TETRA TECH

Modelling Auto-transformers for TRV studies- Lessons Learned

Mohammad Akbari
Alexandre Gariepy

Tetra Tech Canada Inc.

cigre Canada

2022 CIGRE CANADA CONFERENCE & EXPOSITION

ATCO™

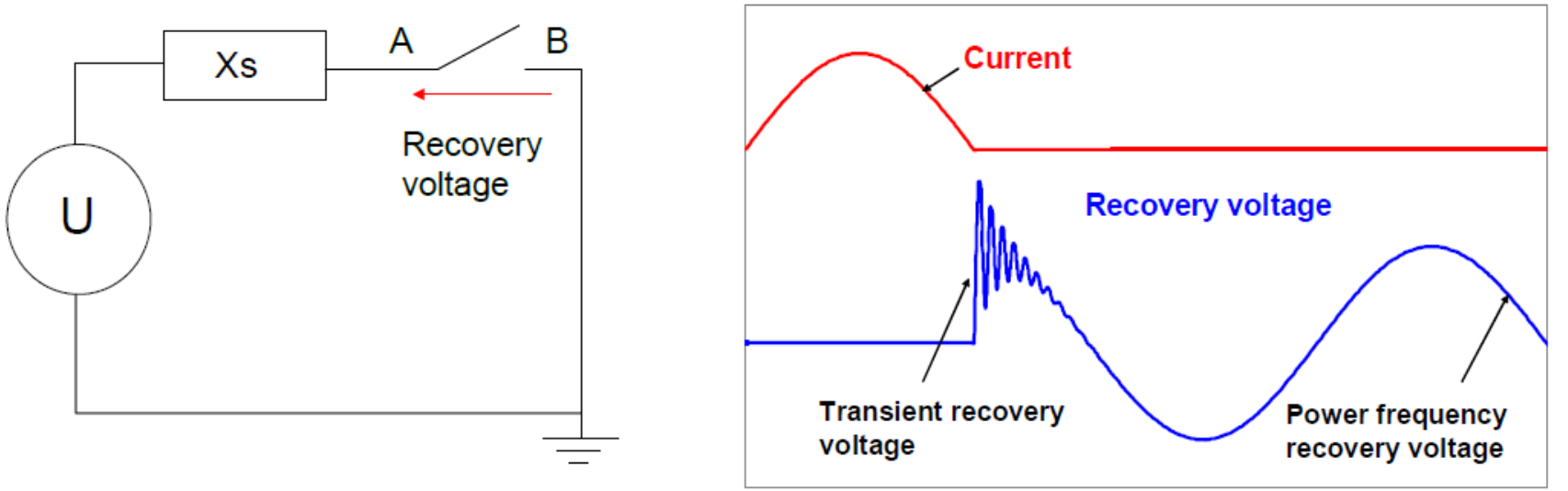
Outlines

- Background
  - Transient Recover Voltage (TRV)
  - Transformer Limited Fault (TLF)
- Transformer Models for TRV Studies
- EPRI Autotransformer Model
- Simulations
- Conclusion

Background

Transient Recovery Voltage (TRV)

- **Point-by-point voltage difference of the load side and source side of the circuit breaker that appears across the terminals of a pole of a circuit breaker immediately after current interruption.**
- **TRV is the difference in the power system response voltages on the sides (source side and load side) of the circuit breaker.**

