EMTP overview

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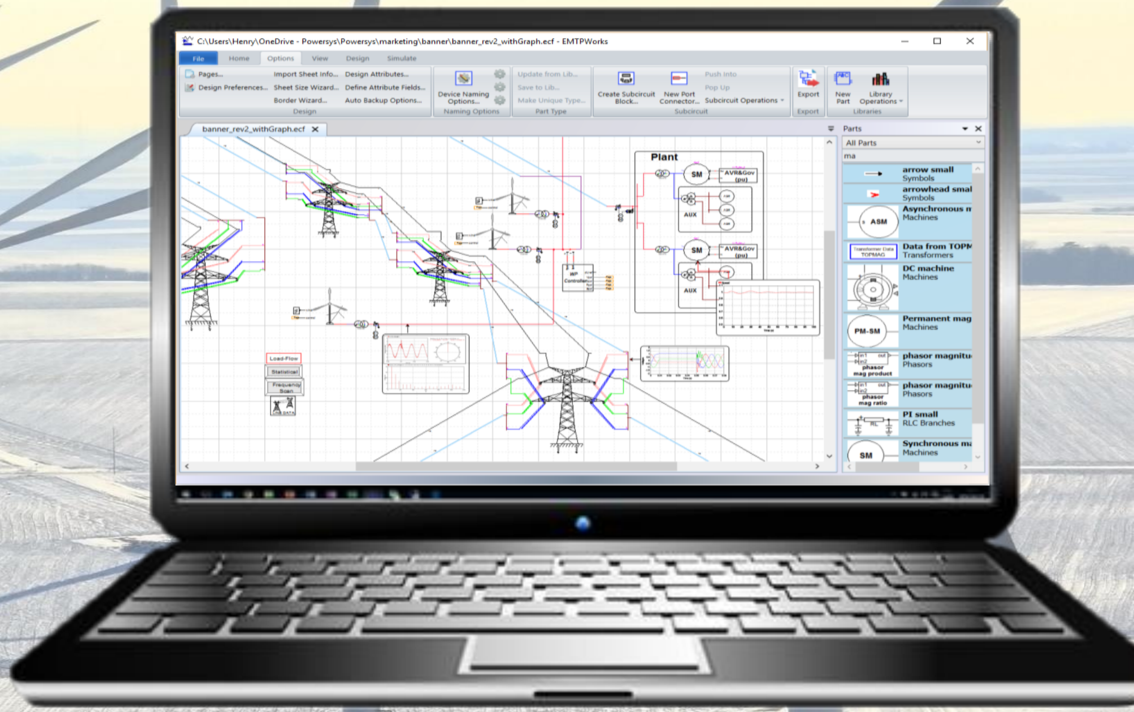

More info

www.EMTP.com

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What is EMTP?

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

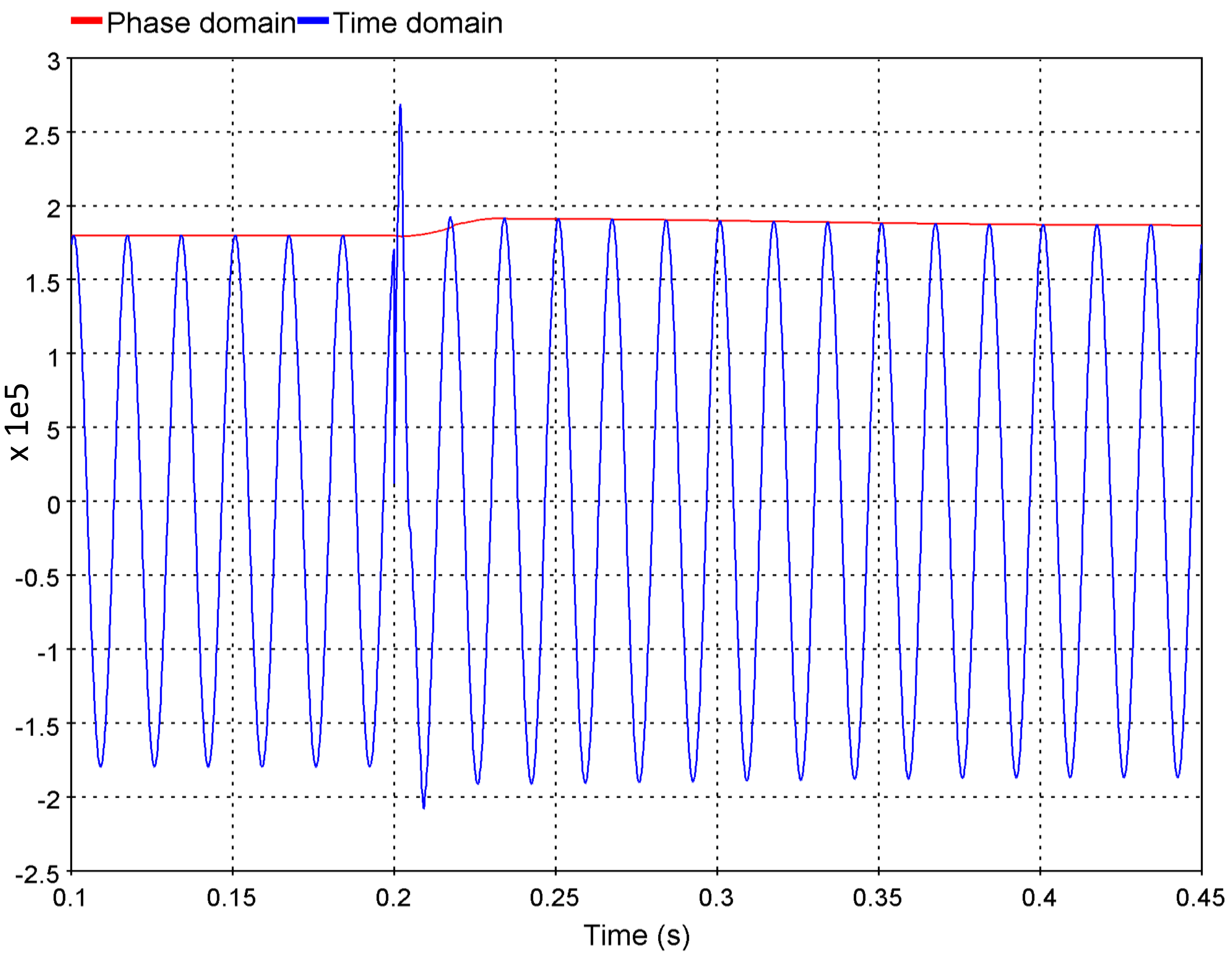
Time domain vs phasor domain

➢Phasor domain

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

➢Time domain

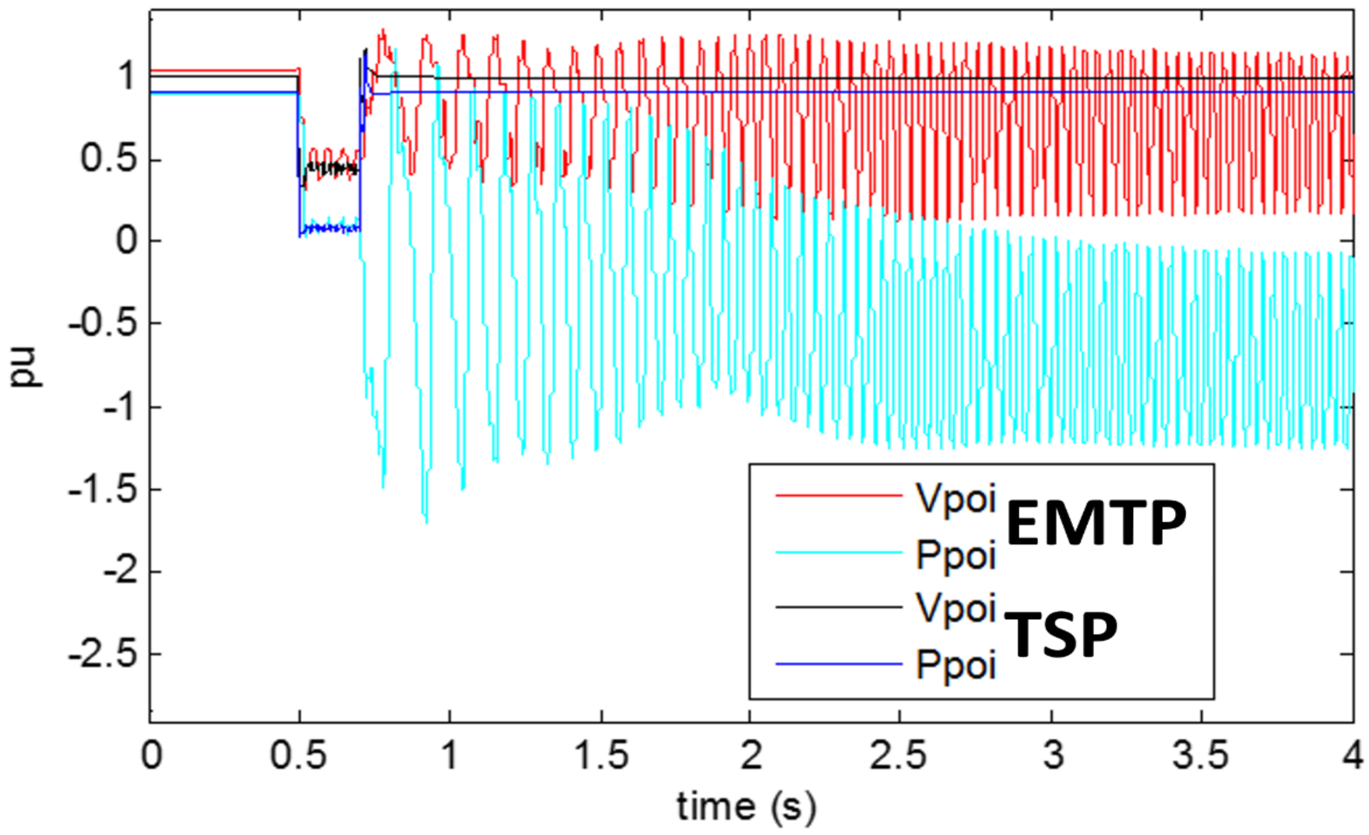
- DC to MHz frequency range
- Instantaneous waveforms
- Detailed control systems
- Nonlinearities
- Etc.

