Real-time SuperLab

PI: Manish Mohanpurkar Ph.D.
Group Lead, Energy Systems Research
Power and Energy Systems
Idaho National Laboratory

Co-PIs: Rob Hovsapian Ph.D. (INL);
Sid Suryanarayanan Ph.D. (Colorado State University)

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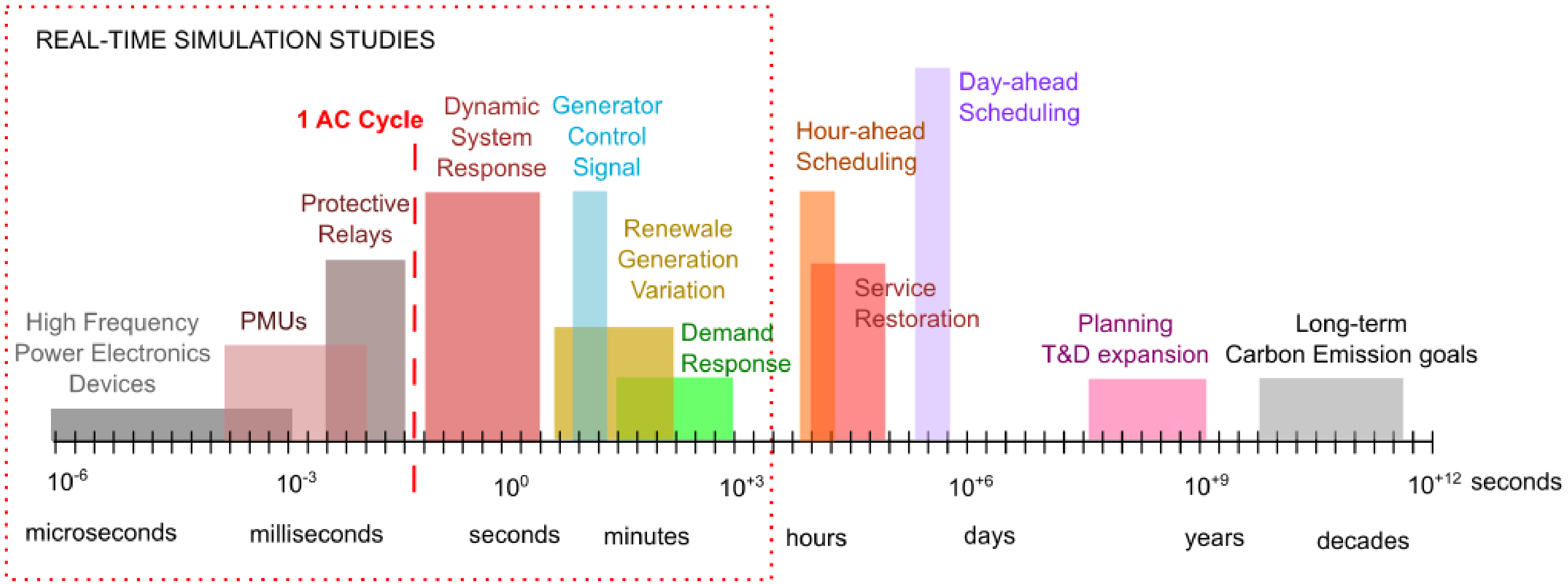
Idaho National Laboratory

Objectives Distributed RTS

- Demonstrate and Test Real-Time Simulation (RTS) that are:
  - Capable of interfacing with geographically distributed RTS assets at other national labs and universities
  - Conduct dynamic, transient analysis of complex power and energy systems
- Relevance to the Department of Energy (DOE) Mission:
  - Advanced study of hypotheses, concepts, or innovative approaches to scientific or technical problems;
  - Experiments and analyses directed towards "proof of principle" or early determination of the utility of new scientific ideas, technical concepts, or devices;
- Two main outcomes
  - Utilization of DOE and academic research assets based on a unique experimental methodology
  - Creation of simulation capabilities that can assess and analyze next generation power grids

