Co-Simulation of Real-time and Offline Power System Simulators

RTDS European User Group Meeting 2023

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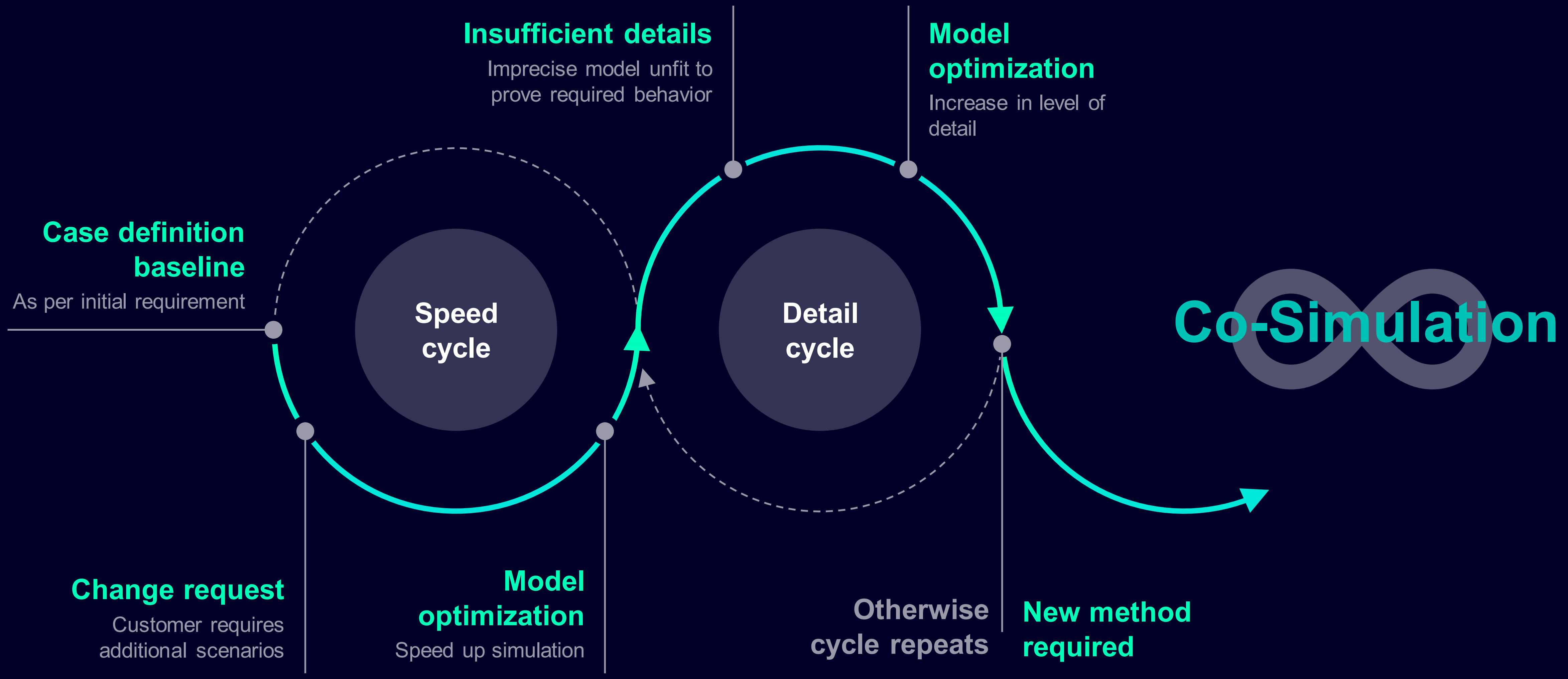
Background: Why Co-Simulation?



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Agenda and Basis of the work

Motivation & Intro
Why Co-Simulation?

Domain-Interconnection
- EMT-RMT
- RMS-EMT
- Electrical Equivalents

Realtime-Offline-Interconnection
- UDP
- FPGA

Analysis Results

Conclusions

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Basis and further Reading

Interfacing Real-Time and Offline Power System Simulation Tools using UDP or FPGA systems

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Co-Simulation of real-time and offline power system models: An application example

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Thank you for the collaboration and support!

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Intro

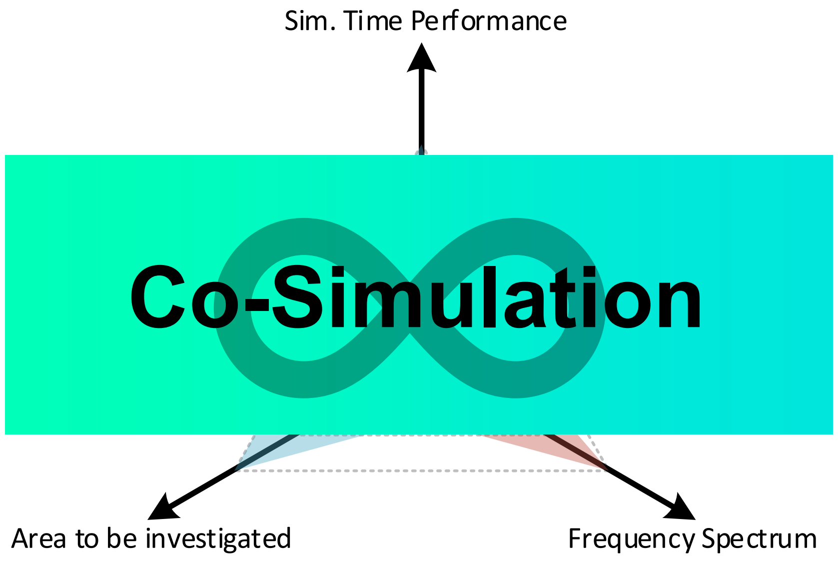
RMS Analysis

Extensive Network sizes

dt ~ 10 ms

(Positive Sequence) Phasor Values

But: limited frequency range



EMT Analysis

High level of details

dt ~ 50 µs

Instantaneous Values

But: computational burden

EMT-RMS Interconnection

RMS → EMT
- Phasor Decomposition
- Interpolation
- Angle Correction

RMS Analysis

dt ~ 10 ms

(Positive Sequence) Phasor Values

EMT Analysis

dt ~ 50 µs

Instantaneous Values

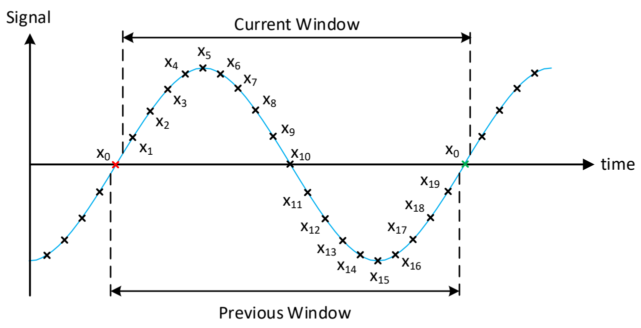
EMT → RMS
- Phasor Composition
- Low Pass Filtering