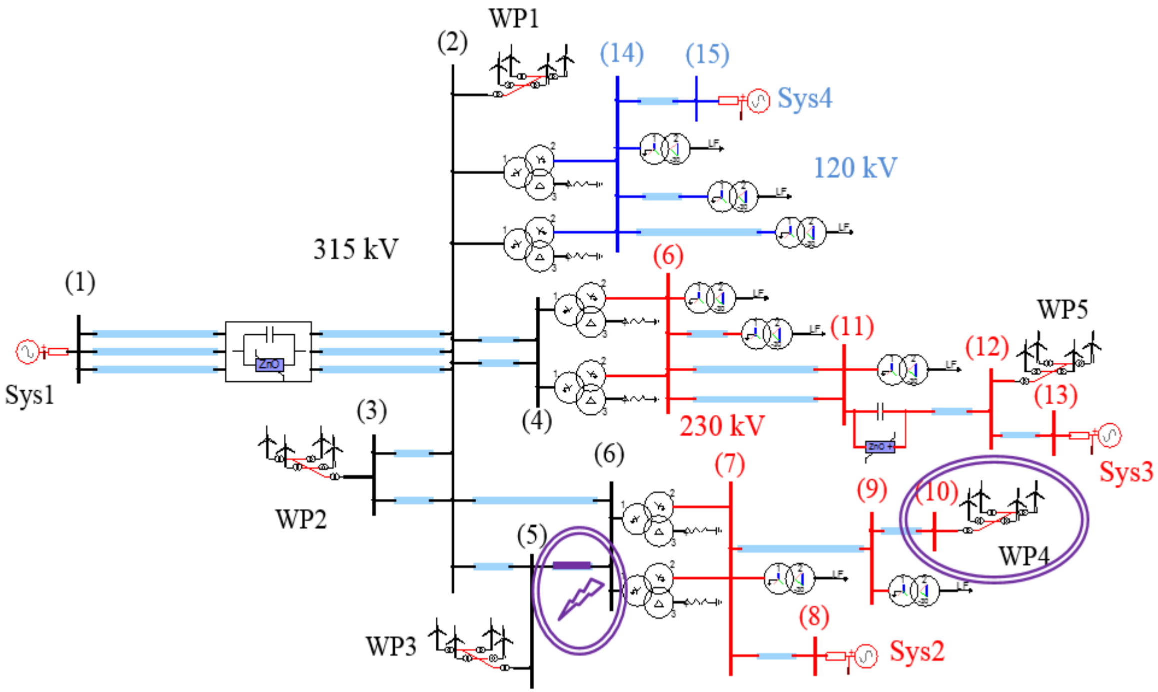


Time domain vs phasor domain

➢ 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





EMTP simulation types and applications

➢Types of Simulations:

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

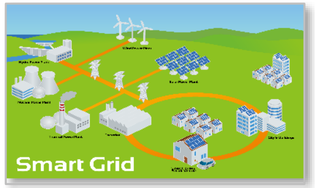
➢Wide variety of power system applications, including but not limited to:

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



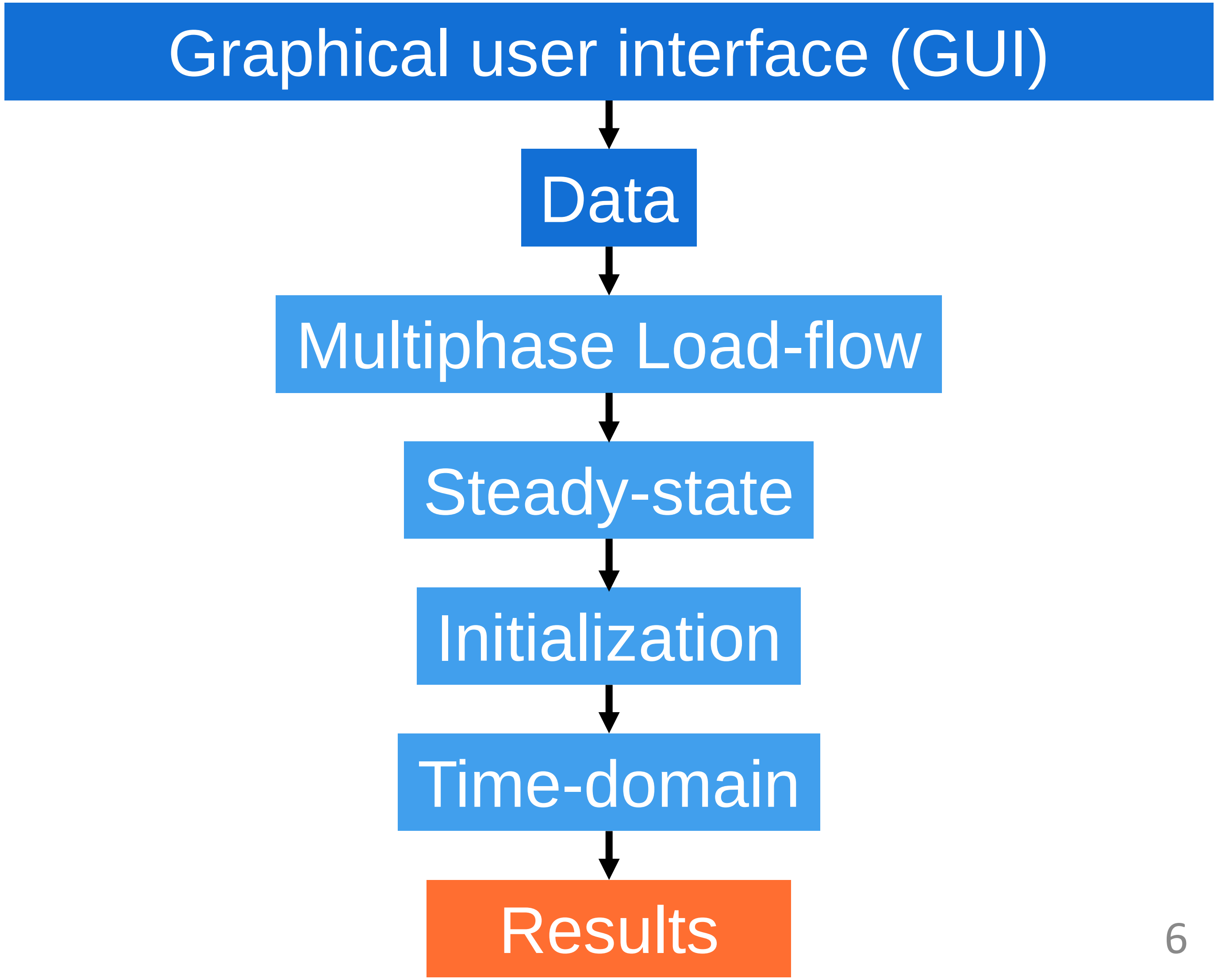




EMTP workflow

- The same design is used for all types of studies
  - Time-domain simulations
  - Statistical analysis
  - Frequency scan
  - Steady-state
  - Load-flow



EMTP benefits

- 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

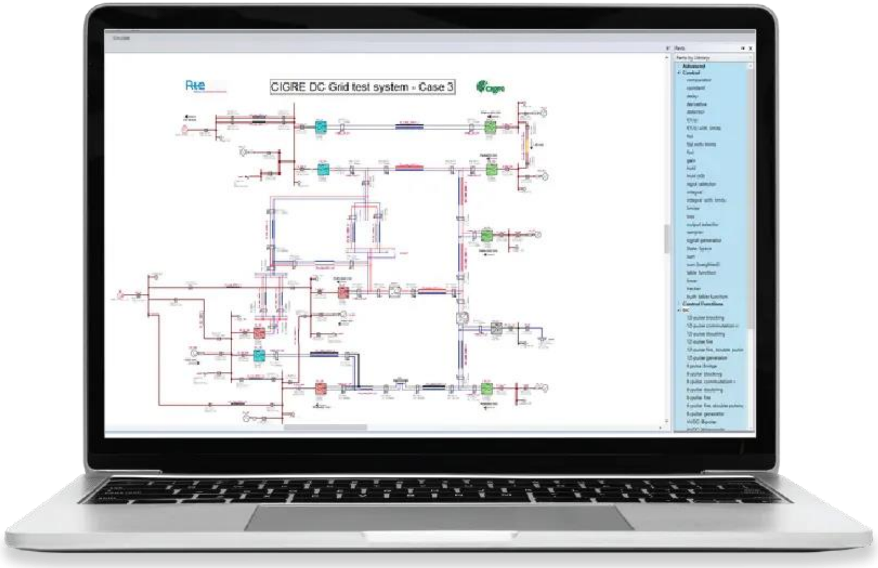
EMTP basic package

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…)

