VILLAS4ERIGrid

Geographically Distributed Real-time Simulation and PHIL between TU Delft, DTU Risø, Lyngby and RWTH Aachen

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Speaker / User Group

- Guests:
  - Steffen Vogel (RWTH)
  - Marija Stevic (RWTH)

- Hosts:
  - Kai Heussen (DTU)
  - Ha Thi Ngyuen (DTU)
  - Vetrivel Subramaniam Rajkuma (TUD)
  - Rishabh Bhandia (TUD)

Transnational Access Exchanges

- ERIGrid Transnational Access Exchange(s)
  - May 2019: TU Delft
    - Improvements to the Co-simulation Interface for Geographically Distributed Real-time Simulation, IECON 2019
  - October 2019: DTU Denmark
    - Distributed PHIL with Quasi Stationary Back-to-Back Converter
    - Energy Based Metric (EBM) for error quantification

Inbetween

- MariNet2 Transnational Access Exchange
  - August 2019

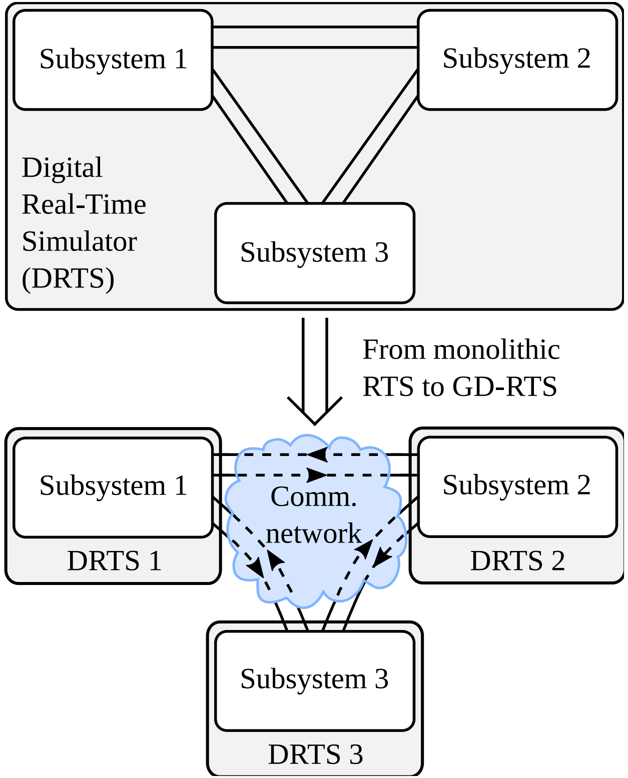
1/ TU Delft

Improvements to the Co-simulation Interface for Geographically Distributed Real-time Simulation

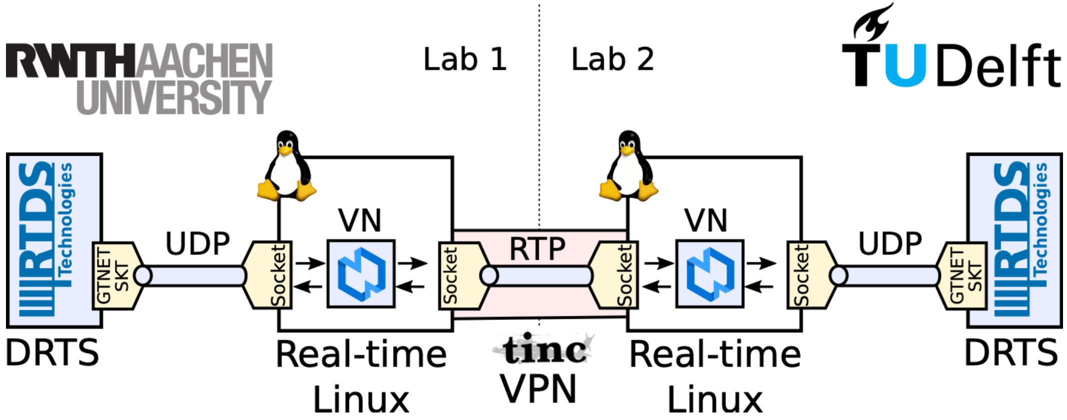
Geographically Distributed Real-time Simulation (GD-RTS)

- A single digital real-time simulation spanning multiple laboratories
  - Globally or
  - on Campus

- Motivation
  - **Large-scale** system-level simulations
  - Exchange of Knowledge, Human- and Hardware **Resources**
  - Overcome constraints caused by **data confidentiality**