EMT-RMS
SVC + LPF

EMT → RMS

- Phasor Composition
- Low Pass Filtering

Discrete Fourier Transformation



$$X = \frac{2}{N} \sum_{i=0}^{N-1} x(i) \cdot e^{-ji2\pi/N}$$

$$with\ N = \frac{1}{f_0 \cdot \Delta t_a}$$

Per phase, results in currents $\underline{I}_R, \underline{I}_S, \underline{I}_T$

Positive Sequence Transformation

$$\begin{bmatrix} 0 \\ \underline{I}_{(1)} \\ 0 \end{bmatrix} = \frac{1}{3} \cdot \begin{bmatrix} 1 & 1 & 1 \\ 1 & \underline{a} & \underline{a}^2 \\ 1 & \underline{a}^2 & \underline{a} \end{bmatrix} \cdot \begin{bmatrix} \underline{I}_R \\ \underline{I}_S \\ \underline{I}_T \end{bmatrix}$$

$$with\ \underline{a} = -0{,}5 + \mathrm{j}\,\frac{\sqrt{3}}{2}$$

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EMT-RMS
SVC + LPF

RMS → EMT
- Phasor Decomposition
- Interpolation
- Angle Correction

Re-Transformation

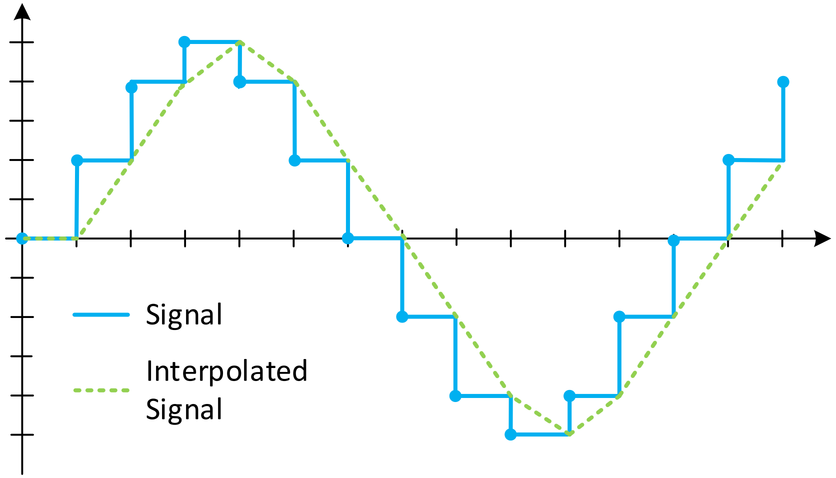
$$y = Y\cos(\omega t + \varphi)$$

$$with\ \varphi = \varphi_0 + \varphi + \varphi_{corr}$$

Angle Correction

$$\varphi_{corr} = 360° * dt * f_0 * n_{steps}$$

Interpolation



$$y_{\mathrm{EMT}}\left(t_{\mathrm{RMS}} + n\Delta t_{\mathrm{EMT}}\right) = y(t_{\mathrm{RMS}}^{-1}) + \frac{y(t_{\mathrm{RMS}}^{-1}) - y(t_{\mathrm{RMS}})}{n_{\max}} n$$

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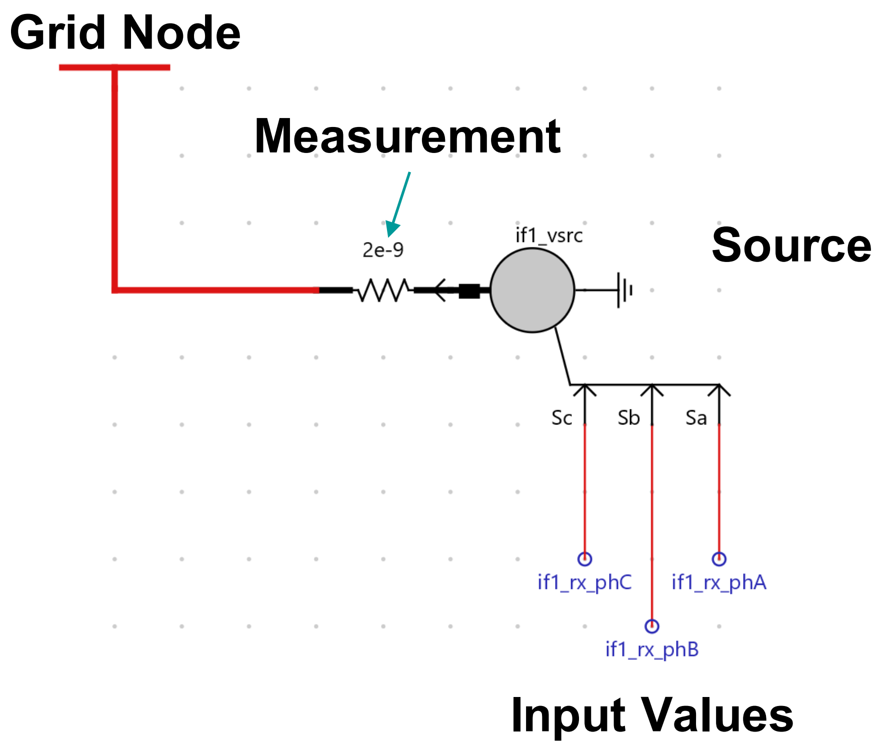
Electrical Equivalents
EMT

