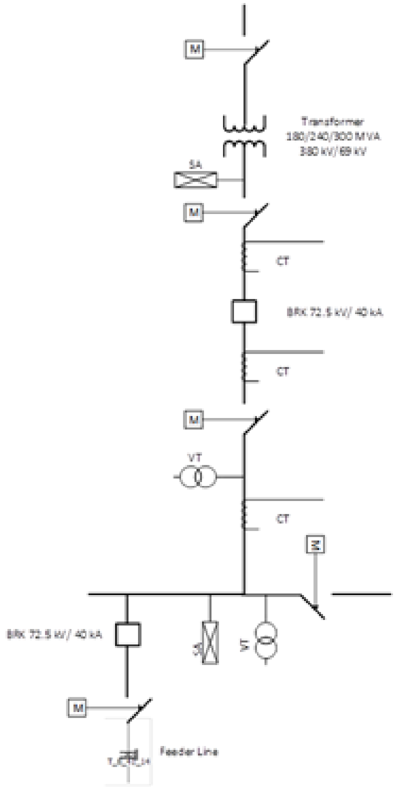
Modeling Considerations

- 1-2 Bus away system model
- Correct short circuit level

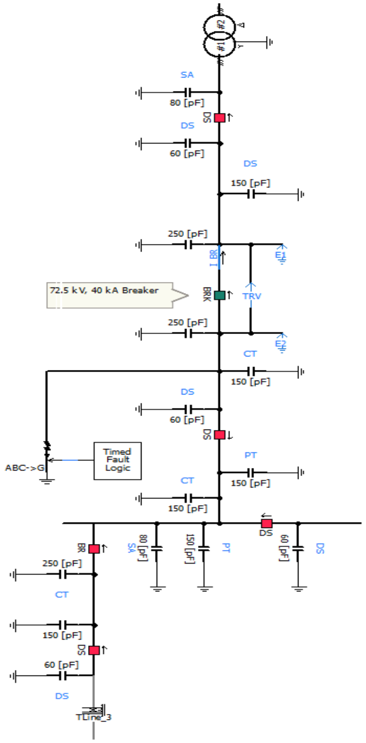


Modeling Considerations

- Detailed station modelling

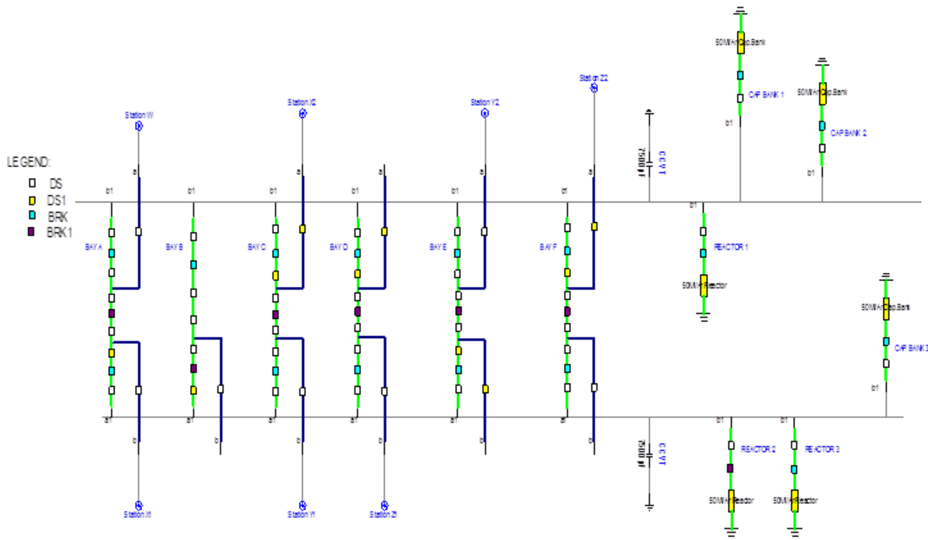


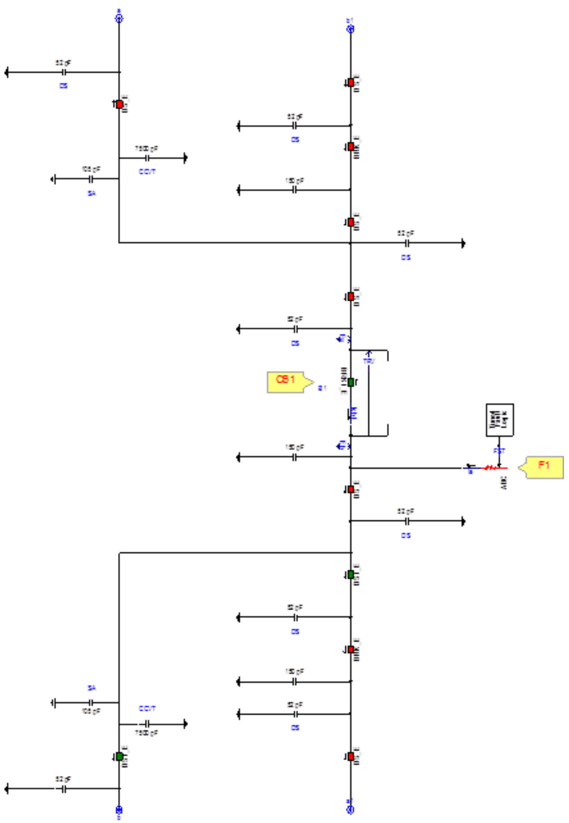
Schematic Diagram



PSCAD Model

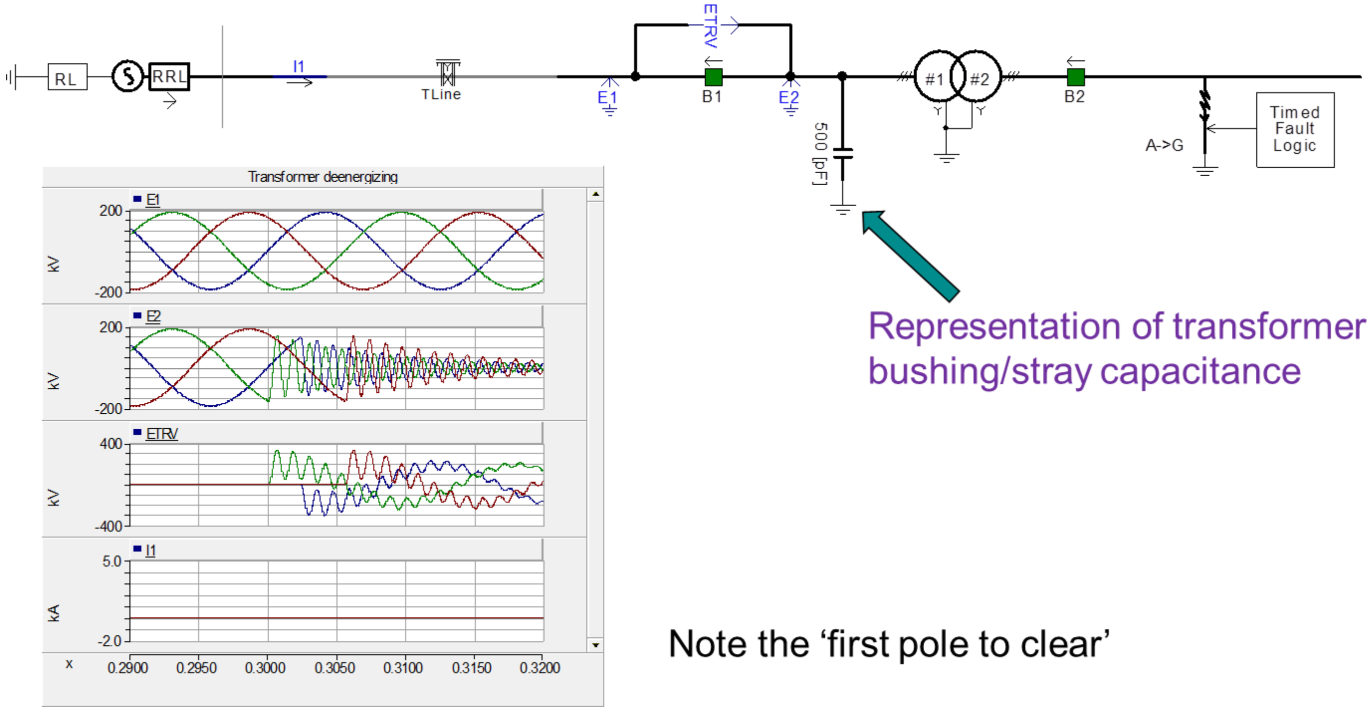
Model Considerations





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

Impact of Bushing/Stray Capacitance



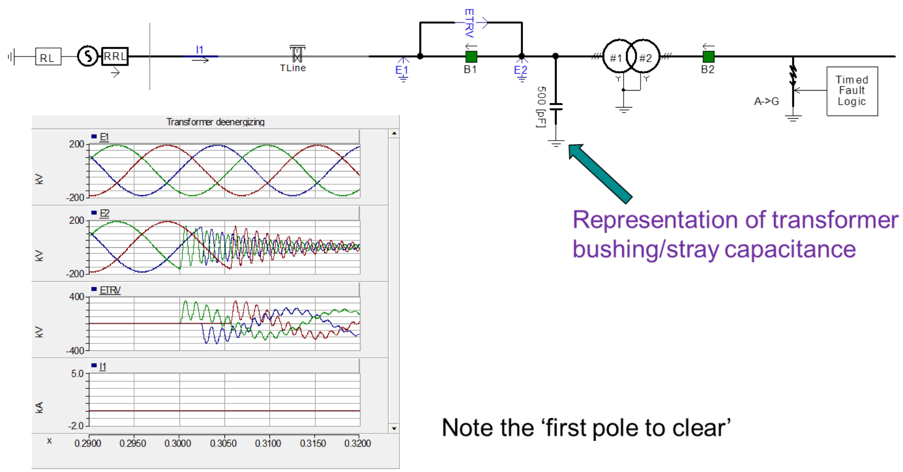
Representation of transformer bushing/stray capacitance

Note the ‘first pole to clear’

TRV is an oscillatory transient. The frequency and magnitude of the transient is thus determined by the L and C of the circuit involved.

Illustration of a simple yet important points

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



Note the 'first pole to clear'

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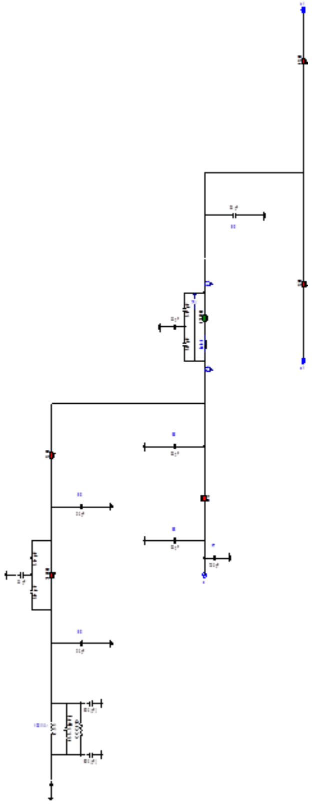
Typical stray capacitance values

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



Types of faults

- 3 phase unground fault (typically gives the worst TRV)
  - Not a credible fault
- Three phase faults
- A-G faults