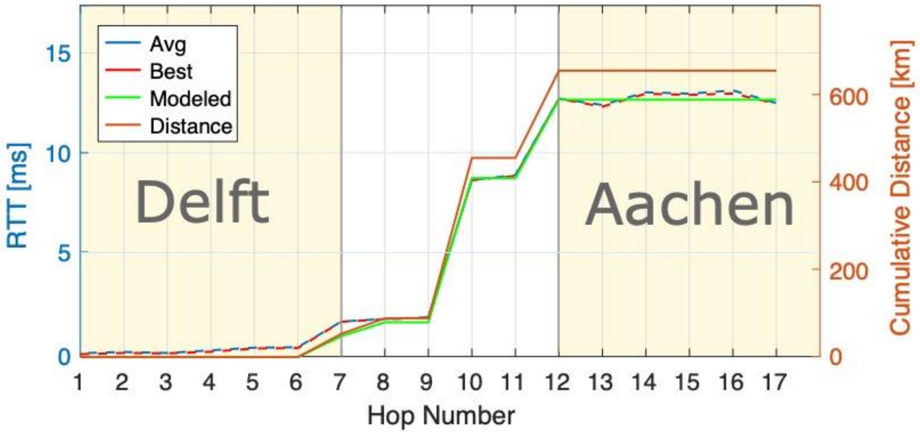


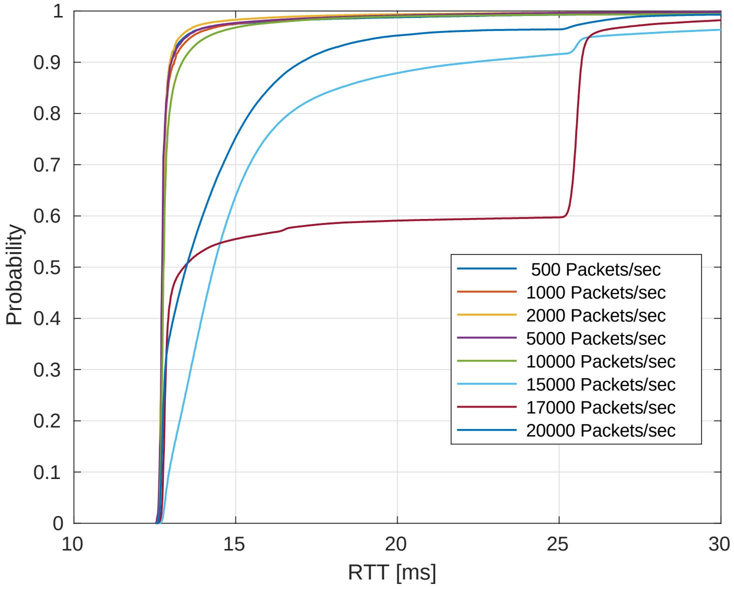
- 2 Labs:
  - 2 RTDS Simulators
  - 2 VILLASnode Gateways
  - Decentral / Fully-meshed VPN for optimal point-to-point connection with lowest latency



- National Research and Education Networks (NRENs)
  - DFN, SURFnet, GÉANT

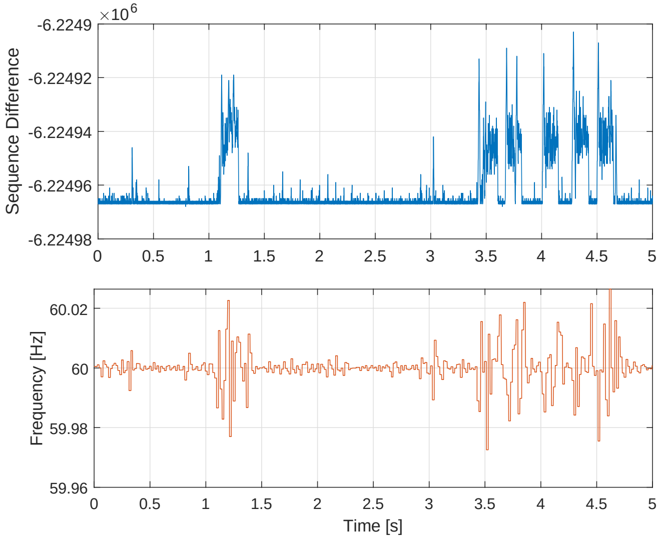
- Mean Round-trip time: $\mathbf{12}\ \boldsymbol{ms}$
- Routing hops: $\mathbf{13}$
- Sending rate: $\leq \mathbf{10}\ \boldsymbol{kPkt/s}$

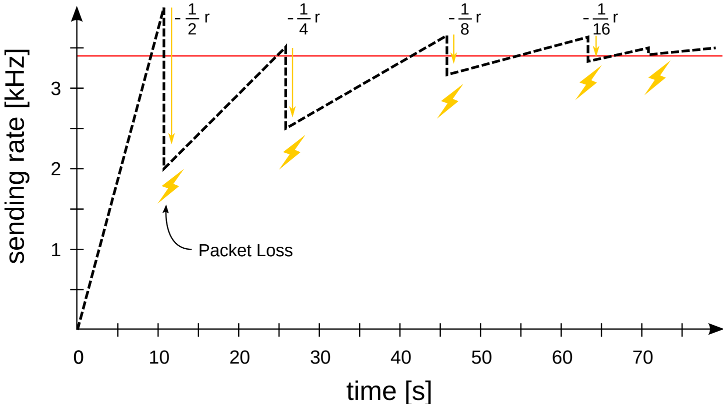




Real-time Transport Protocol (RTP)

- Different co-sim links vary significantly in quality of serivce (QoS)
- Adaptive adjustment of communication parameters is helpful
- Additive Increase – Multiplicate Decrease (AIMD)

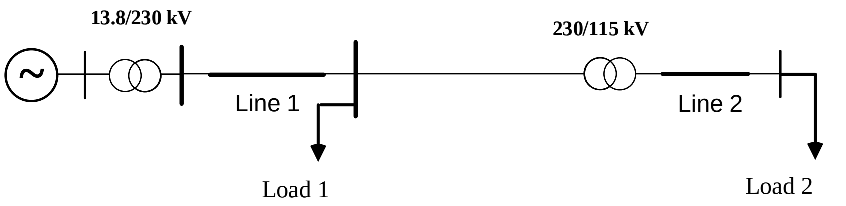




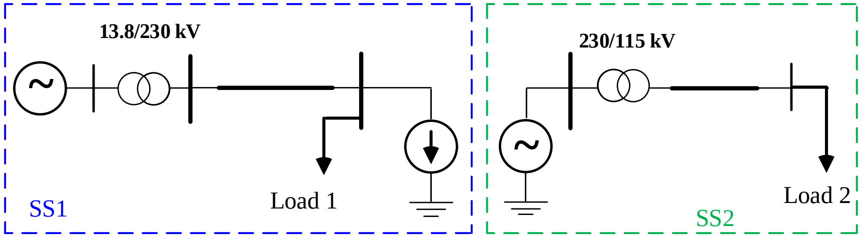
- Discontinuties in sending rate cause frequency disturbances in simulation
- Only useful for initial estimation, not during live simulation

