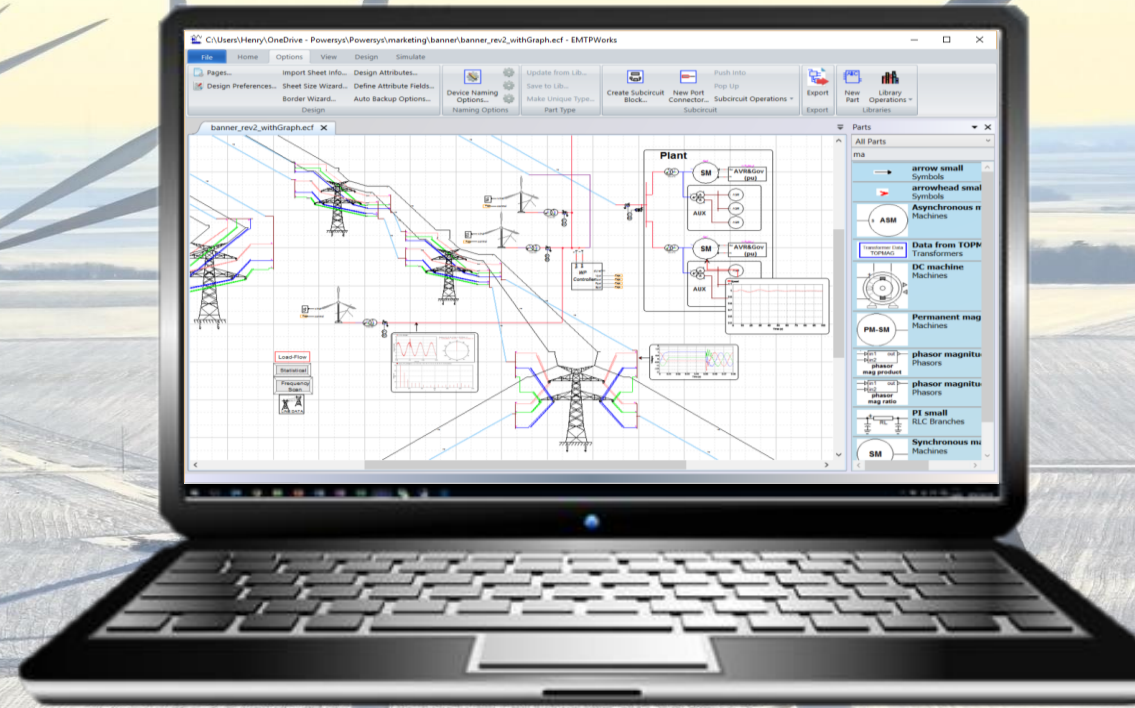


EMTP overview

Anton Stepanov, PhD
Research & Development specialist
PGSTech
anton.stepanov@emtp.com



More info

www.EMTP.com

info@emtp.com

What is EMTP?



- Emergency Medical Technician-Paramedic?
- Emergency Management Training Programme?
- Enhanced Mail Transfer Protocol?
- **Electromagnetic Transients Program!**