EMTPWorks: overview

- 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



EMTPWorks: GUI

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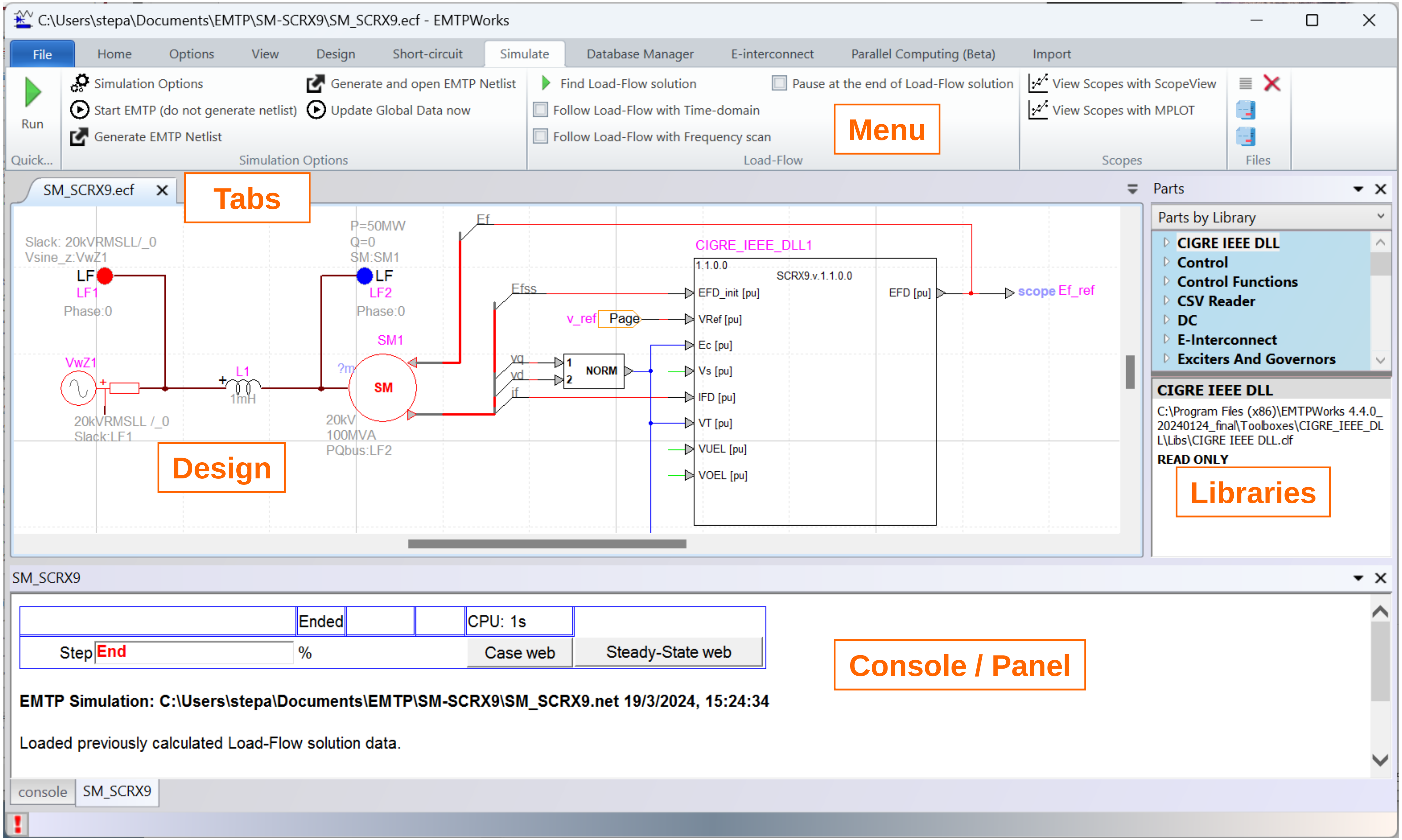
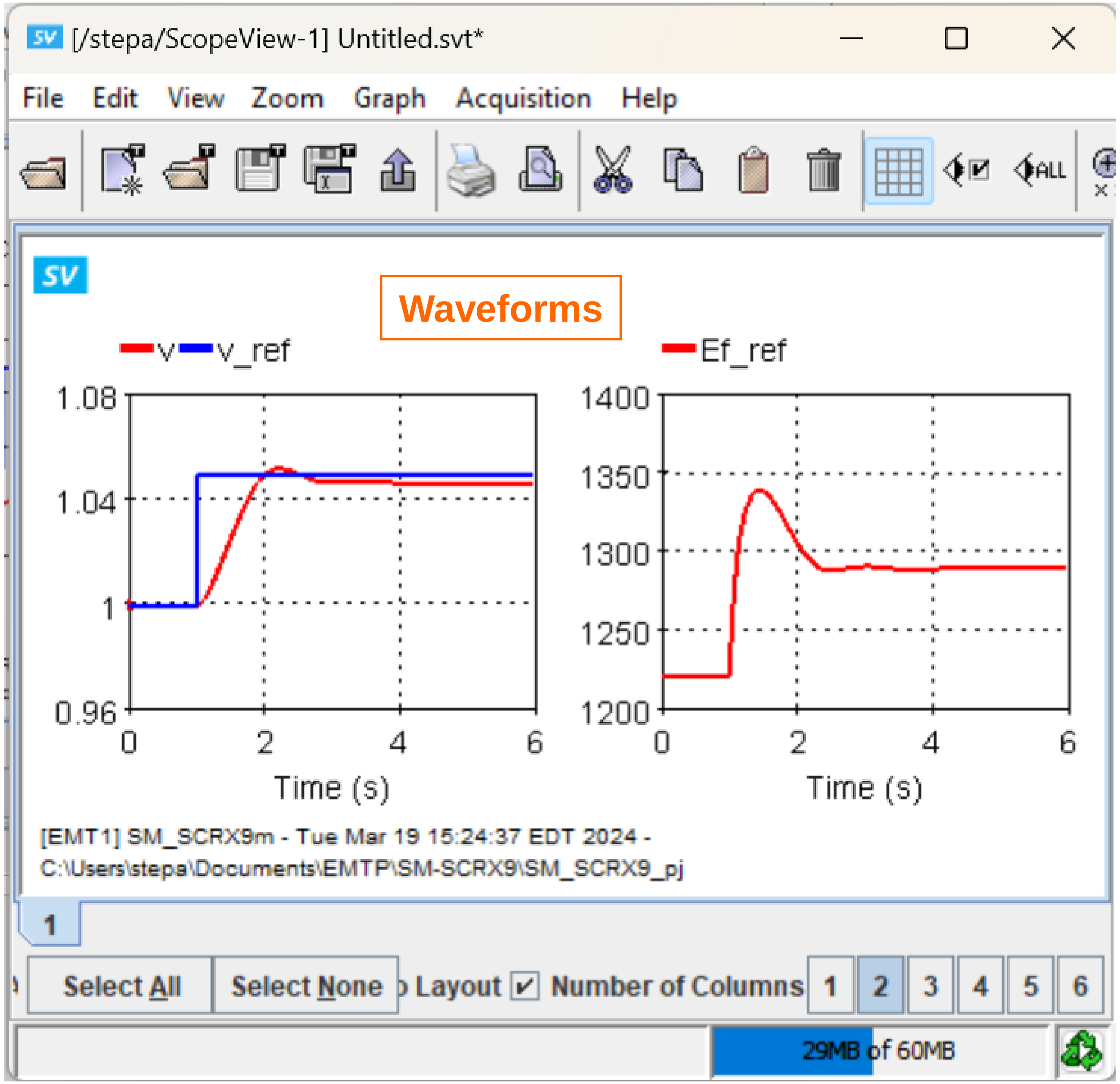
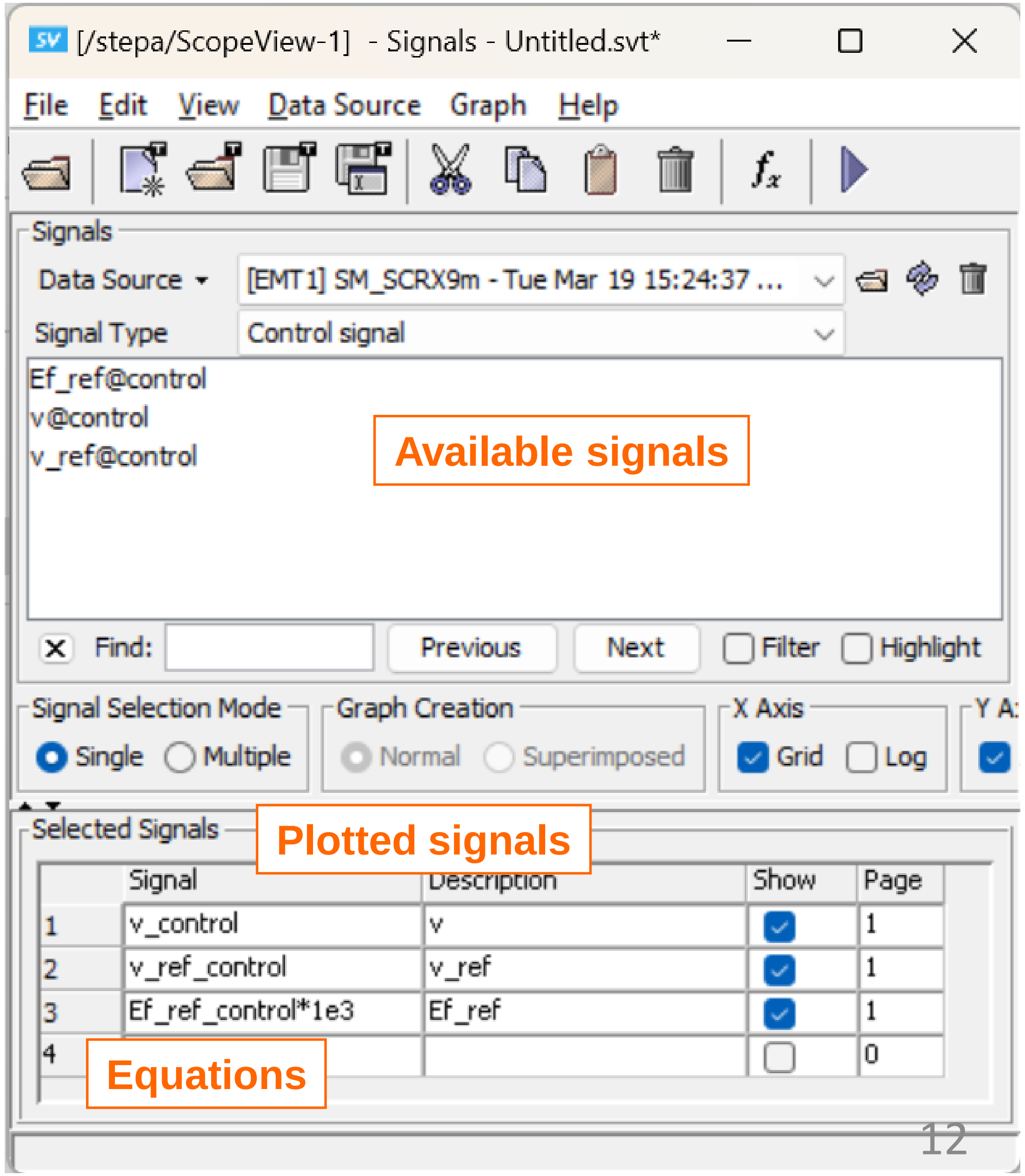