Test Scenario & Methodology

- Simple scenario helped debugging and understanding
- 3 Stages: monolithic, decoupled, distributed



a) Monolithic Model



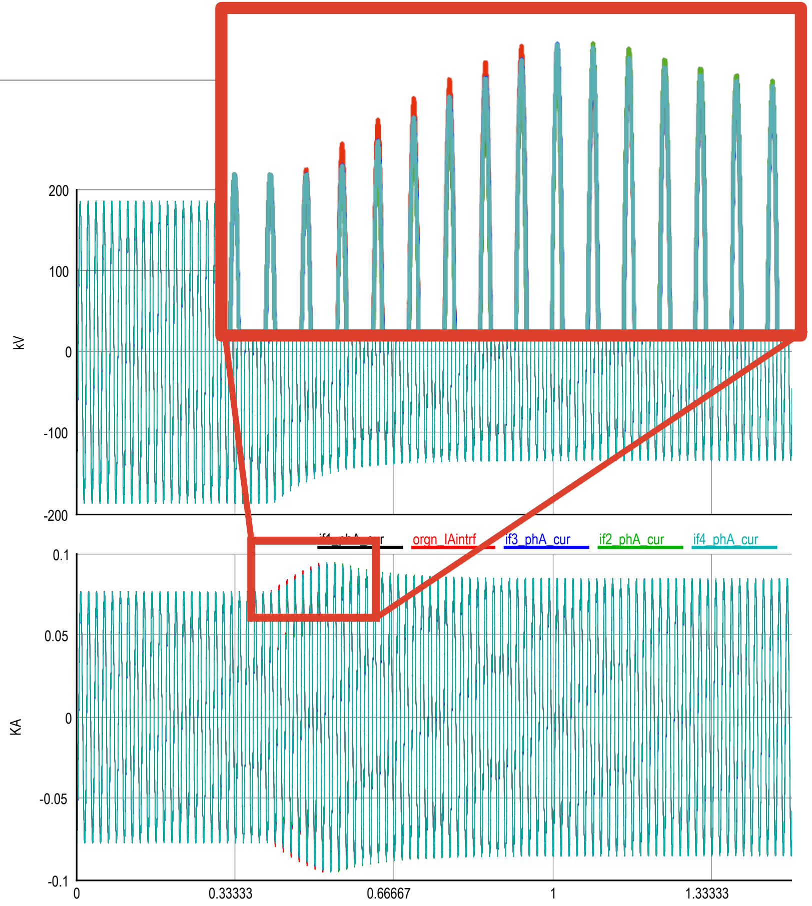
b) Decoupled / Distributed Model

Simulation Results: Instantaneous V/I

- Test cases:
  - Voltage Source in SS1 (left)
  - Change of magnitude, freuquency, phase

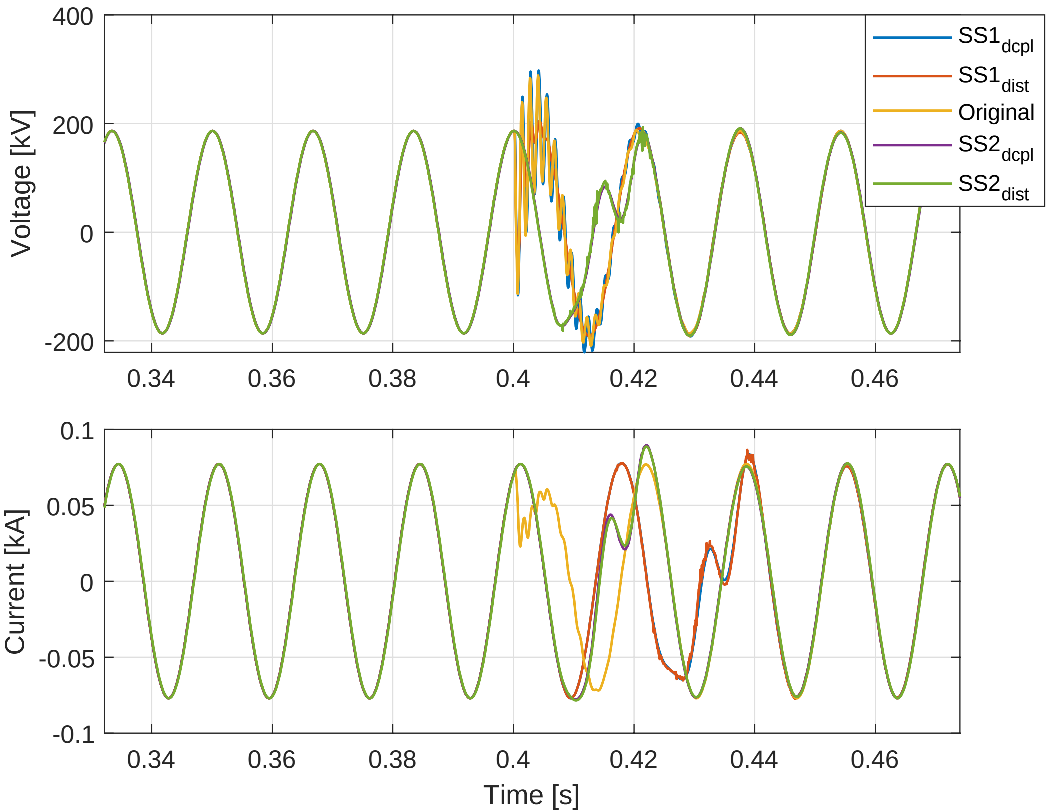
- No error in steady-state

- Delayed update of
  - Voltage magnitude SS1 (1/2 RTT)
  - Current magnitude on left side (1 RTT)



