Application of EMTP for Simulating Transient Phenomena in High-Voltage Laboratory Test Circuits

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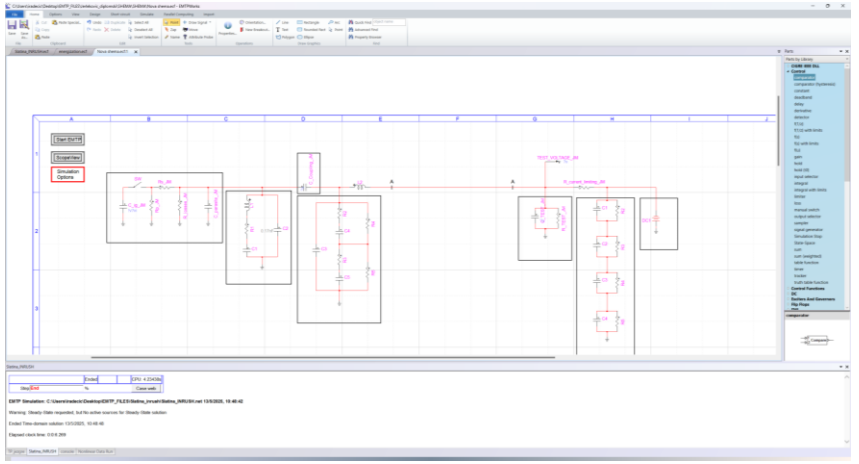
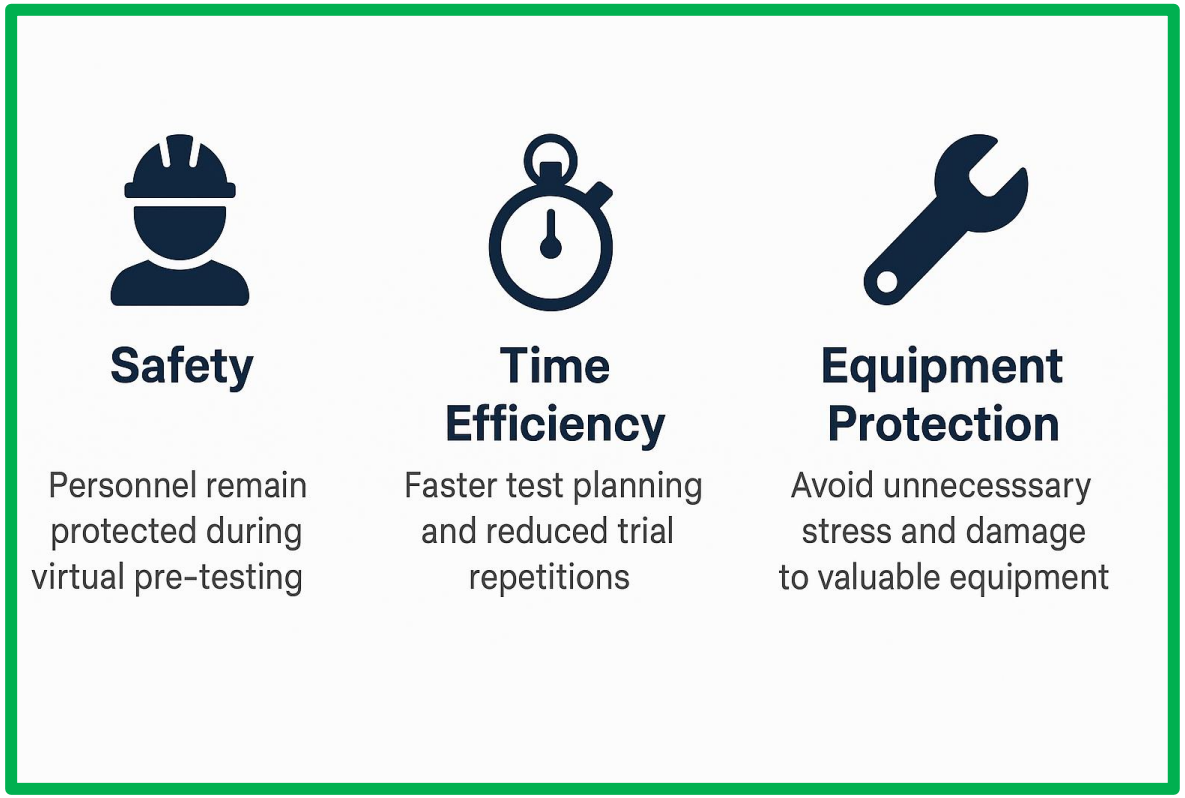
Agenda

- Introduction & Motivation
- Applications in HVDC Cable Testing
  - **Superimposed Impulse Voltage Tests**
- Evaluation of scenarios in EMTP considering equipment limitations
  - **Very Slow Temporary Overvoltage (TOV)**
  - **Combined Heat & BIL**
- Exploration of innovative diagnostic methods
  - **Earth Fault Detection**
- Resonance / ferroresonance – interaction between IVT and CB grading capacitors



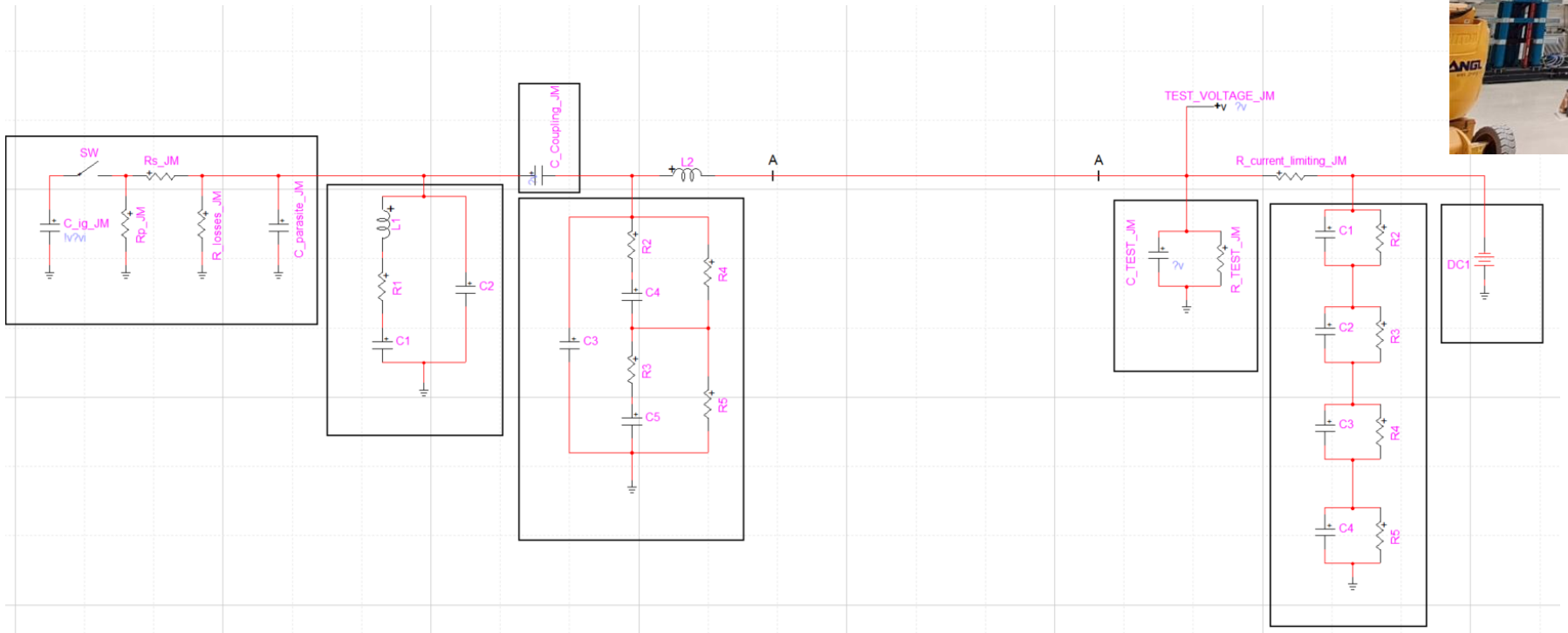
Introduction & Motivation

- The growing need for high-voltage (HV) testing of all types of power equipment
- Development and implementation of both standard and non-standard test procedures
- Technical and operational limitations of HV test equipment
- Test circuits can be modelled using simplified RLC networks or more advanced frequency-dependent / nonlinear models in EMTP for accurate simulation of transient behavior



Example 1 – Superimposed Impulse Voltage Test on HVDC Cable

- Verification of cable under combined stress
  - Simultaneous impulse and DC voltage
  - Realistic operating conditions



EMTP model

- Complex test setup in HV Lab
- Measurement-based validation

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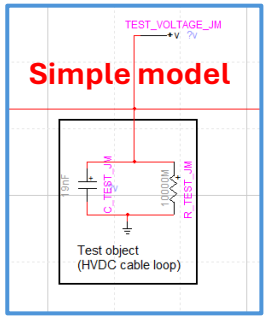
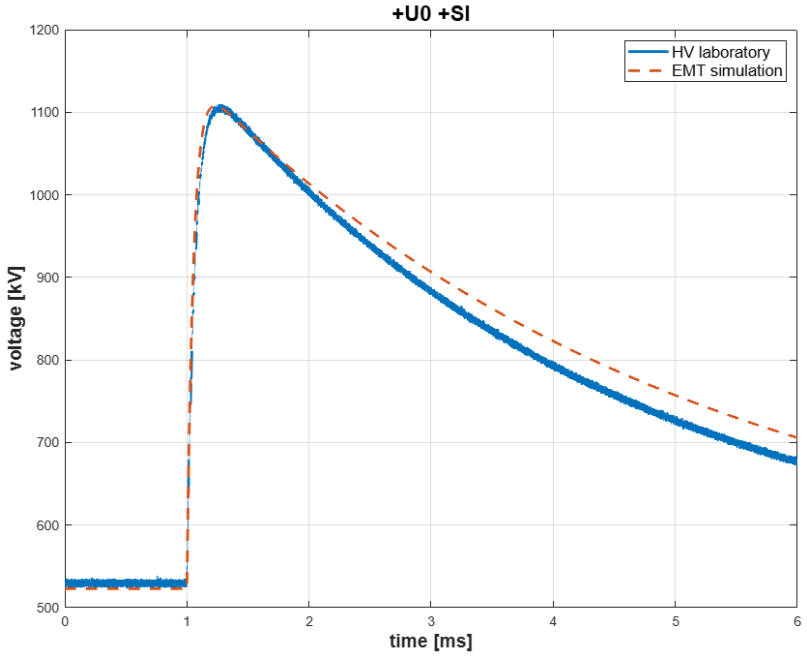
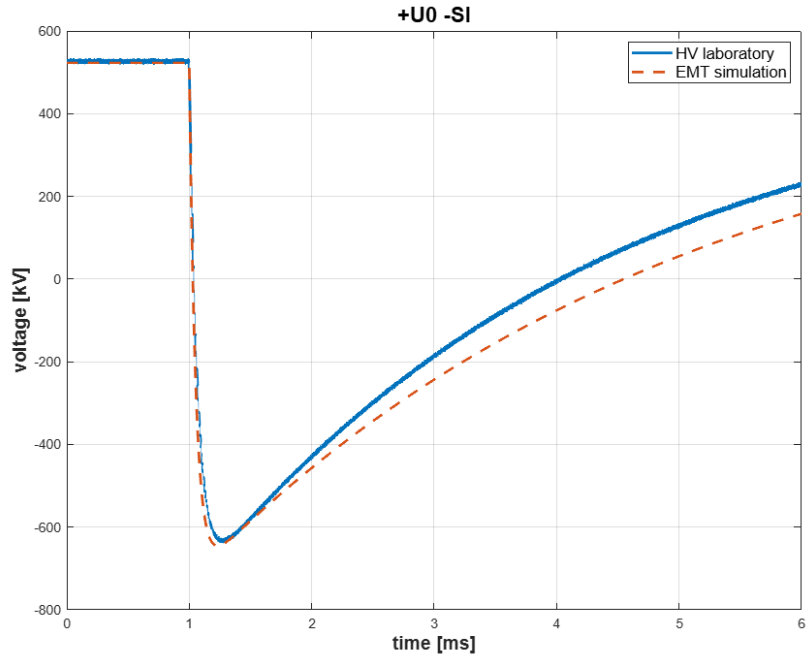


