

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

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45th Annual Conference of the IEEE Industrial Electronics Society (IECON) 15th – 17th October 2019, Lisbon Paper: LD-029874



ERIGrid Transnational Access Exchange



- The concept of Geographically Distributed Co-simulation
- System Architecture
- Test case description

Main contributions

- 1. Improved calculation of Dynamic Phasor Coefficients by moving window average
- 2. Investigation of IETF RTP protocol for streaming real-time simulation data
- 3. Fidelity Improvements / Bug Fixes
- 4. CoSiF A reusable library for distributed real-time simulation

Future plans



Geographically Distributed Real-time Simulation (GD-RTS)

- A single digital real-time simulation spanning multiple simulators / simulation sites
- Motivation
 - Large-scale system-level simulatoins
 - Exchange of Knowledge, Human- and Hardware **Ressources**
 - Overcome constraints caused by data confidientiality





Background / Motivation





System Architecture





Network Connectivity

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

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- Mean Round-trip time: 12 ms
- Routing hops:
- Sending rate: $\leq 10 \ kPkt/s$



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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





Dynamic Phasor Interface Algorithm (DP-IA)



Calculation of Dynamic Phasor Coefficients from Time-domain Signals.



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



Reconstruction of Time-domain Signals from Dynamic Phasor coefficients.



Simulation Results: Instantaneous V/I

Test cases:

- Voltage Source in SS1 (left)
- E 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)





Simulation Results: P/Q RMS

Change of source magnitude in SS1 (left side)





Limits of GD-RTS

Phase jump of π of V_{src}





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



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

n_{SS1}	n_{SS2}	P_{SS1}	Q_{SS1}	P_{SS2}	Q_{SS2}	S	Vrms
$[T_s]$	$[T_s]$	[MW]	[MVar]	[MW]	[MVar]	[MVA]	[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



Usability Improvements

- Use of GPS time (GTSYNC) to coordinate synchronized simulation start
 - Alignment of measurements
 - Synchronized reference phasors
- Open problem for OPAL-RT systems





Co-Simulation Interface Library: "CoSiF

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









Future Plans

More tests with off-nominal frequencies at the interface

Ongoing ERIGrid Transnational Access with DTU Denmark

- Distributed-PHIL with Quasi Stationary Back-to-Back Converter
- Energy Based Metric (EBM) for error quantification

FPGA / PCIe-based DRTS interfaces

Migration of DP-IA into VILLASnode



Acknowledgements

TU Delft

- Prof. Palensky
- Rishabh Bhandia
- DTU Denmark
 - Prof. Kai Heussen
- Funding

≡ ERIGrid	H2020
≡ Urban Energy Lab 4.0	EFRE.NRW
≡ RESERVE	H2020



Connecting European Smart Grid Infrastructures

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







EUROPÄISCHE UNION Investition in unsere Zukunft Europäischer Fonds für regionale Entwicklung





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