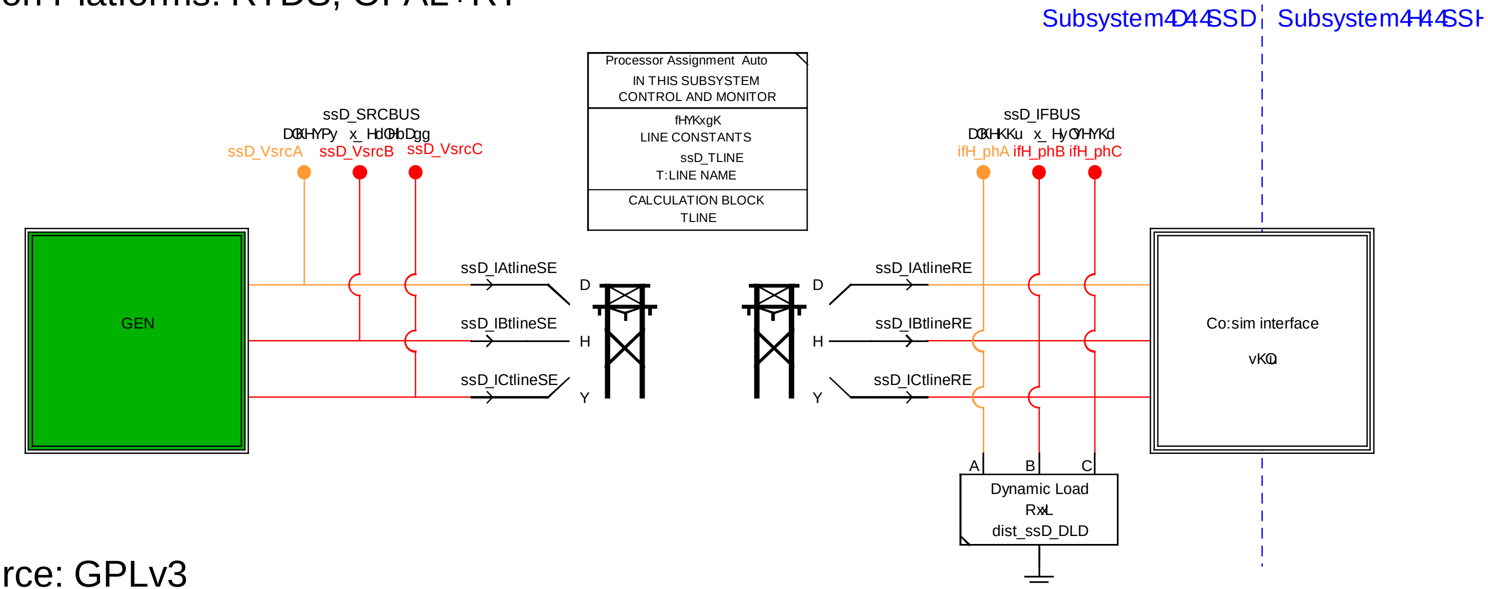
Limits of GD-RTS

- Phase jump of π of V_{src}



Co-Simulation Interface Library: „CoSiF

- Re-usable library blocks for different:
  - Interface Algorithms: Dynamic Phasors, $PQ + V_{rms}, f, \phi$
  - Simulation Platforms: RTDS, OPAL+RT



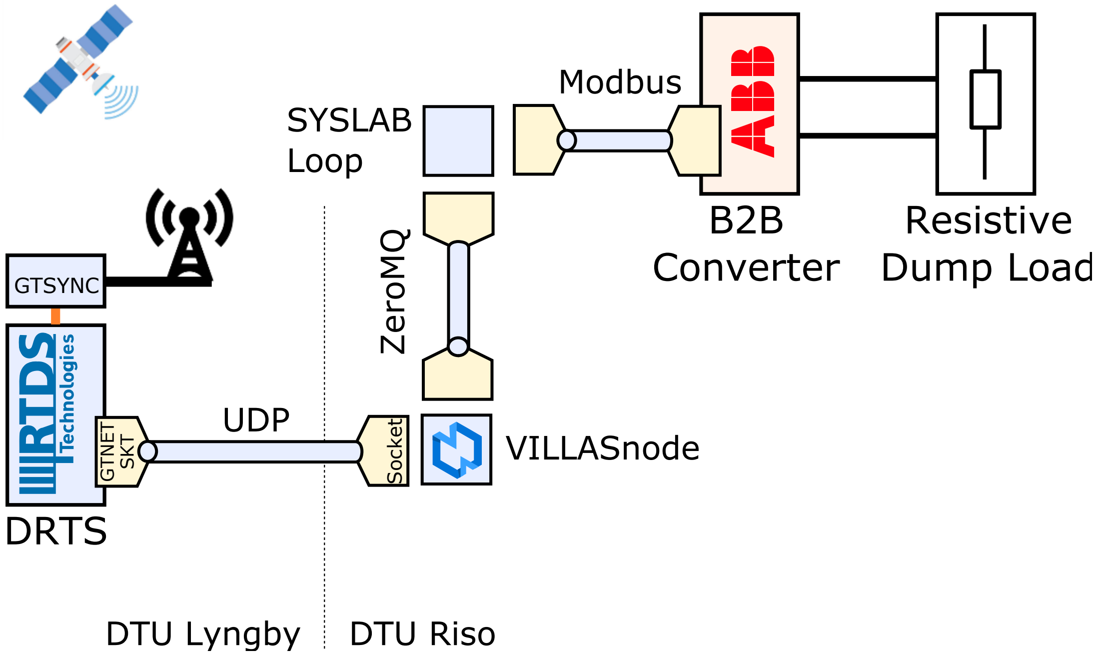
- Open Source: GPLv3
  - https://fein-aachen.org/projects/cosif/