- Validation of model using real measurement in HV Laboratory
  - Simple cable model (only insulation representation by using capacitance to ground)

Superimposed switching impulse





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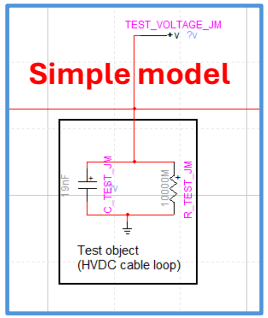

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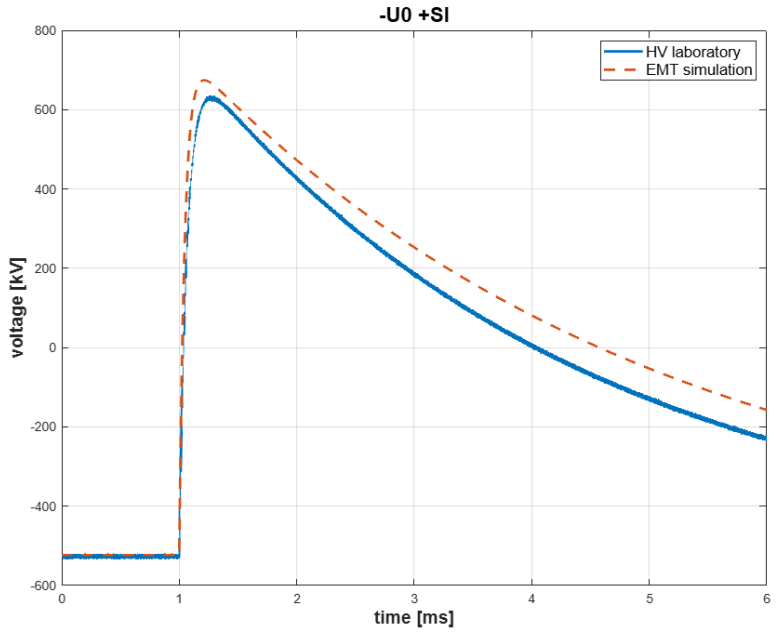

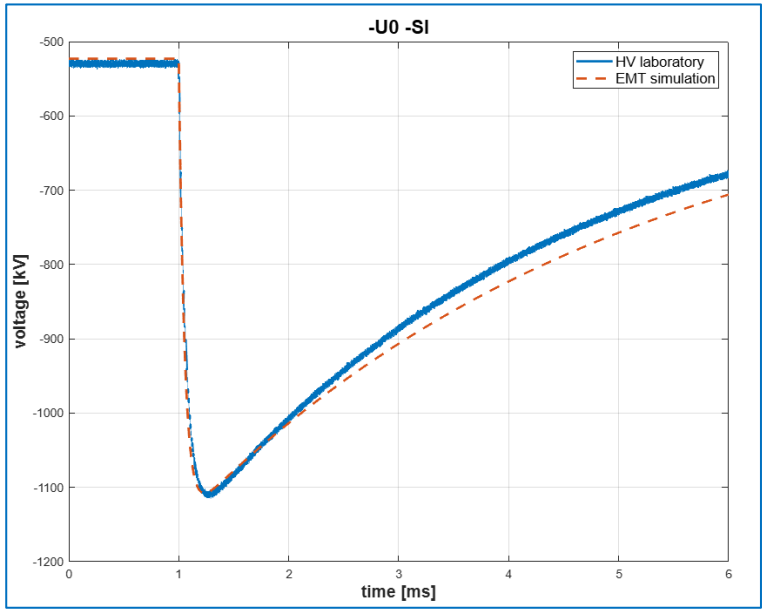

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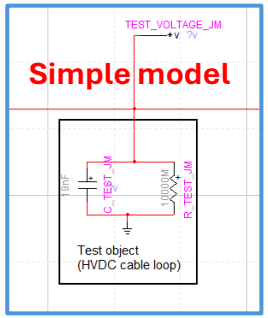

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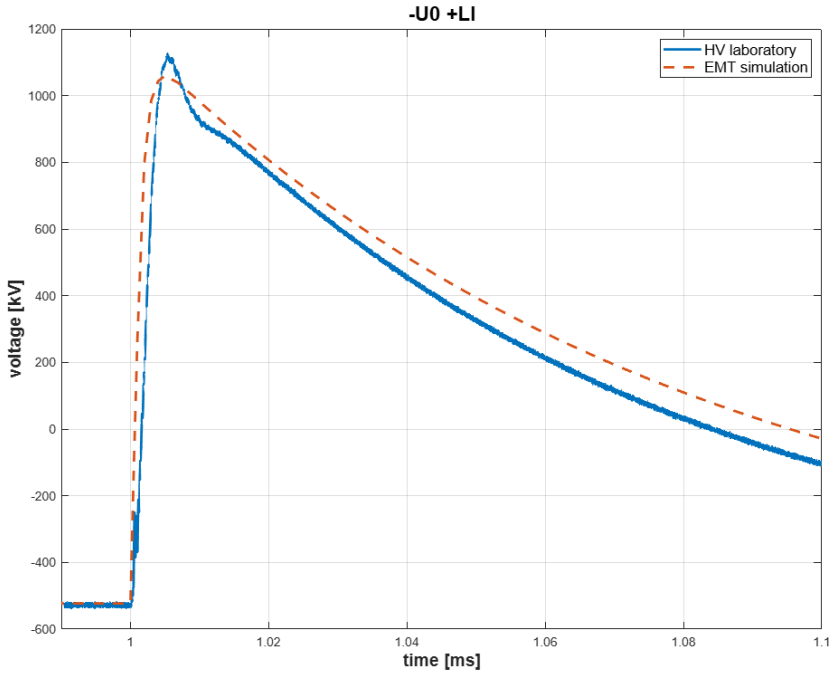
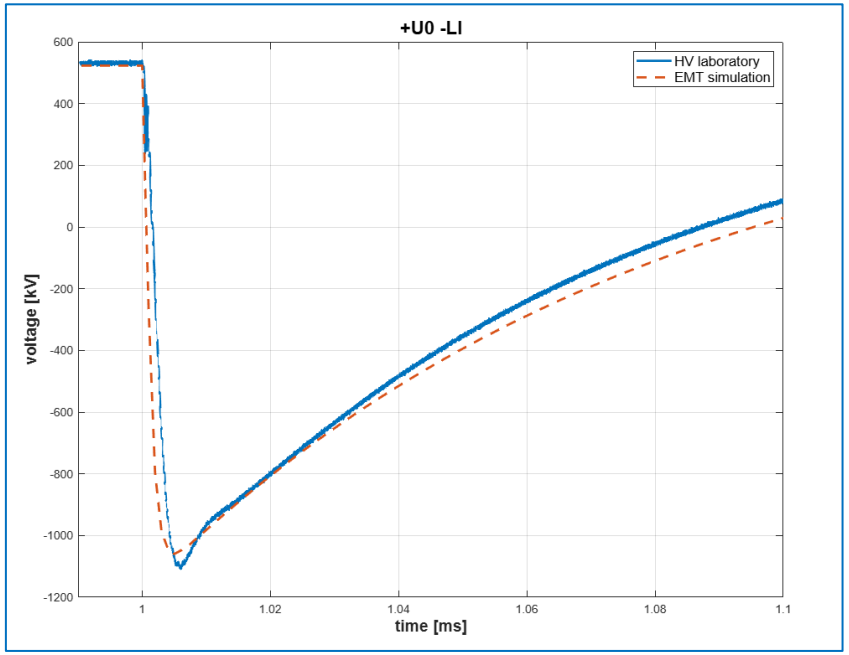
  - Simple cable model (only insulation representation by using capacitance to ground)