Motivation

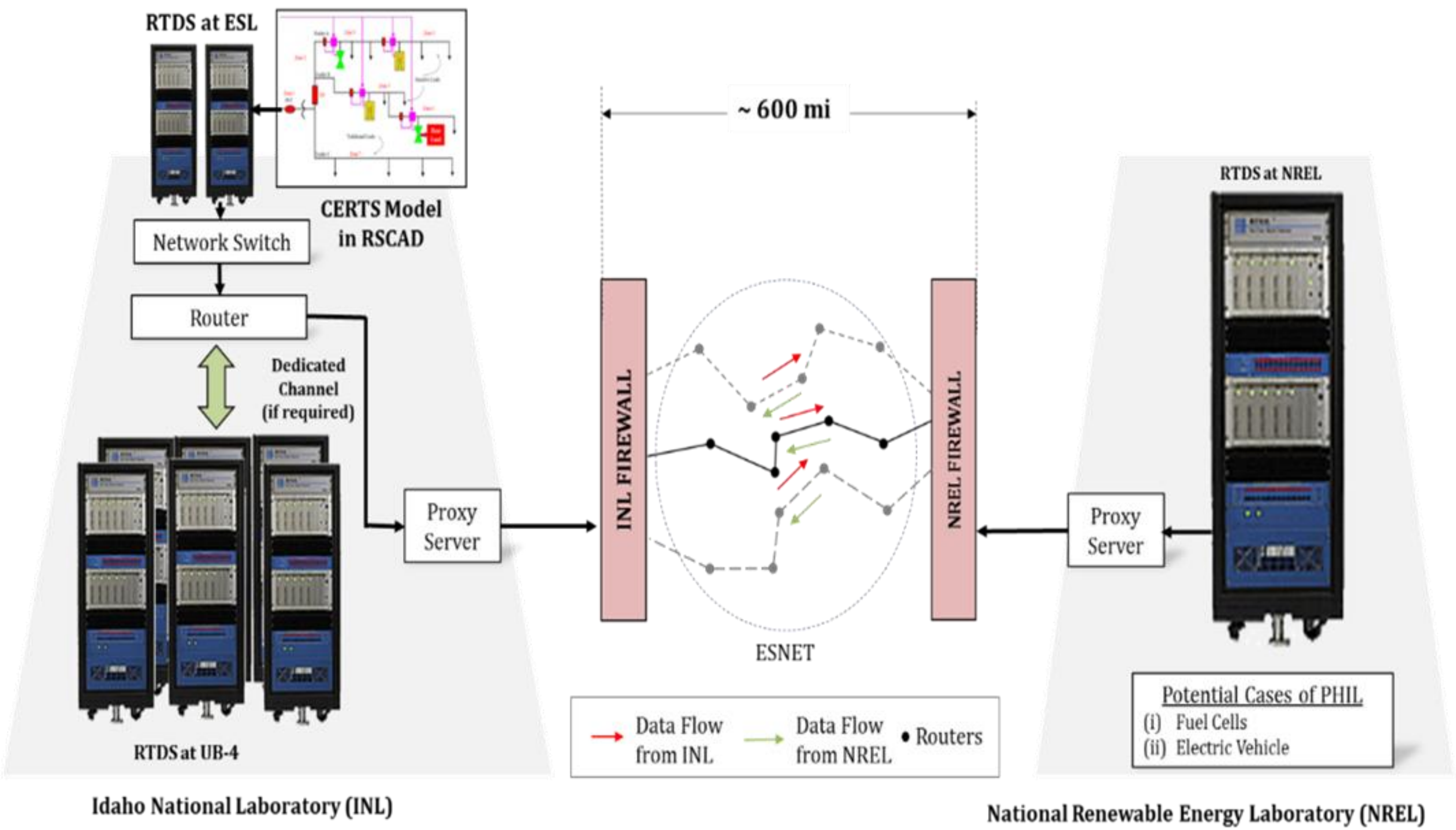
- RT simulators provides a highly accurate mechanism of modeling
  - Low overhead; specialized processors & communications; Hardware-In-the-Loop
  - Limited computation capability due to "REAL-TIME" feature
- RTS capabilities with unique assets located at numerous research labs
- DOE and Labs will be at forefront of the science, and better able to address those larger power and energy challenges if RT capabilities are leveraged