EMT voltage source

- Three-phase instantaneous values from decomposition and interpolation
- Allows for initialization of the realtime model

Current source possible as well

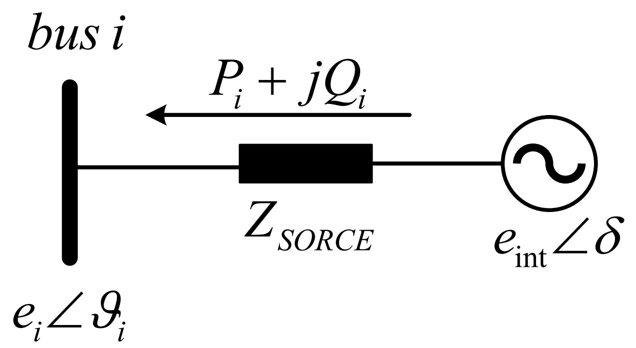
- Must use a voltage source in the RMS model then



Electrical Equivalents
RMS

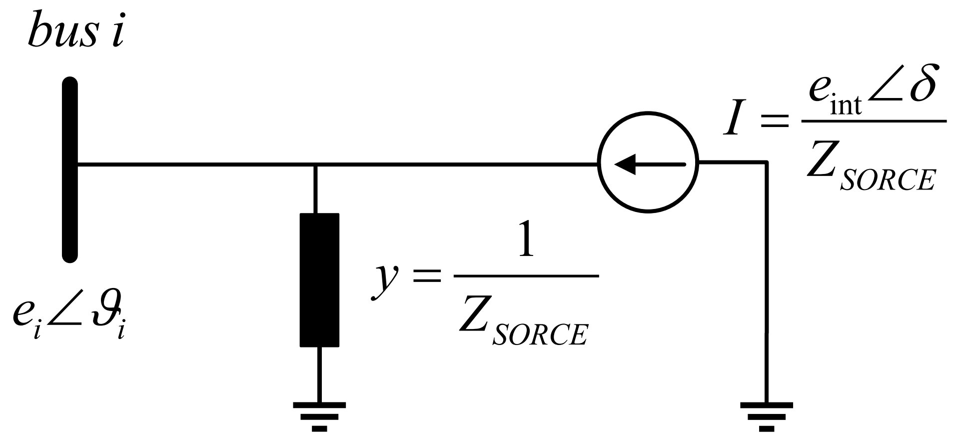
Loadflow Model

- Thévenin Equivalent
- Fixed Active and Reactive Power
- ‚Renewable Machine' in PSSE



Dynamics Model

- Norton Equivalent ‚ISORCE'
- Values from data Handler
- Exchanged via a Shared Memory implementation



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Realtime-Offline Interconnection
Ethernet: UDP

Socket to Realtime-Machine

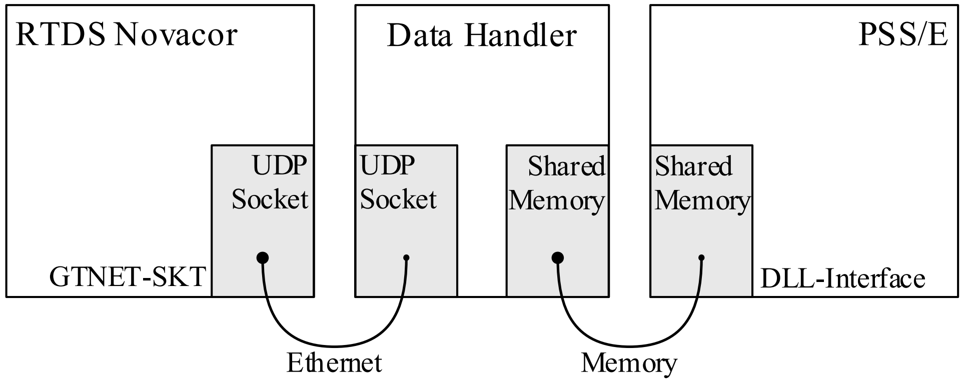
- GTNET in RTDS

Data Handler Software (PC)

- Sends and receives from/to the Realtime Machine, via UDP Socket
- Sends and receives from/to PSS/E Source Model
- Via a Shared Memory Core instance
- Handles missing data

Phasellus nec sem

- Compiled into the Source Model (C++ and Fortran)



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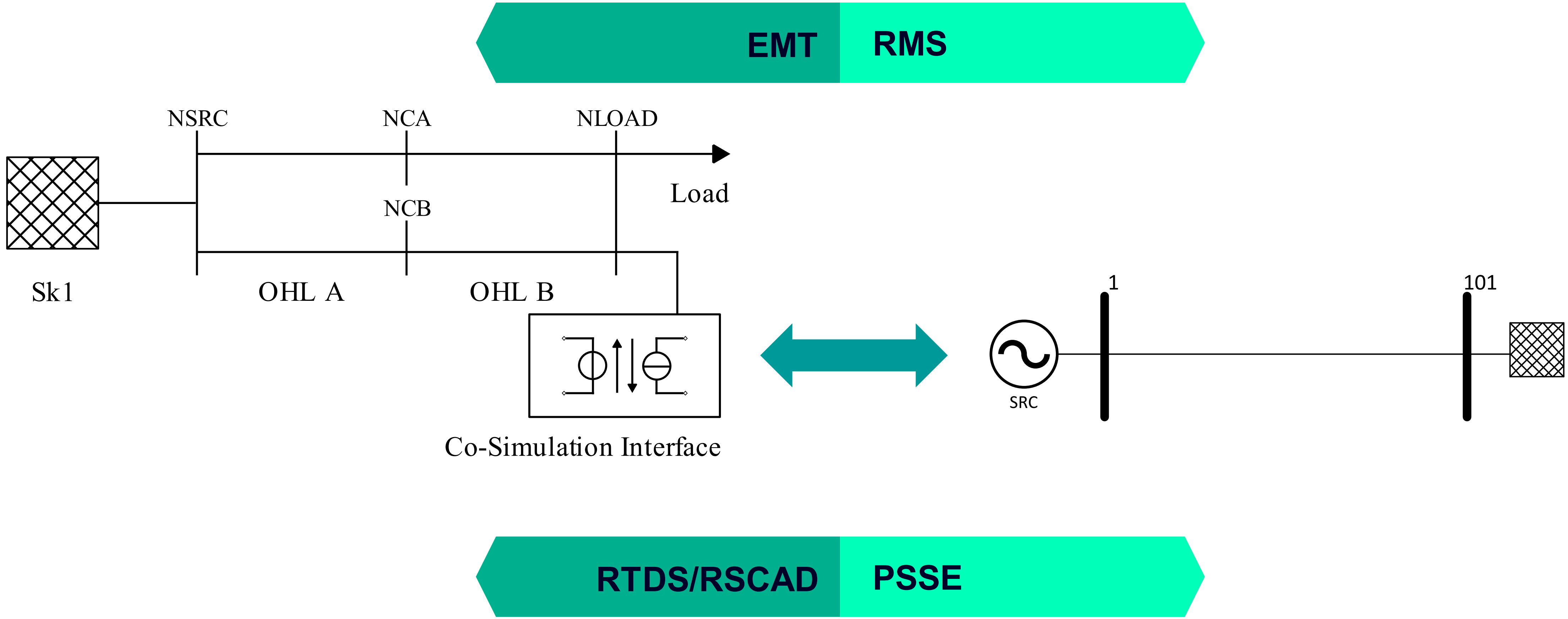
Simulations
Test Model