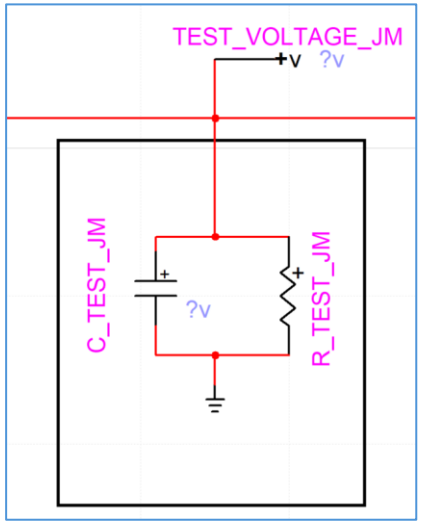
Superimposed lightning impulse



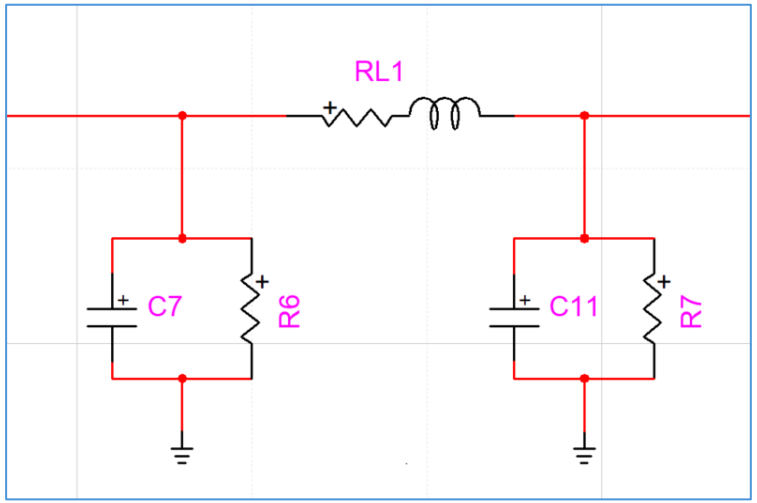


Example 1 – Superimposed Impulse Voltage Test on HVDC Cable

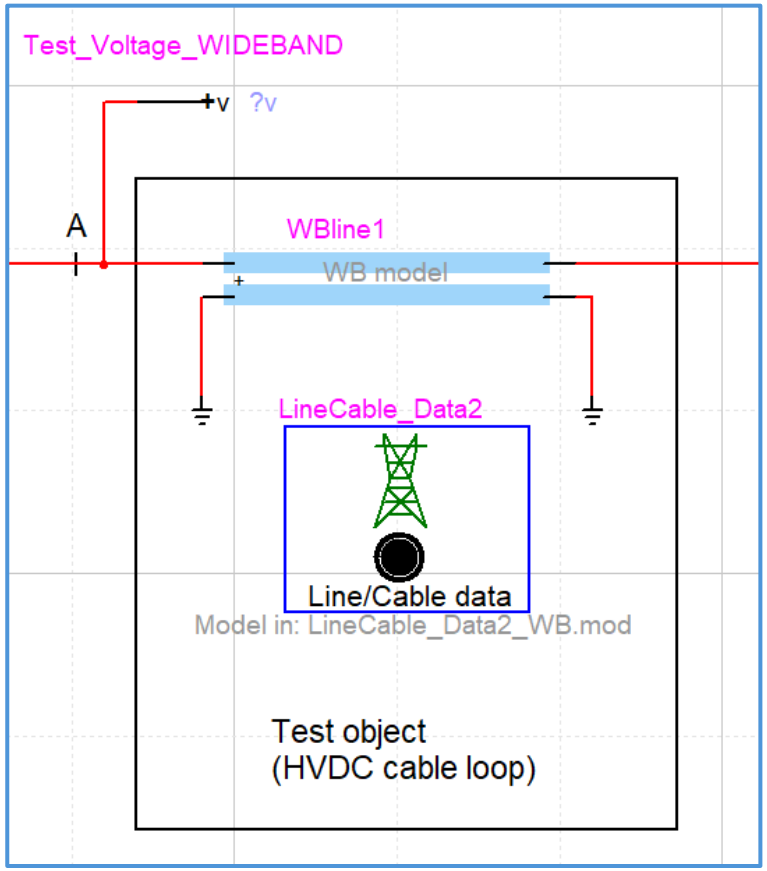
- Upgrading the cable model
  - Simple Model
  - PI Model
  - Wideband Model