2/ DTU Denmark

Distributed PHIL with Quasi Stationary B2B Converter

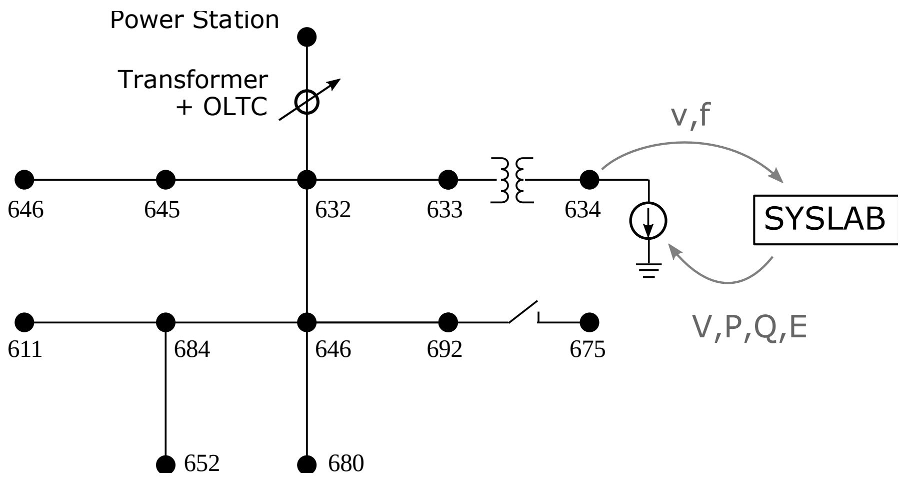
Setup

- Distributed across DTU Lyngby and Riso Campus
- Time-stamped measurements via GTSYNC (GPS) and NTP
- Separate SYSLAB Loop for interfacing Modbus Converter
- Security concerns



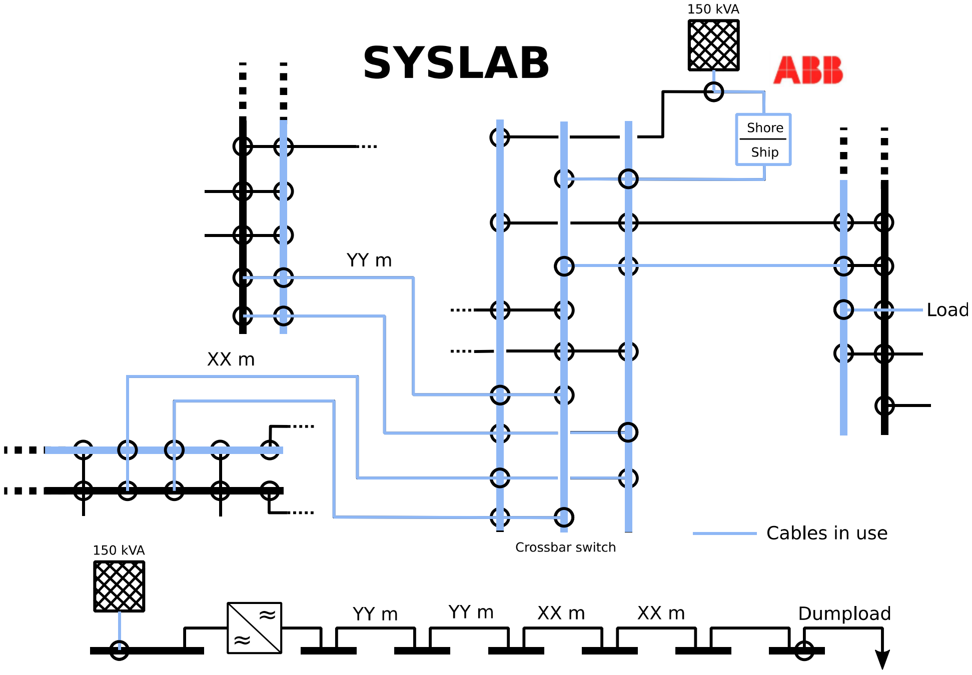
DRTS Simulation

- RTDS with GTNET & GTSYNC
- IEEE 13-bus Distribution Grid Benchmark
  - Balanced Loads
- SYSLAB PCC at Node 634
- Voltage Control via OLTC
  - Triggered via change of setpoint of dump load