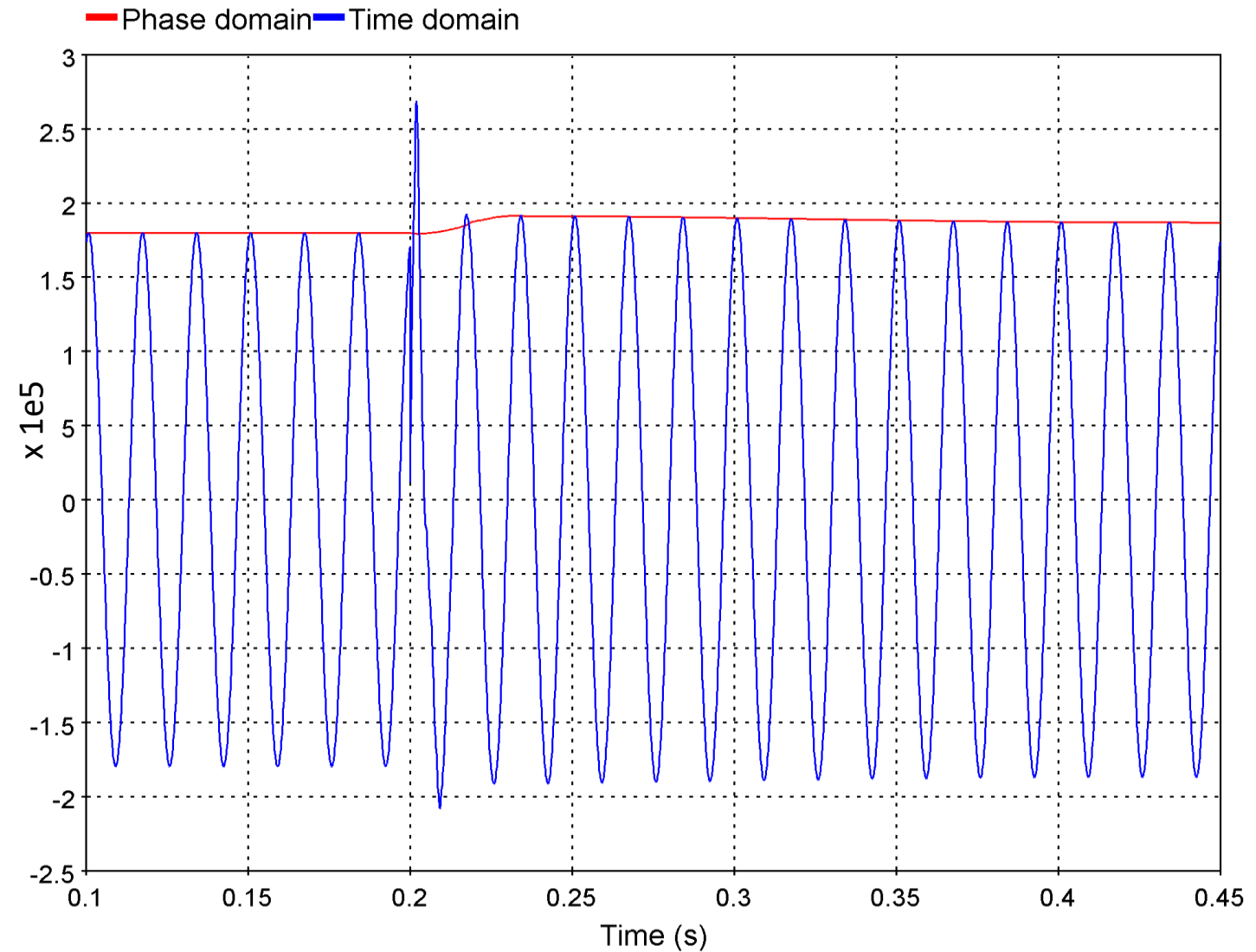


➤ Phasor domain

- Restricted frequency range
 - ~1 kHz
- Simplified models
- RMS values

➤ Time domain

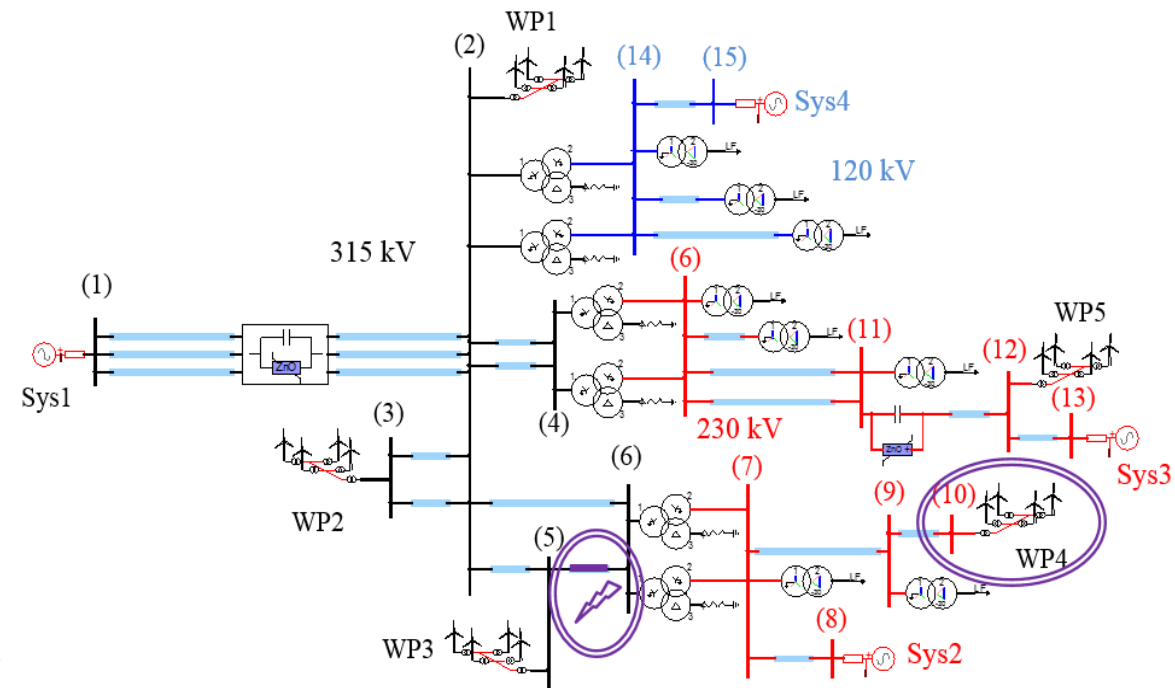
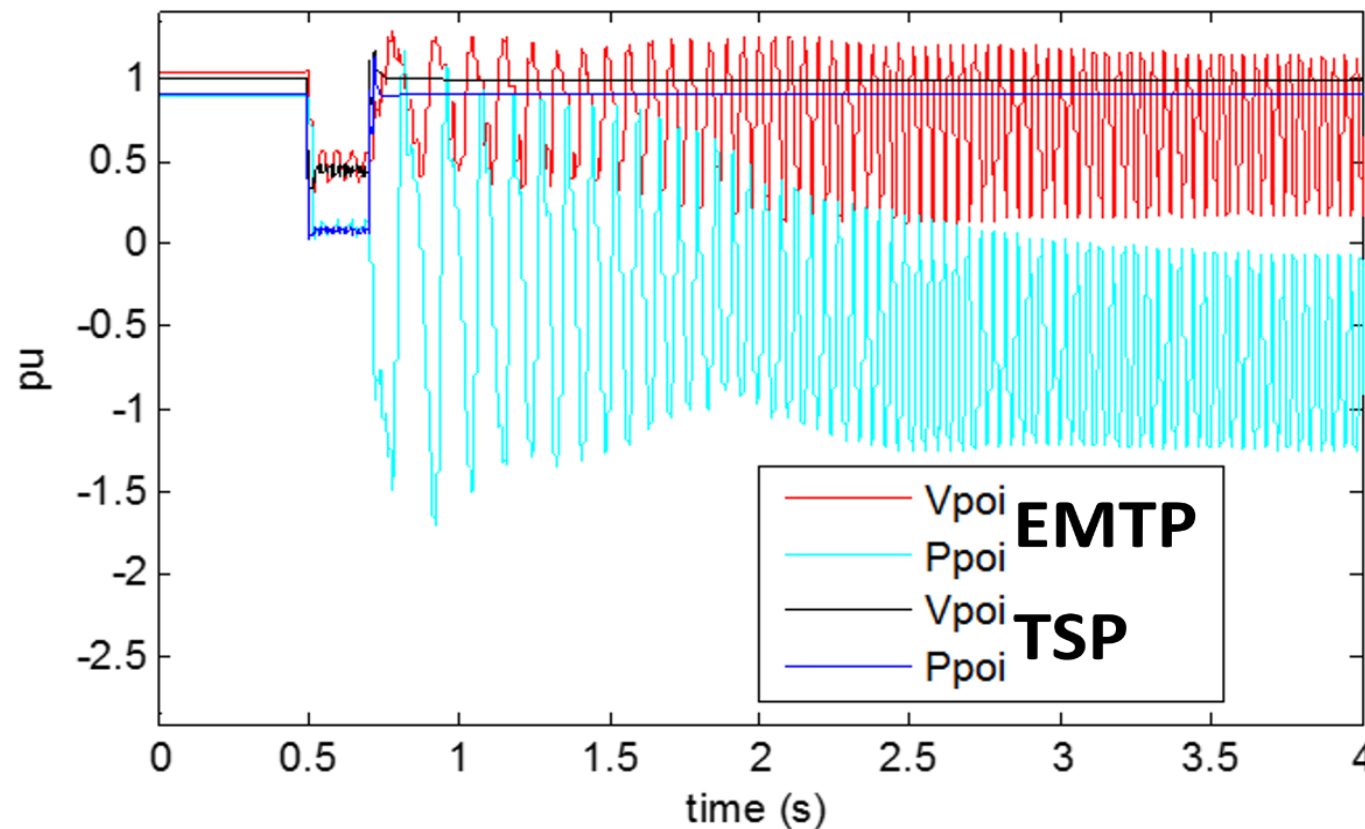
- DC to MHz frequency range
- Instantaneous waveforms
- Detailed control systems
- Nonlinearities
- Etc.



Time domain vs phasor domain

➤ Practical case: 3-phase fault in a grid with wind parks

- TSP disregards inner control and PLL dynamics, unable to capture instability of WP4
- EMTP shows more realistic result

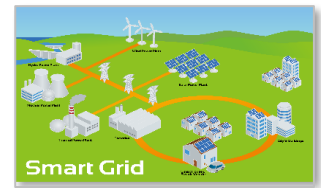


➤ Types of Simulations:

- Load-Flow
- Steady-State
- Time-domain
- Frequency Scan

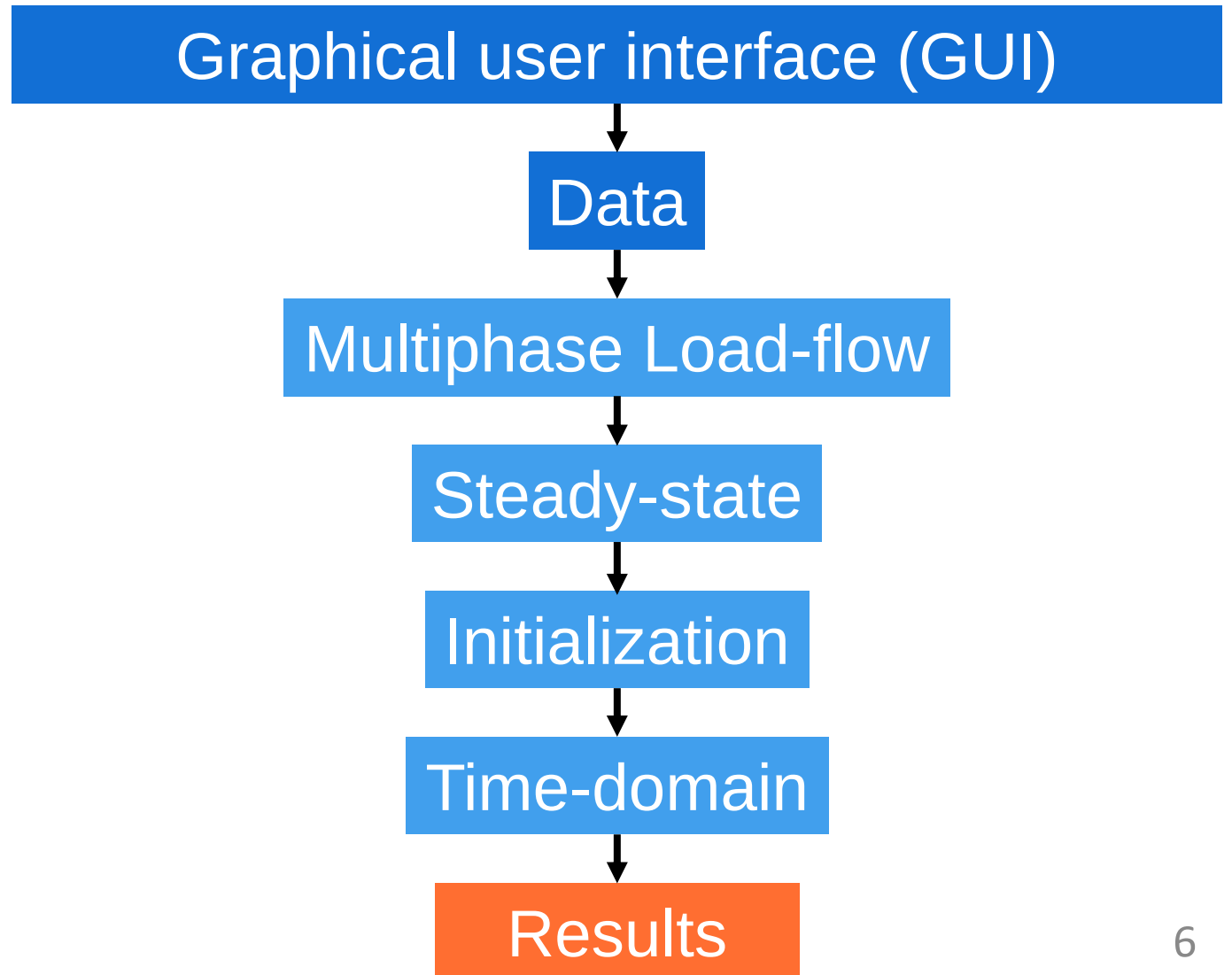
➤ Wide variety of power system applications, including but not limited to:

- Large grids
- Renewable energy
- Grid Forming Converters
- HVDC & FACTS
- Lightning & Switching transients
- Insulation Coordination
- Transient Stability
- Power Quality
- Railway systems
- Protection
- Ferroresonance
- Smart-Grid



➤ The same design is used for all types of studies

- Time-domain simulations
- Statistical analysis
- Frequency scan
- Steady-state
- Load-flow



➤ Superior modelling flexibility

- Numerous device models in the standard libraries
- Scriptable and customizable easy-to-use GUI
- Automatic data calculation
- Interfaces for DLLs

➤ Multiphase unbalanced Load-flow

➤ Robust time-domain simulation engine

- Sparse Matrix solver
- Automatic initialization of time-domain models from load-flow results

➤ Interface with other simulation tools

➤ Many application examples are provided with EMTP



- EMTPWorks: user-friendly Graphical User Interface
 - The user-friendly and intuitive Graphical User Interface

- EMTP: computational engine
 - Powerful and super-fast computational engine

- ScopeView: data display and analysis
 - Performs complete and complex signal processing (FFT...)