ScopeView: features

- 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, …

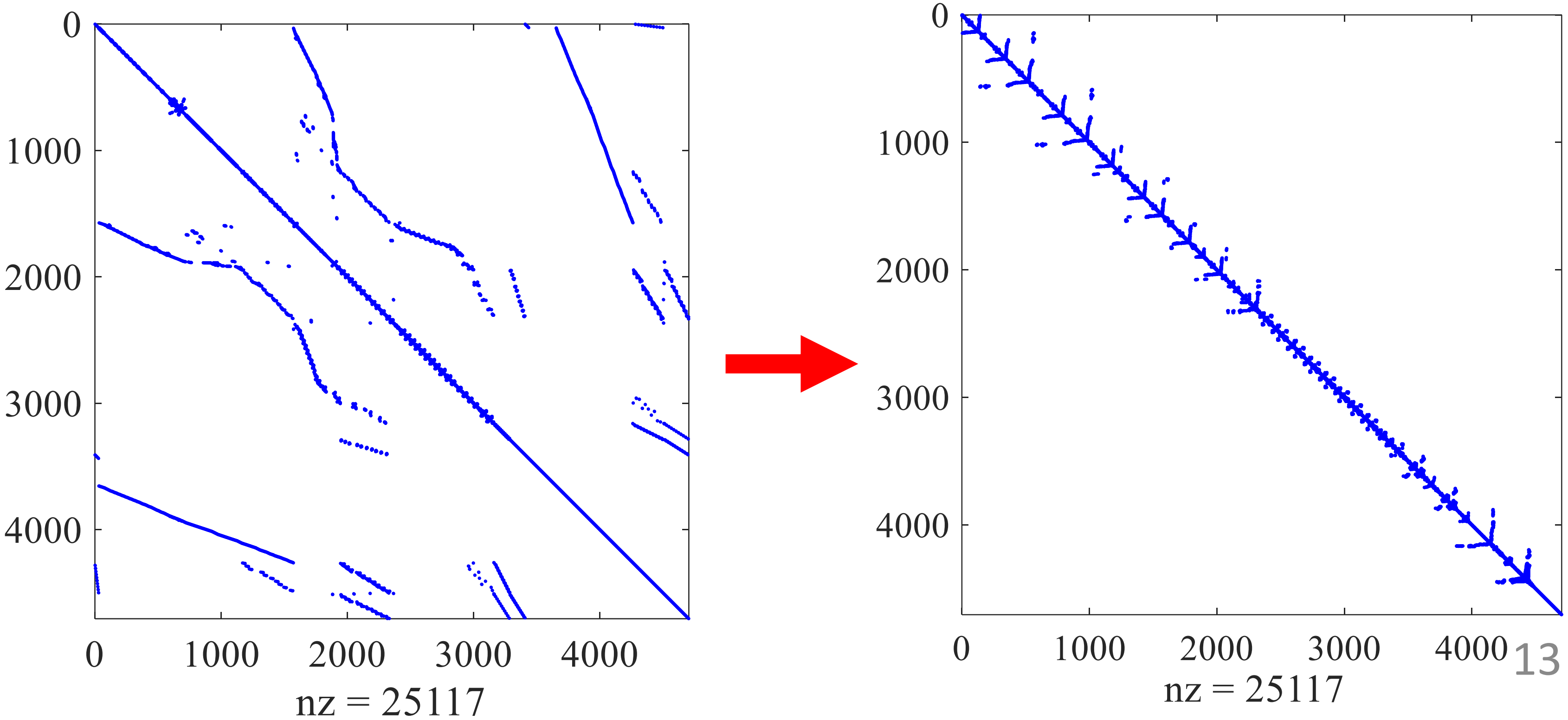
ScopeView: data visualization





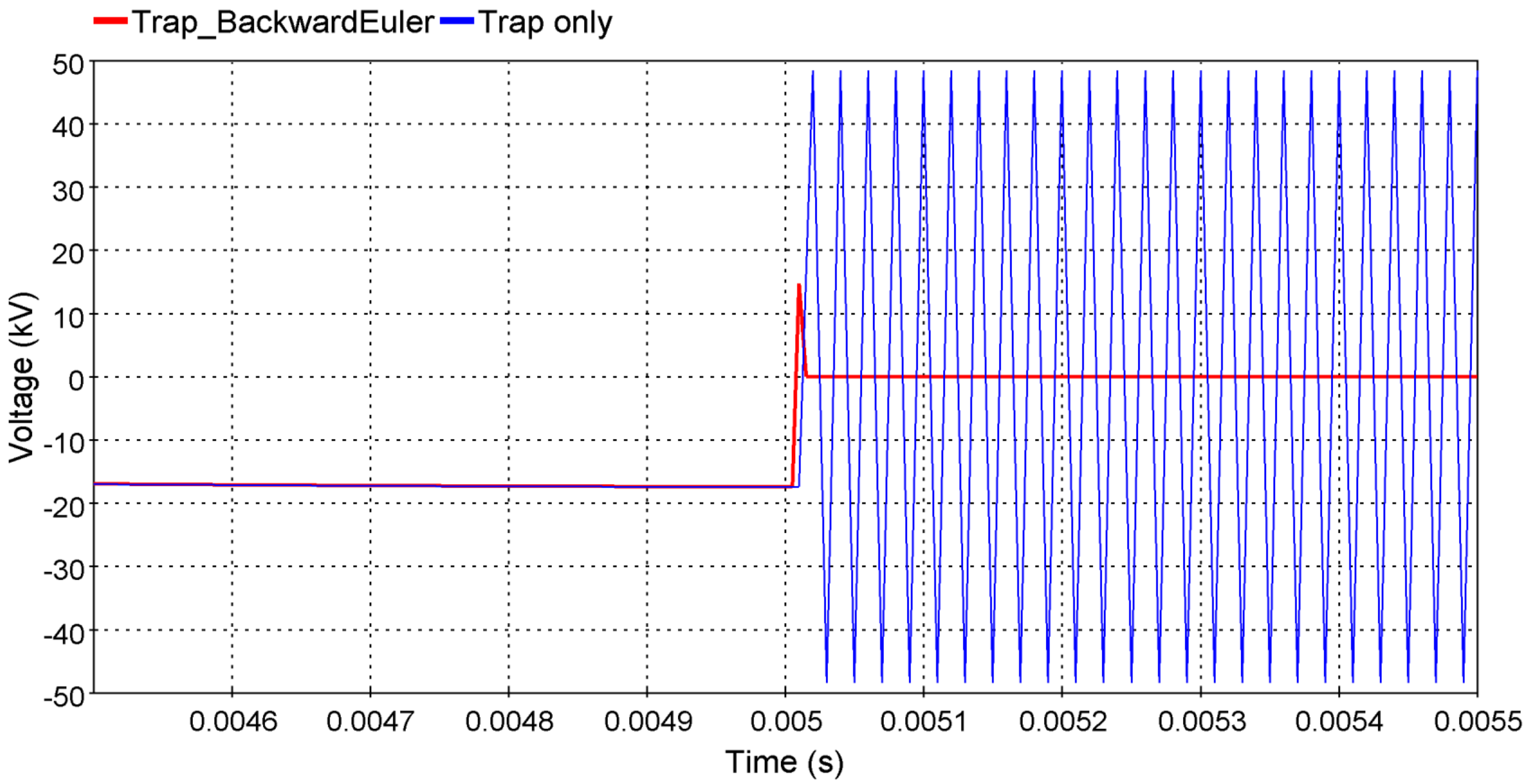
EMTP solver: overview

- 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



EMTP solver: numerical stability

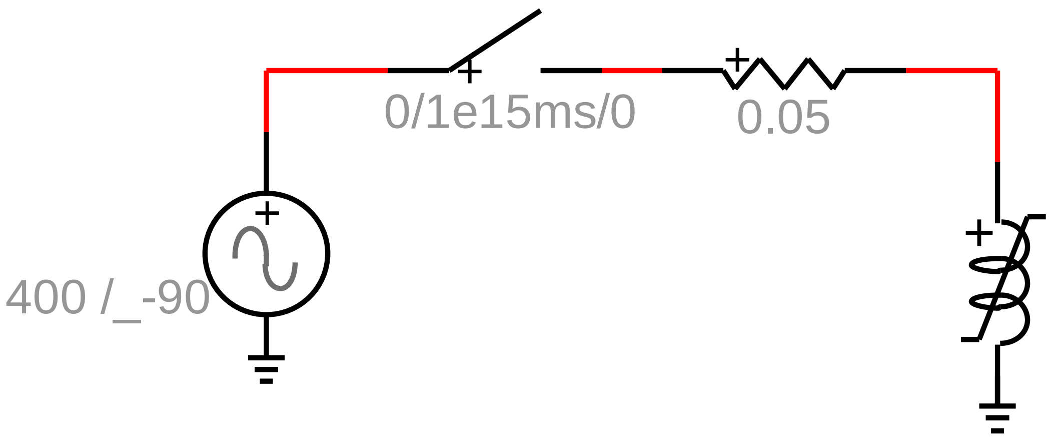
- Numerical oscillations can be caused by state variables discontinuity
- EMTP solution
  - Default integration method: Trapezoidal
  - When discontinuity is detected: use Backward Euler Integration method