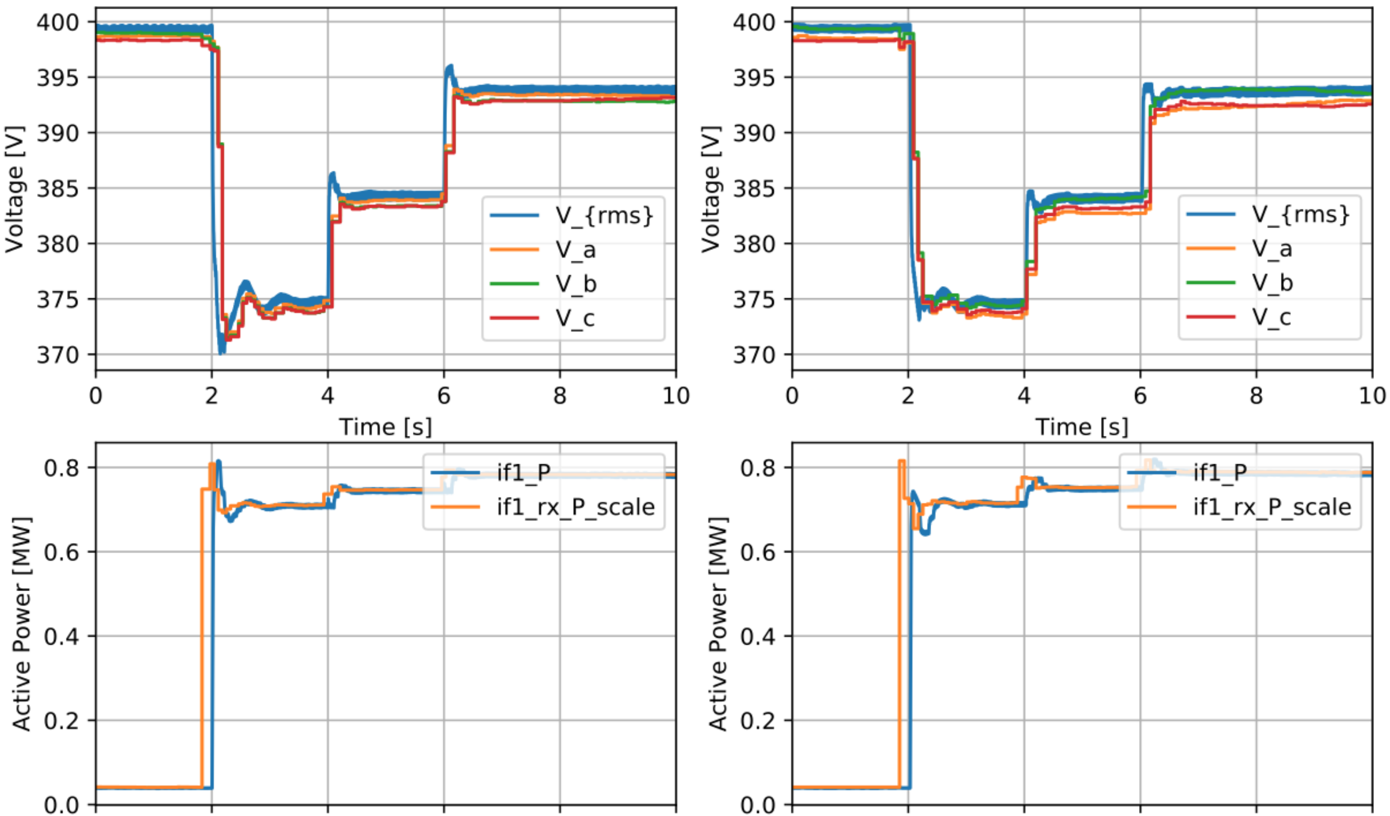
SYSLAB Configuration

- Simplet setup with ABB Ship-to-Shore converter
- All Lines of SYSLAB are connected in series
- Resistive Dump Load
- Scaling of current injections into simulation



Results /1

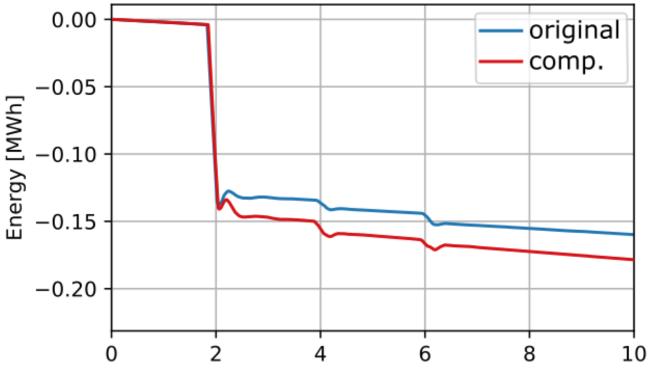
- Tap-Changer Operatio
- Left: Original
- Right: Compensated

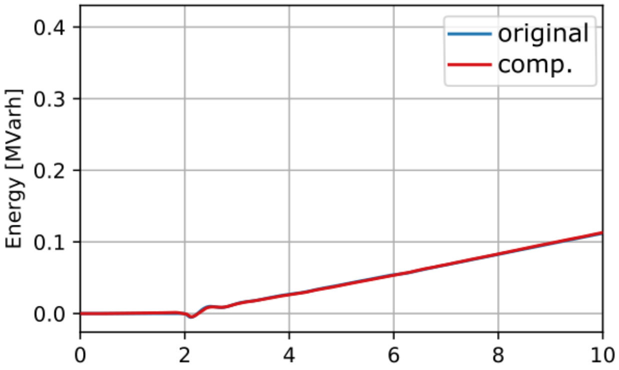


Results /2: Energy Balance

- Energy (Im-) Balance between both ports of the interface

- Compensated case shows even larger error
  - Caused by unsynchronized measurements, random factor…





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Contributions & Conclusion

- Contributions
  1. PoC of IETF Real-Time Transport Protocol (RTP) for streaming simulation data
  2. CoSiF – A reusable library for distributed real-time simulation
     1. Improved calculation of Dynamic Phasor Coefficients by moving window average
     2. Fidelity Improvements & Bug Fixes
  3. **GD-RTS Simulation Infrastructure for ERIGrid II:**
     DTU, TUD, SINTEF & RWTH

- Conclusions
  - Internet routing is critical for GD-RTS and can often be improved
  - Sending rate adapation during a GD-RTS should be avoided
    - But good for tuning parameters upfront
  - Time-synchronized measurements are crucial for distributed PHIL
    - Compensation requires accurate measurements

Lessons Learned

- DTU‘s SYSLAB is a great and versatile environment!
- Automation was really useful

- We tried to cover too many topics in a *single* TA
  - Tri-lateral TAs are nice for collaboration but should target a single objective
  - We actually worked on separate topics

- Future Plans
  - More tests with off-nominal frequencies at the interface
  - FPGA / PCIe-based DRTS interfaces
  - Improved measurements for distributed PHIL

Acknowledgements

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  - RESERVE H2020

- Software Development / Distribution
  - Fein Aachen e.V.

Förderer der Energie- und Informationstechnik für zukünftige Netze Aachen e.V.

Connecting European Smart Grid Infrastructures

EFRE.NRW
Investitionen in Wachstum und Beschäftigung

EUROPÄISCHE UNION
Investition in unsere Zukunft
Europäischer Fonds für regionale Entwicklung