➤ Easy to use, user-friendly GUI

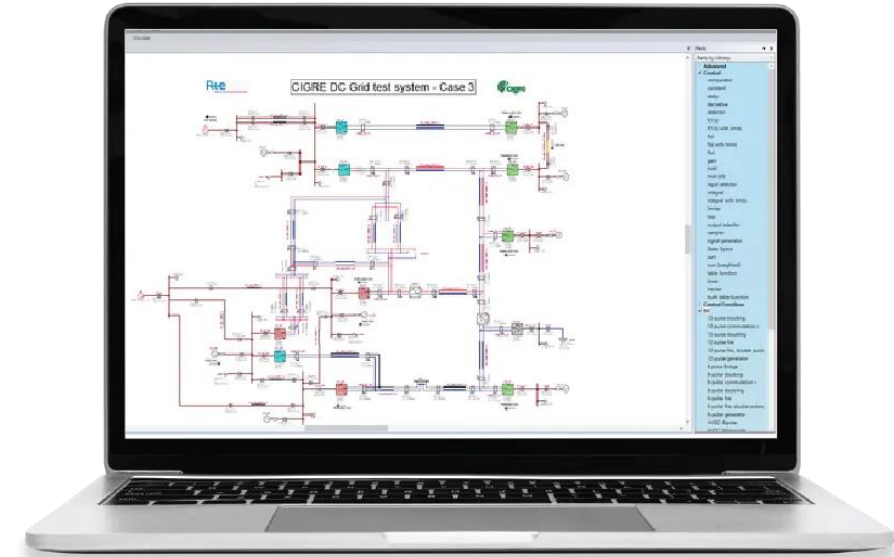
- Hierarchical architecture based on subcircuits
- No restrictions on the number of elements
- Can handle very large grids
- Masking

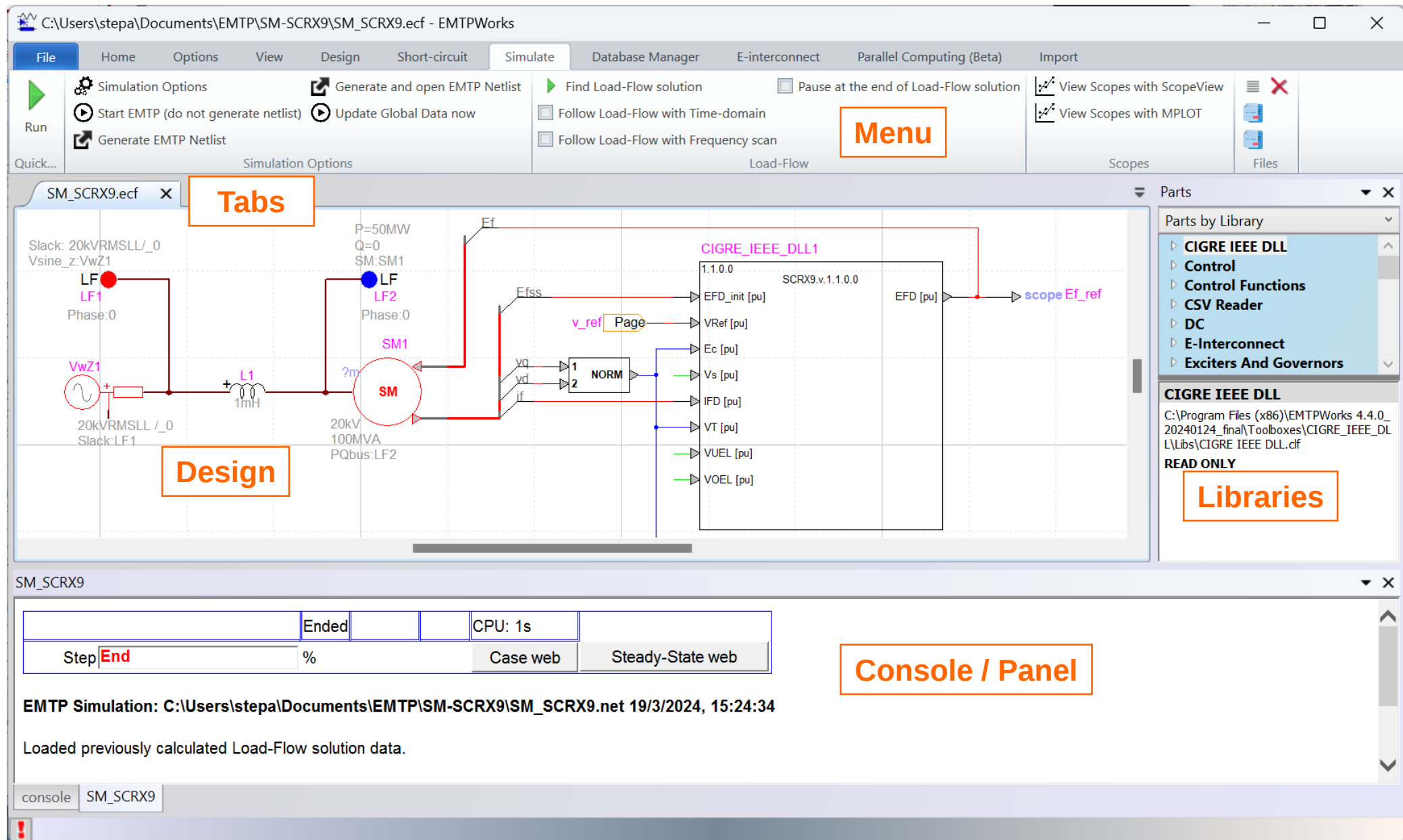
➤ Completely scriptable

- Full access to GUI components and data through scripts
- What can be done by hand, can be automated by scripts

➤ External API

- C#
- Python
- JavaScript
- MATLAB





The screenshot displays the EMTPWorks GUI with the following components:

- Menu:** Located at the top, it includes tabs for File, Home, Options, View, Design, Short-circuit, Simulate, Database Manager, E-interconnect, Parallel Computing (Beta), and Import. Below these are buttons for Run, Simulation Options, Generate and open EMTP Netlist, Find Load-Flow solution, Pause at the end of Load-Flow solution, View Scopes with ScopeView, and View Scopes with MPLOT.
- Simulation Options:** A section on the left side of the top bar containing buttons for Start EMTP (do not generate netlist), Update Global Data now, and Generate EMTP Netlist.
- Load-Flow:** A section on the right side of the top bar containing checkboxes for Follow Load-Flow with Time-domain, Follow Load-Flow with Frequency scan, and a checkbox for Pause at the end of Load-Flow solution.
- Scopes:** A section on the far right of the top bar containing buttons for View Scopes with ScopeView and View Scopes with MPLOT.
- Files:** A section on the far right of the top bar containing buttons for Files and a close button.
- Design:** The central workspace showing a circuit diagram. It includes a voltage source (VwZ1), a switch (LF1), a transformer (L1), a synchronous motor (SM), and a CIGRE IEEE DLL block. The diagram is labeled with various parameters and components.
- Parts:** A panel on the right side of the design workspace showing a list of parts by library, including CIGRE IEEE DLL, Control, Control Functions, CSV Reader, DC, E-Interconnect, and Exciters And Governors.
- Console / Panel:** A panel at the bottom of the GUI showing simulation status. It includes a table with columns for Step, End, CPU time, Case web, and Steady-State web. The current step is 1, and the CPU time is 1s. The status is "Ended".

➤ Data visualization

- Results of EMTP simulations
- Also works with COMTRADE, MATLAB®, csv, ...
- Many visual customizations for plotting the data

➤ Advanced analysis tool

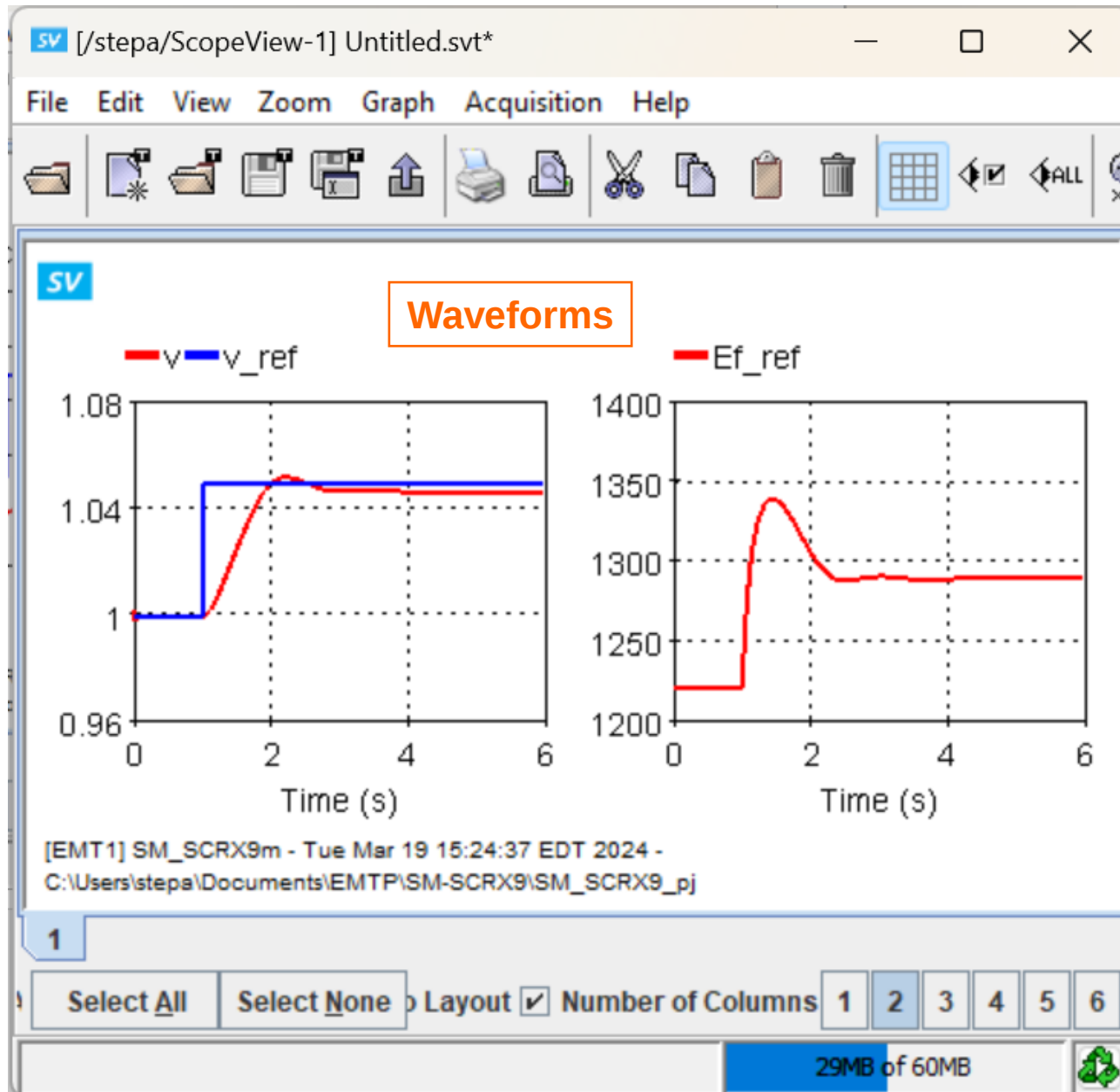
- Trigonometric functions
- Harmonic analysis
- Statistical
- Etc.