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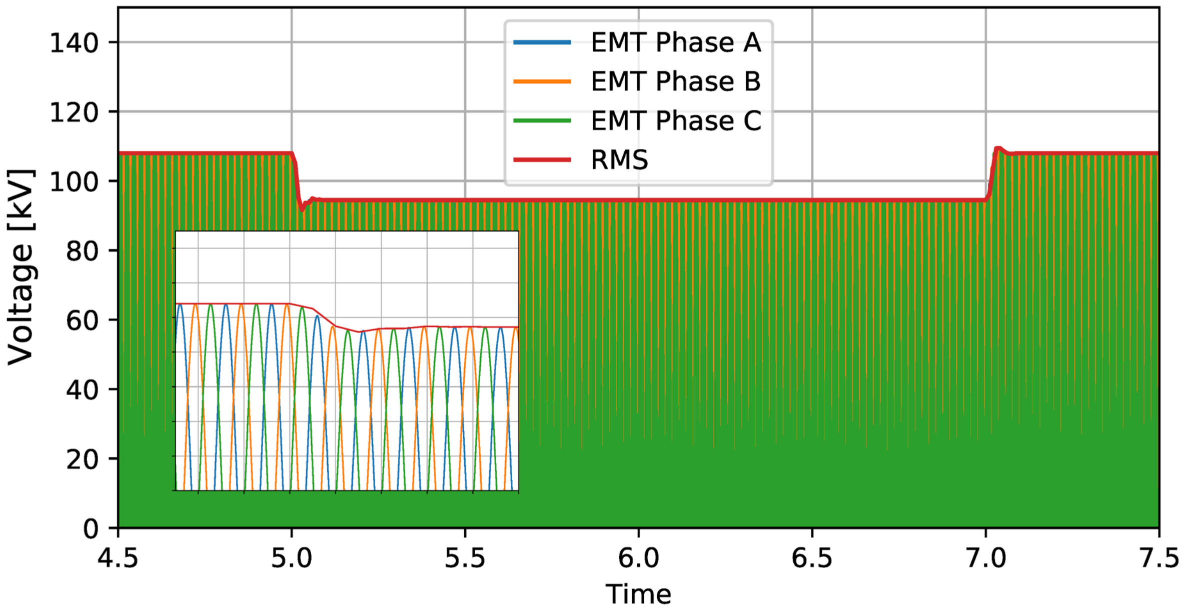
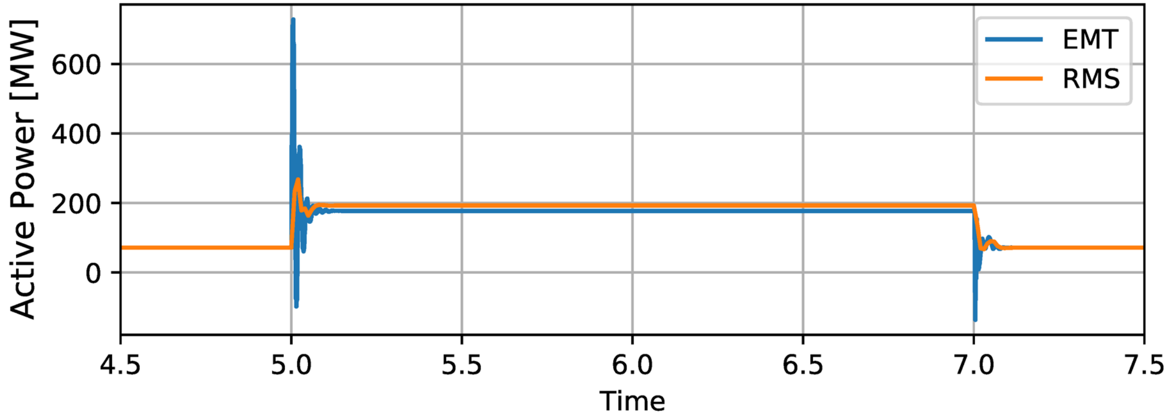
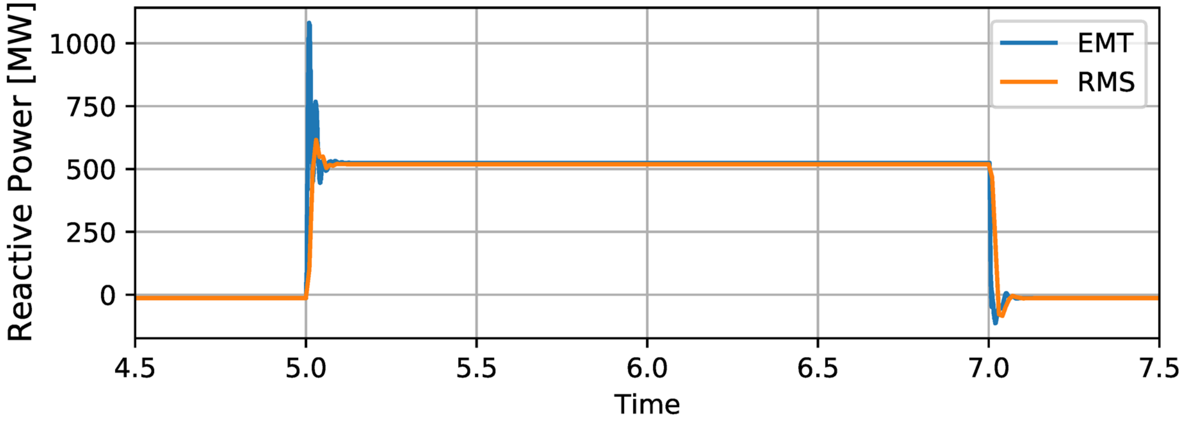
Simulations
Case: 3ph Fault in EMT-Section