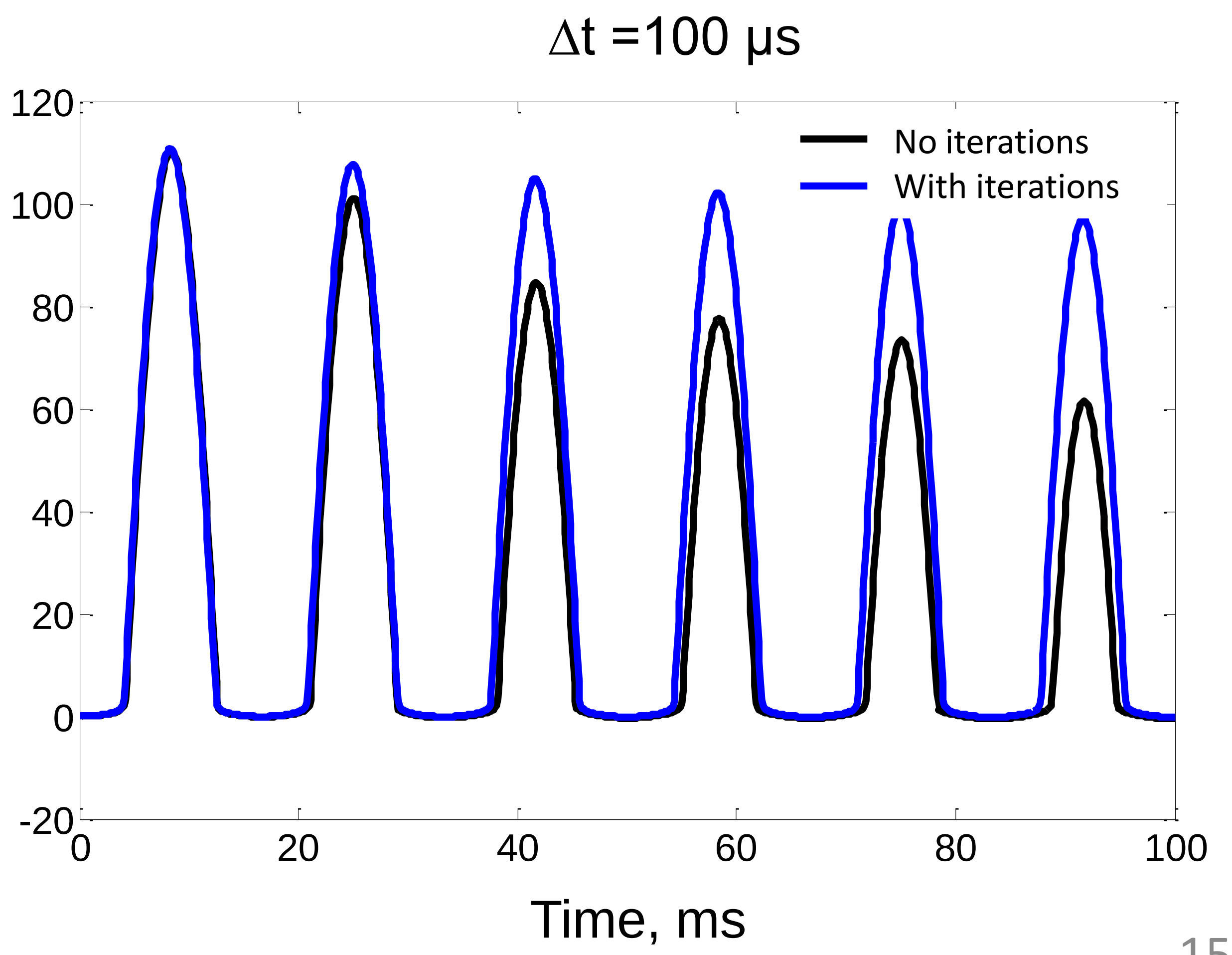


EMTP solver: nonlinear devices

➢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





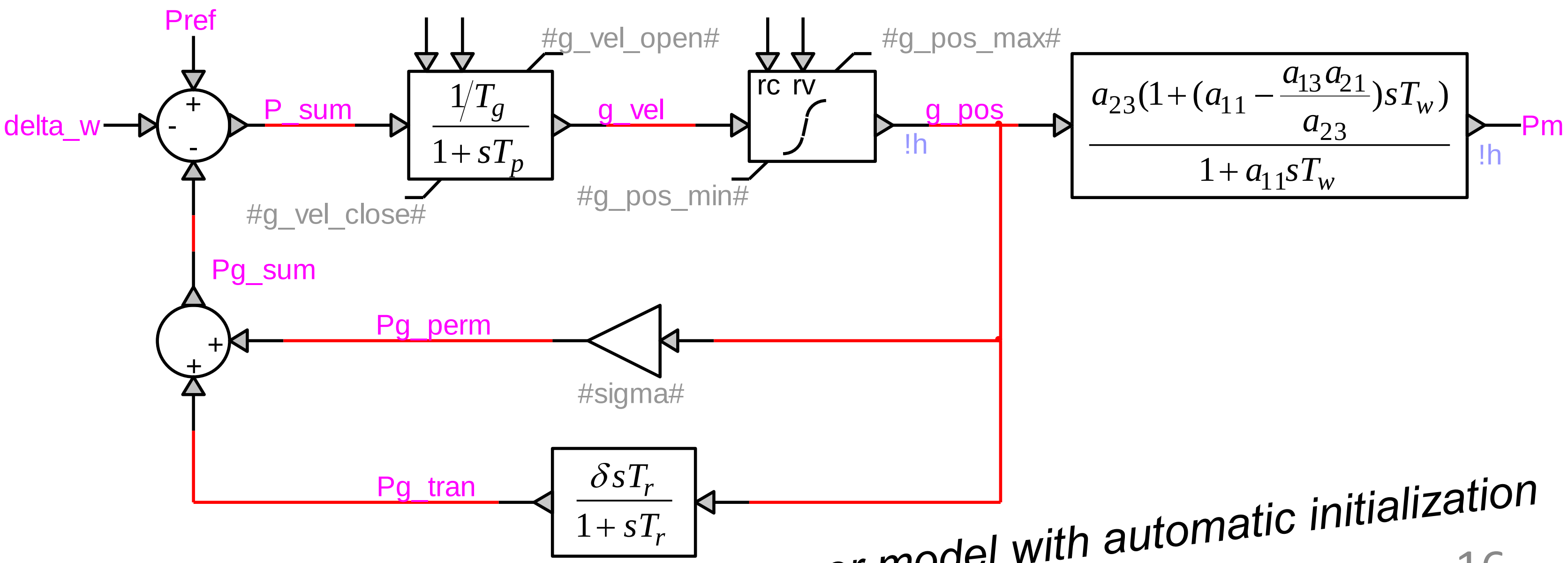
EMTP solver: control system

➢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.