➤ Can export waveforms in a variety of formats

- COMTRADE, MATLAB®, csv, jpeg, png, ...



ScopeView: data visualization



SV [/stepa/ScopeView-1] - Signals - Untitled.svt*

File Edit View Data Source Graph Help

Signals

Data Source [EMT1] SM_SCRX9m - Tue Mar 19 15:24:37 ...

Signal Type Control signal

Ef_ref@control
v@control
v_ref@control

Available signals

Find: Previous Next Filter Highlight

Signal Selection Mode Graph Creation X Axis Y Axis

Single Multiple Normal Superimposed Grid Log

Selected Signals

Plotted signals

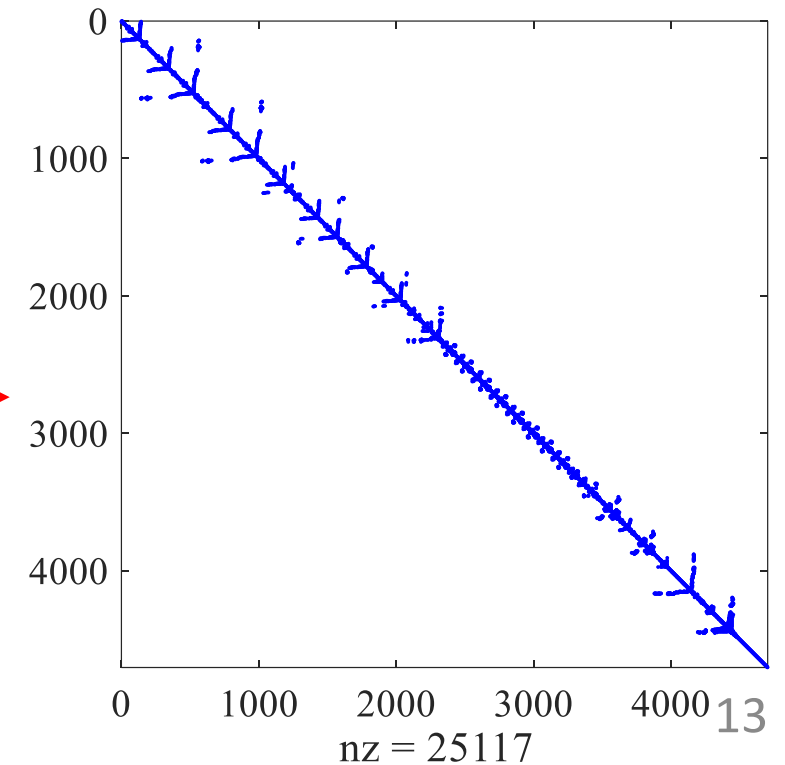
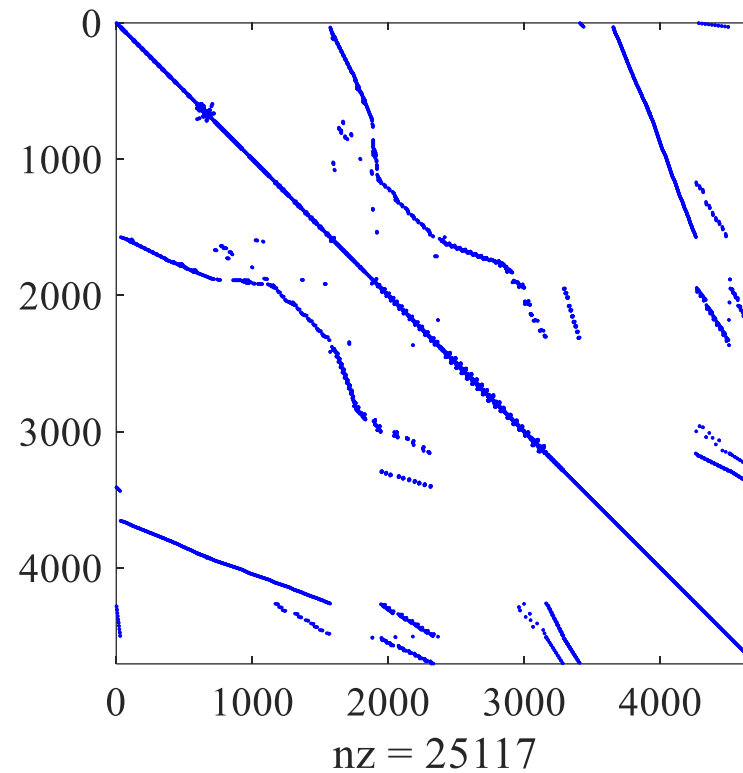
	Signal	Description	Show	Page
1	v_control	v	☒	1
2	v_ref_control	v_ref	☒	1
3	Ef_ref_control*1e3	Ef_ref	☒	1
4			☐	0

Equations

12

➤ EMTP uses innovative matrix solver techniques

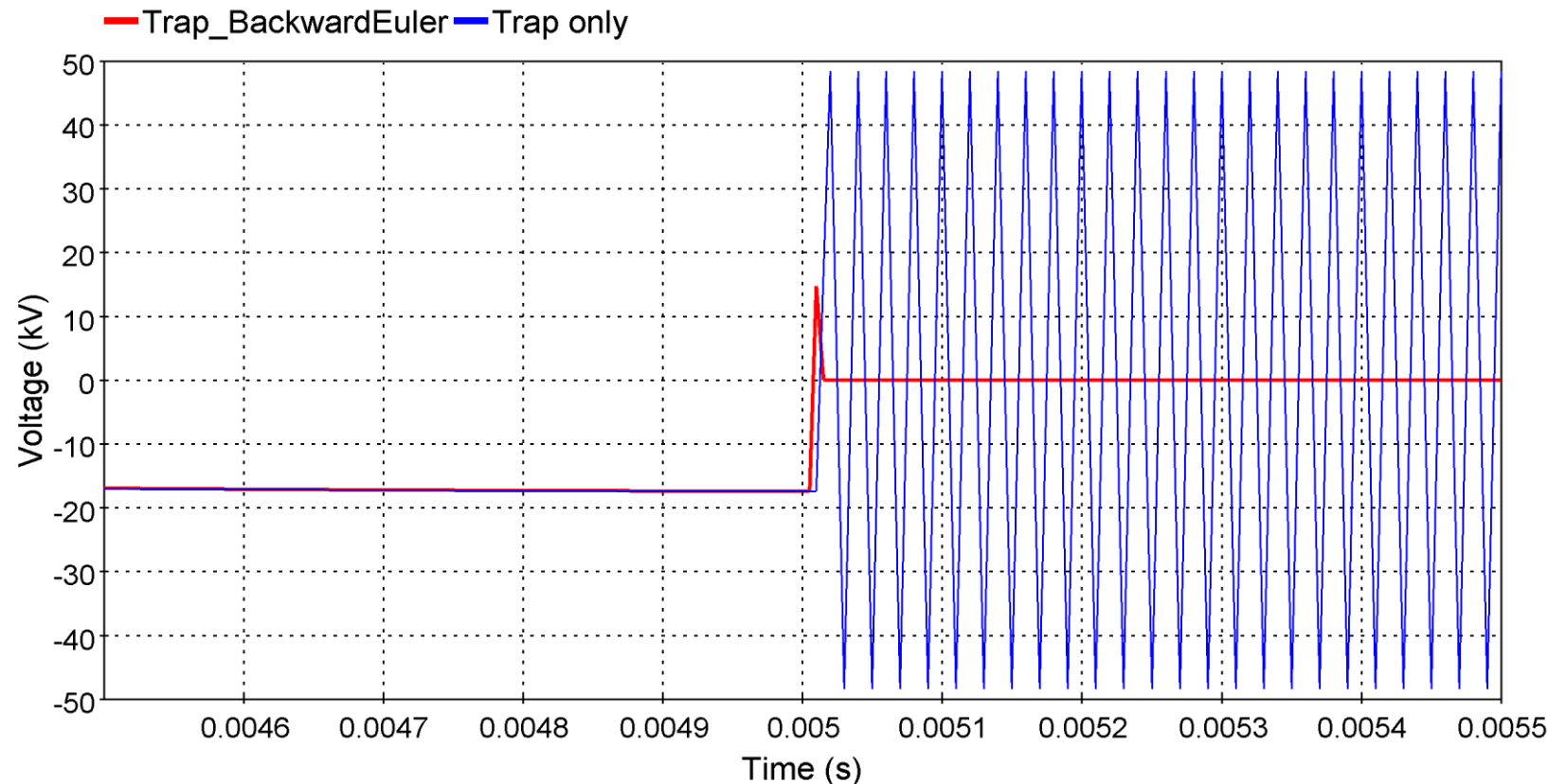
- Modified Augmented Nodal Analysis
- KLU-based sparse matrix solver
- Advanced control system solver
- Partial refactorization
- Parallel processing
- DLL interfaces