First pole to clear

- The three poles 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

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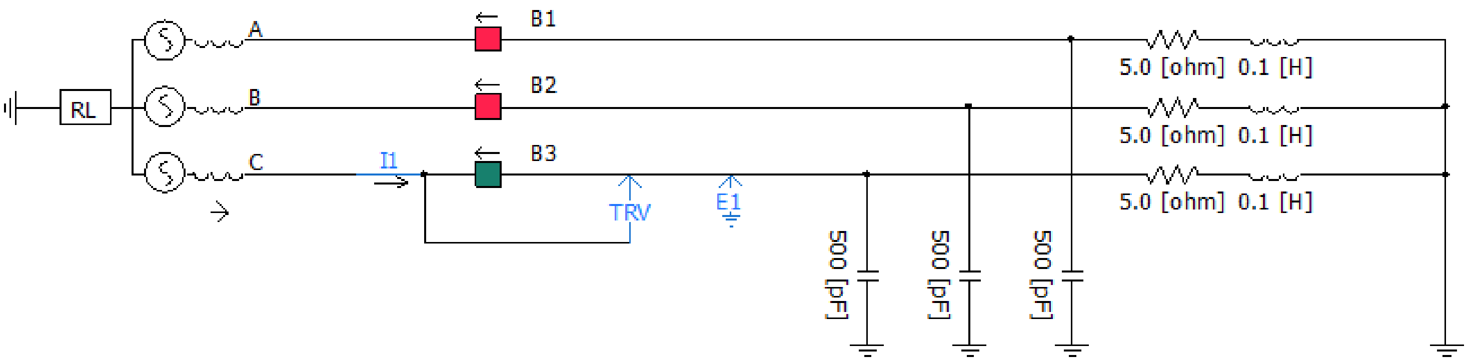
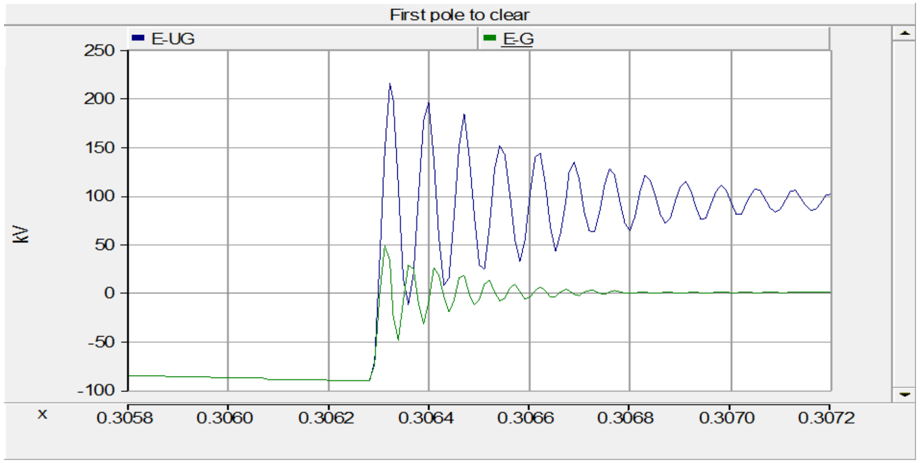
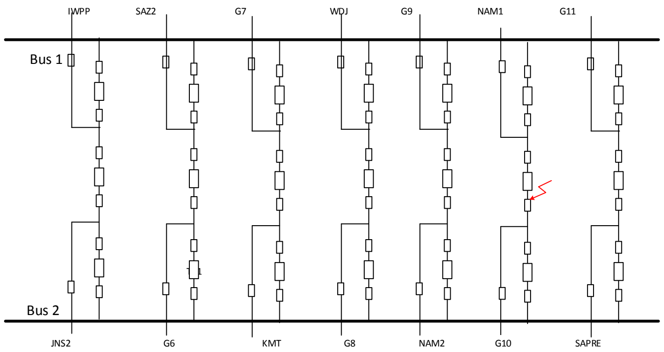
First pole to clear impact on ground/unground fault clearance