Simple Model



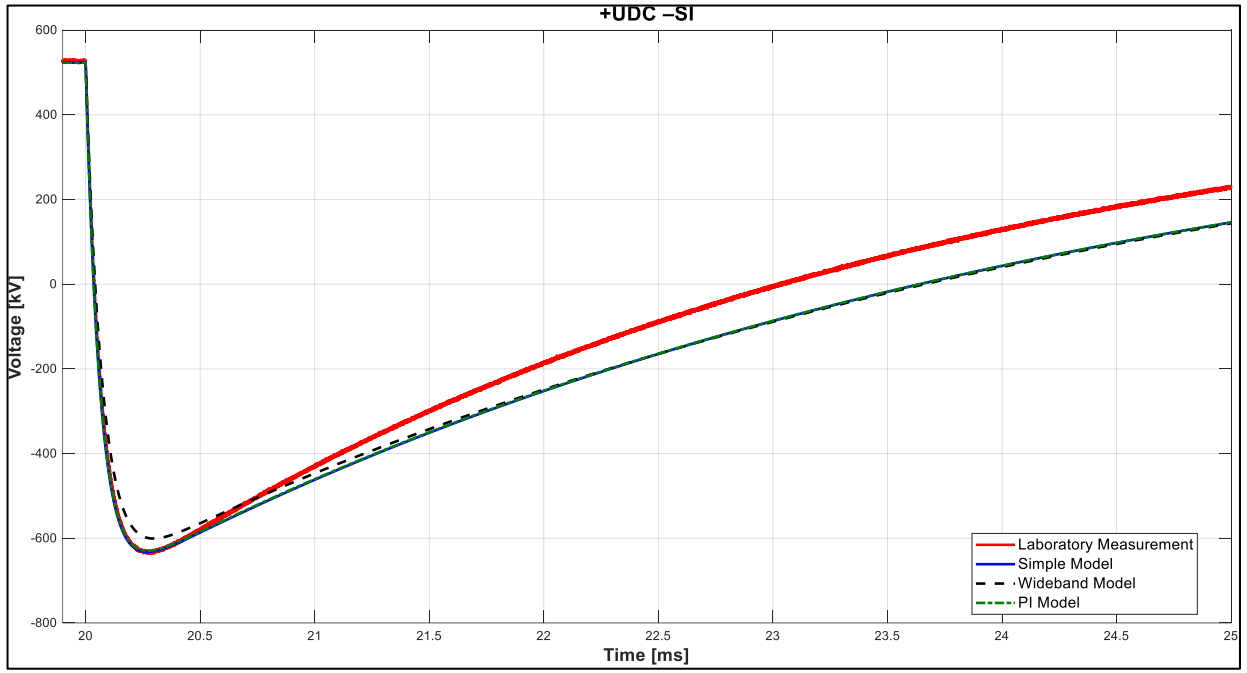
PI Model

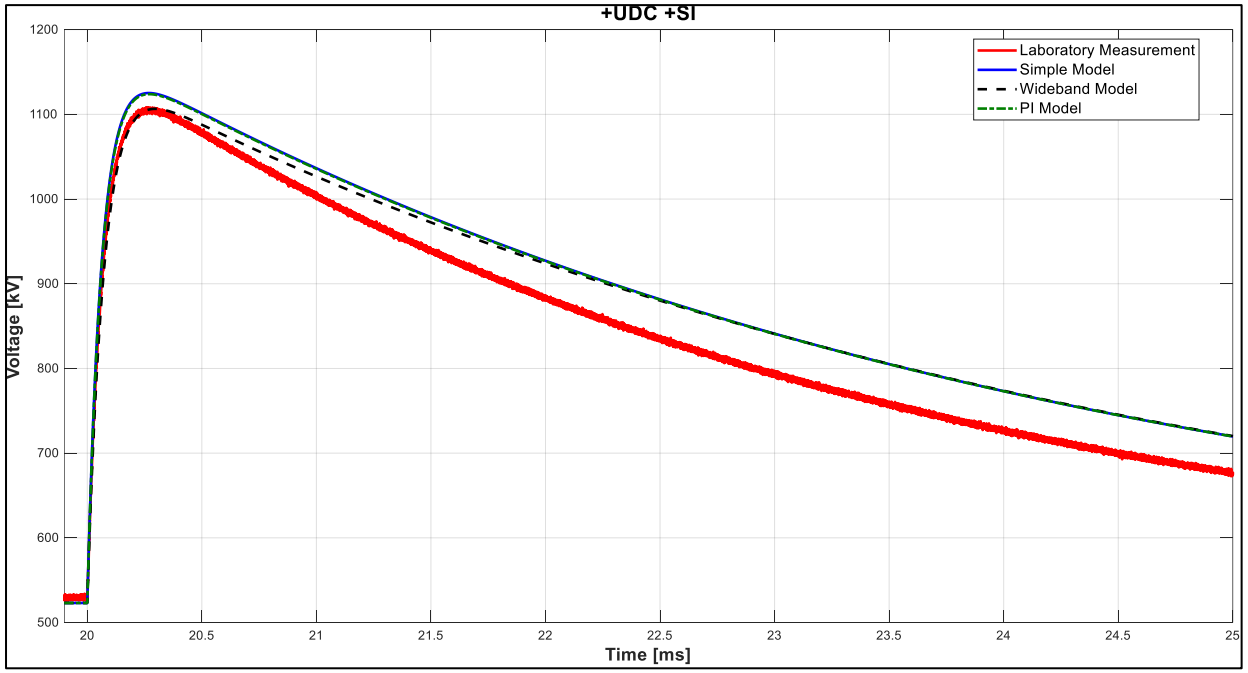


Wideband Model

Example 1 – Superimposed Impulse Voltage Test on HVDC Cable

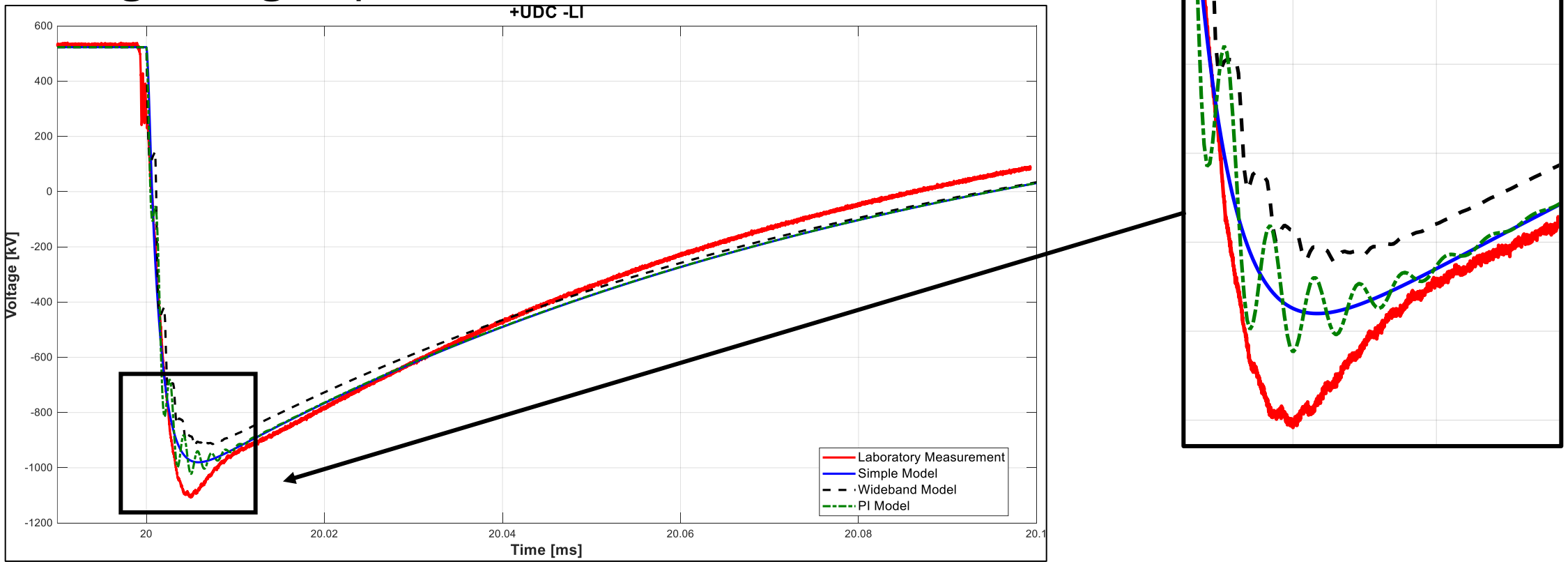
- Switching impulse +/-





Example 1 – Superimposed Impulse Voltage Test on HVDC Cable

- Lightning Impulse -



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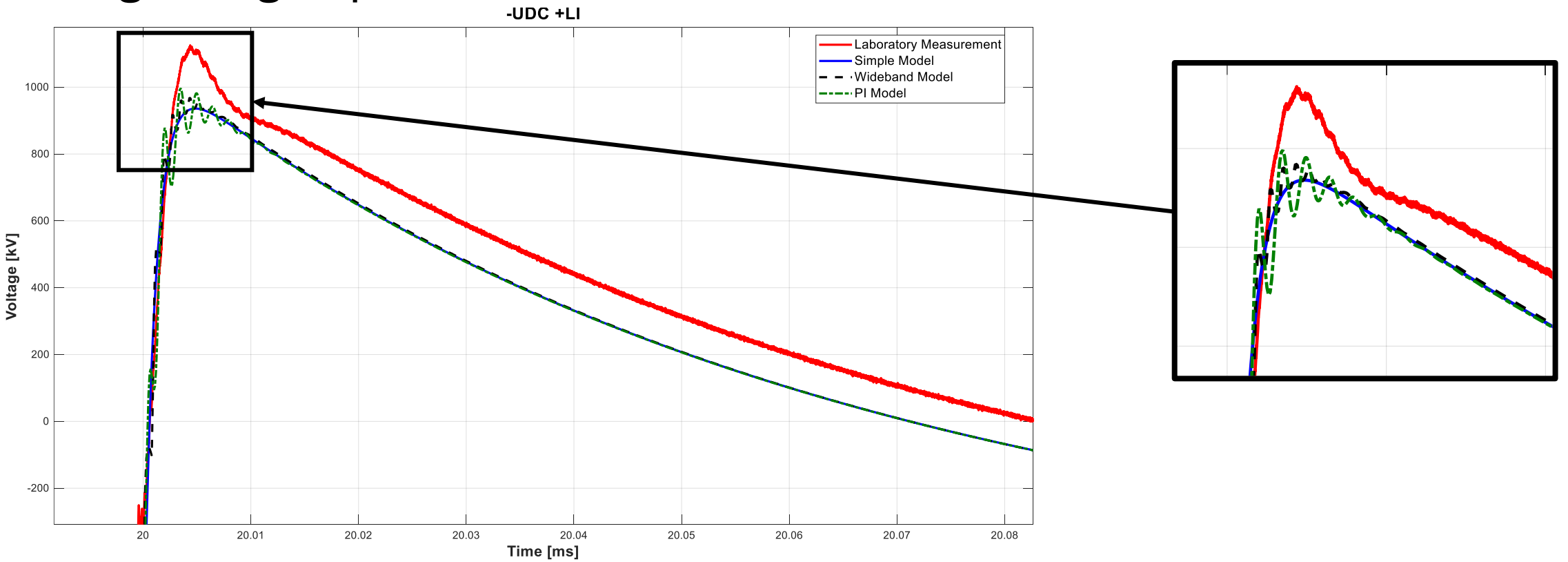
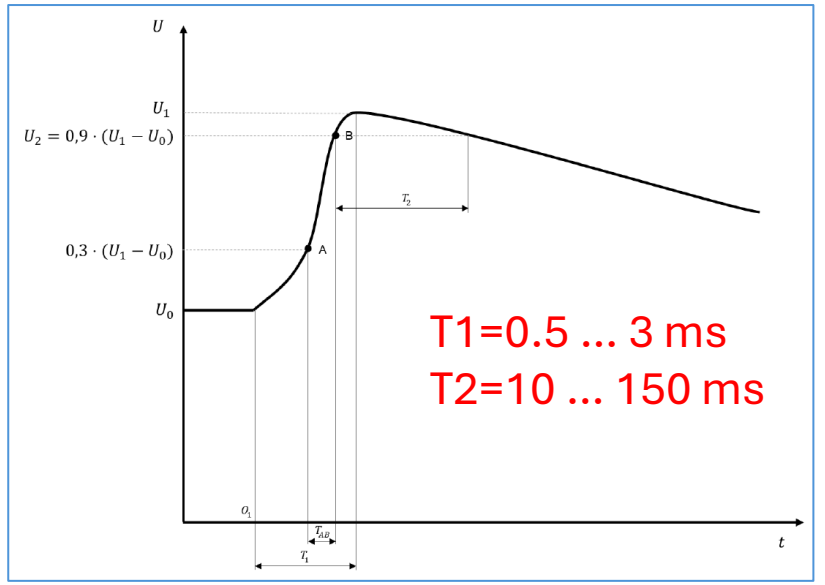
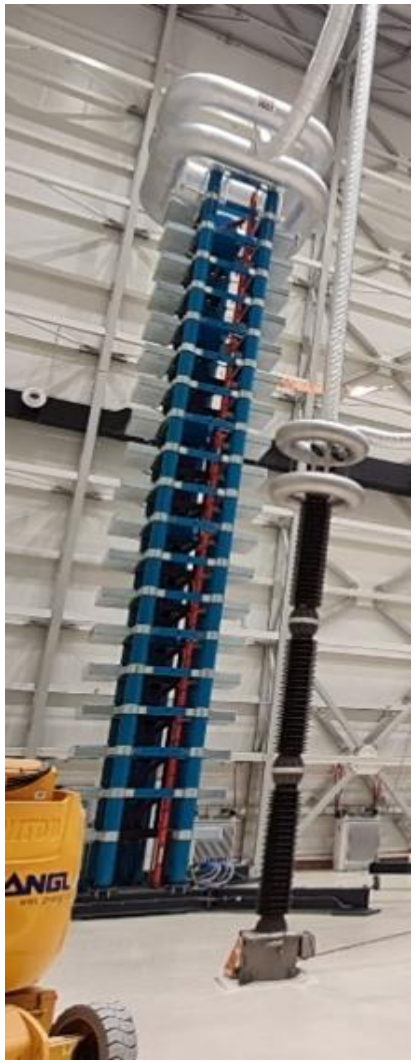
- Lightning Impulse +



Example 2 – Very Slow TOV

- HVDC Cable testing
- Assess whether existing HV lab equipment, specifically the impulse generator, can be used to generate a very slow TOV (Temporary Overvoltage)
- Prolonged impulse duration
  - **Does the impulse generator have enough energy to produce it?**





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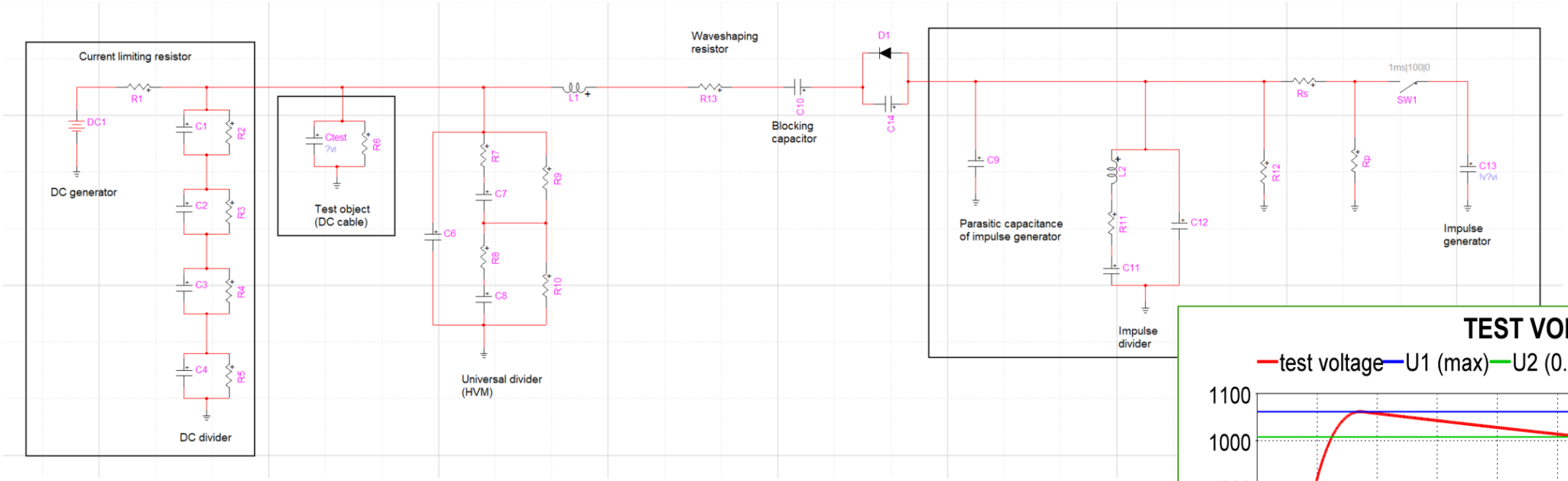
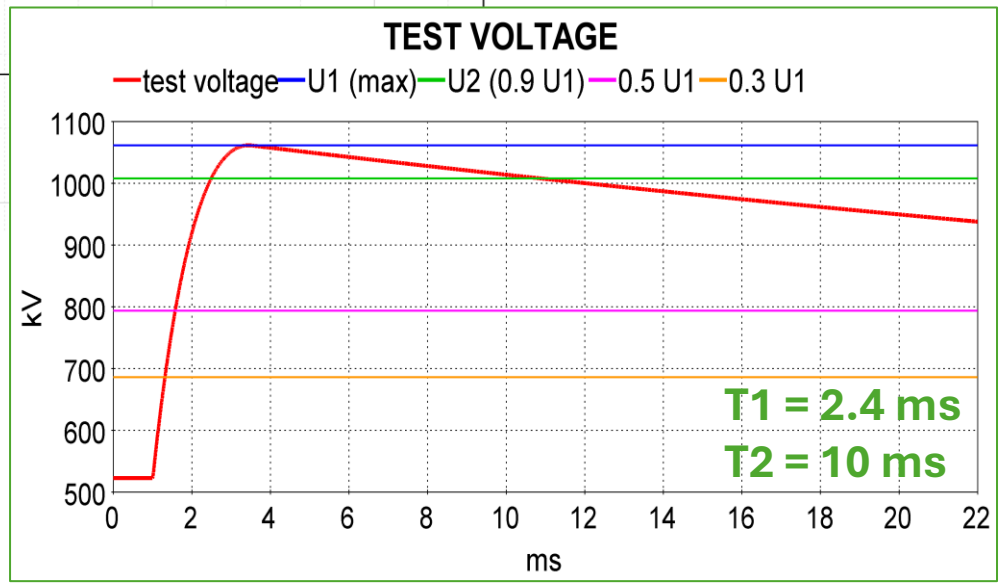
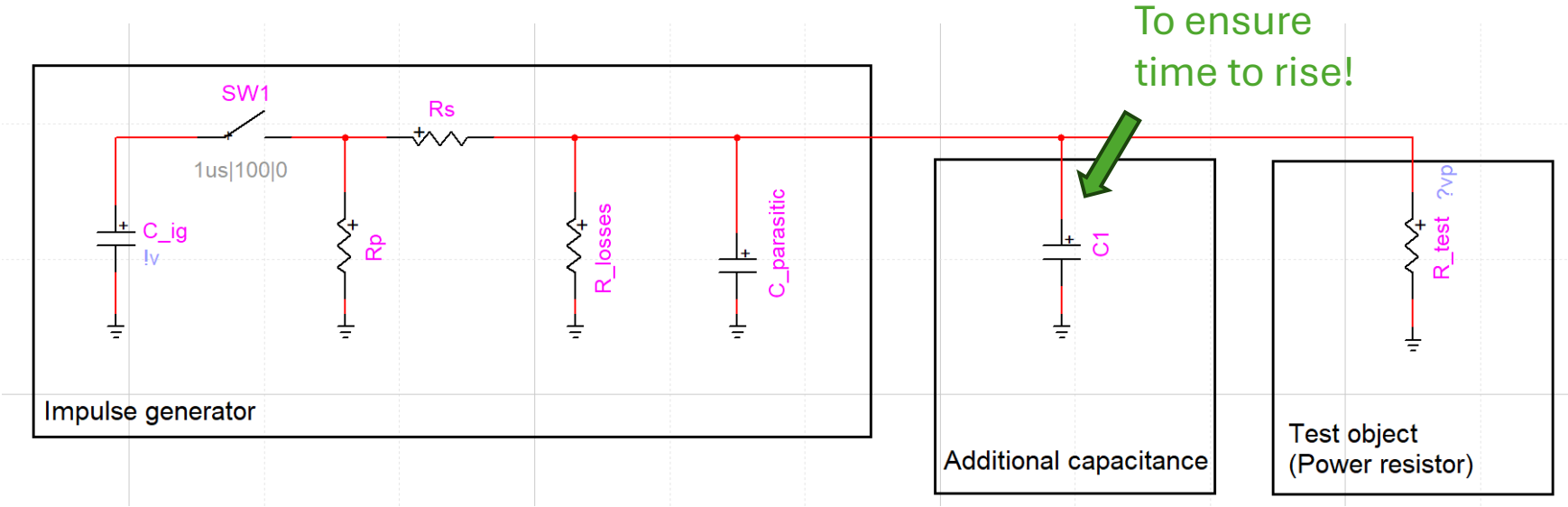