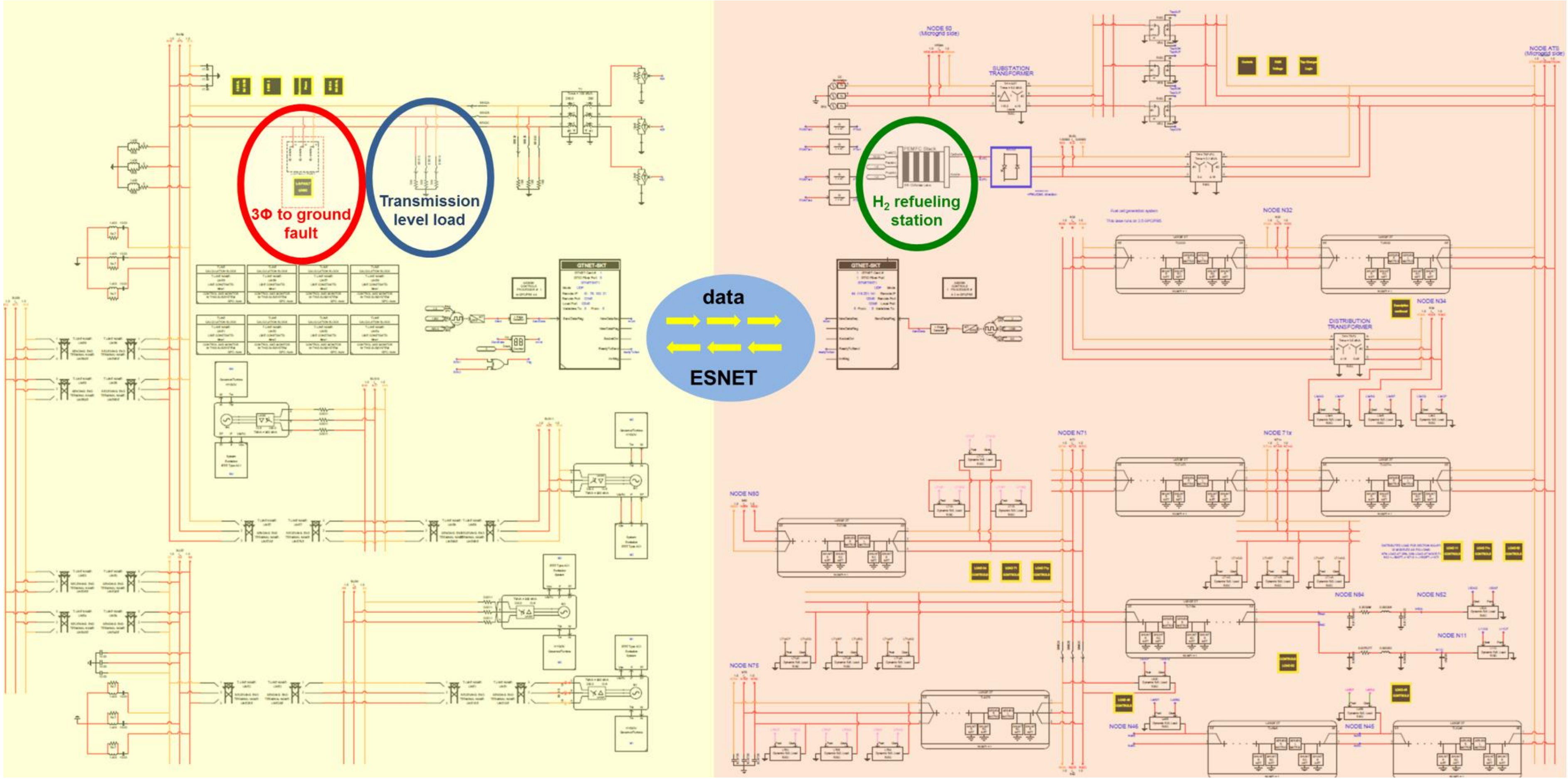
Discover, demonstrate, and secure innovative nuclear energy solutions, other clean energy options, and critical infrastructure

Methodology

- 2 models 4-bus 2-area test system & IEEE 13 node feeder test system
  - Transmission network comprises of a current source that approximates the load
  - Distribution network comprises of a voltage source that approximates the source
- Data exchange with TCP/UDP over Energy Sciences Network (ESNET)