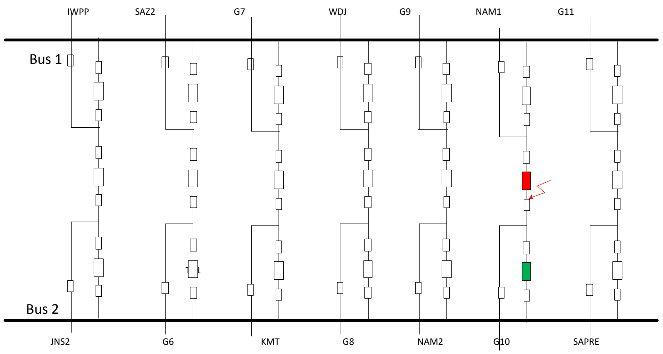




Study Scenarios



(a)



(b)

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

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

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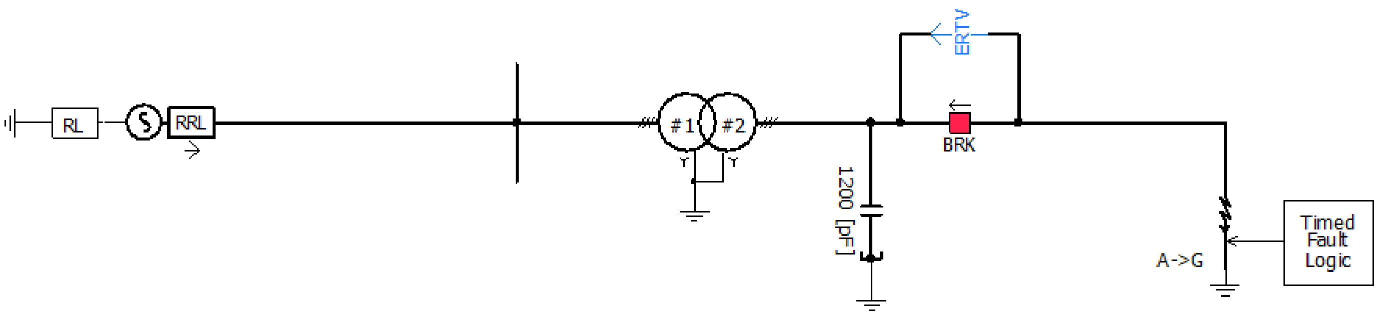
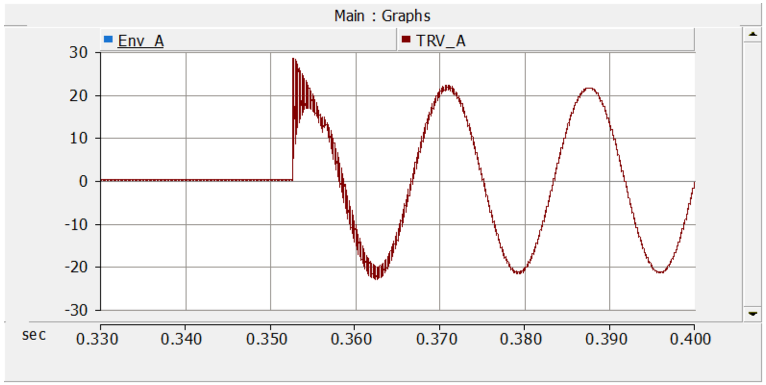
Scenarios to consider