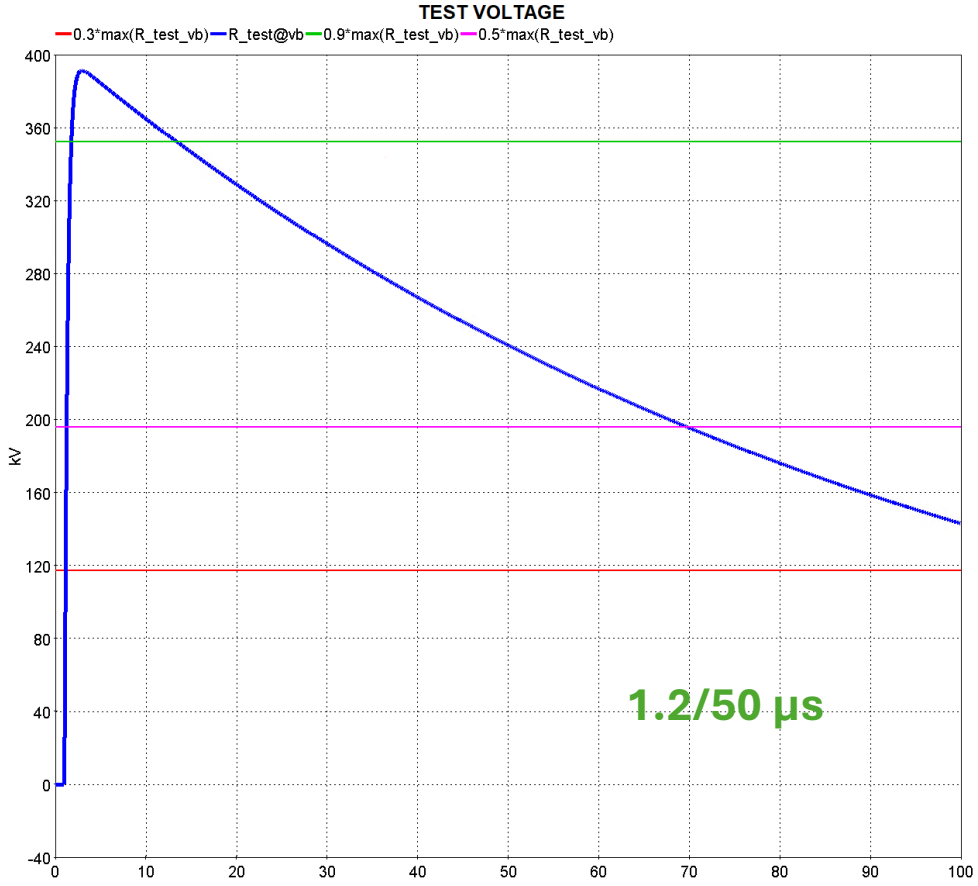
Example 3 – Combined Heat & BIL

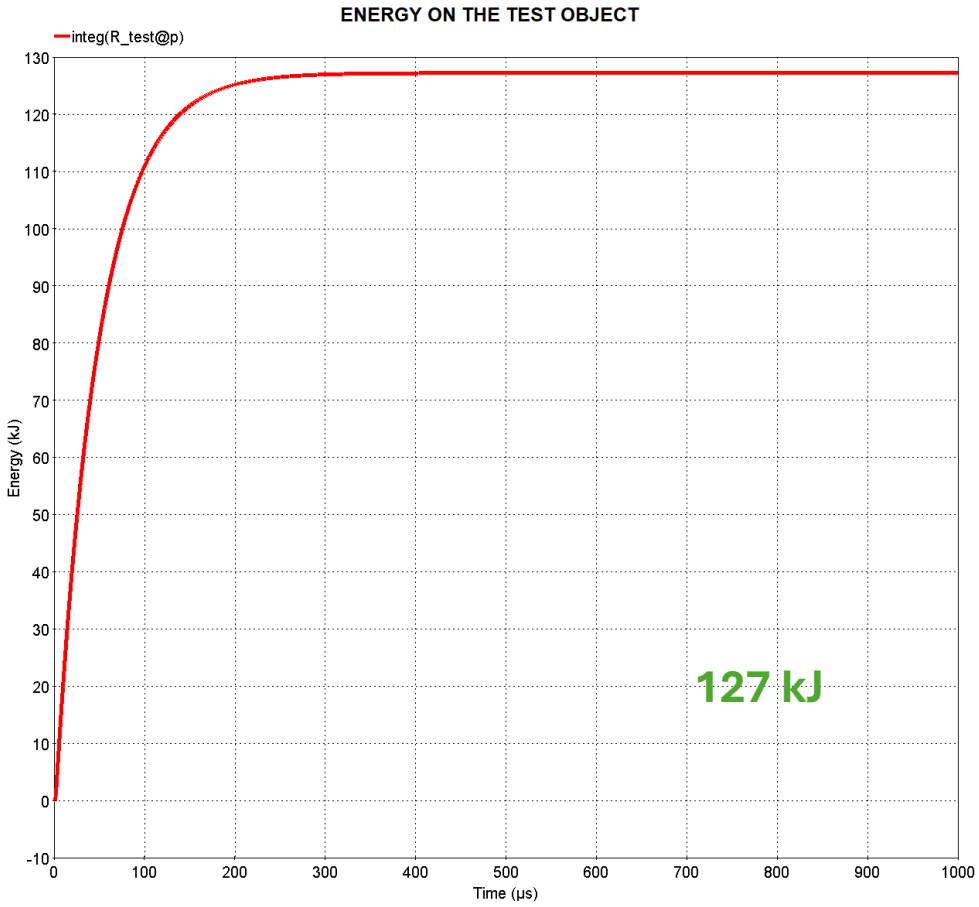
- Special non-standard test procedure for power resistor
- Combined heat and basic impulse level (BIL) test
  - LI 1.2/50 µs ensuring that at least 100 kJ of energy is injected during it



- ✓ Verification of different simulation combinations
- ✓ Selection of the optimal combination
- ✓ Fast quotation delivery to the customer

Example 3 – Combined Heat & BIL

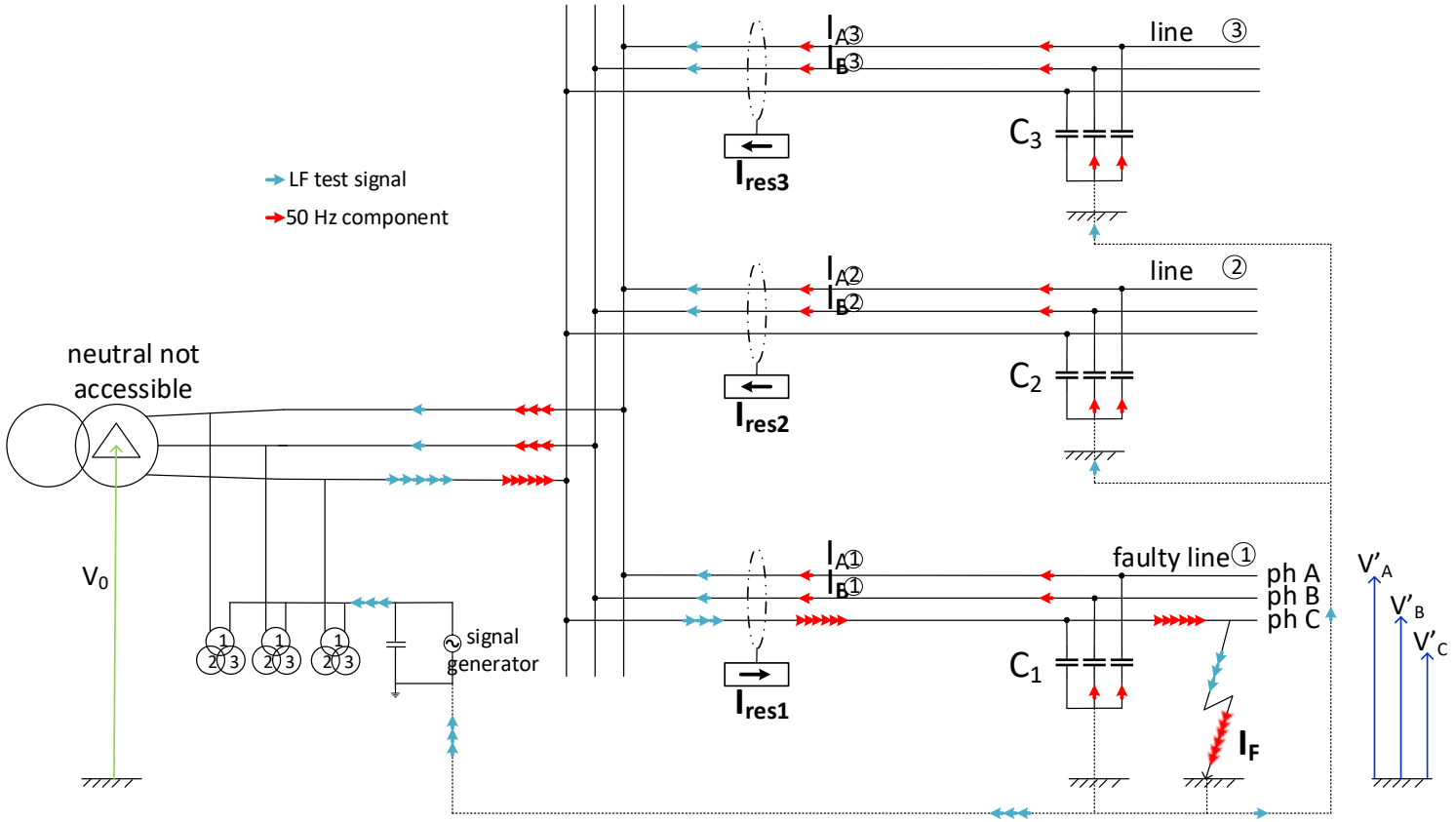




Example 4 – Innovative Diagnostic Methods, Earth Fault Detection

- Low frequency and DC signal injection in the MV isolated network using the primary windings of inductive voltage transformers

$$E_{rms} = 4.44 \cdot N \cdot f \cdot \Phi_{max} \rightarrow \quad \Phi_{max} = \frac{E_{rms}}{4.44 \cdot f \cdot N}$$