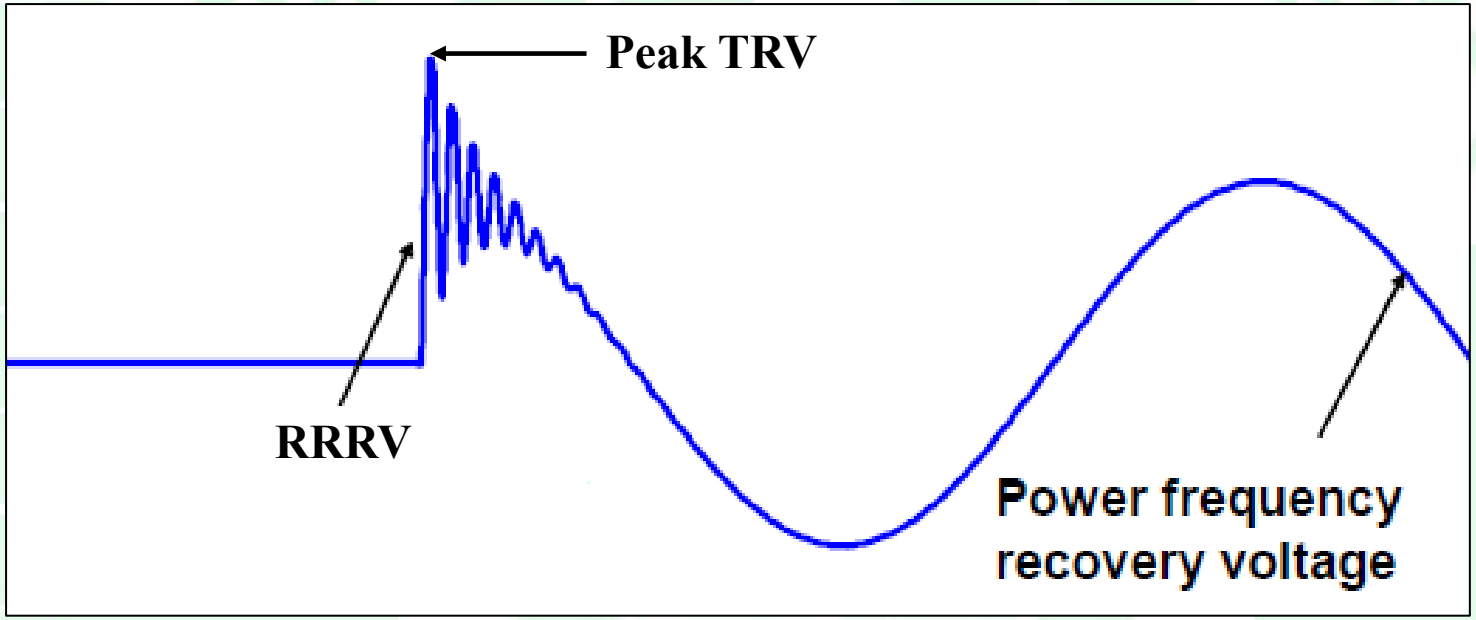


[1]

Background

TRV Characteristics

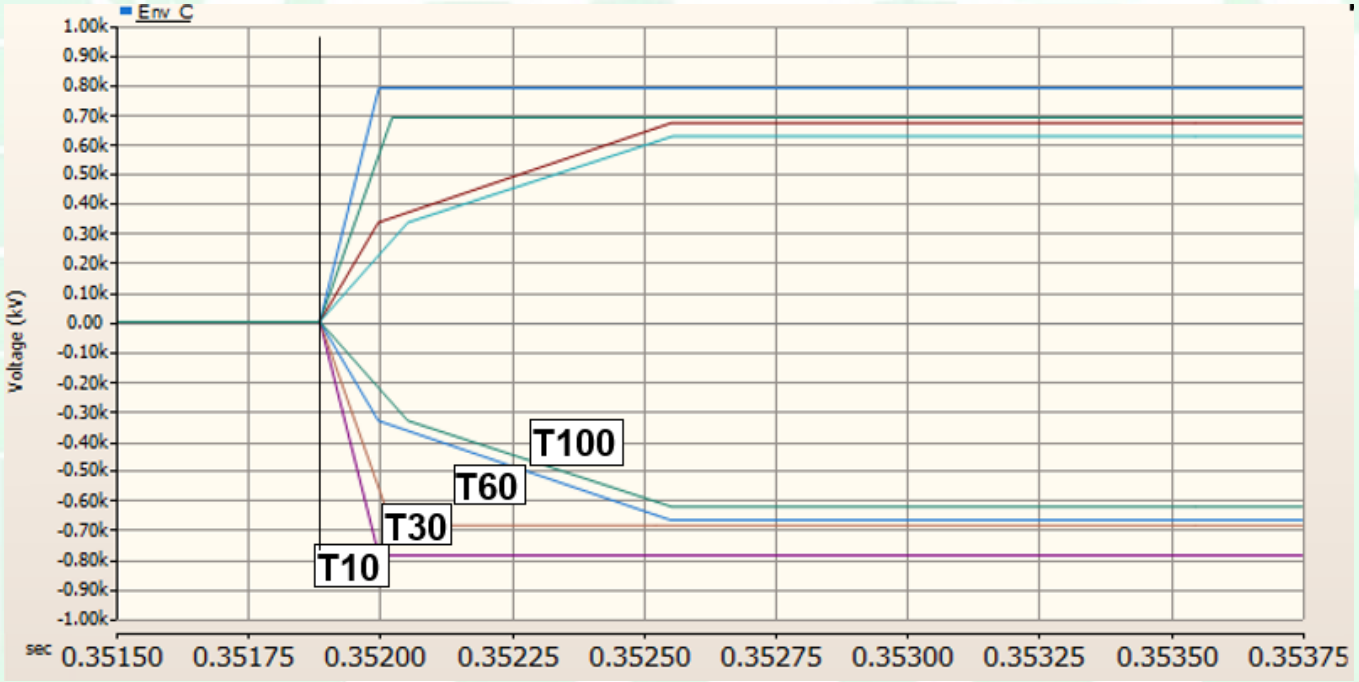
- The TRV peak and the Rate of Rise of Recovery Voltage (RRRV) are the key factors in determining whether the fault can be cleared successfully.
- The interruption operation is deemed successful if the circuit breaker is able to interrupt the fault current and is also able to withstand the TRV and the power frequency recovery voltage.