➤ Numerical oscillations can be caused by state variables discontinuity

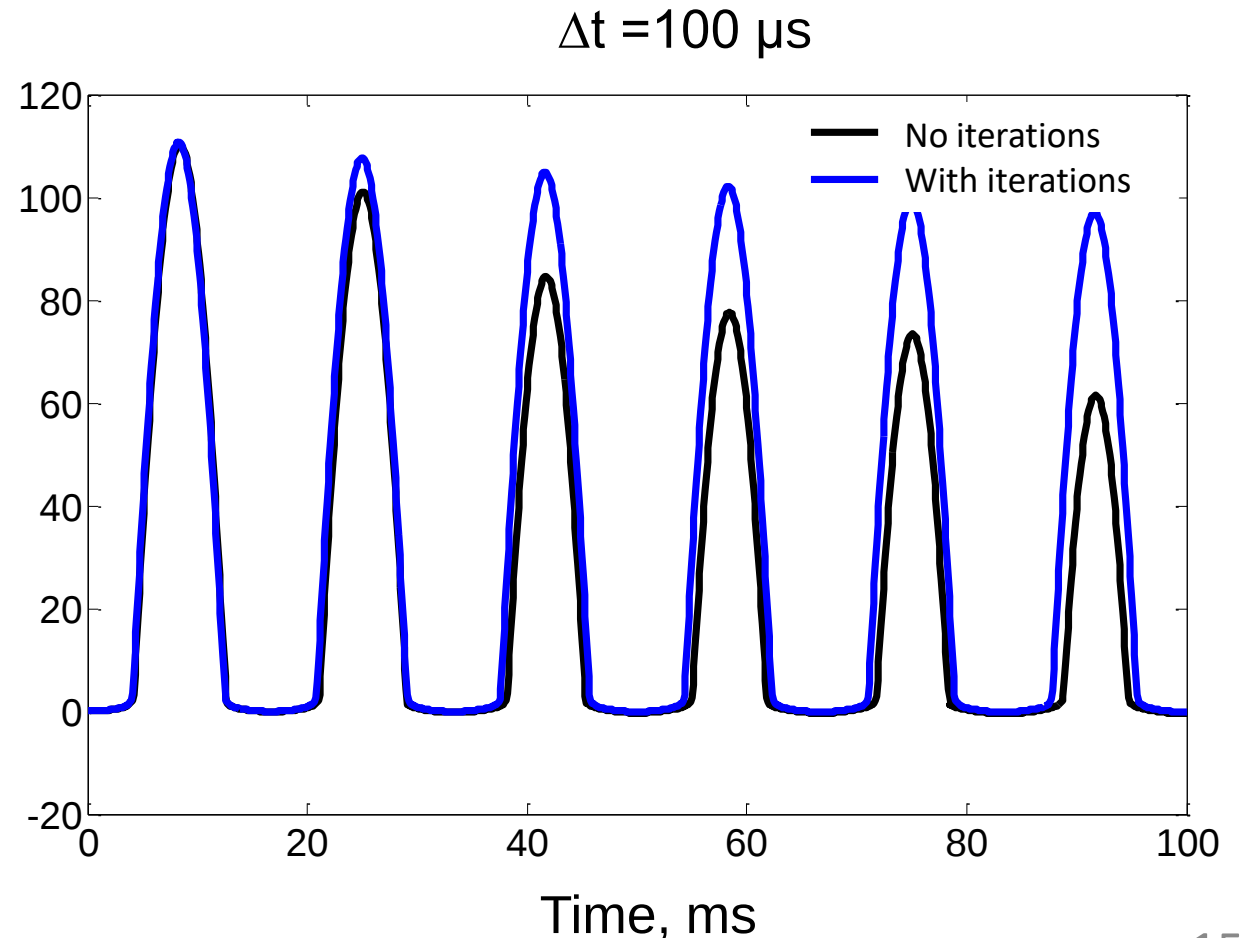
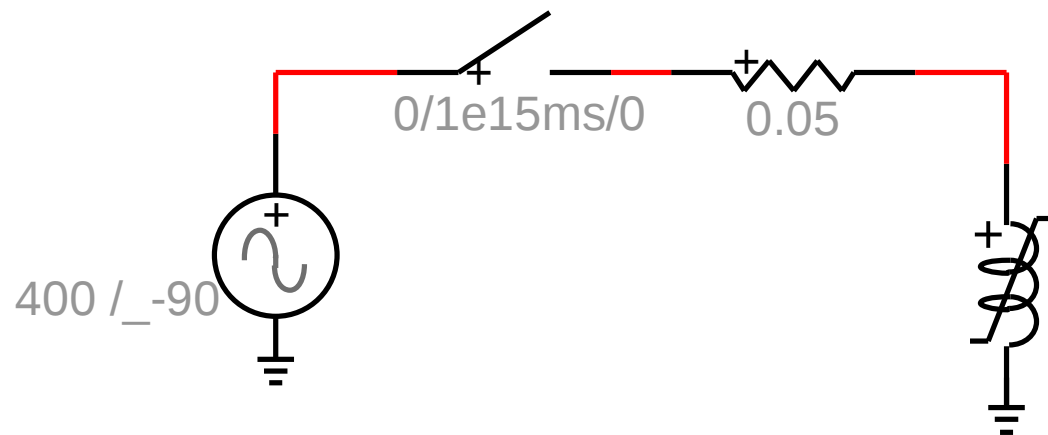
➤ EMTP solution

- Default integration method: Trapezoidal
- When discontinuity is detected: use Backward Euler Integration method



➤ EMTP solution method for nonlinear devices

- All nonlinear models solved simultaneously
- Fully iterative Newton-based method
- Works with large time-steps
- No topological restrictions
- Super-fast convergence

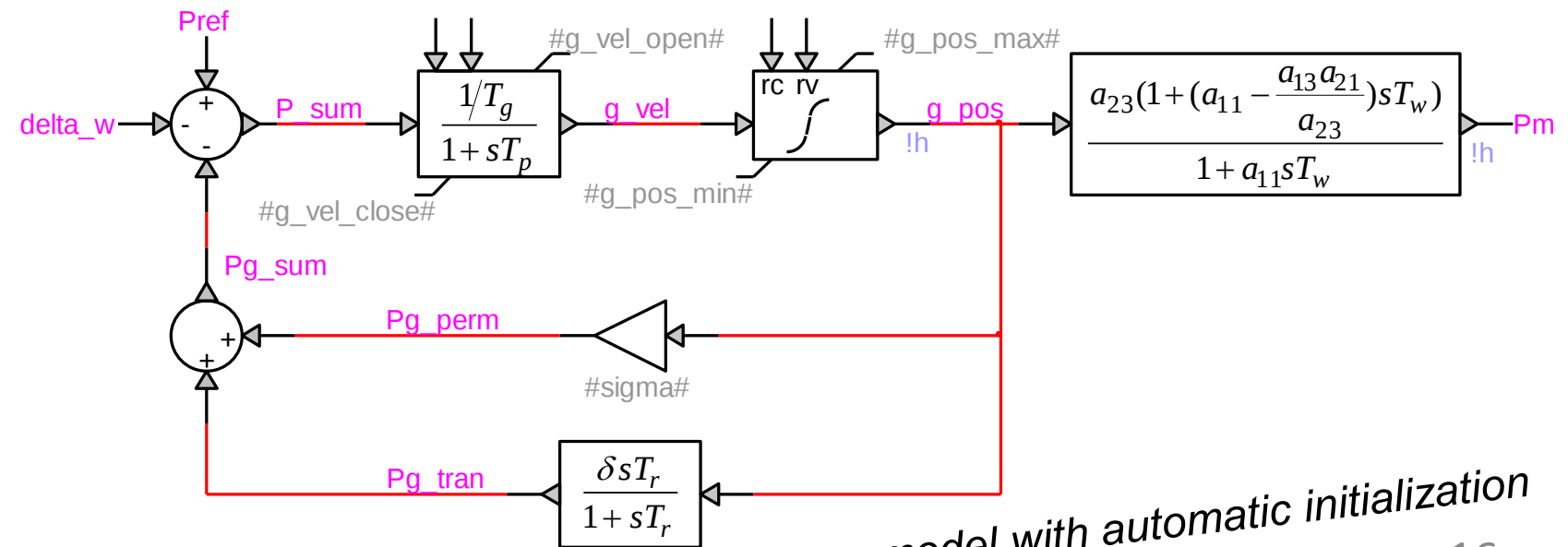


➤ EMTP control system solver

- Separate solution from network equations
- Solution of algebraic loops (iterates if required)
- **Automatic initialization**

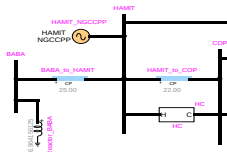
➤ Various control blocks available

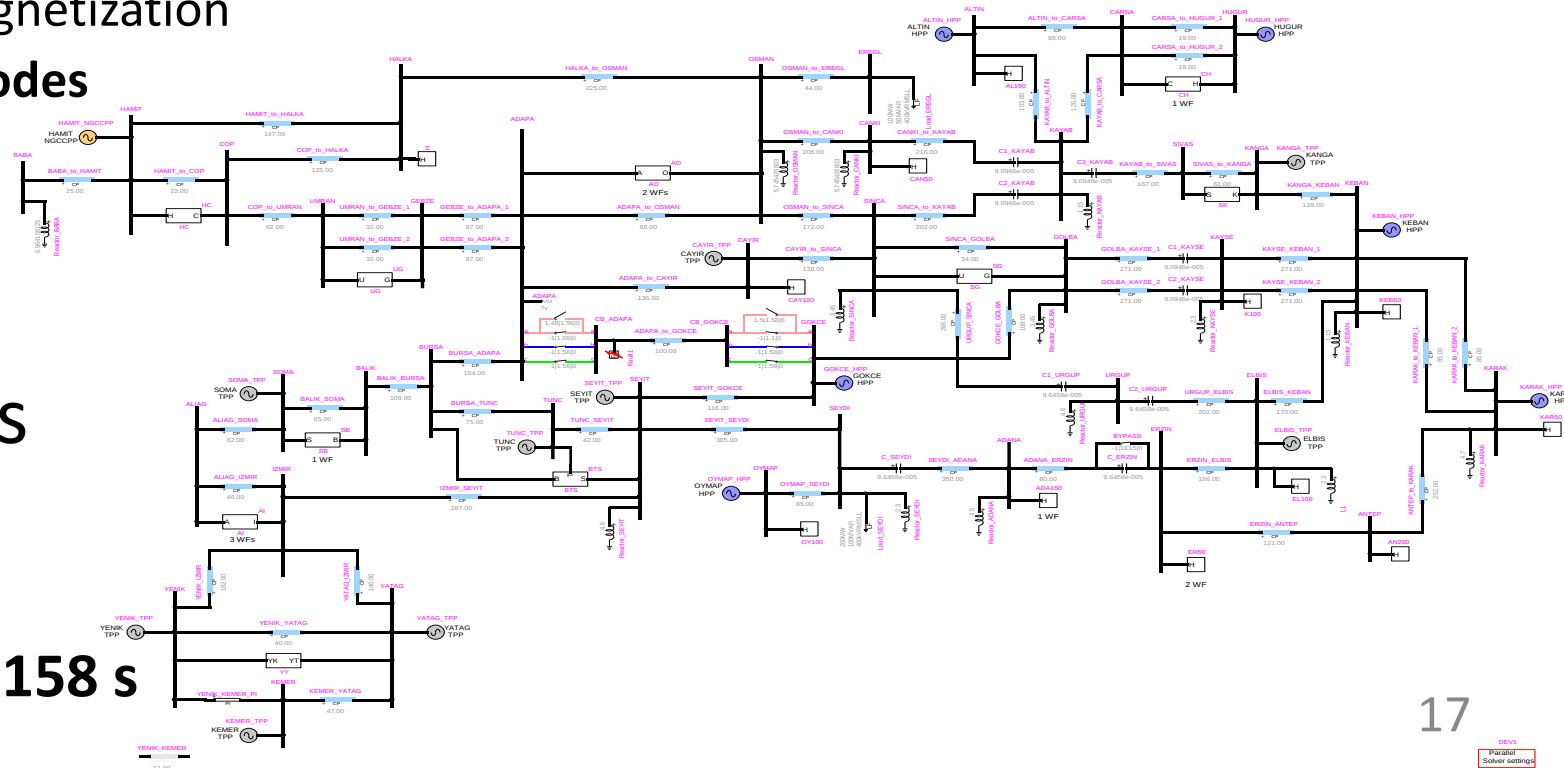
- Transfer functions
- Discrete systems
- Integrators
- Limiters
- DLLs (custom models)
- Etc.