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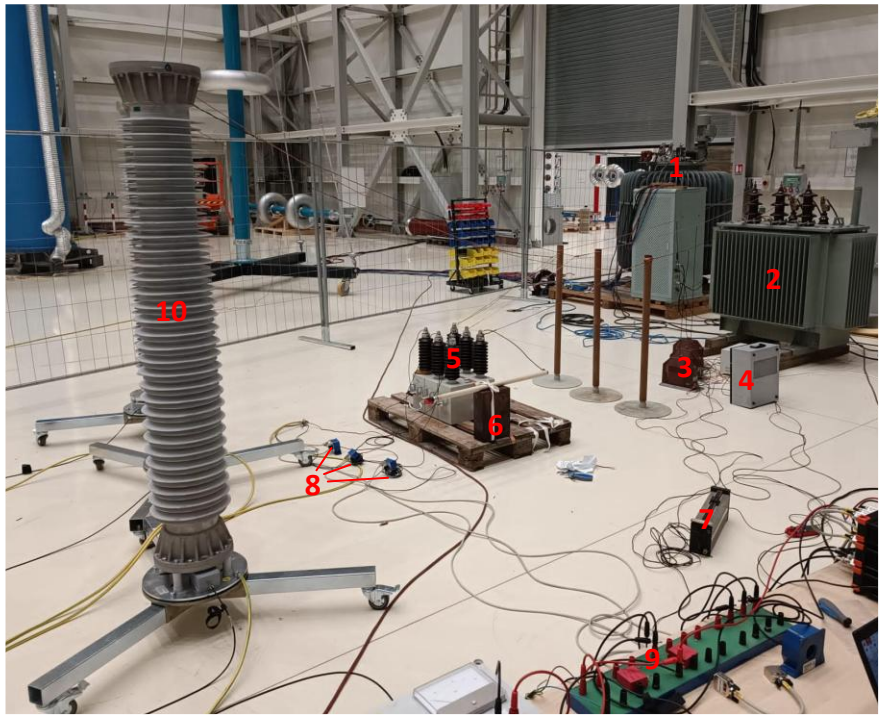
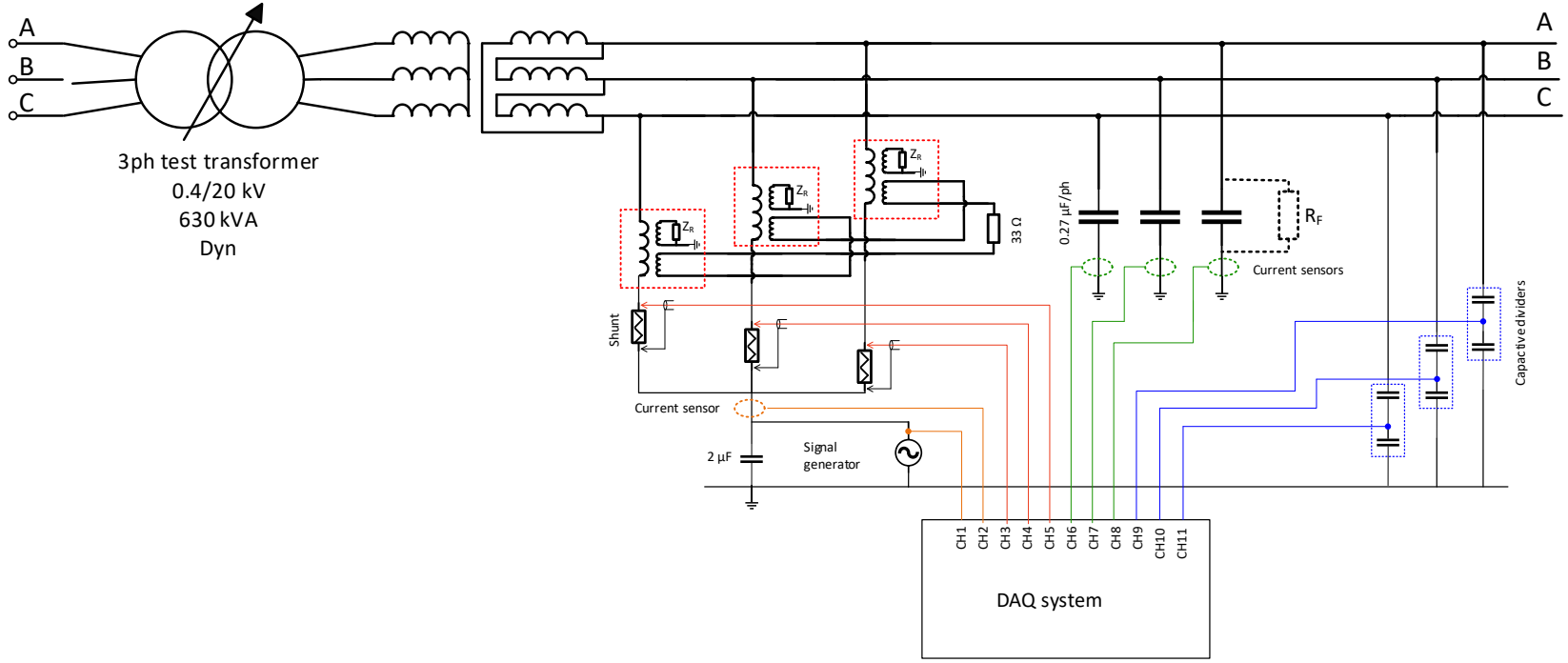


HV Laboratory Test Arrangement



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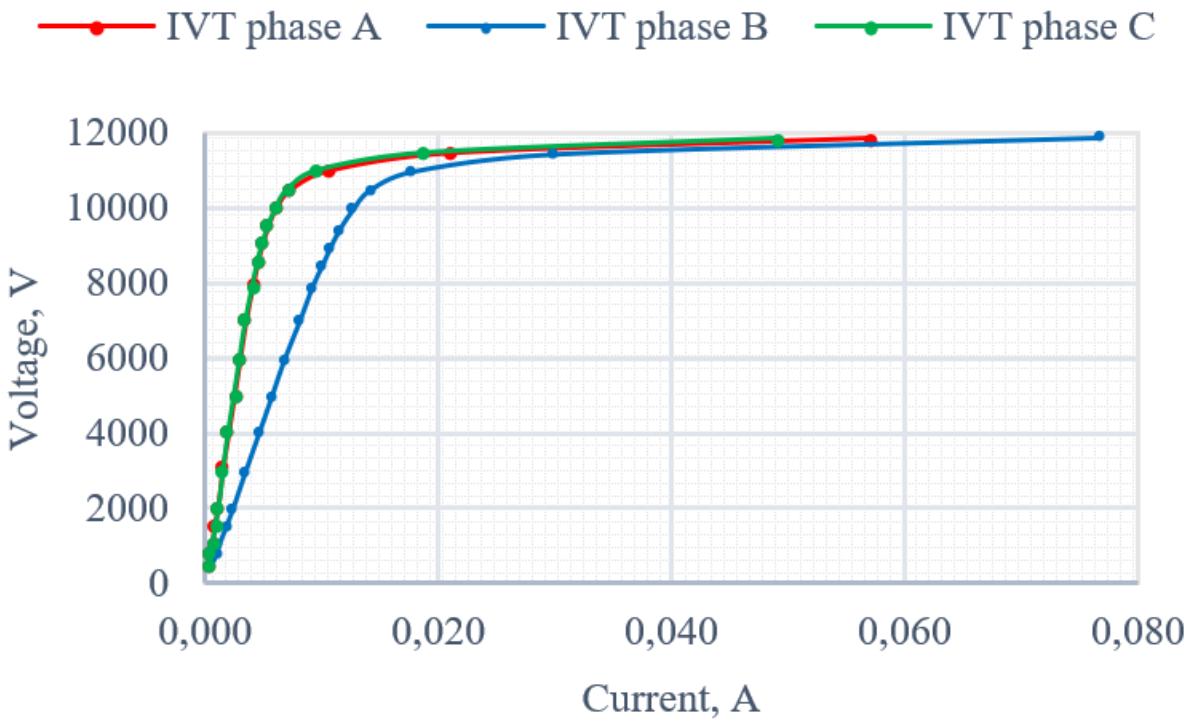
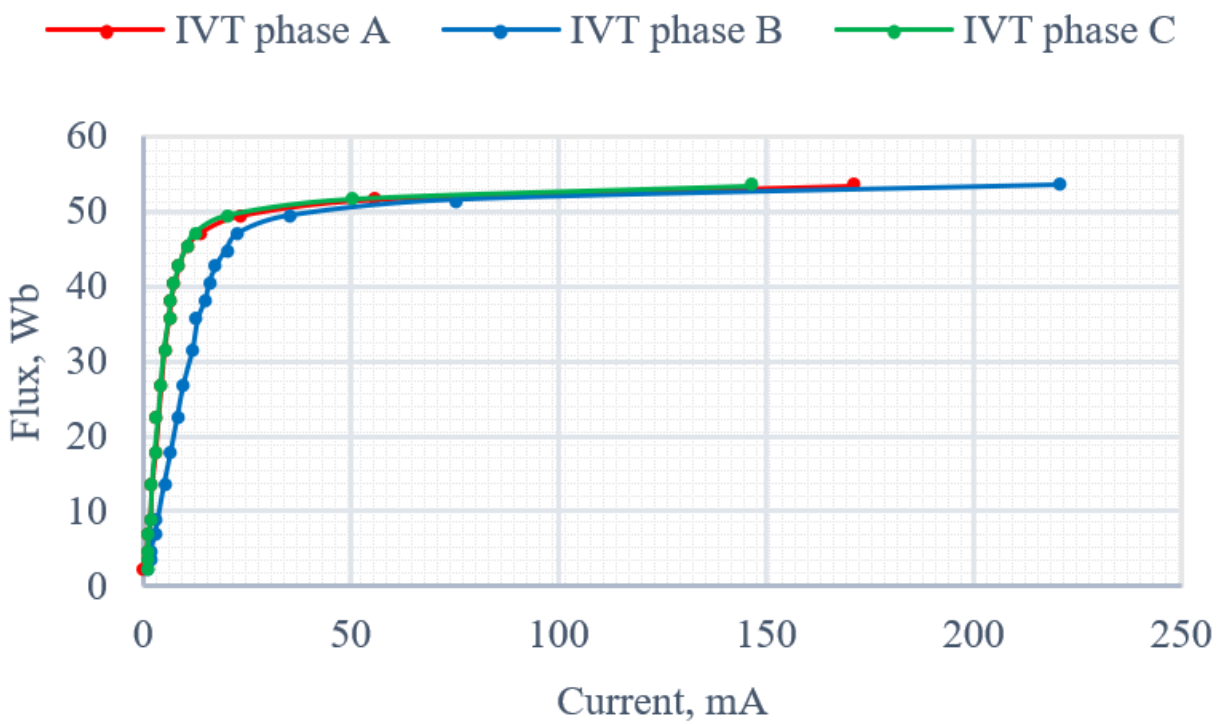
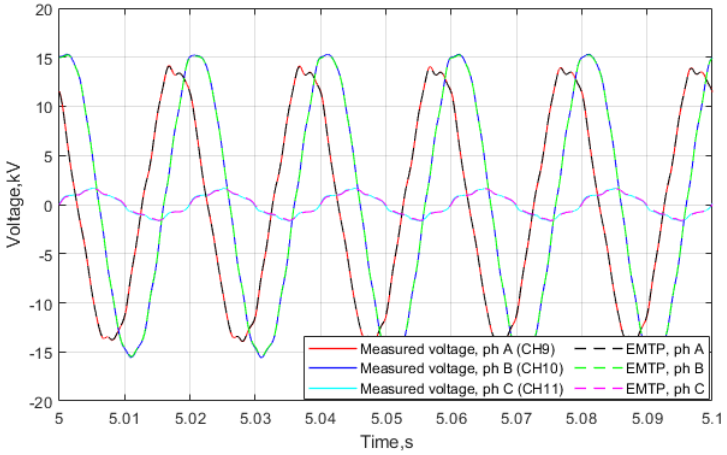