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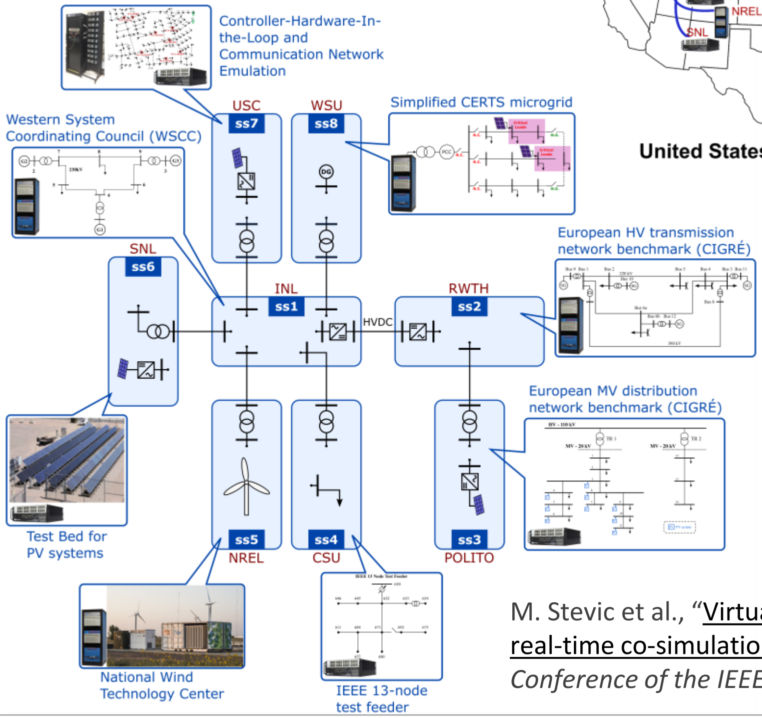
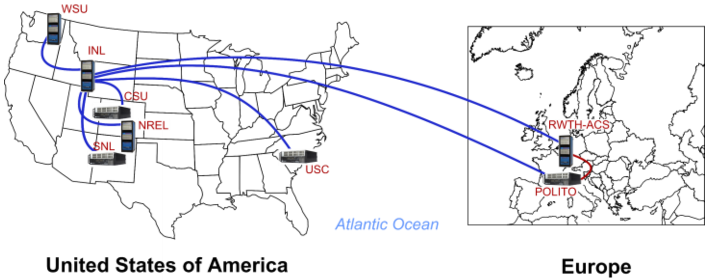
Background / Motivation

- Global Real-time SuperLab:
  - 8 sites, 10 simulators, 8 links



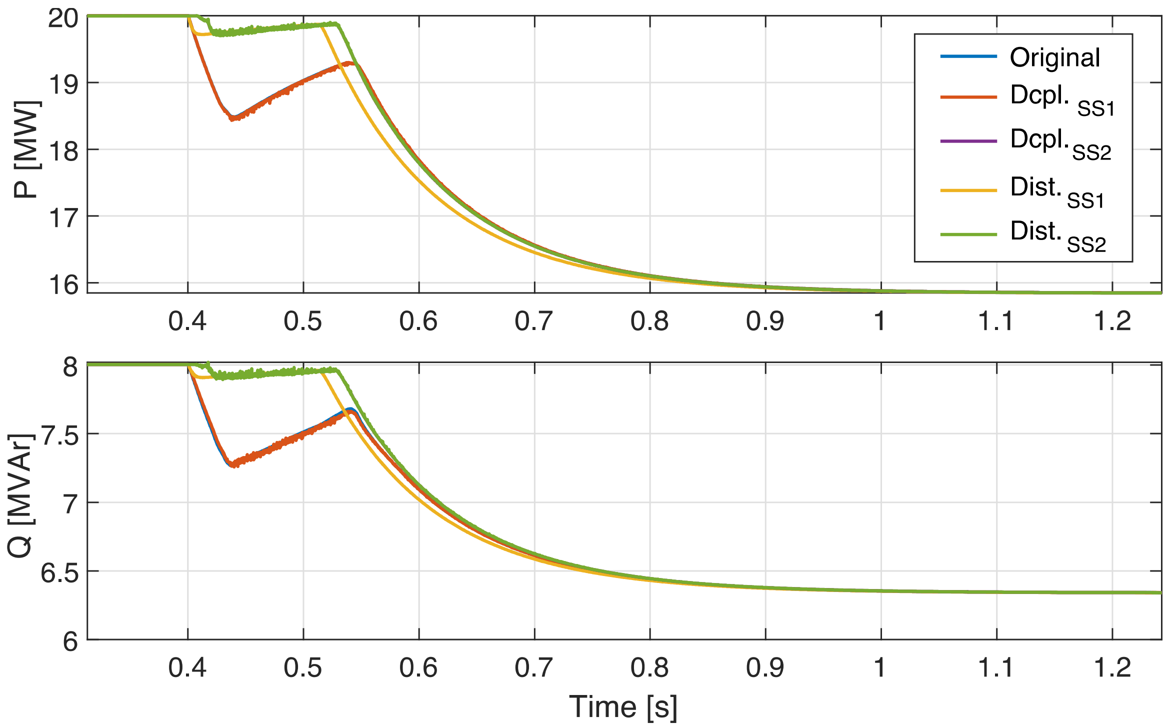


- Simple ITM or P/Q, Vrms, f Interface Algorithms
- Long setup time
- Huge variations in network quality

M. Stevic et al., "Virtual integration of laboratories over long distance for real-time co-simulation of power systems," in *IECON 2016 - 42nd Annual Conference of the IEEE Industrial Electronics Society*, 2016, pp. 6717–6721.

Simulation Results: P/Q RMS

- Change of source magnitude in SS1 (left side)



Fidelity Improvements I

- Mismatch in DFT window length for 60 Hz systems
- Fundamental period of 60 Hz is not evenly dividable by a $T_s = 50\ \mu s$ time-step

- Optimal Simulation Timestep: $$T_s = (1/f_0)/334 \approx 49,9\ \mu s.$$

TABLE I
IMPACT OF THE DFT WINDOW LENGTH ON INTERFACE QUANTITIES.