Background

TRV withstand capability

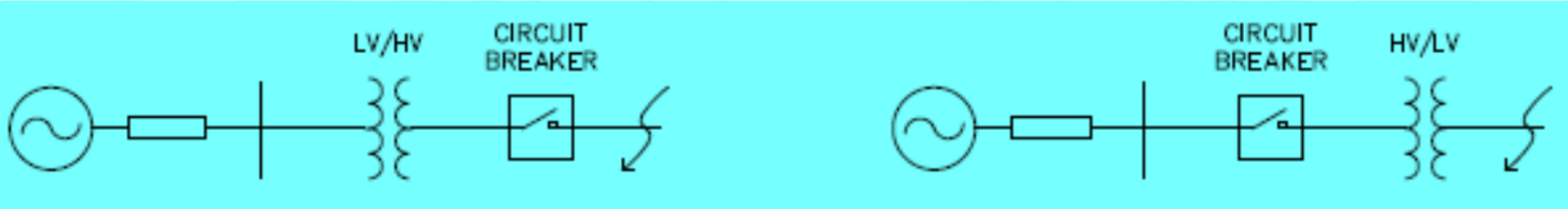
- **TRV withstand capability is defined by the breaker manufacturer or set of curves in standards IEC 62271-100 or IEEE Std. C37.011.**
- **The characteristics of the TRV withstand capability curves depends on the Breaker Ratings (voltage and interrupting current) and the actual current being interrupted.**



Background

Transformer Limited Fault (TLF)

A condition where the fault current is fed or limited by a transformer without any transmission lines or cables connected in parallel with the transformer. Two states might occur for circuit breaker:



Characteristics of TLFs:

- **Short circuit current levels are much lower than the circuit breaker rated short circuit current rating**
- **High frequencies dominated by natural frequency of the transformer which is determined by the surge capacitance and leakage inductance of the transformer**
- **Peak TRV and RRRV voltage may exceed the TRV capability limits**

Transformer models for TFL studies

- The models including the equipment inductance and stray capacitance of different elements like transformer, bus work, and instrument transformers are widely used in TRV studies.
- The transformer stray capacitance is the dominant portion of effective stray capacitance of the system.
- IEEE Standard C37.011, provides typical stray capacitance for different apparatus
- IEEE Standard C37.011 recommended to use Figures B.1 and B.2 graphs to estimate TRV frequencies of transformer-limited faults and calculate the effective capacitances
- These graphs have been obtained based on the research and tests in early 1970 and only a few autotransformers were included in the test set