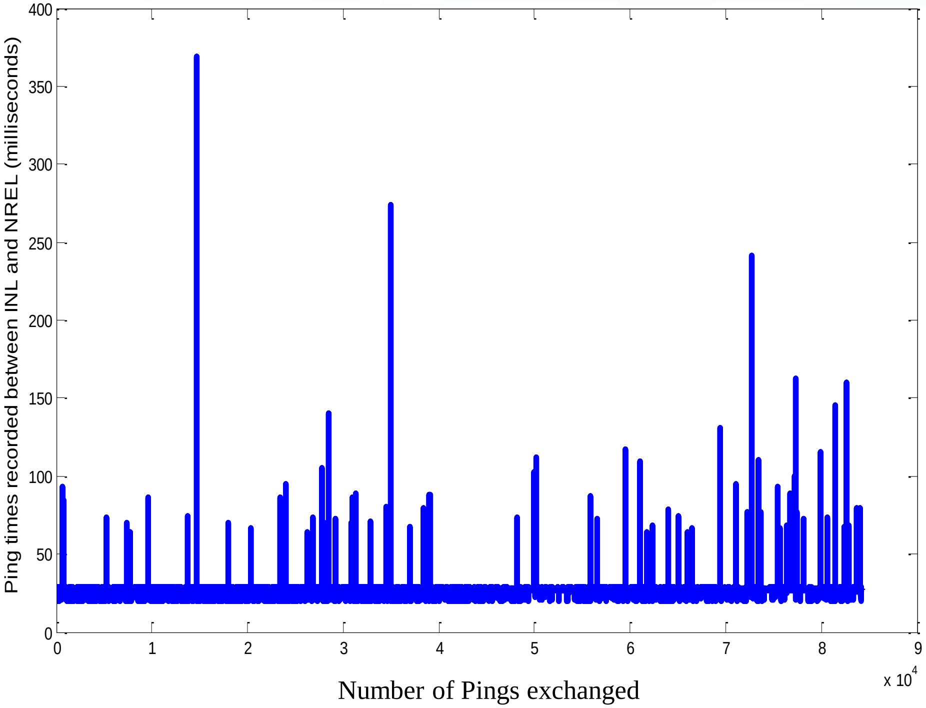
Methodology



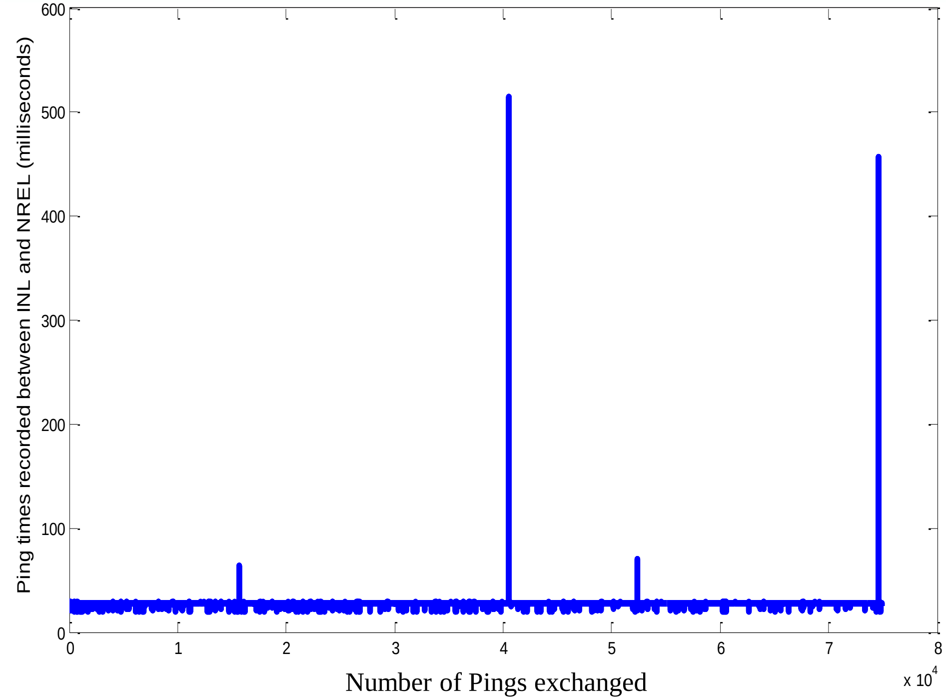
INL
TRANSMISSION NETWORK

NREL
DISTRIBUTION NETWORK