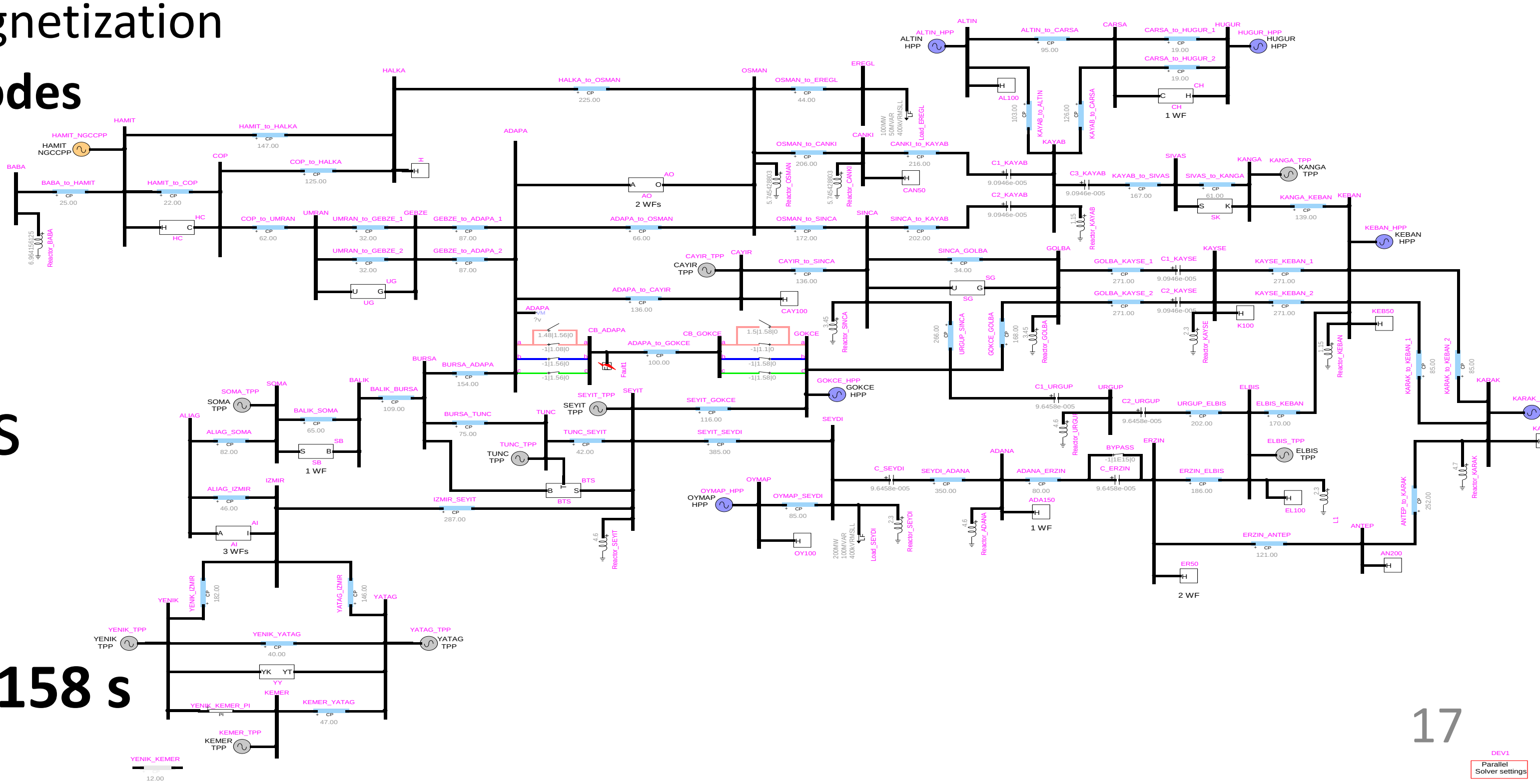


Governor model with automatic initialization

EMTP solver: simulation speed (1)

➢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 µs**



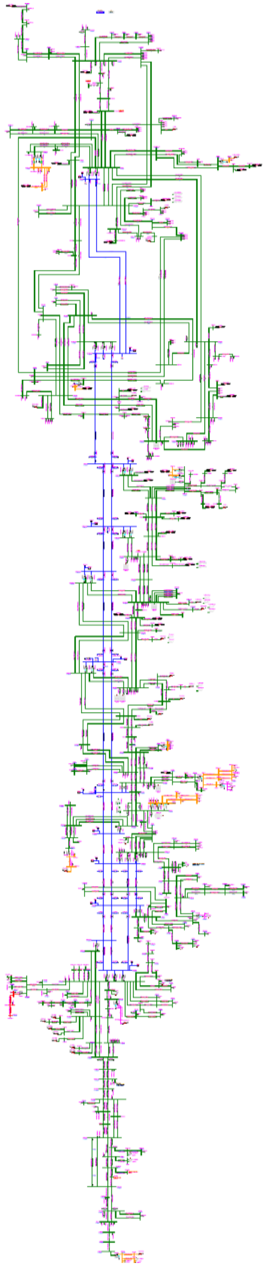
➢Simulation speed results

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

EMTP solver: simulation speed (2)

➢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 μs



➢Simulation speed results

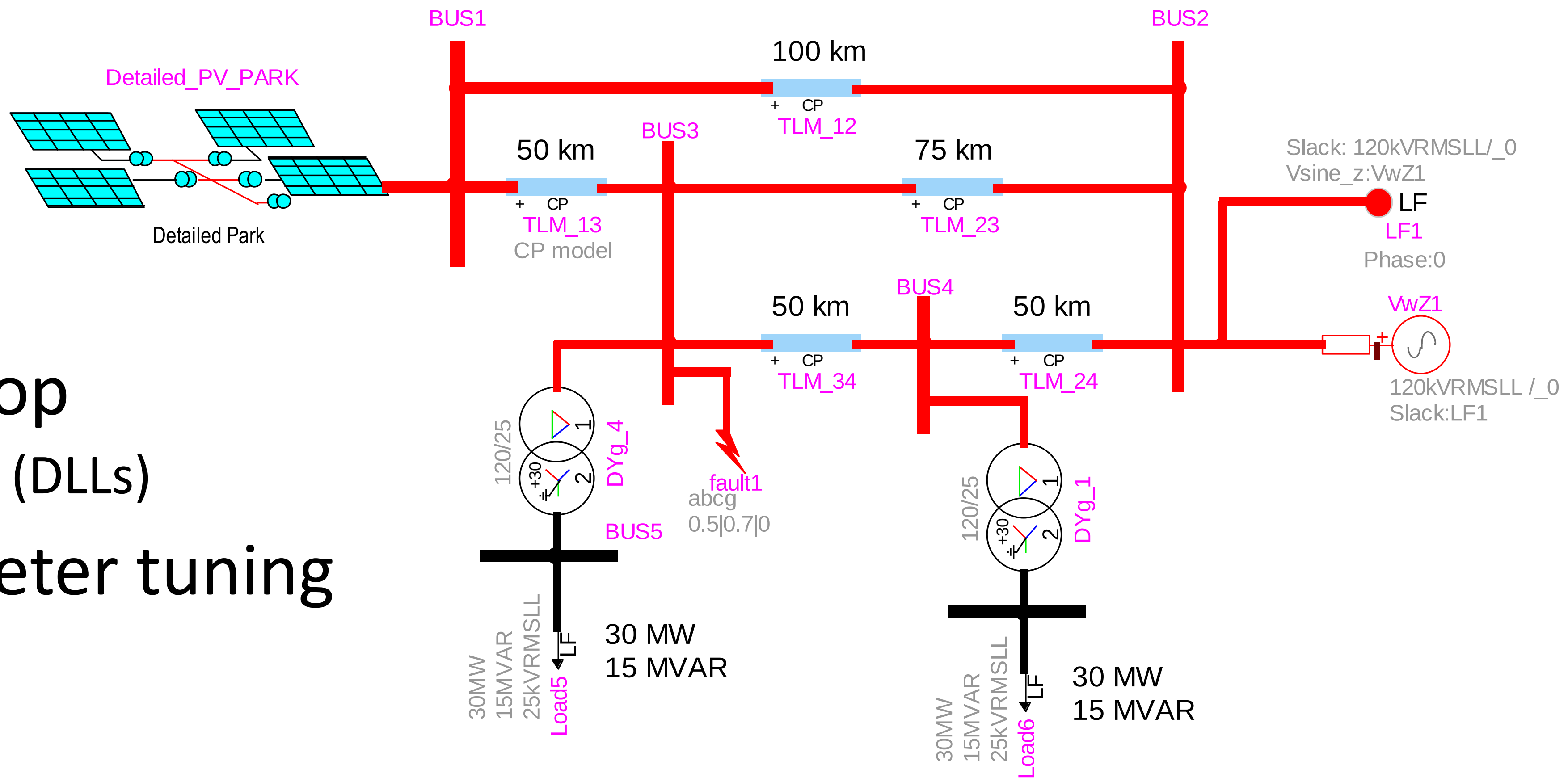
- ~ 2 iterations per time-point
- Simple laptop (8 CPUs): **total time ≈ 30 s**
  - Control system (including DLL-based manufacturer type): 8 s
  - Network equations: 21 s

Some extra modules and add-ons

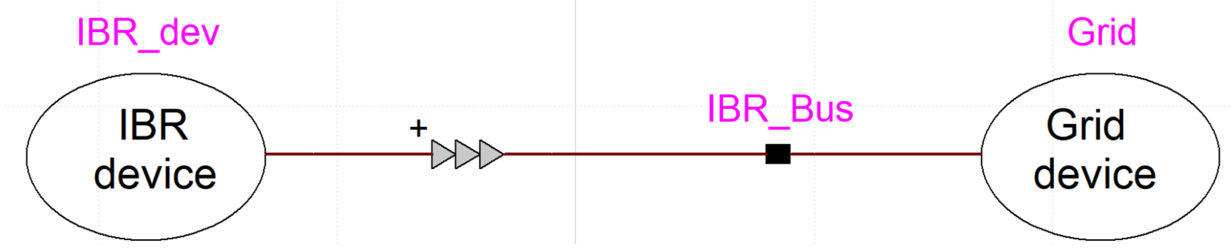
- **Exciters & Governors library**
  Various models from IEEE Standard 421.5-2005
- **Renewables toolbox**
  PV and WT models for renewables integration analysis
- **E-Interconnect**
  Offline screening tool for IBR models verification
- **Simulink® toolbox**
  Import Simulink® models into EMTP in two 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