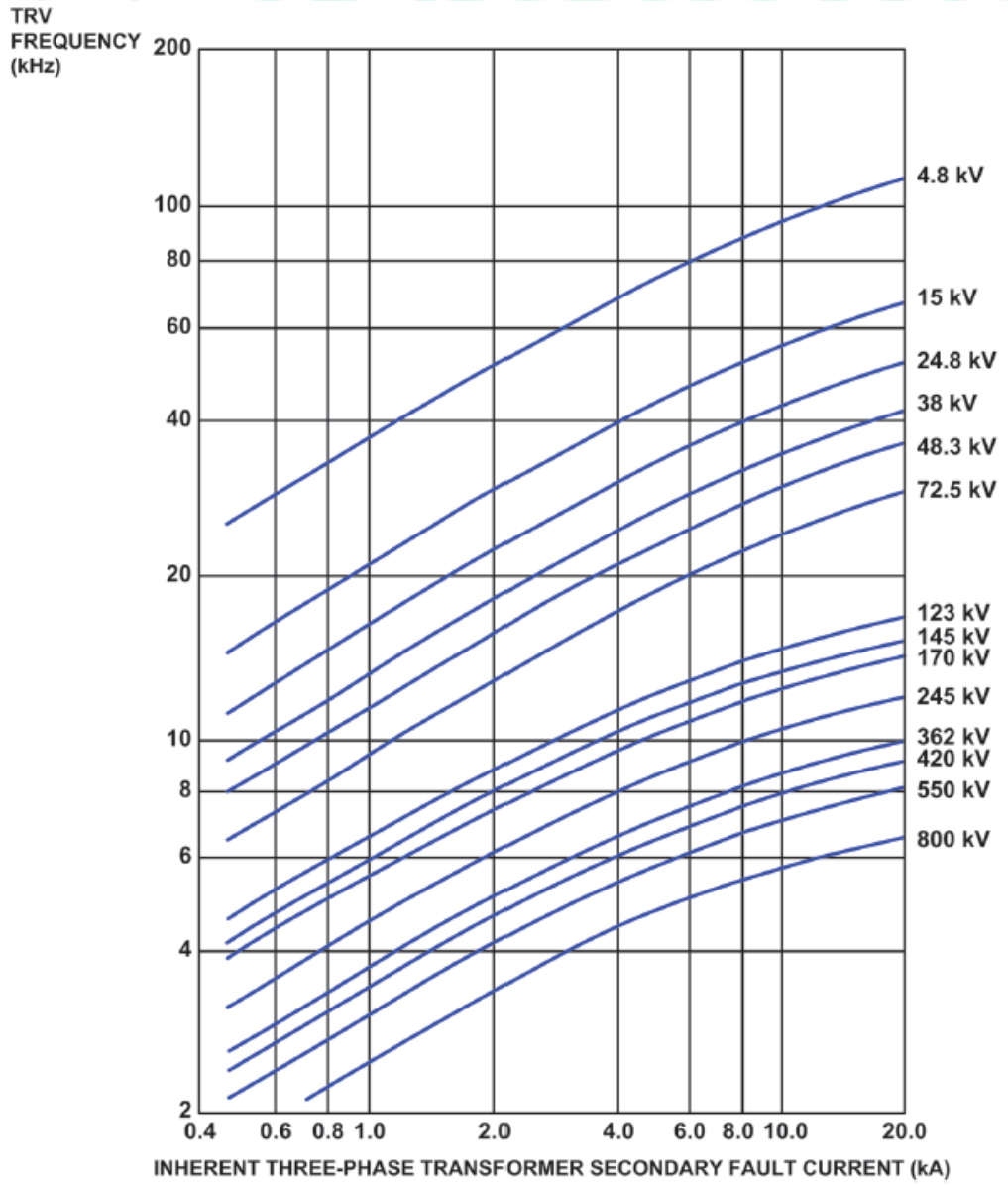


Figure B.2 IEEE Standard C37.011 [2]