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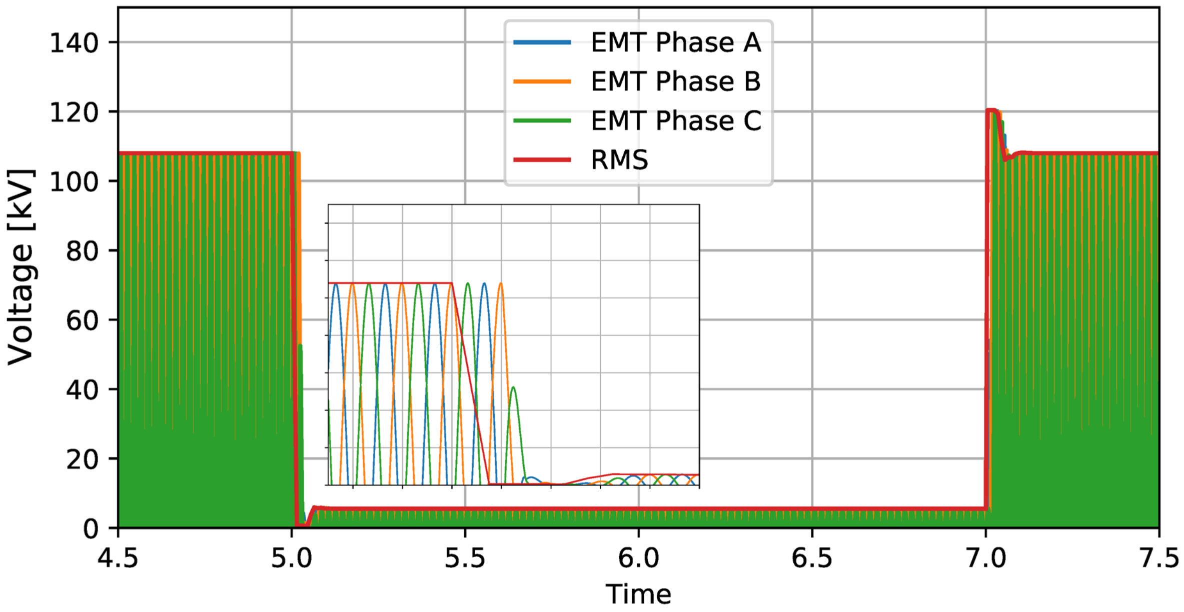
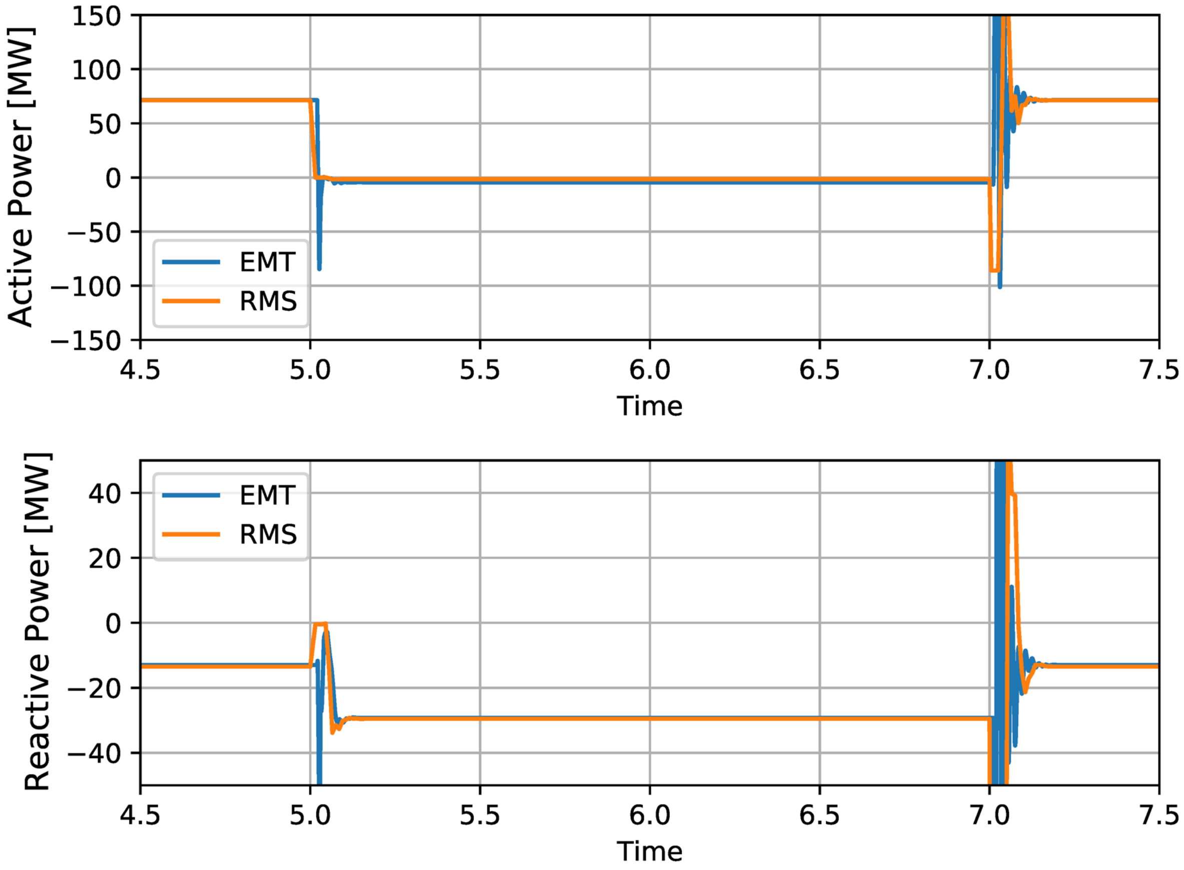
Simulations
Case: 3ph Fault in RMS-Section