Internet Based Communication & Performance



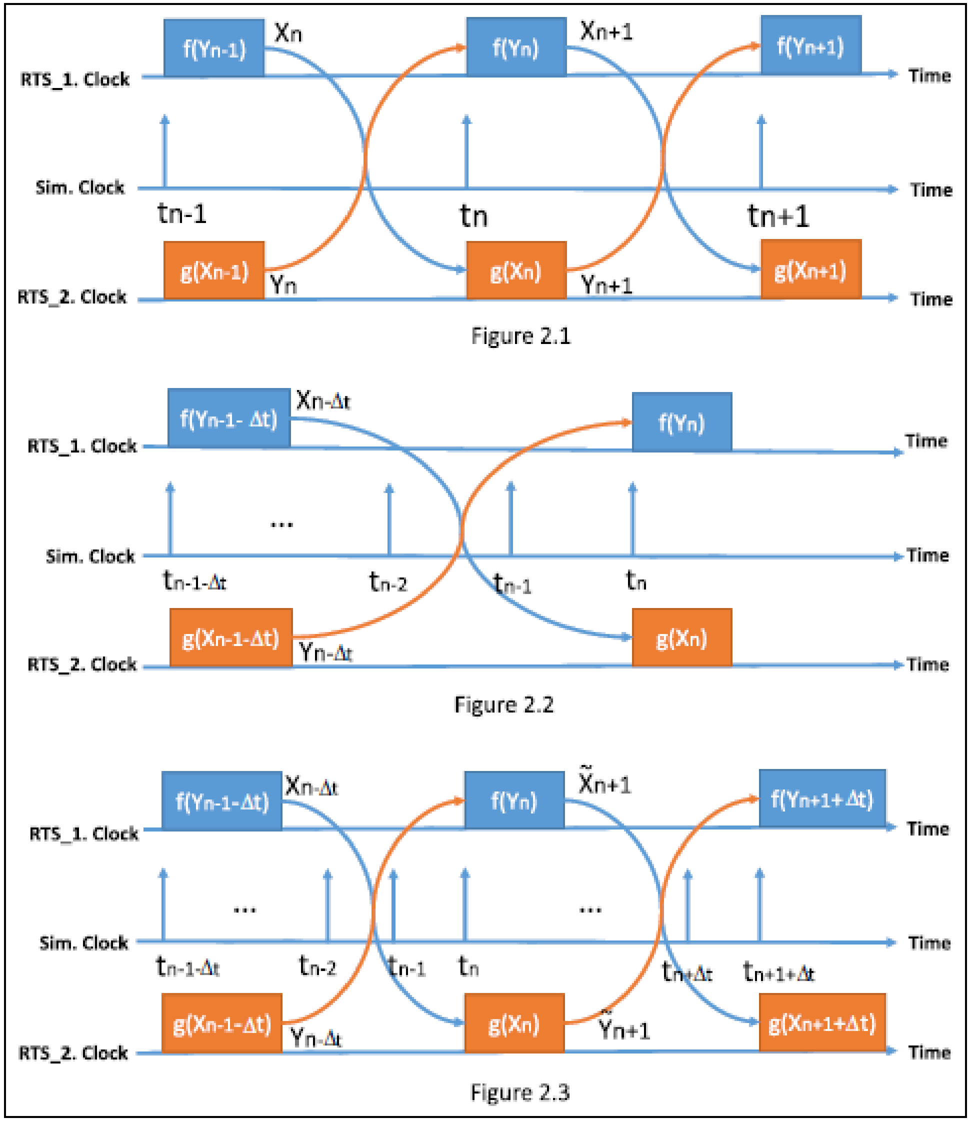
- Maximum = 369 milliseconds
- Minimum =20 milliseconds
- Average = 27.1557 milliseconds
- Data drops =24