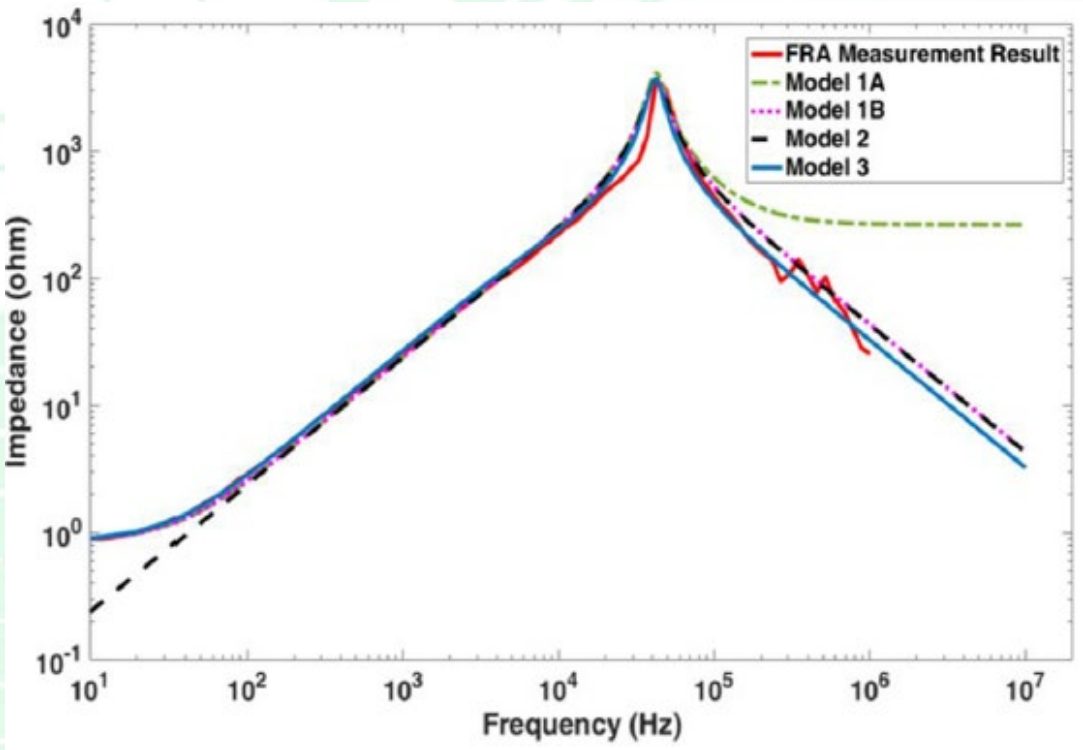
Transformer models for TFL studies

More accurate transformer models can be developed from Frequency Response Analysis (FRA) test of the transformers:

- **The models are L-C multi-mesh circuits composed of many elements and the calculation of the parameters is not straightforward**
- **FRA test result are not readily available**

EPRI has developed an improved multi-frequency autotransformers model:

- **The FRA data is not required**
- **Parameters are calculated using the transformer impedance data and measured capacitance during insulation tests.**
- **The model has been validated using FRA data from factory tests.**

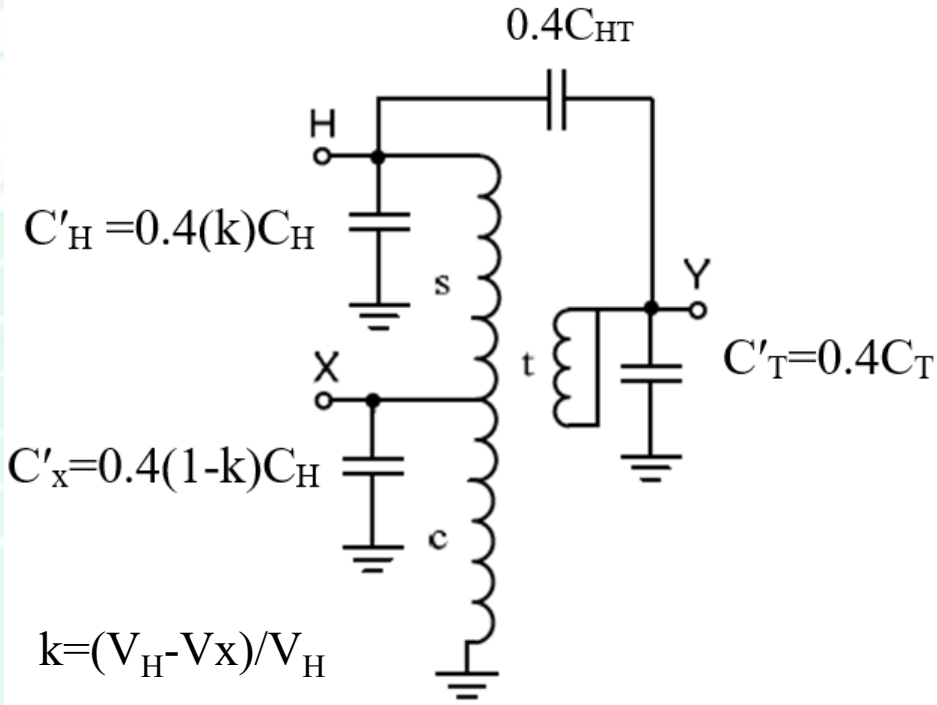


Typical FRA measurement [3]