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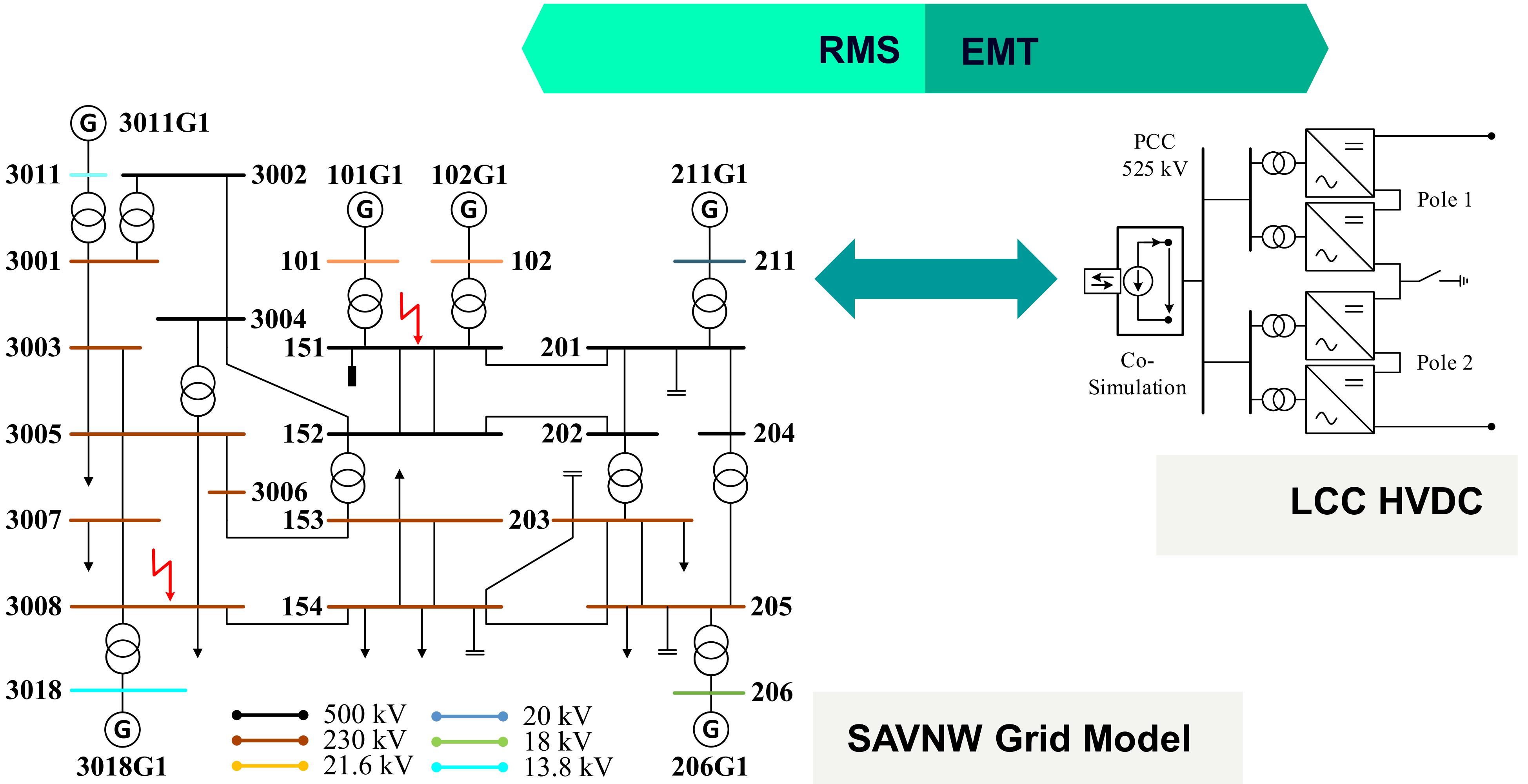
1st Scope Extension: Transmission Grid (RMS) and HVDC (EMT)