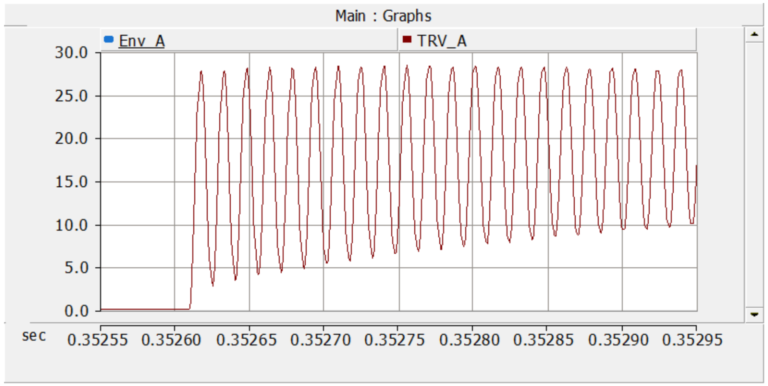
- Station faults (breaker terminal faults)
- Short line faults
- Remote faults
- Faults on Series compensated lines
- Reactor and transformer de-energization

Oscillatory TRV

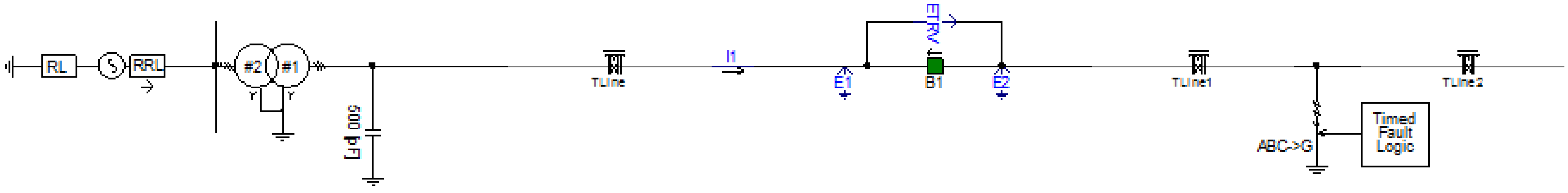
- Resulted from lumped LC oscillations

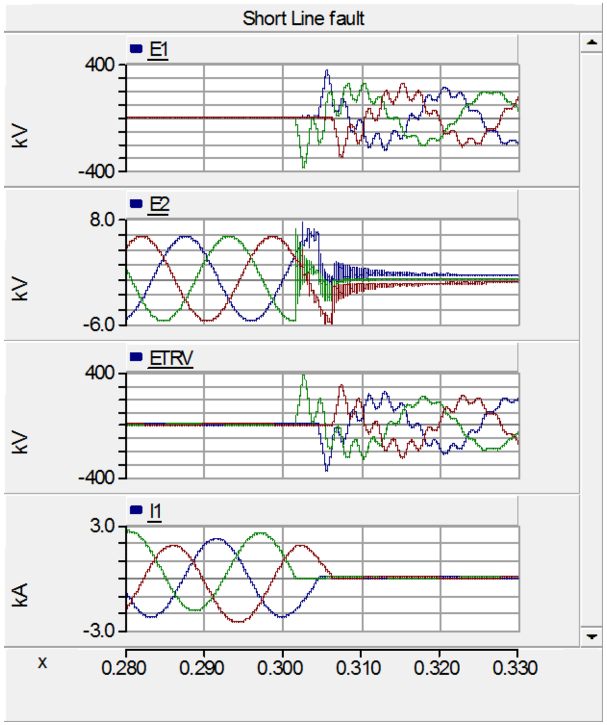


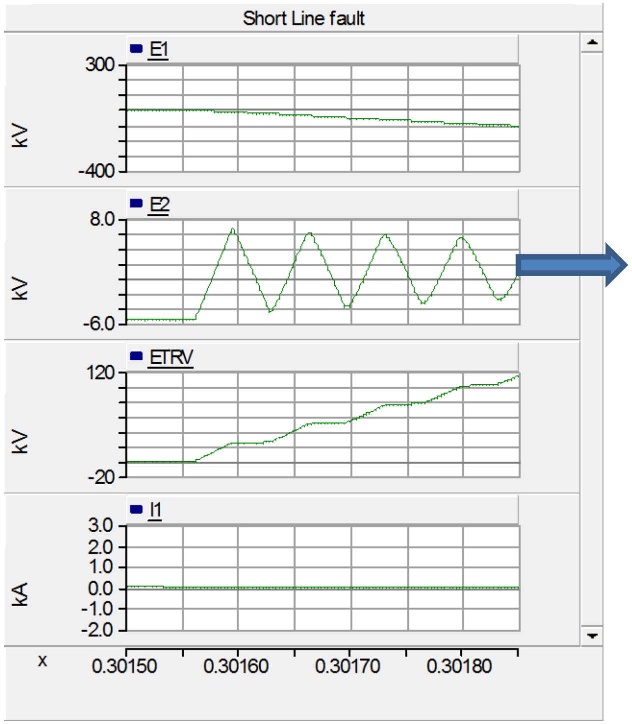




Triangular TRV - Travelling waves in lines impact TRV