DFT window			Interface quantity			
			$V_{A,rms}$ [kV]		$I_{A,rms}$ [A]	
T_s [µs]	N	*length* [ms]	SS1	SS2	SS1	SS2
50	333	16.65	136.7	136.0	51.64	51.9
50	334	16.7	136.6	137.9	52.56	52.05
49.9	334	16.6666	136.6	136.6	52.56	52.56

- Uneven time-steps might cause other issues in relation to synchronization of simulators

Fidelity Improvements II

- Mismatch in active / reactive power due to internal time-step delays between network solution and control systems of DRTS
- Phase compensation for controlled sources required

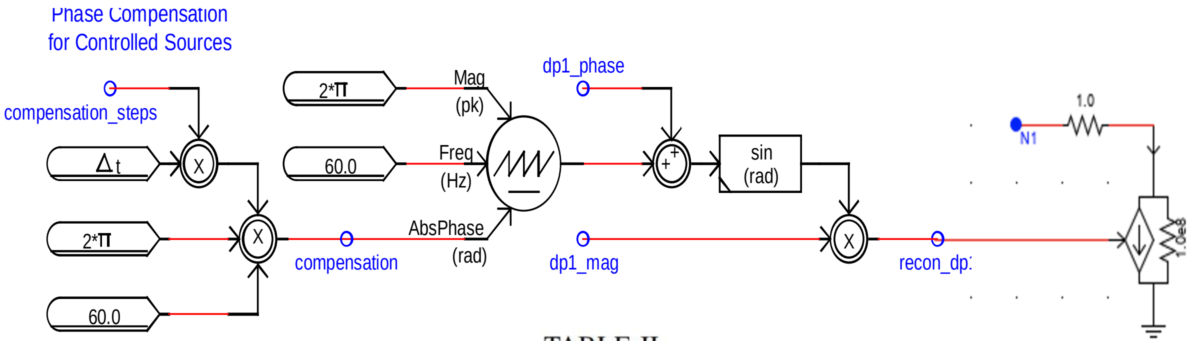
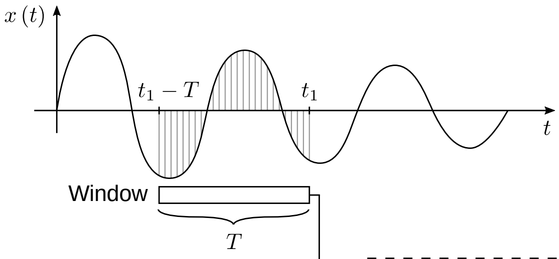


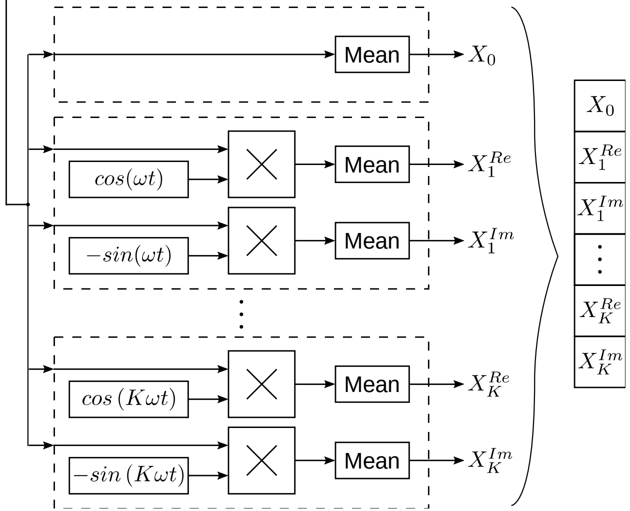
TABLE II
IMPACT OF PHASE COMPENSATION OF SOURCE SIGNALS ON STEADY-STATE POWER BALANCE AT THE CO-SIMULATION INTERFACE

n_{SS1} $[T_s]$	n_{SS2} $[T_s]$	P_{SS1} [MW]	Q_{SS1} [MVar]	P_{SS2} [MW]	Q_{SS2} [MVar]	S [MVA]	V_{rms} [kV]
0	0	19.16	9.846	20.0	8.003	21.54	227.7
1	1	19.52	9.118	20.0	8.003	21.54	227.9
2	1	19.69	8.749	20.0	8.003	21.54	227.9
3	2	20.0	8.003	20.0	8.003	21.54	228.1

Dynamic Phasor Interface Algorithm (DP-IA)



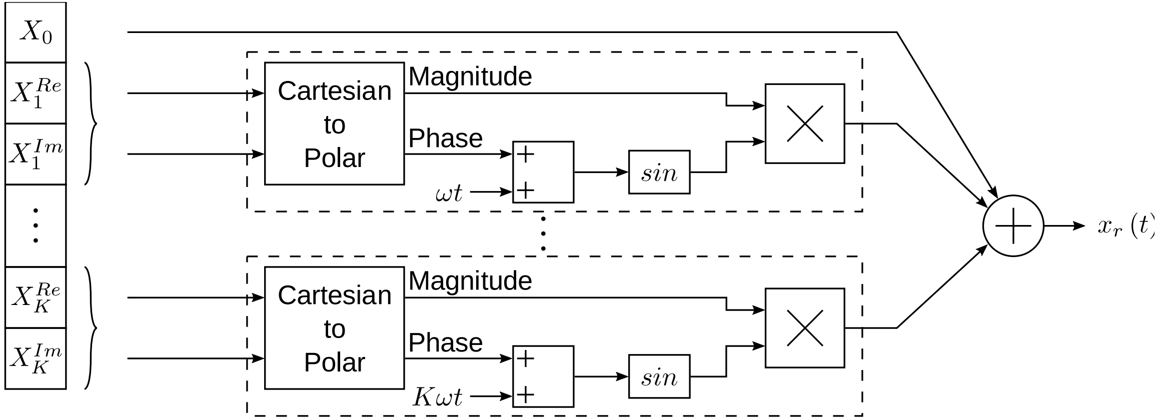
$$X_k[m] = \frac{1}{N} \sum_{n=m-N}^{m} x[n] \cdot e^{-j2\pi f_0 kn}$$



Calculation of Dynamic Phasor Coefficients from Time-domain Signals.

Dynamic Phasor Interface Algorithm (DP-IA)

$$x[n] = \sum_{k=0}^{K} X_k[n] \cdot e^{j(2\pi f_0 kn + \varphi_c)}$$



Reconstruction of Time-domain Signals from Dynamic Phasor coefficients.