LCC HVDC

SAVNW Grid Model

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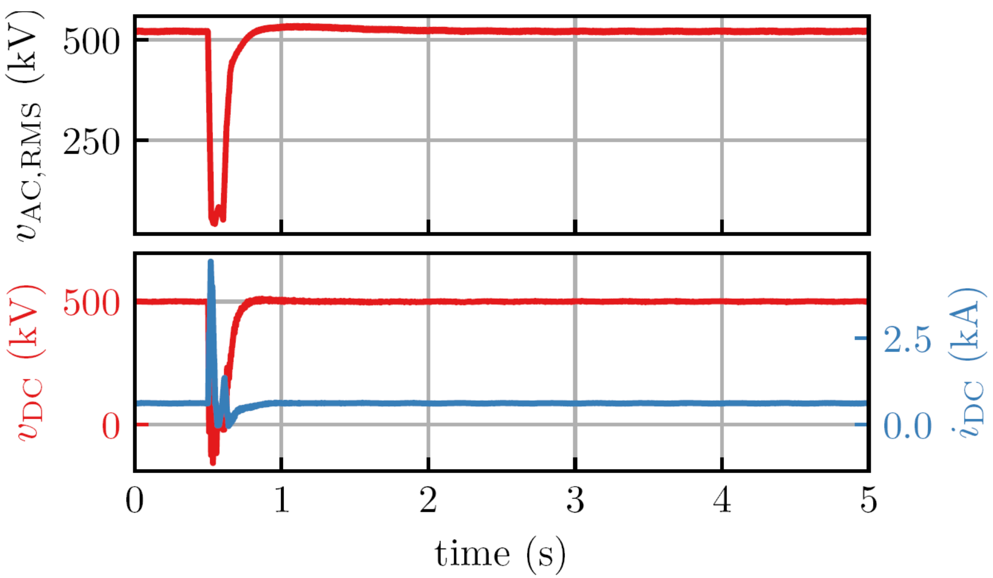
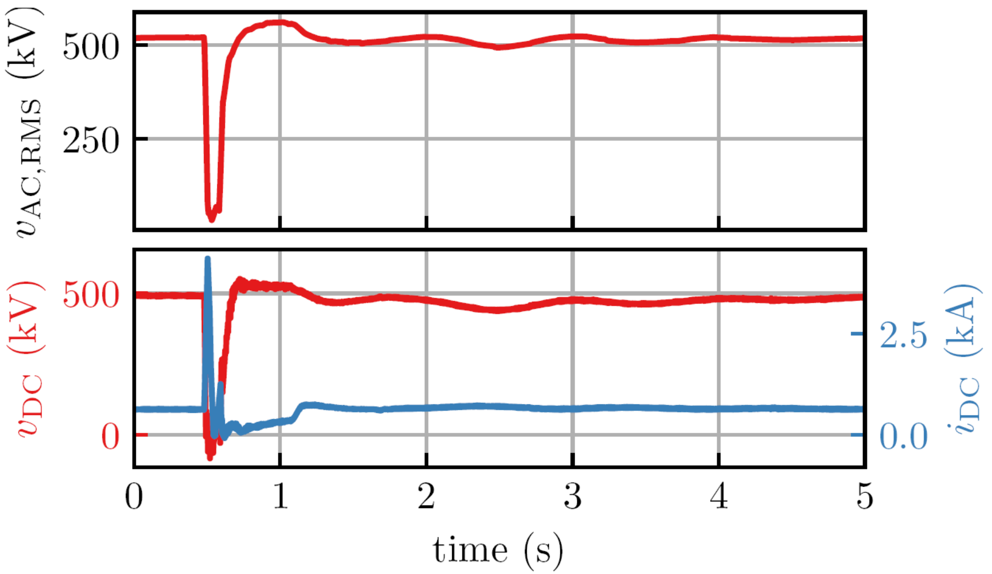
HVDC: Fixed Sources vs. Dynamic Grid Model



LCC HVDC @Fixed Source Model



LCC HVDC @SAVNW Grid Model

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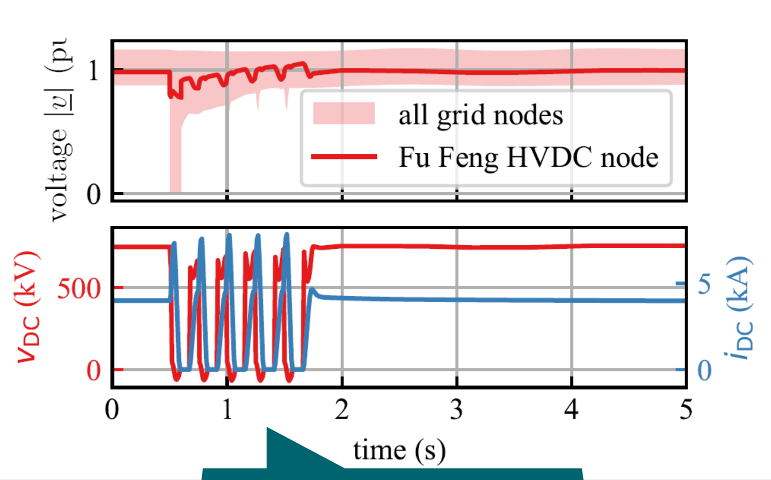
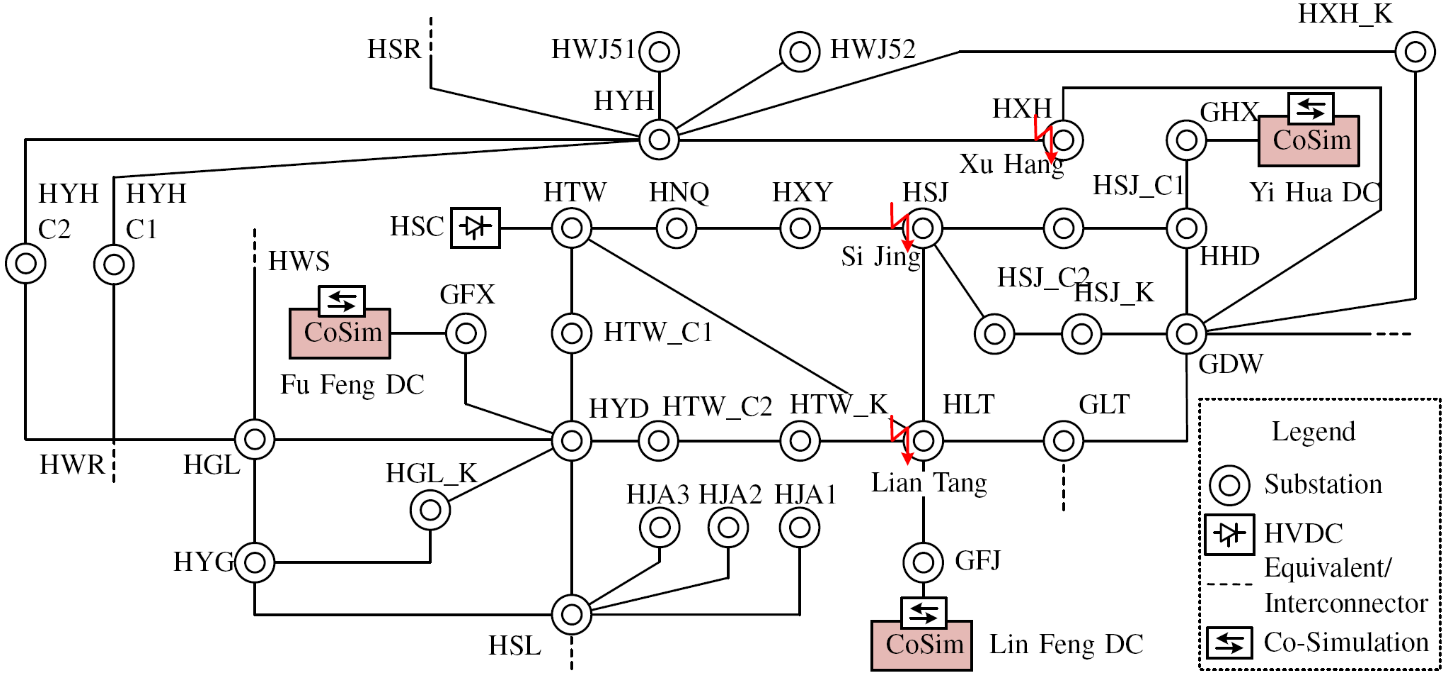
2nd Scope Extension: East China Power Grid Model