EPRI Autotransformer Model

The measured capacitances during transformer insulation tests are used to calculate stray capacitances:

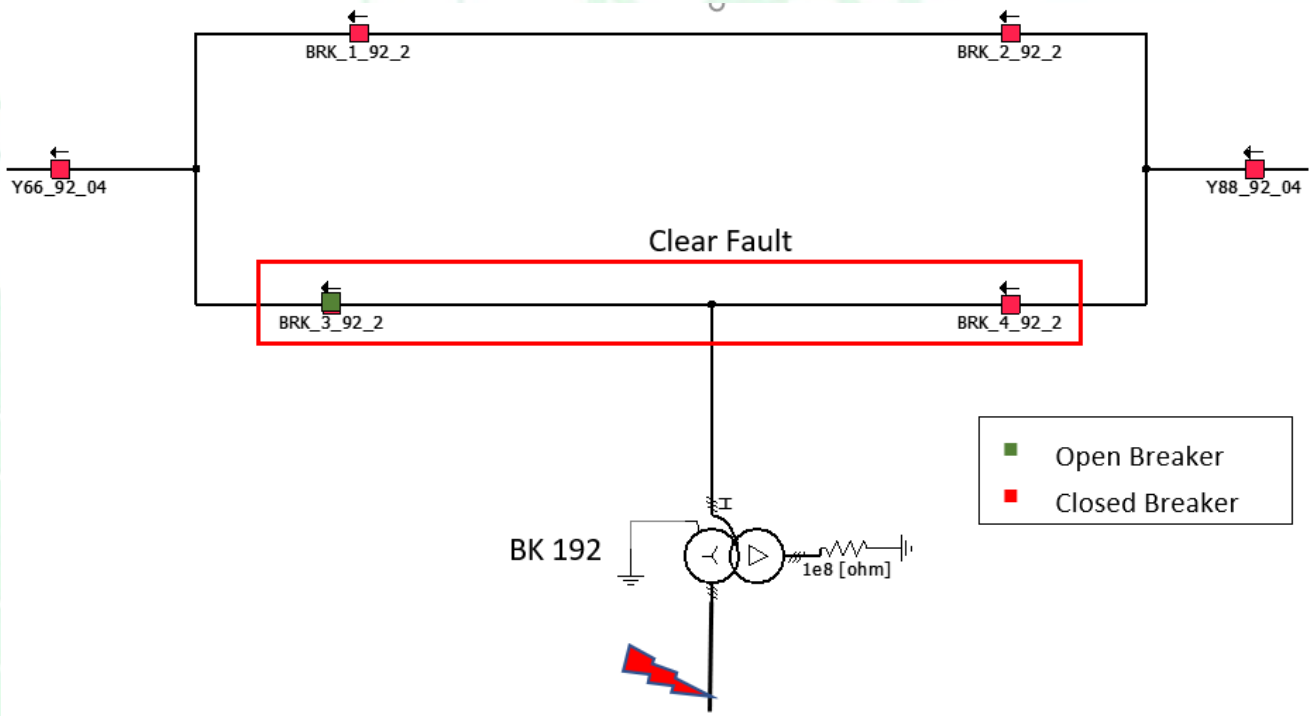
- C_H the total capacitance to ground of the common and series winding
- C_{HT} the total capacitance between the common and series winding and the tertiary winding
- C_T the capacitance to ground of the tertiary winding to ground