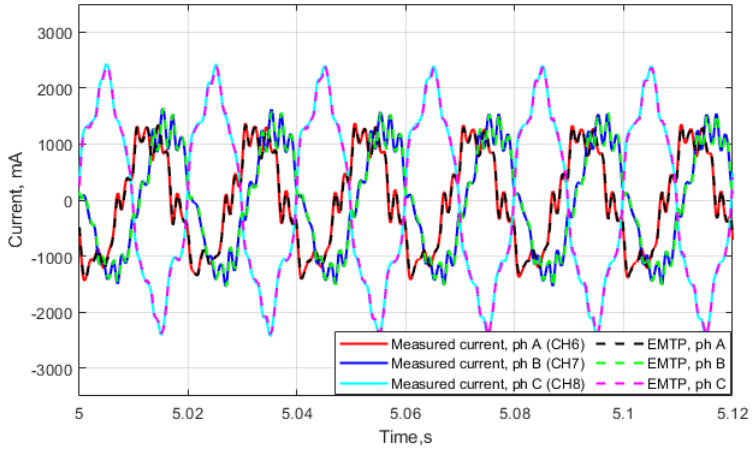


Example 4 – Innovative Diagnostic Methods, Earth Fault Detection

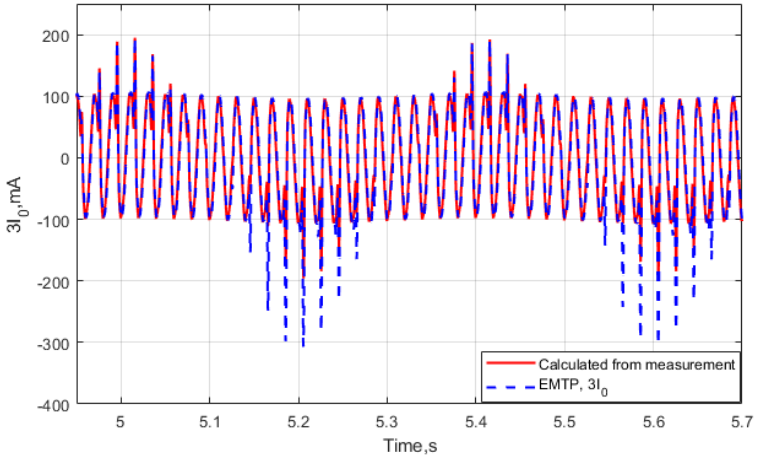
- 2.5 Hz, 100 V_{peak} injection in case with fault resistance of 690 Ω



Comparison between EMTP simulations and phase voltages measured over capacitor dividers



Comparison between EMTP simulations and measurements of currents through capacitors



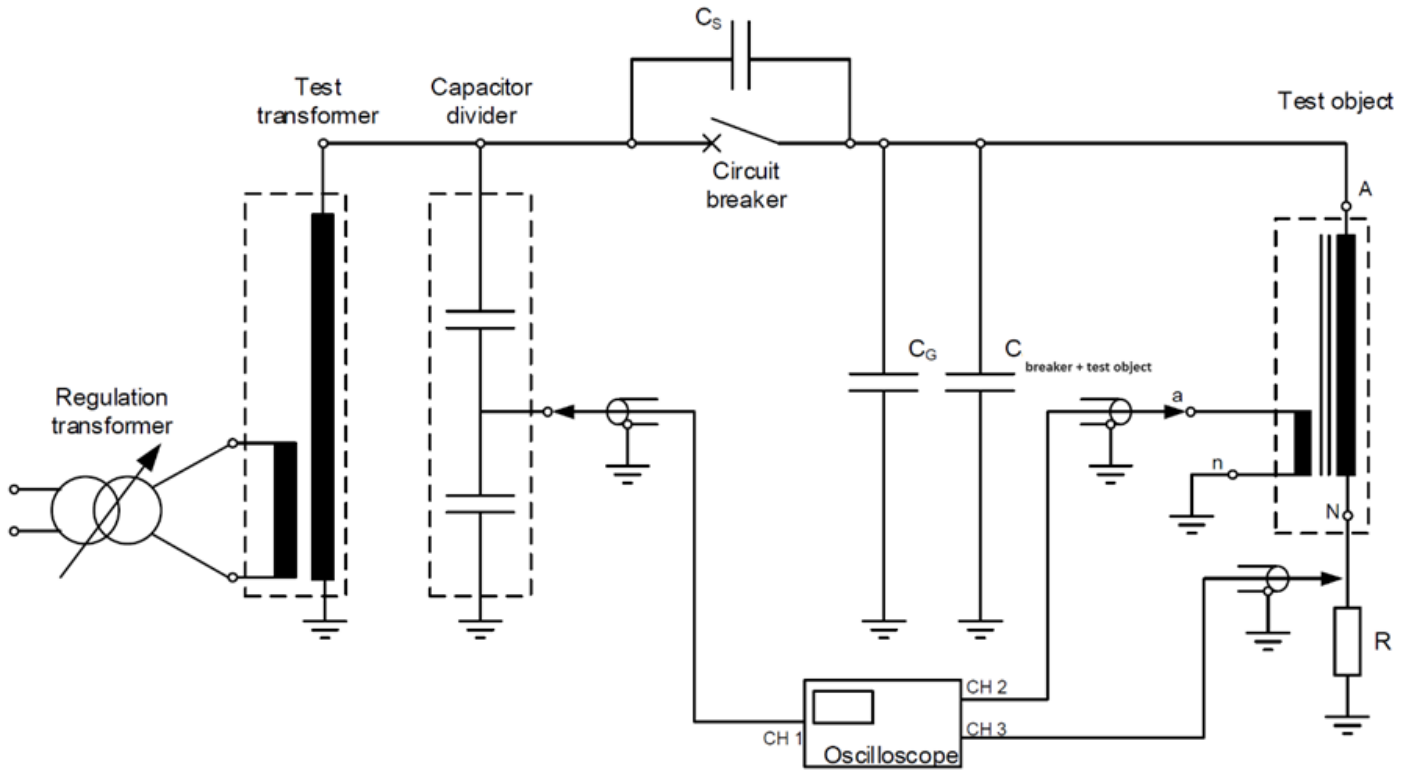
Measured and simulated residual current

Example 5 – Ferroresonance - interaction between grading capacitors of CB and IVT

- Interaction between circuit breaker and inductive instrument transformer through grading capacitors installed across breaking chambers
- It may lead to excessive temporary overvoltages causing failure of the primary power equipment
- It is necessary to dimension equipment properly and to check if there is a possibility for resonance inception in the particular network configuration
- This test is not covered in IEC 61869-3

Example 5 – Ferroresonance - interaction between grading capacitors of CB and IVT

- Test procedure includes changing the test network topology by exchanging the grading capacitors and capacitors to the ground
- Realistic range of capacitances depending on substation topology: C_s ranges from 250 pF to 300 pF, C_g ranges from 0 to 700 pF and U ranges from 0.9 to 1.5 U_r (rated voltage)



Example 5 – Ferroresonance - interaction between grading capacitors of CB and IVT

Cs=250 pF, Cg=250 pF, U=1.5 Ur

	170 kV voltage transformer			
	Transient measured	Transient simulated	Steady state measured	Steady state simulated
Voltage across CB [kV]	554.8	519.5	296.5	267.0
Primary current [mA]	138.4	149.0	41.5	43.3
Secondary voltage [V]	219.0	229.4	53.7	57.4

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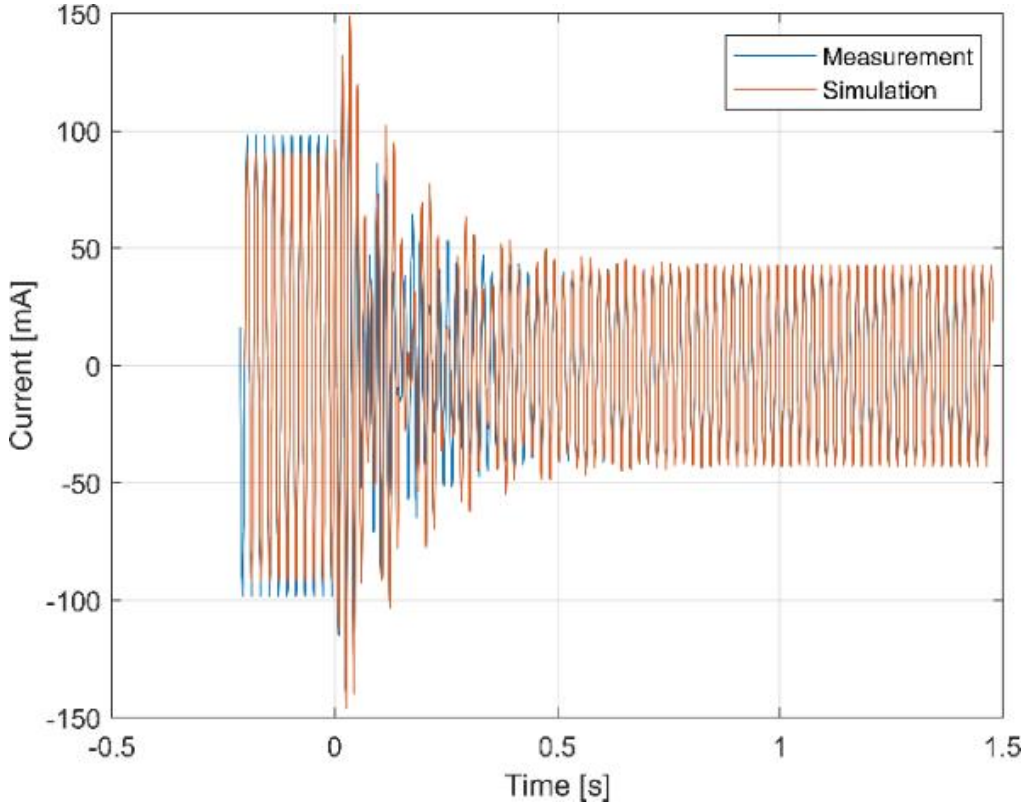