Note: The more severe TRV condition is imposed from line side

Breaker TRV capability

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

Pick relevant curve based on actual % current being interrupted.
Ex: if the fault current is 24 kA and the breaker is rated for 40 kA, use the 60% curve.

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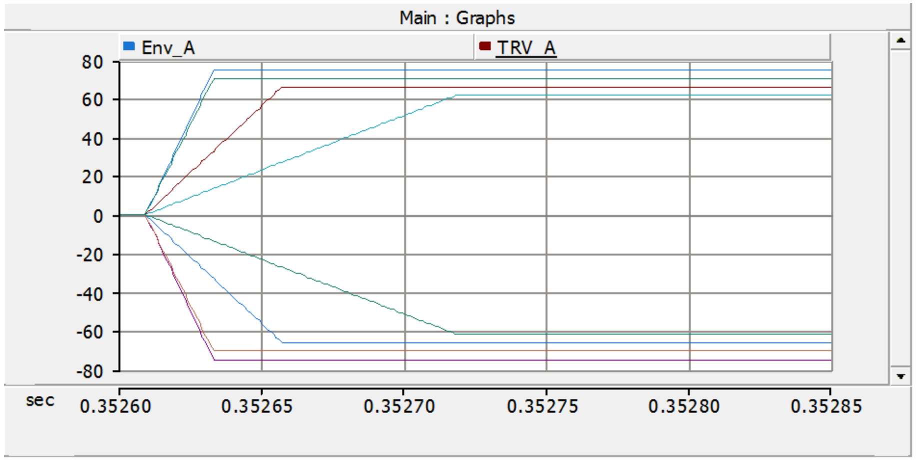
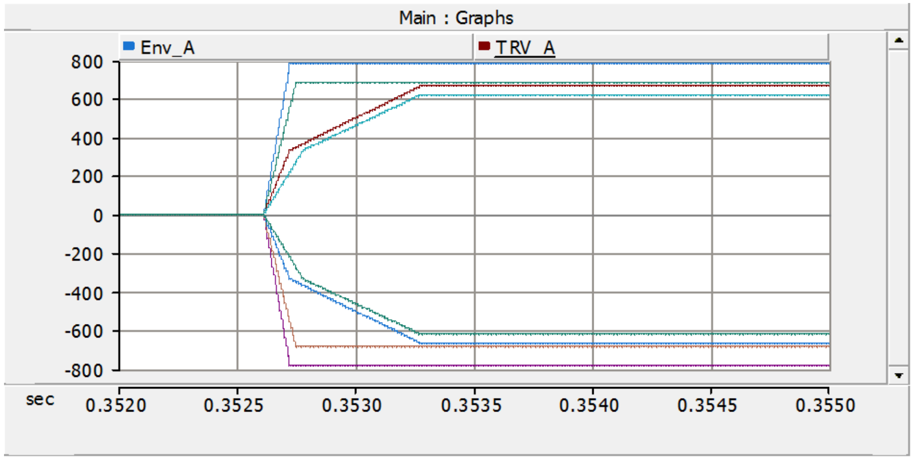
Breaker TRV Capability Curves