Governor model with automatic initialization

➤ Detailed Turkish grid model

- 400/154/34.5 kV voltage levels
 - ~4k electrical nodes
 - 10 DFIG wind parks
 - Nonlinearities
 - Transformer and machine magnetization
 - **Smooth v-i curve of IGBTs/diodes**
 - Simulation time = 1 s
 - **Time step = 10 μ s**
- 
- The diagram illustrates a power electronic circuit for a DFIG system. It features a three-phase AC source labeled 'BASA' connected to a bridge rectifier. The rectifier's output is connected to a DC link containing an inductor 'L' and a capacitor 'C'. This DC link is connected to a bridge inverter. The inverter's output is connected to a three-phase AC network. This network includes a transformer model 'HAMIT_300000' and a capacitor 'NGCCPH'. The network is also connected to a three-phase AC source labeled 'HAMIT_30_000'. The diagram is annotated with various labels and values, including '25.00' and '22.00' near the capacitor, and '10.00' near the inductor. The circuit is shown in a schematic representation with various components and their interconnections.



➤ Simulation speed results

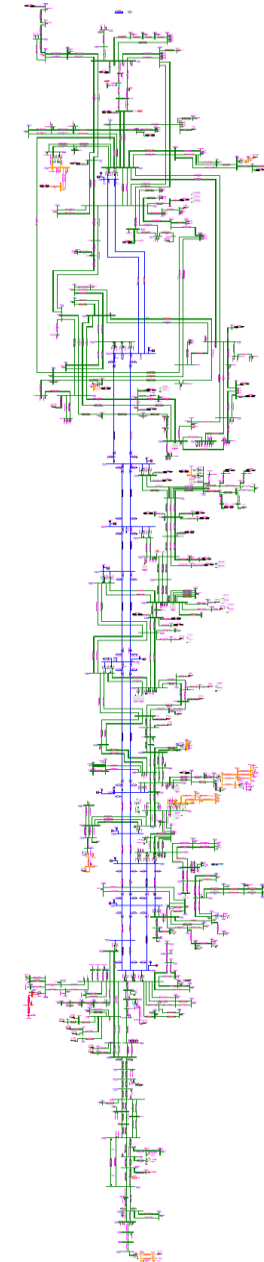
- ~ 5 iterations per time-point
- 1 CPU: 352 s
- Parallel processing (8 CPUs): **158 s**

➤ Chilean grid model

- 75 IBRs (PVs and wind turbines): Average Value Models
- 500/220 kV voltage levels
- **~8k electrical nodes**
- Nonlinearities
 - Transformer magnetization
- Simulation time = 1 s
- Time step = 50 μ s

➤ Simulation speed results

- ~ 2 iterations per time-point
- Simple laptop (8 CPUs): **total time $\approx$ 30 s**
 - Control system (including DLL-based manufacturer type): 8 s
 - Network equations: 21 s



➤ Exciters & Governors library

Various models from IEEE Standard 421.5-2005

➤ Renewables toolbox

PV and WT models for renewables integration analysis

➤ E-Interconnect

Offline screening tool for IBR models verification

➤ Simulink® toolbox

Import Simulink® models into EMTP in two clicks

➤ IEEE CIGRE real code toolbox

Interface DLLs that follow the real-code standard

➤ Protection toolbox

Devices for simulation and analysis of protection systems in steady-state and time-domain

➤ PAMSuite

Complete set of tools for parametric analysis with EMTP

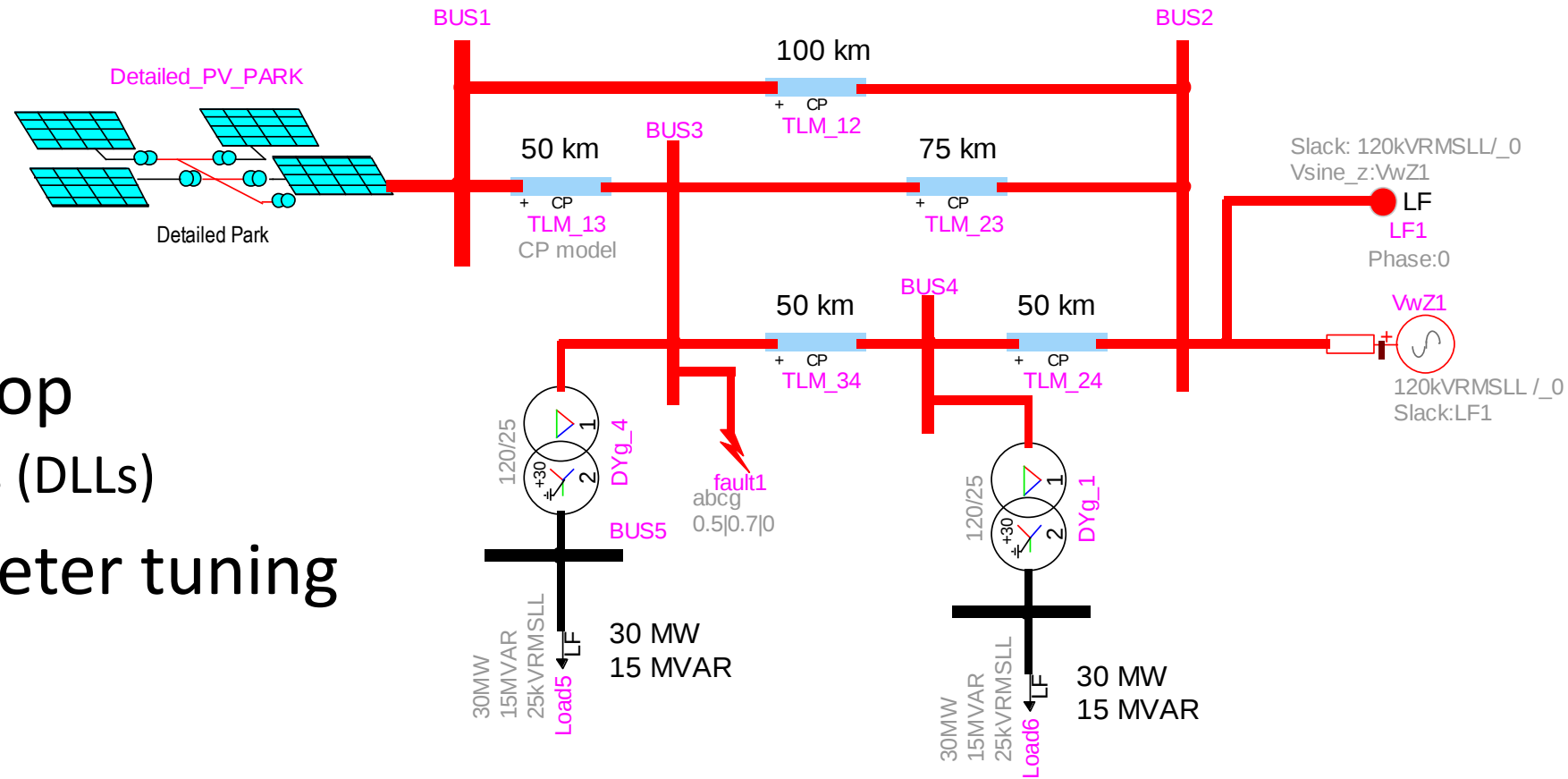
➤ LIOV Toolbox

Calculation of lightning-induced overvoltages on overhead distribution networks

➤ PSS/E® Import tool

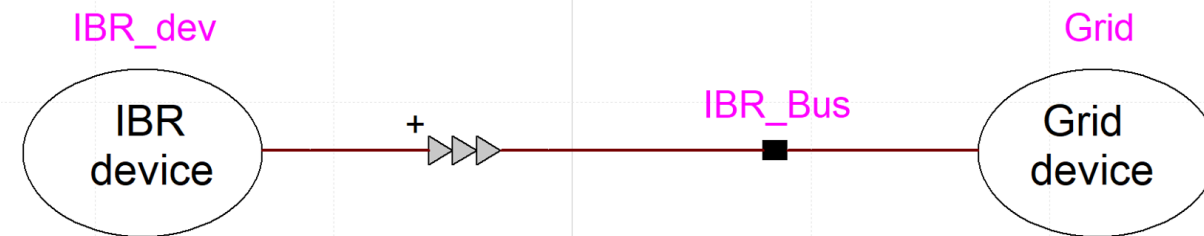
Import your PSS/E® models into EMTP

- Grid code requirements
- LVRT/OVRT
- Harmonics
- Stability
- SSCI
- Software in the Loop
 - Manufacturer models (DLLs)
- Automated parameter tuning



➤ E-Interconnect

- Easy to use, highly customizable tool
- Tests if IBR model meets interconnection requirements
 - IEEE Standard 2800-2022, ...