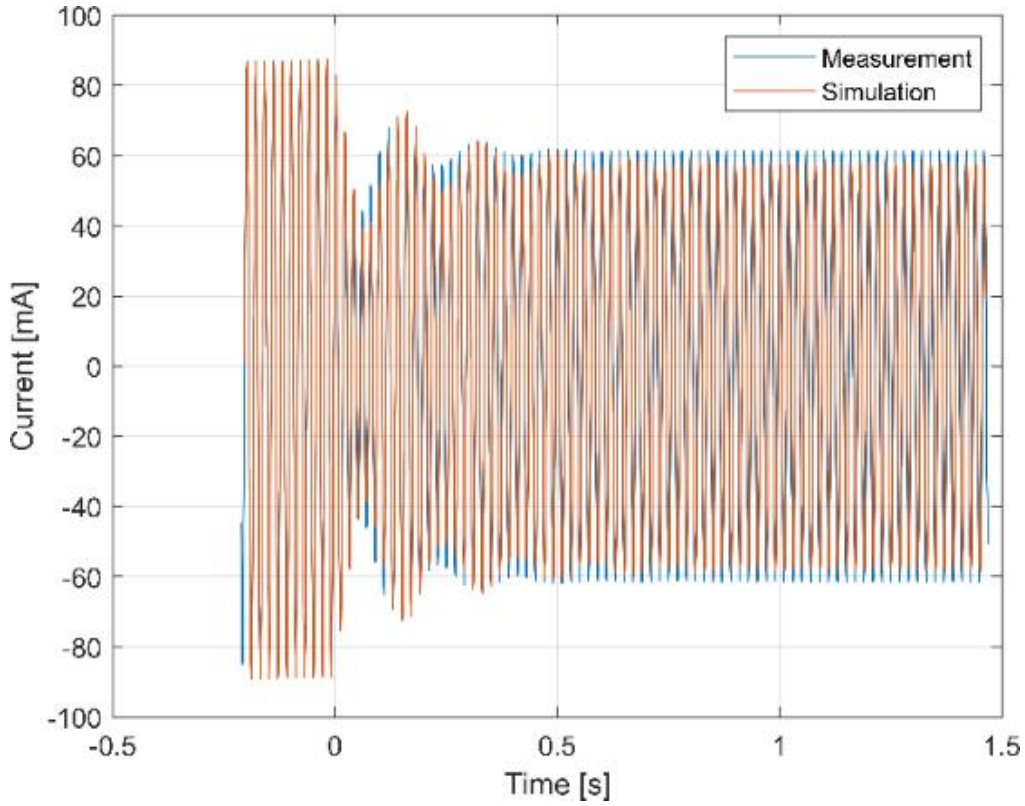

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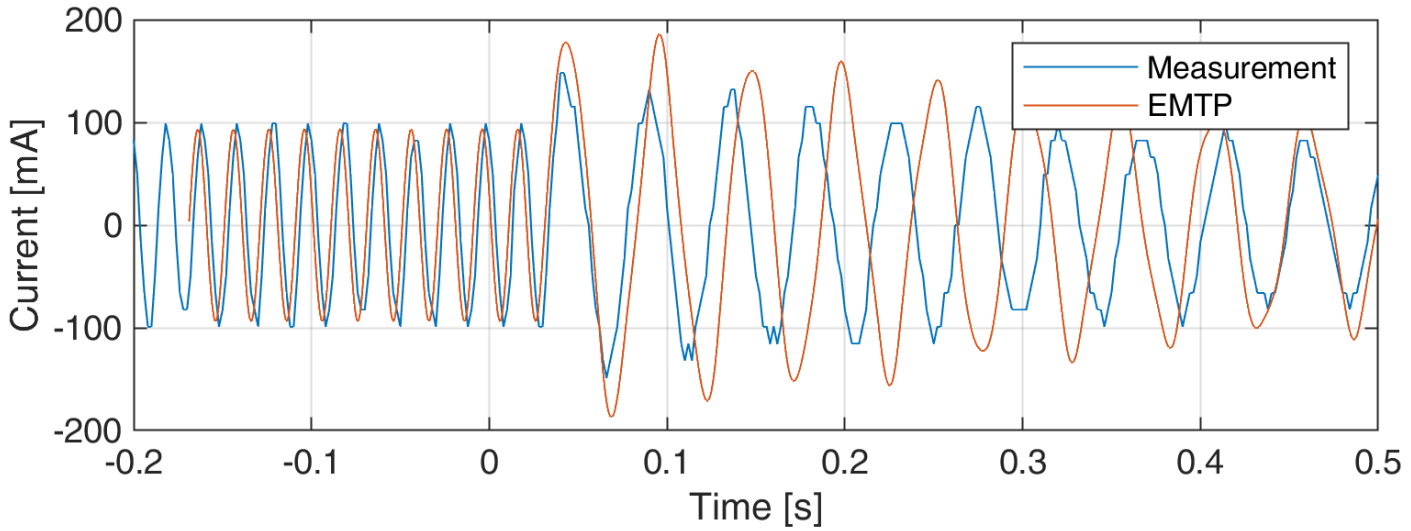
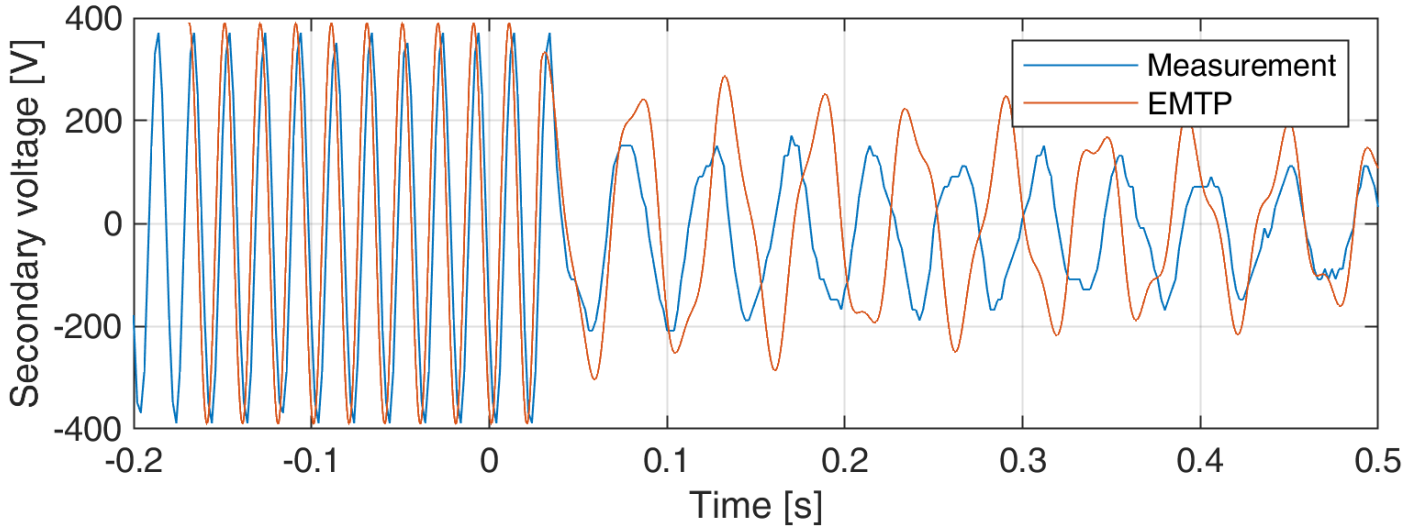
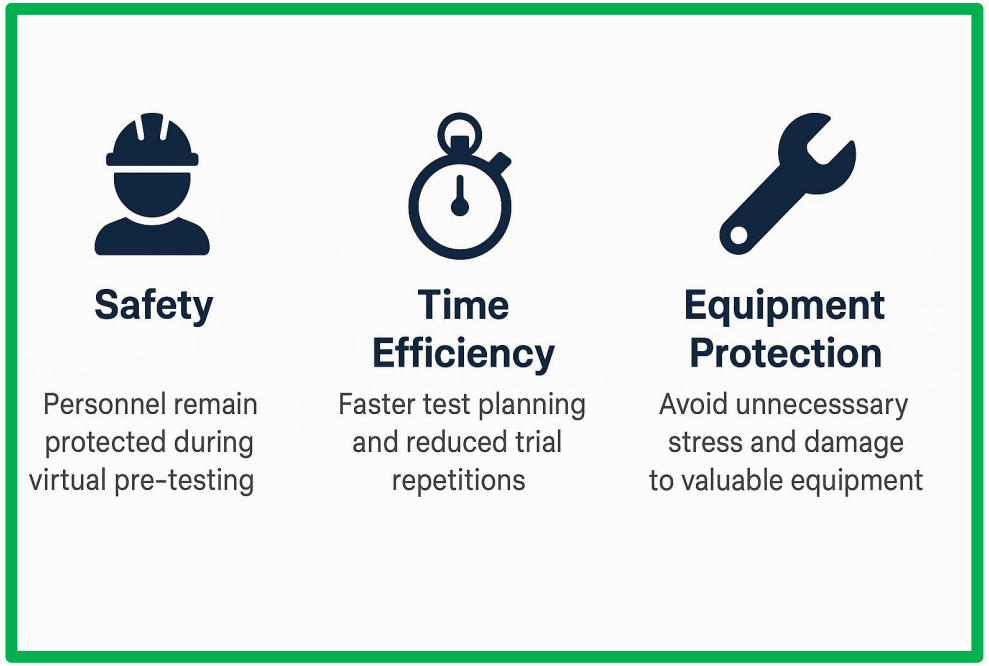




Conclusions

- EMTP successfully used for replicating different test circuits in HV laboratory
- Good matching between measurements and simulations achieved for both LF and HF transients
- Model validation through measurements
- EMTP can be applied before performing for new standard and non-standard testing or introducing new diagnostic of fault detection techniques in power networks



Thank you for your attention!
Questions?

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