Two Parameters



Four Parameters

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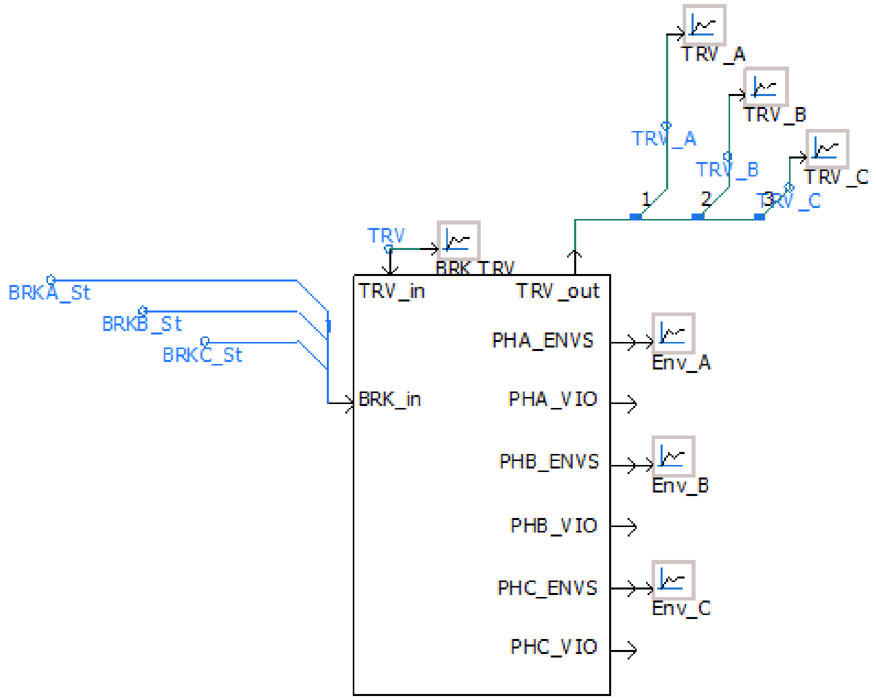
Breaker TRV capability

- 2 and 4 parameter curves
- Modification for SLF (always higher capability than station fault)



Breaker TRV capability

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

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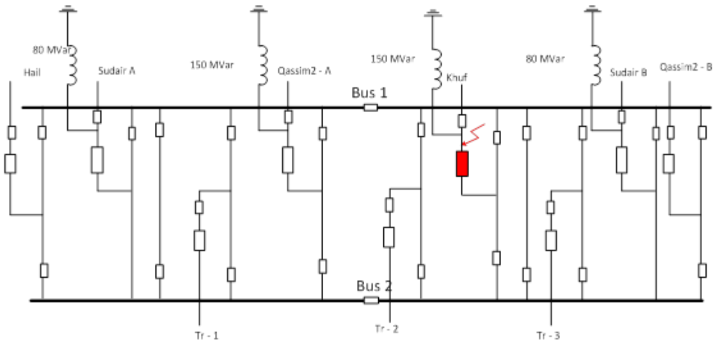
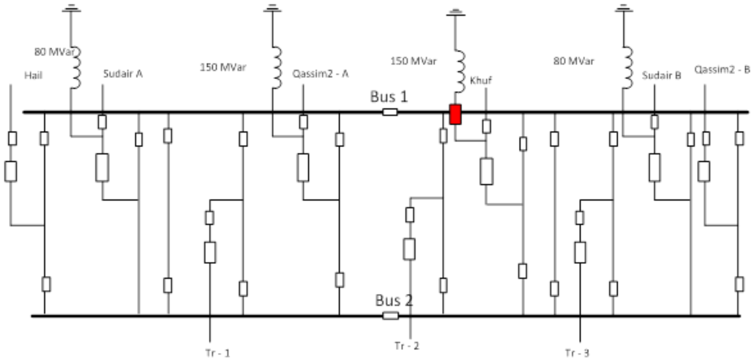
Typical results – station fault