➤ Workflow of E-Interconnect

- Select the grid code and requirements to verify
- Indicate operating conditions of the IBR model
- Click the Start button
 - All previously defined configurations will be simulated
- Report is automatically generated
 - All relevant tests descriptions
 - Pass/fail note for each test
 - All necessary waveforms
 - Summary of tests

1 EXECUTIVE SUMMARY

This document is automatically generated by the E-Interconnect screening tool of EMTP® and presents validation in EMTP (version 4.2.1) of the myInterconnectProject project for an interconnection following MISO requirements.

The PCC voltage is 230kVRMSLL
The maximum three-phase short-circuit power at PCC is 5000 MVA
The minimum three-phase short-circuit power at PCC is 3000 MVA
The maximum single-phase short-circuit power at PCC is 2500 MVA
The minimum three-phase short-circuit power at PCC is 1700 MVA
The IBR power base is 250MVA.

Project Developer have certified:

- The IBR control model is a replica of the real controller
- The model parameters are project specific of myInterconnectProject
- Transformer saturation curves are excluded.
- The physical process (PV panel, Wind Turbine, etc) behind the DC bus is modeled
- Some protections which will be enabled on field may be disabled in the model

The IBR modeled has been verified for 3 parameter configurations.

Configuration 1:

IOM parameter 1: 0.2
IOM parameter 2: -0.4
IOM parameter N: 1

Flat start test: successful
Multi time-step: not successful
Reactive power step: successful
Three-phase faults LVRT: successful
Single-phase faults LVRT: successful
Three-phase faults tripping: successful
Single-phase faults tripping: successful
SSCI signature calculated successfully

Configuration 2:

IOM parameter 1: 0.5
IOM parameter 2: 0
IOM parameter N: 2

Flat start test: successful
Multi time-step: not successful
Reactive power step: not successful

- Skin effect, proximity, ground return
- Wave propagation solution
- Using MoM-SO technique
- Valid from DC to MHz
- Applies to:
 - Overhead lines
 - Cables
 - GIS circuits
 - Pipelines
 - etc.

Conductors | Model | Help |

Geometrical data and materials | Insulated cable | Help

Insulated cables

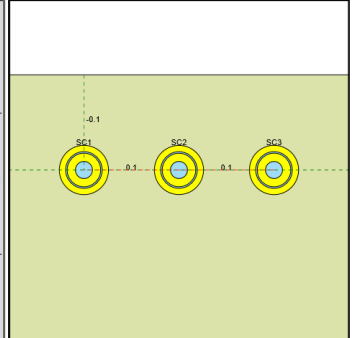
Single-core (SC) cables: 3
Pipe-type (PT) cables: 0
Stranded pipe-type cable: ☐

Soil

Multi-layer soil: ☐
Resistivity: 100 Ωm
Relative permeability (μ_r): 1
Relative permittivity (ϵ_r): 1

Length

Units: Metric
Line/Cable length: 193.1 km



Drawing options

List of tables

Single-core (SC) cable main data

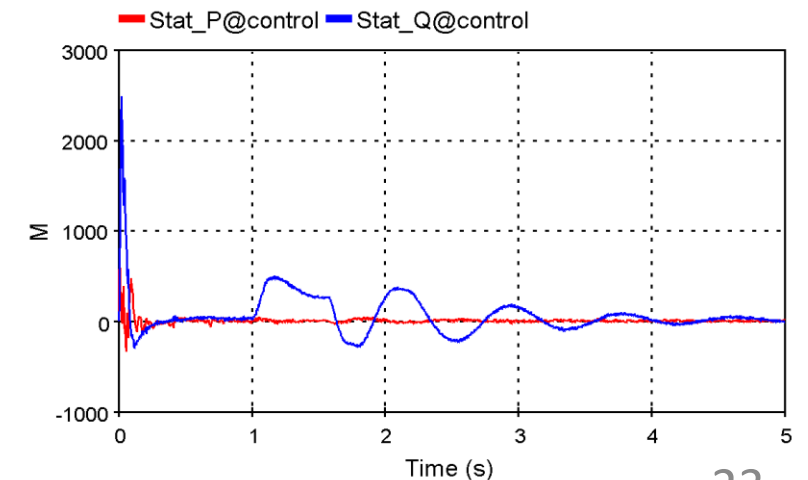
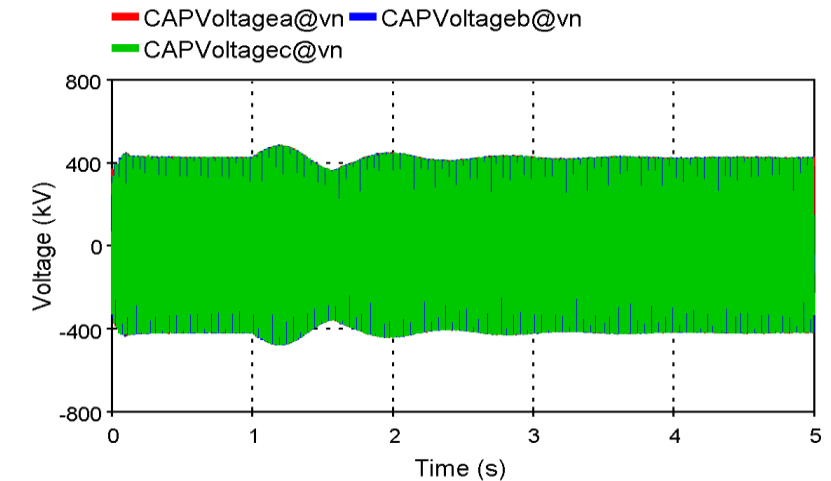
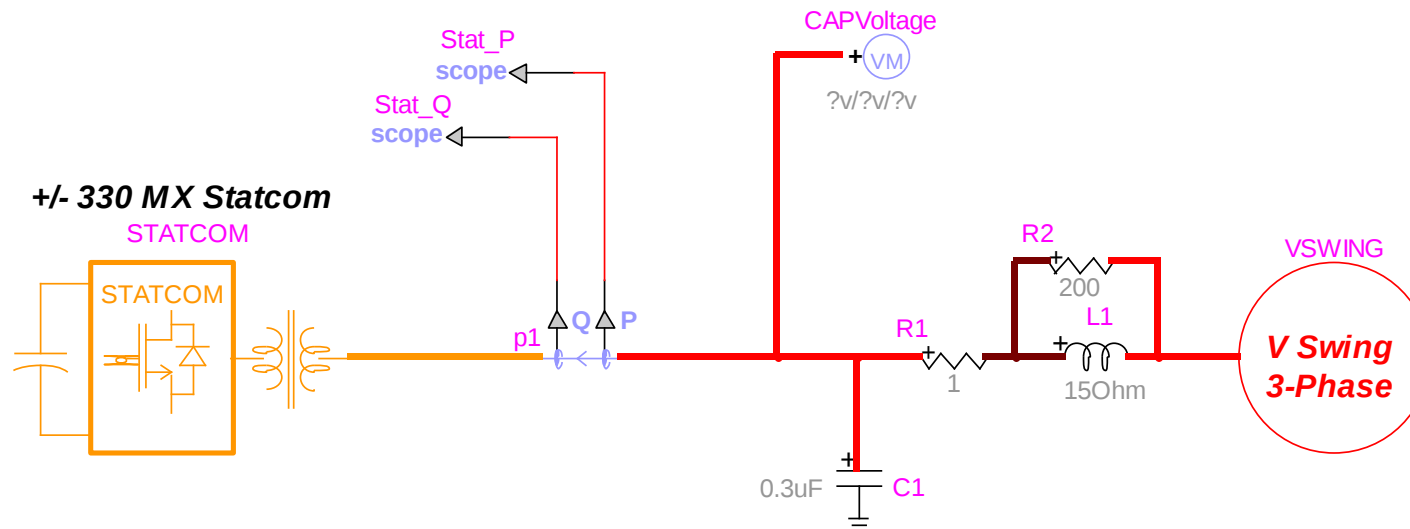
Cable	Number of conductors	Horizontal position (m)	Ground depth (m)	Radius (cm)
1	2	-0.10	-0.1	2.58475614
2	2	0	-0.1	2.58475614
3	2	0.1	-0.1	2.58475614

Load single-core cable from database for selected row

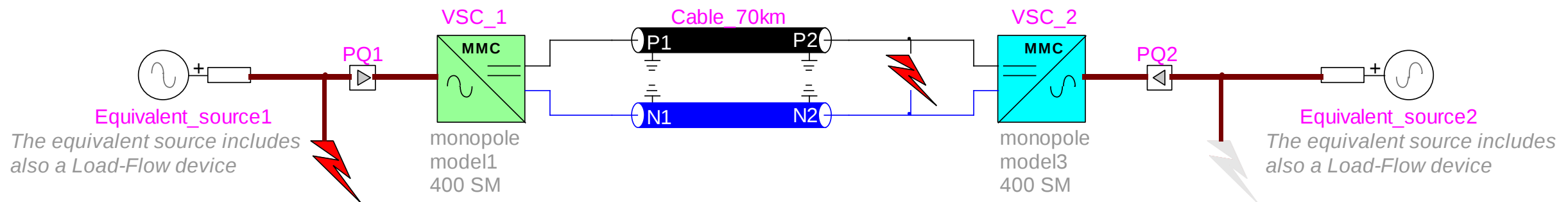
Single-core (SC) cable conductors/insulators data