Previous Model, Monolithic BPA:



Not realistic



- 12,000 nodes
- 7 HVDC Converter Stations, 3 in RTDS
- Voltage levels 525 kV, 775 kV and 1050 kV

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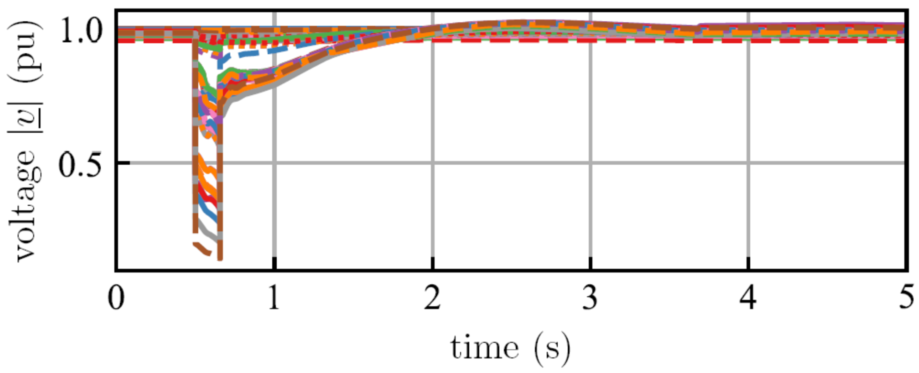
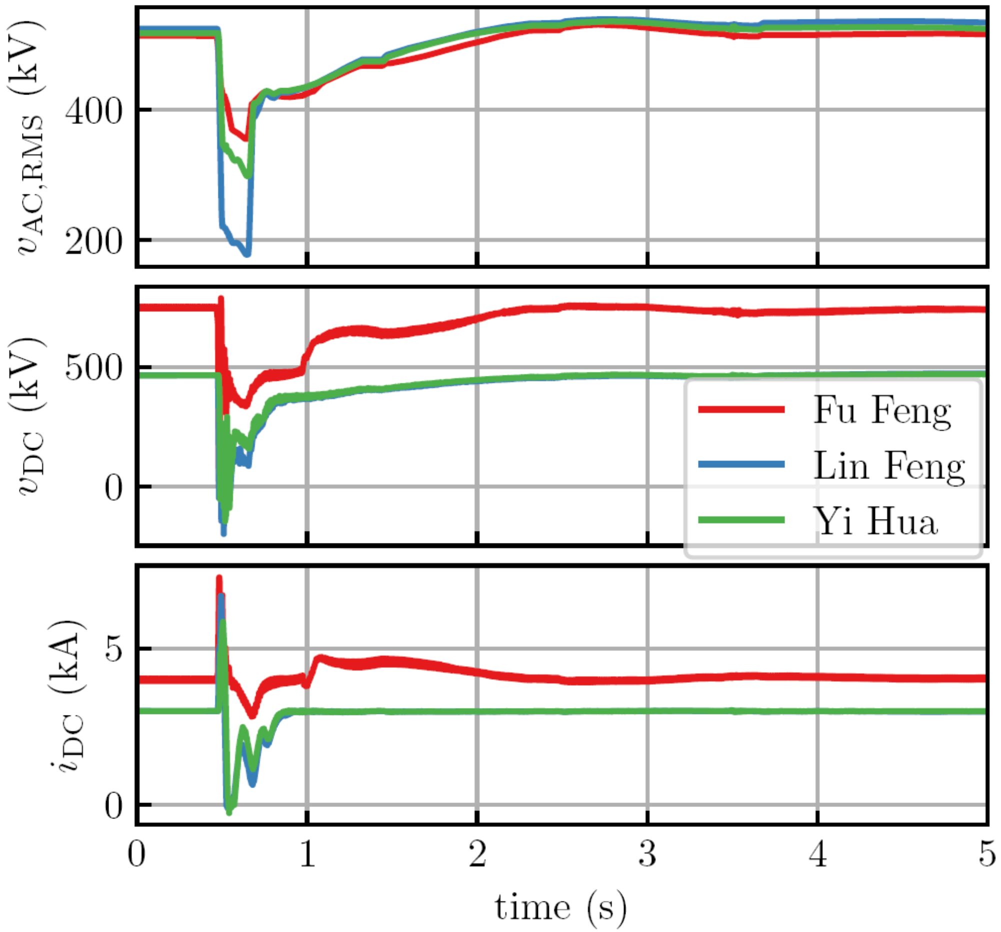
HVDC and Grid reaction to a fault

HVDC Stations

RMS Grid Voltages





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Conclusions
And further work

A feasible enhancement of real-time capabilities

- Good match for electrical values
- UDP interface needs no futher hardware
- PQ identical in steady state

Broad utility in the real-time space

- Reduced demand for network reduction techniques
- Enables multi-vendor capabilities
- Prevents re-modelling efforts, cuts iteration processes

WiP: From prototype to everyday’s tool

- Extend network sizes and interface numbers
- Standardize interfacing

Thank You

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