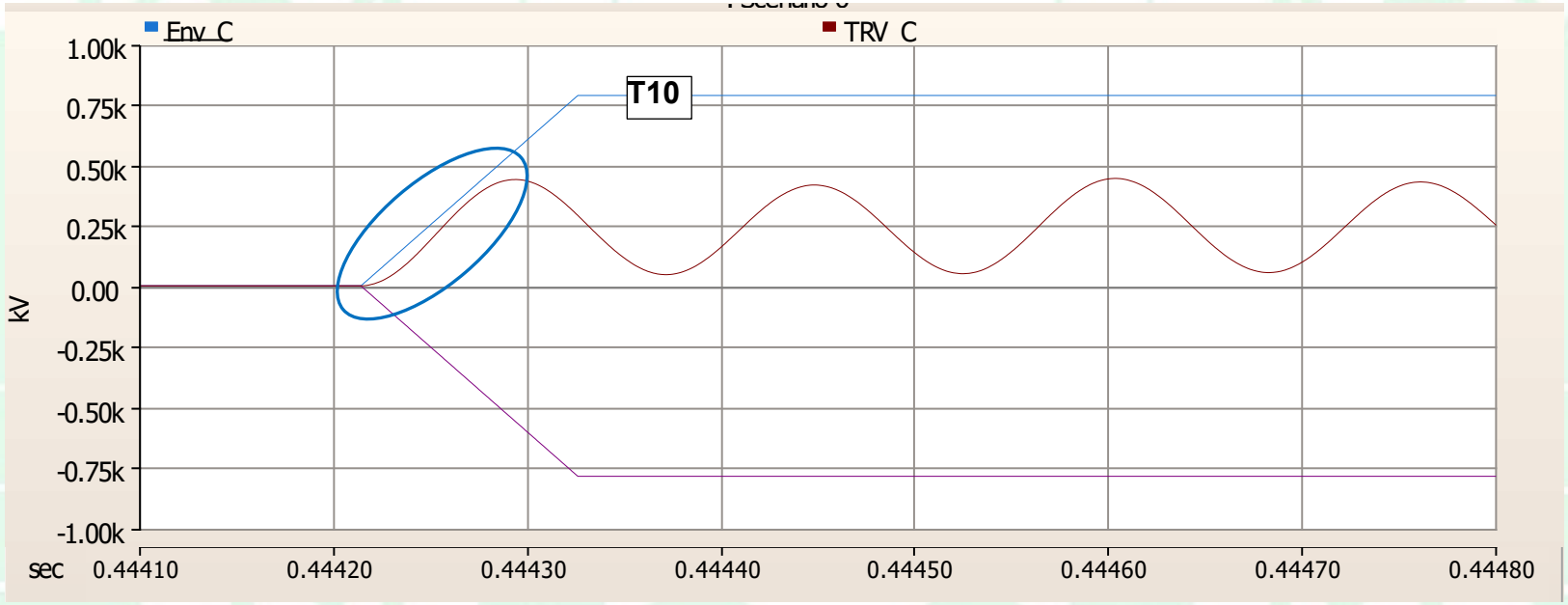
Autotransformer model for TLF studies [4]

Simulation Studies

- A four-element 345 kV Gas Insulated Substation (GIS) and the power grid connected to it were modelled in PSCAD
- The stray capacitance of air/gas insulated apparatuses like sectionalizes, surge arresters, Capacitive Voltage Transformers (CVTs), line traps were modelled
- The autotransformer stray capacitance was initially approximated by the IEEE Standard C37.011 method and added as a lumped capacitor at primary winding.