Applications: Inverter Based Resources

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



Applications: Inverter Based Resources



➢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

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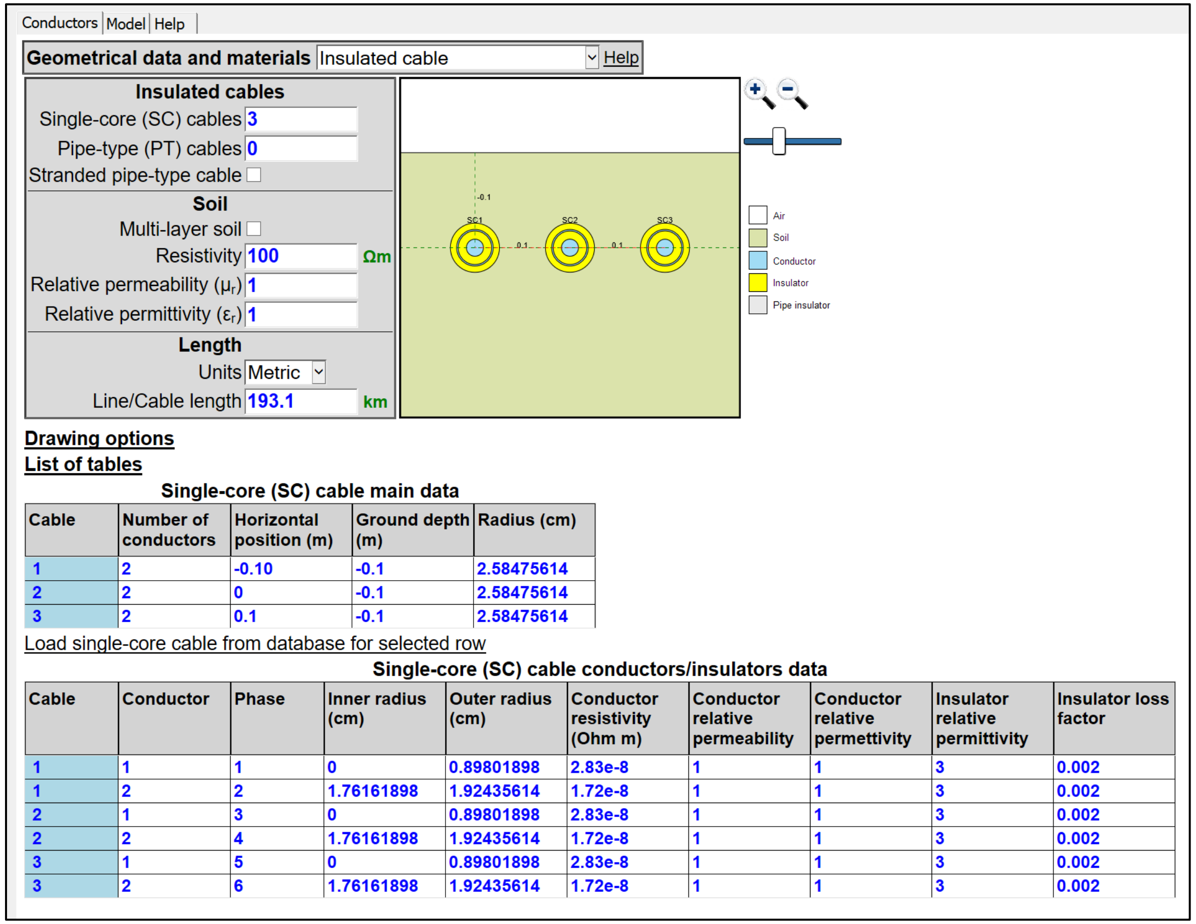
Applications: line/cable modeling

- 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.



Single-core (SC) cable main data

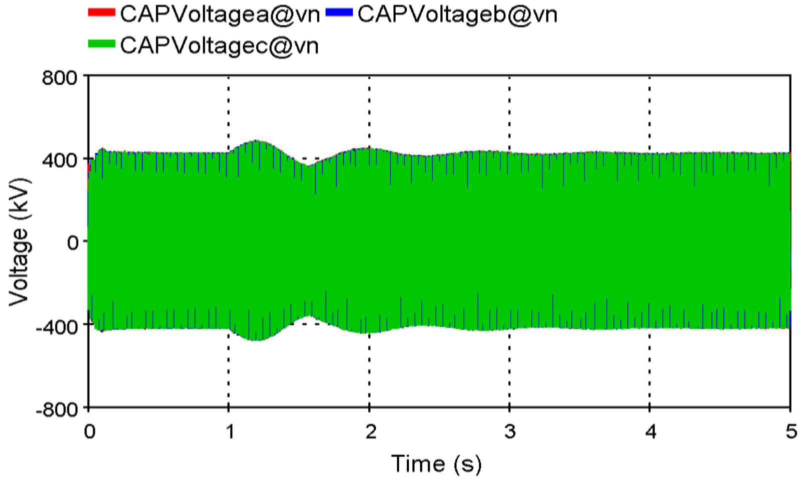
Cable	Number of conductors	Horizontal position (m)	Ground depth (m)	Radius (cm)
1	2	-0.10	-0.1	2.58475614
2	2	0	-0.1	2.58475614
3	2	0.1	-0.1	2.58475614

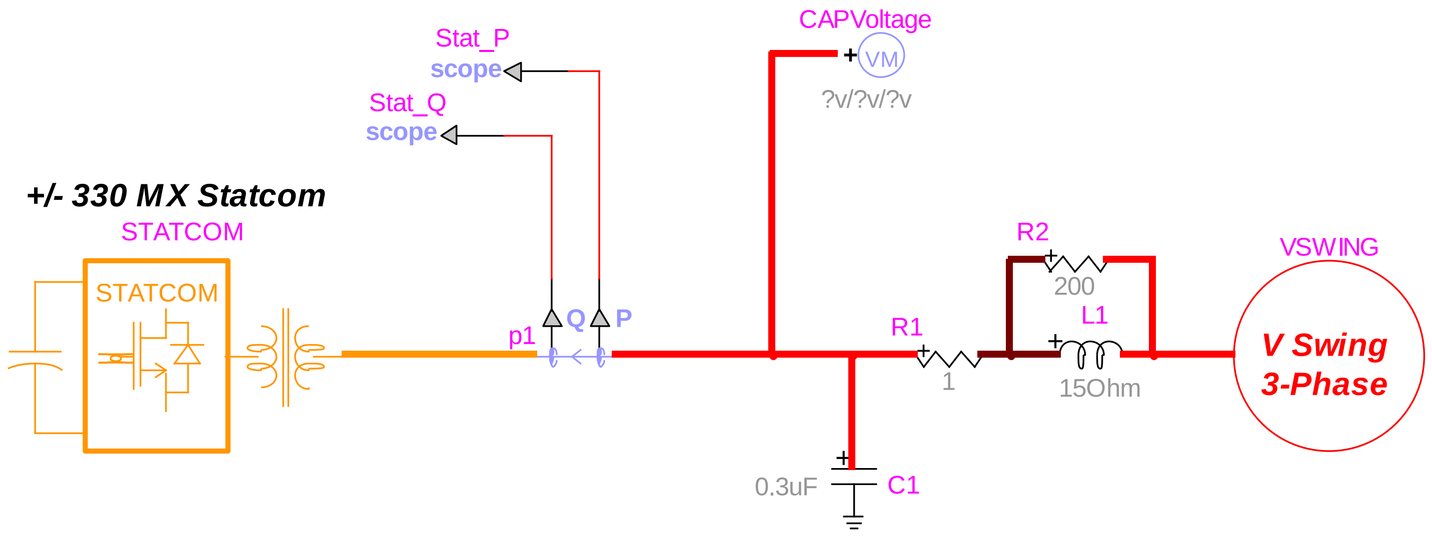
Single-core (SC) cable conductors/insulators data

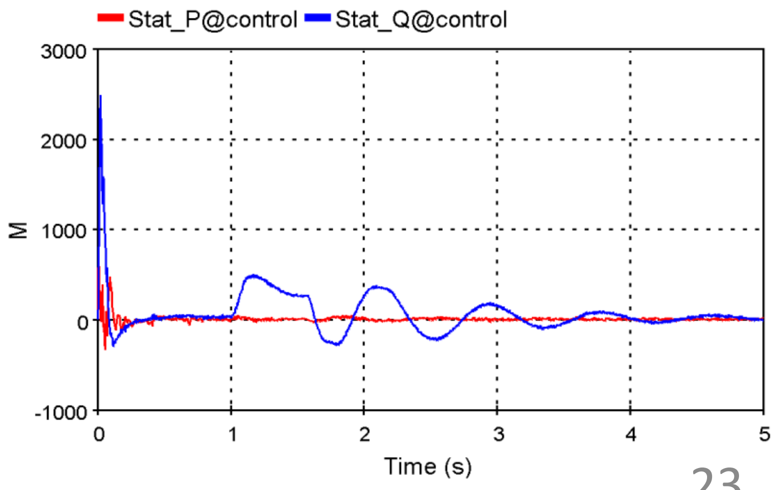
Cable	Conductor	Phase	Inner radius (cm)	Outer radius (cm)	Conductor resistivity (Ohm m)	Conductor relative permeability	Conductor relative permettivity	Insulator relative permittivity	Insulator loss factor
1	1	1	0	0.89801898	2.83e-8	1	1	3	0.002
1	2	2	1.76161898	1.92435614	1.72e-8	1	1	3	0.002
2	1	3	0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

Applications: power electronics and FACTS

- 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





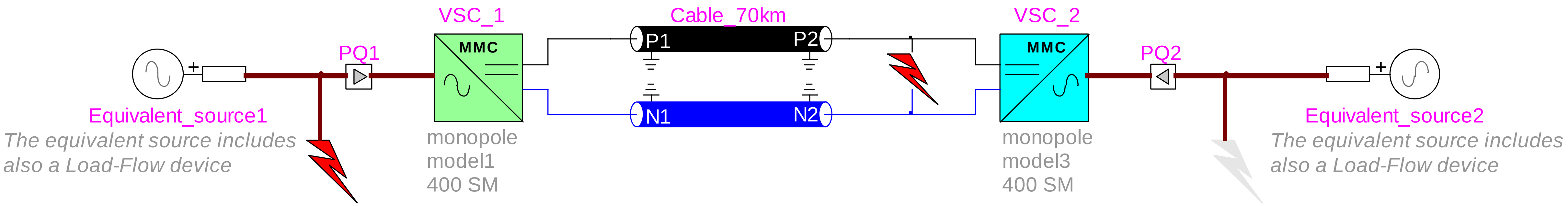


Applications: HVDC

- HVDC simulations require a good solver and precise models (IGBTs, Control, Lines/Cables)