Cable	Conductor	Phase	Inner radius (cm)	Outer radius (cm)	Conductor resistivity (Ohm m)	Conductor relative permeability	Conductor relative permittivity	Insulator relative permittivity	Insulator loss factor
1	1	1	0	0.89801898	2.83e-8	1	1	3	0.002
1	2	2	1.76161898	1.92435614	1.72e-8	1	1	3	0.002
2	1	3	0	0.89801898	2.83e-8	1	1	3	0.002
2	2	4	1.76161898	1.92435614	1.72e-8	1	1	3	0.002
3	1	5	0	0.89801898	2.83e-8	1	1	3	0.002
3	2	6	1.76161898	1.92435614	1.72e-8	1	1	3	0.002

- EMTP solver provides **advanced algorithms** to avoid numerical instability when switching
- Advanced models can be implemented
 - Detailed models of switches
 - Complex control systems
- Many examples are provided



- HVDC simulations require a good solver and precise models (IGBTs, Control, Lines/Cables)
- **Bipolar, Back-to-Back, Multi-terminal HVDC** systems are available
- Generic and complete models of **Modular Multilevel Converter (MMC)** are provided
 - From Full Detailed models to Average-Value



Applications: switching transients

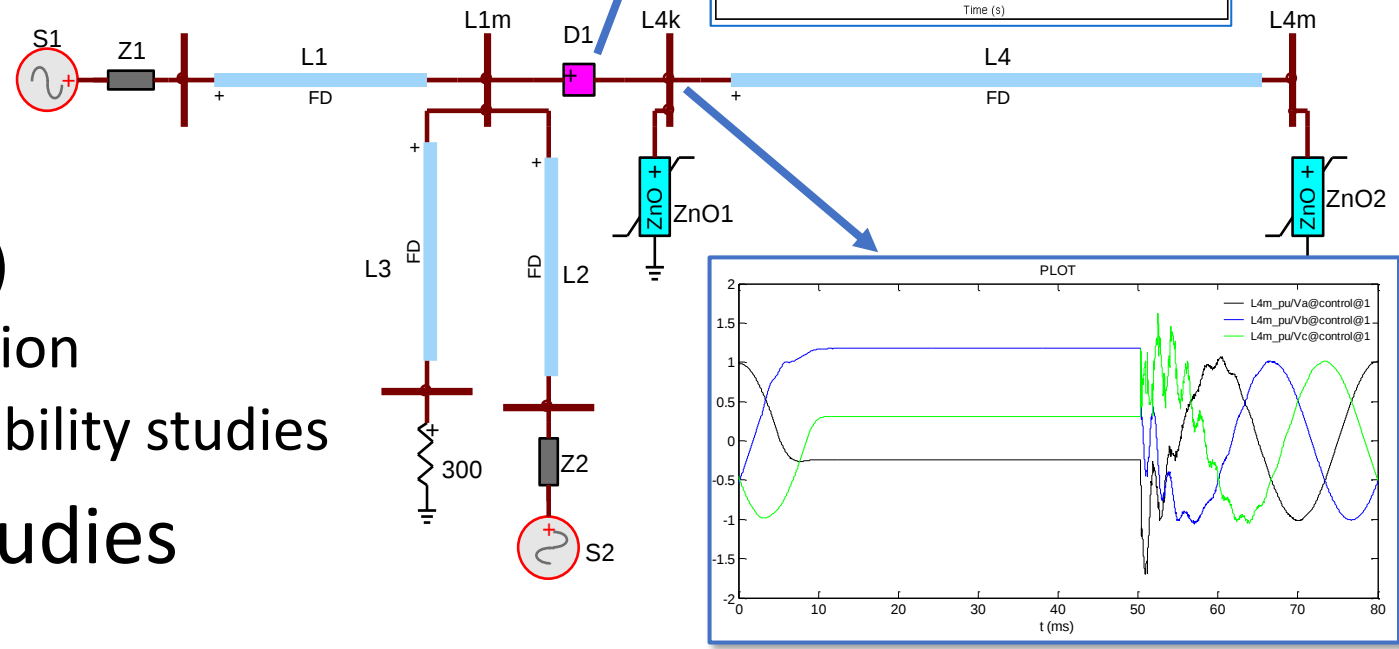
➤ Typical network events

- Switching of transmission lines
- Fault inception and clearance
- Capacitor bank switching
- Reactor switching

➤ Breaker models:

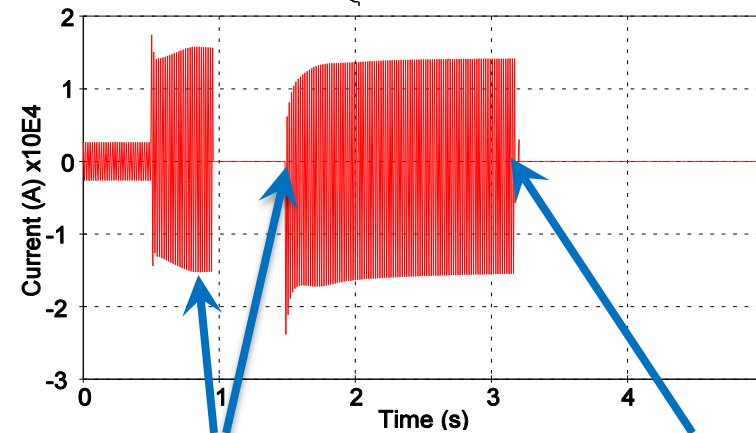
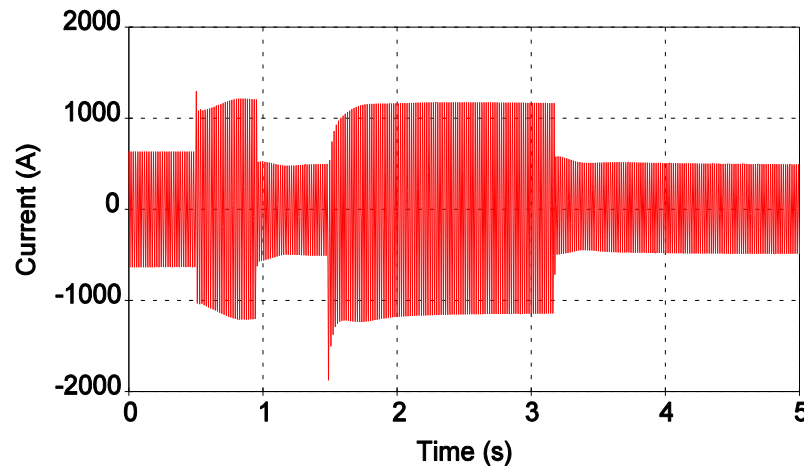
- Ideal switches for TRV studies
- (IEEE C37.06, C37.013, IEC 62 271)
- Degrees of asymmetry determination
- Arc models for arc quenching capability studies

➤ Statistical and parametric studies



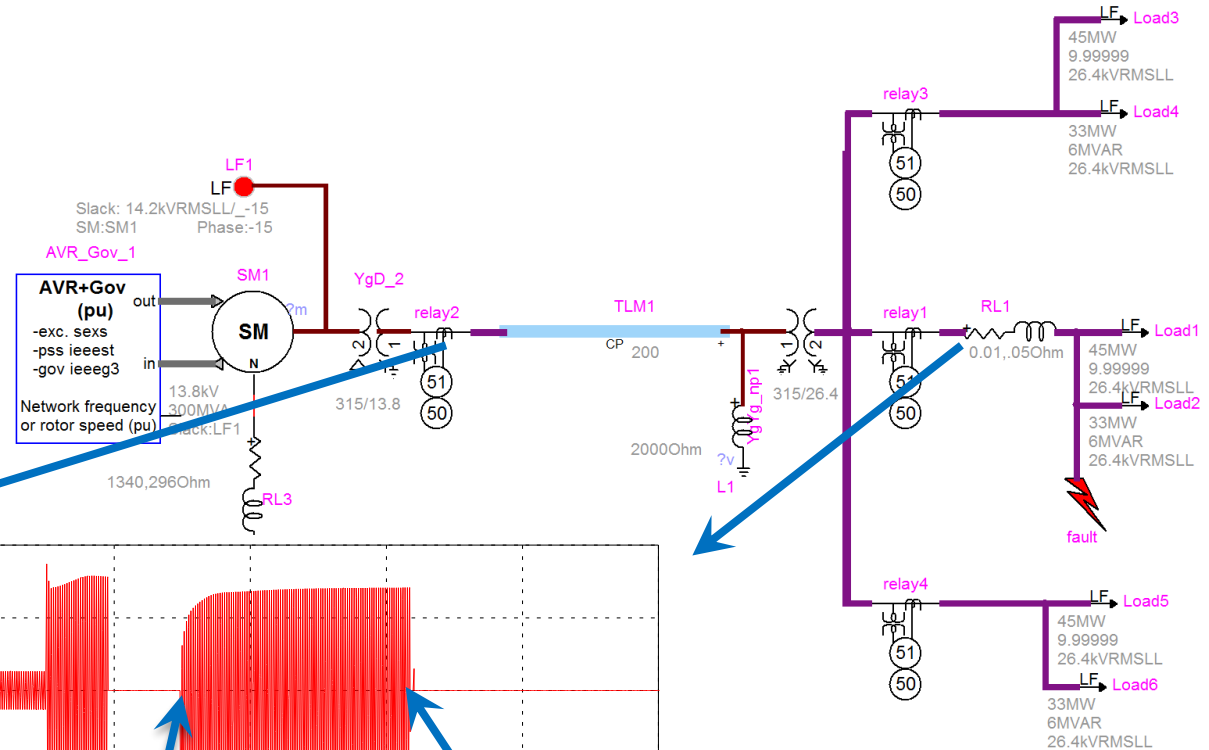
➤ Inverse Curves Coordination

- **Fault line** to ground on a feeder
- **Fast neutral**: IEEE extremely inverse
 - Tap = 2, pickup = 0.2pu
- **Slow neutral**: IEEE inverse
 - Tap = 3, pickup = 0.2pu



Fast neutral protection
with 1 reclosing

Slow neutral protection.
Definitive!





Thank you!

- Do you have any questions?
- info@emtp.com
- emtp.com