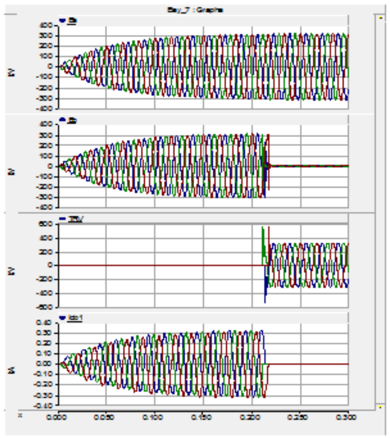
Scenario 1

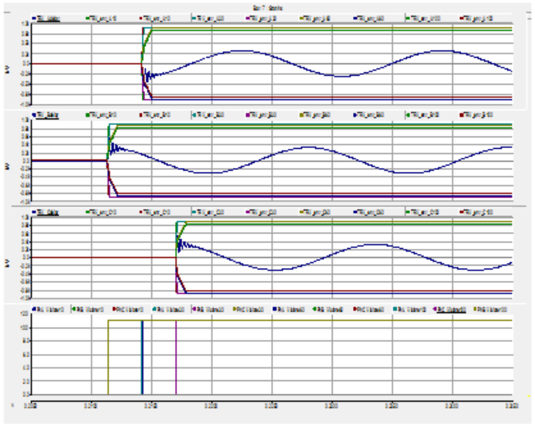
- Fault current through the breaker = 11.3 (18%)
- No violations to any TRV envelopes

Typical results – reactor switching (opening)

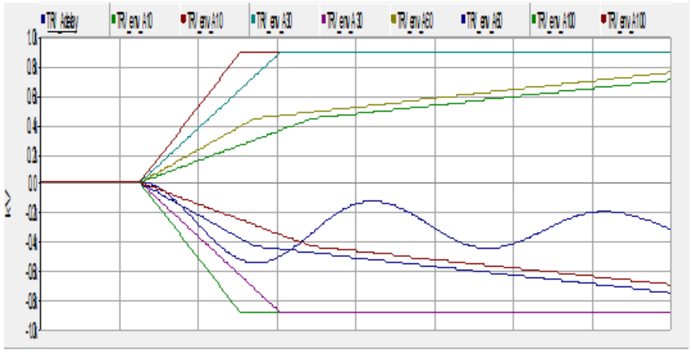


Reactor opening



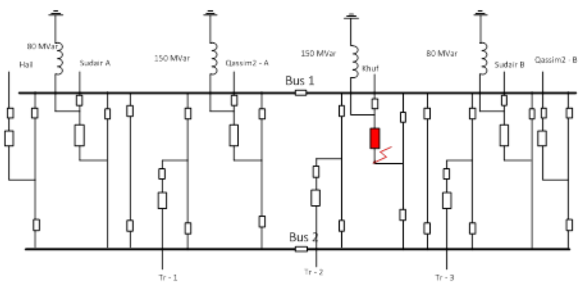


- Interrupting current through the breaker is very small (less than 10%) of breaker rating.
- No violations to 10% and 30% TRV envelopes
  - TRV is above the 60% (and 100%) interrupting envelops but those are not applicable as the actual current being interrupted is much smaller)

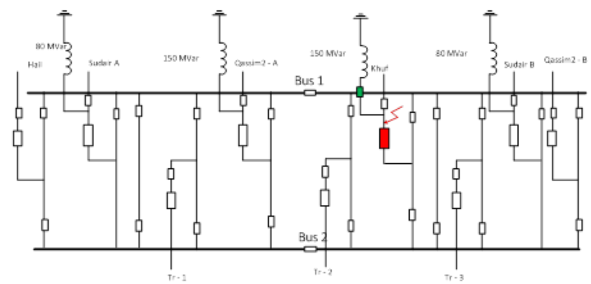


Study scenarios

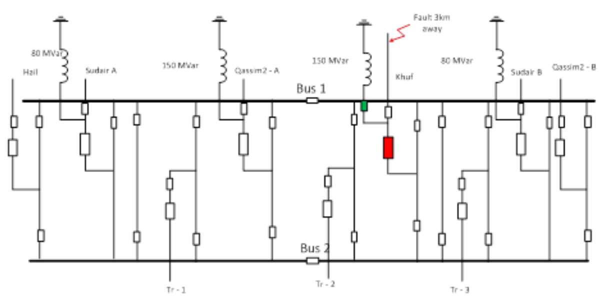
- In this example case, 22 scenarios were studied for TRV compliance (3 selected scenarios illustrated below)
- TRV during the clearing of a 3 phase Unground fault clearance is considered the worst case.



Terminal fault on Line 1



Terminal fault– reactor out of service



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

Thank you