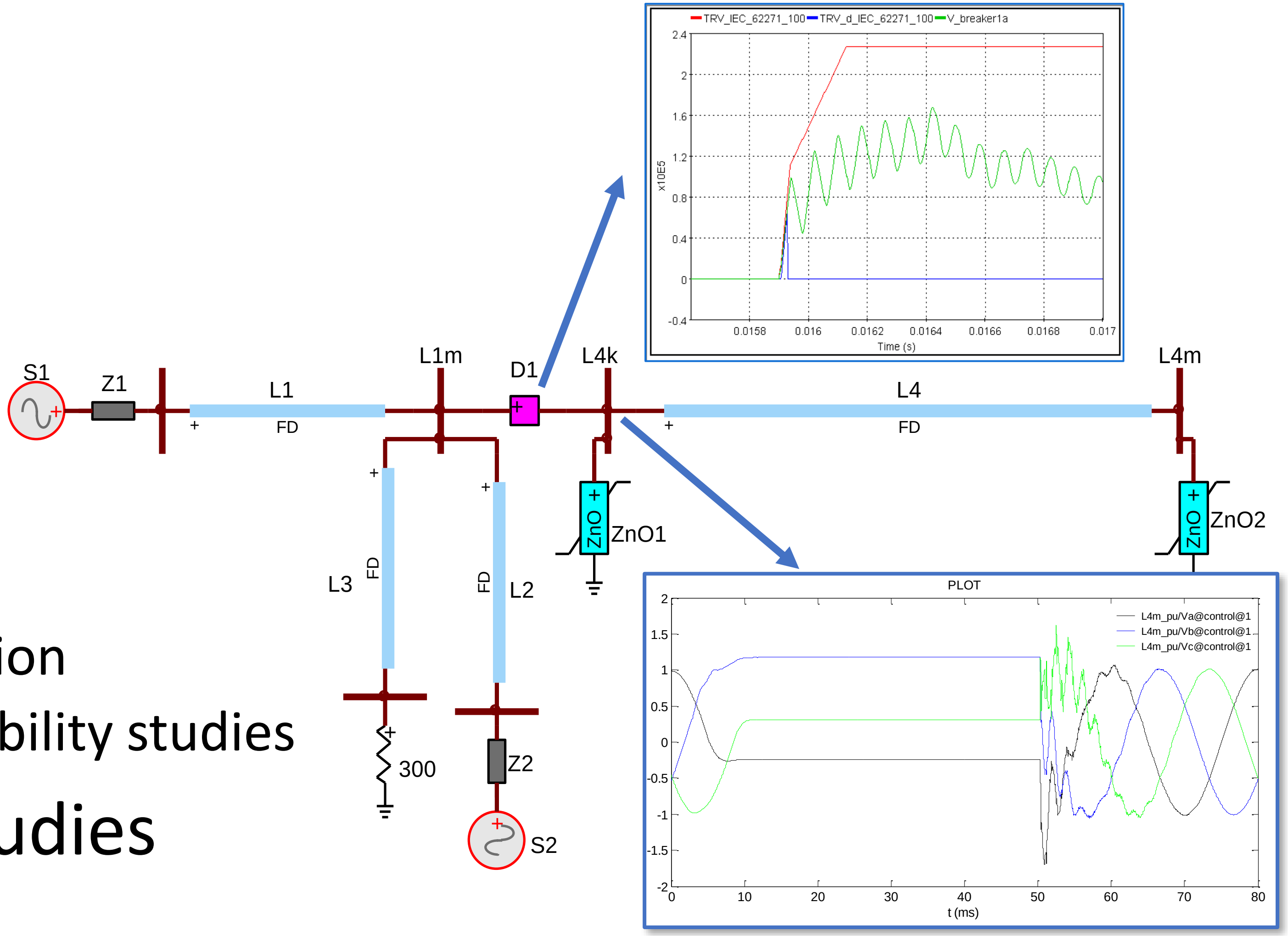
- **Bipolar, Back-to-Back, Multi-terminal HVDC** systems are available

- Generic and complete models of **Modular Multilevel Converter** (MMC) are provided
  - From Full Detailed models to Average-Value



Applications: switching transients

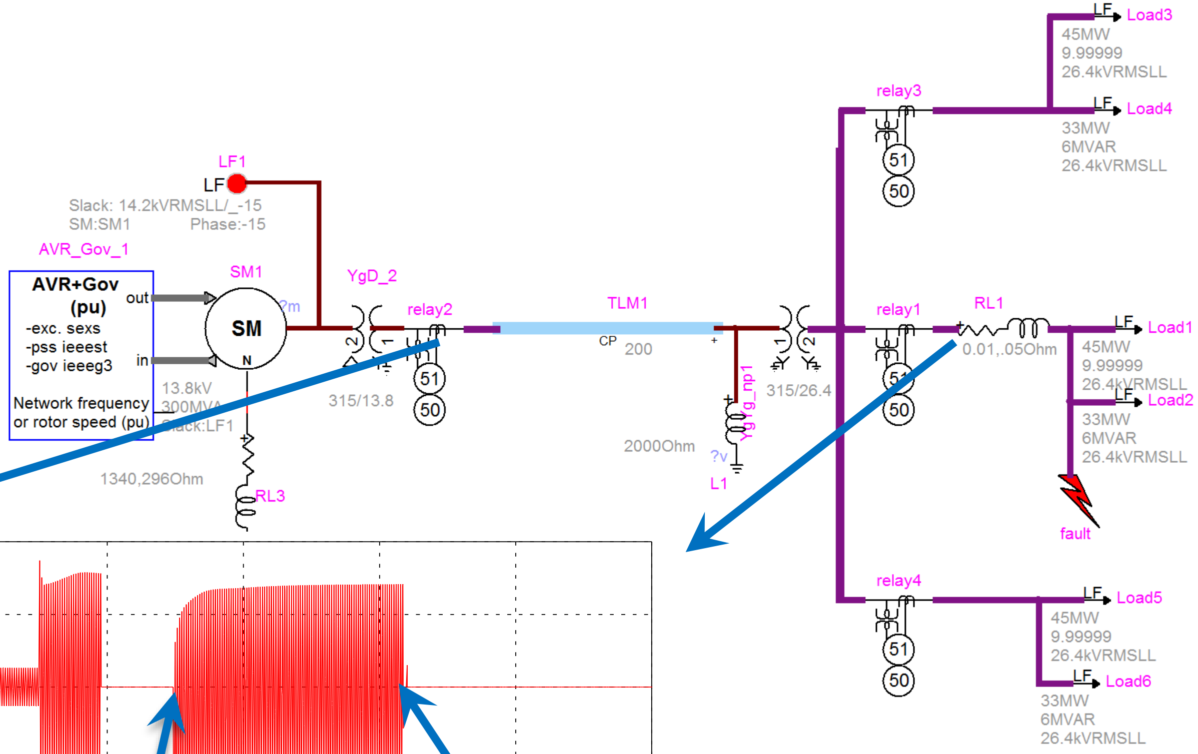
- Typical network events
  - Switching of transmission lines
  - Fault inception and clearance
  - Capacitor bank switching
  - Reactor switching
- Breaker models:
  - Ideal switches for TRV studies
  - (IEEE C37.06, C37.013, IEC 62 271)
  - Degrees of asymmetry determination
  - Arc models for arc quenching capability studies
- Statistical and parametric studies

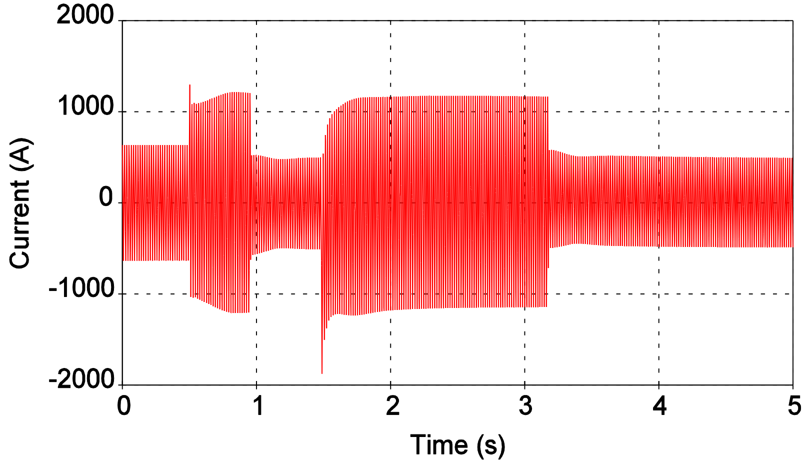


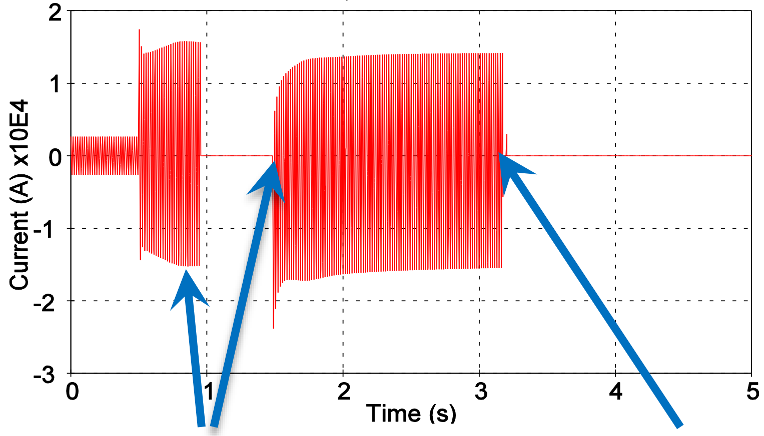
EMTP

➢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!

EMTP References

Thank you!

- Do you have any questions?
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