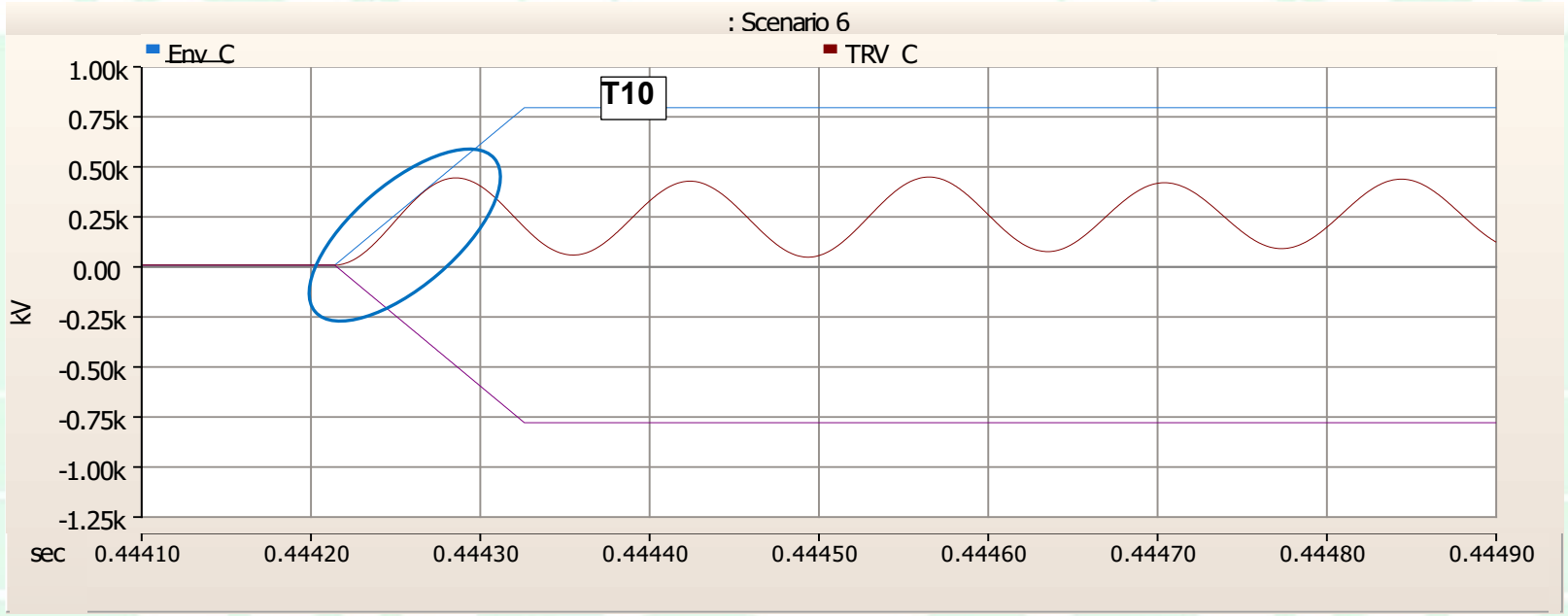
Simulation Studies



TRV of GIS breaker No.4 during interruption of a Transformer Limited Fault. (IEEE Std. C37.011 transformer model).

- **RRRV is high yet within the 10% fault duty (10T) TRV capability limits.**
- **The result are marginal**
- **More accurate autotransformer models are required to ensure safe operation of the GIS**

Simulation Studies



TRV of GIS breaker during interruption of a Transformer Limited Fault (EPRI autotransformer model).

- **RRRV is violated**
- **EPRI model provided more conservative TRV results**
- **A 2000 pf capacitor were added to gas-to-air bushing of the GIS**

Conclusion

- Transformer limited faults result in high Peak TRV and RRRV
- The transformer should be modelled accurately to study TLFs
- IEEE Standard C37.011 methodology may overestimate the transformer stray capacitance
  - Based on test in 1970s and old transformer designs
  - Single Frequency
  - A few autotransformer were included in the test set
- EPRI has developed and validated a simple autotransformer model
  - Multi-Frequency
  - Parameters are calculated from data available in the test reports
  - The model has been validated
- The simulation studies on a real GIS showed TRVs calculated by the EPRI model are more conservative

References

[1] D. Dufournet, Transient recover Voltage for High Voltage Circuit Breakers,2013
[2] IEEE Guide for the Application of Transient Recovery Voltage for AC High-Voltage Circuit Breakers, in: IEEE Std C37.011-2019, Nov 2019.
[3] A. Teymouri, B. Vahidi, and M. Eslamian. "A comparative review of different transformer modelling methods in TRV studies in case of transformer limited faults." *Int. Journal Engineering Science and Technology*, 22, no. 2 (2019): 600-609.
[4] R. Horton, R. C. Dugan, K. Wallace and D. Hallmark, "Improved Autotransformer Model for Transient Recovery Voltage (TRV) Studies," in *IEEE Transactions on Power Delivery*, vol. 27, no. 2, pp. 895-901, April 2012, doi: 10.1109/TPWRD.2011.2176757.

Thank you!