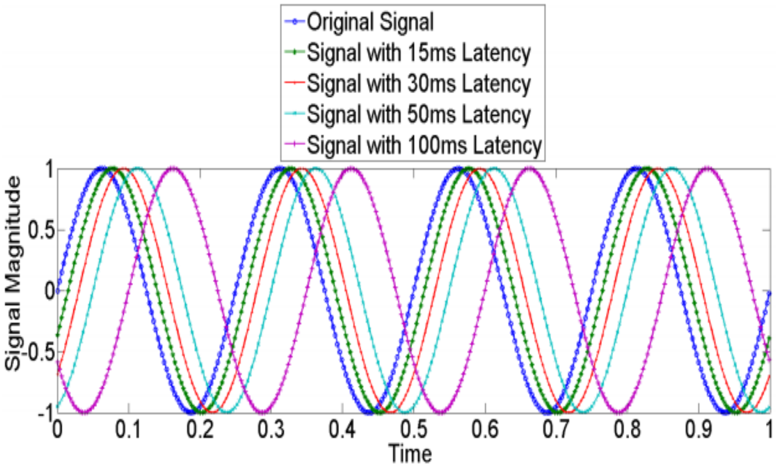
- Maximum = 515 milliseconds
- Minimum =20 milliseconds
- Average = 27.0409 milliseconds
- Data drops =17

Demonstration shows that most data packets took less than 30 milliseconds to travel between INL and NREL

Challenges in Distributed RTS



Step 1: Identify communication latency issues on distributed real-time simulation

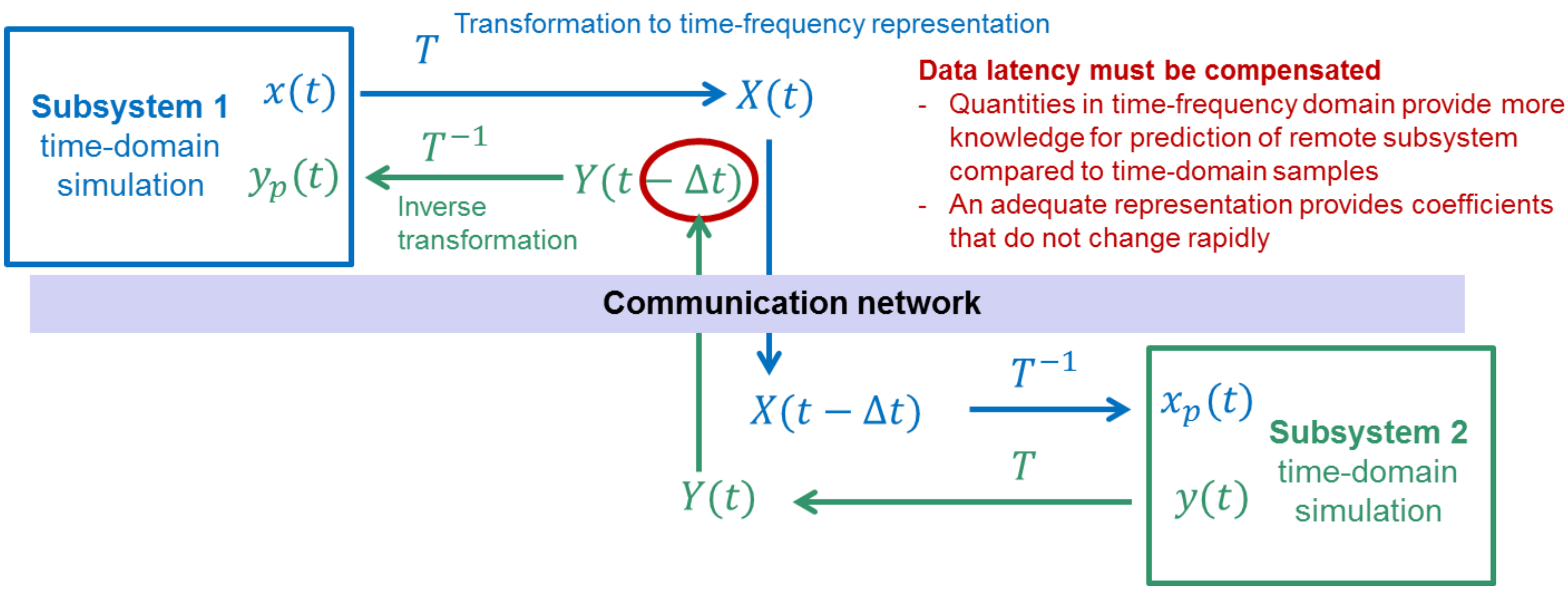


Effect of communication latency on simple sine wave

Step 2: Mitigate communication latency issues.

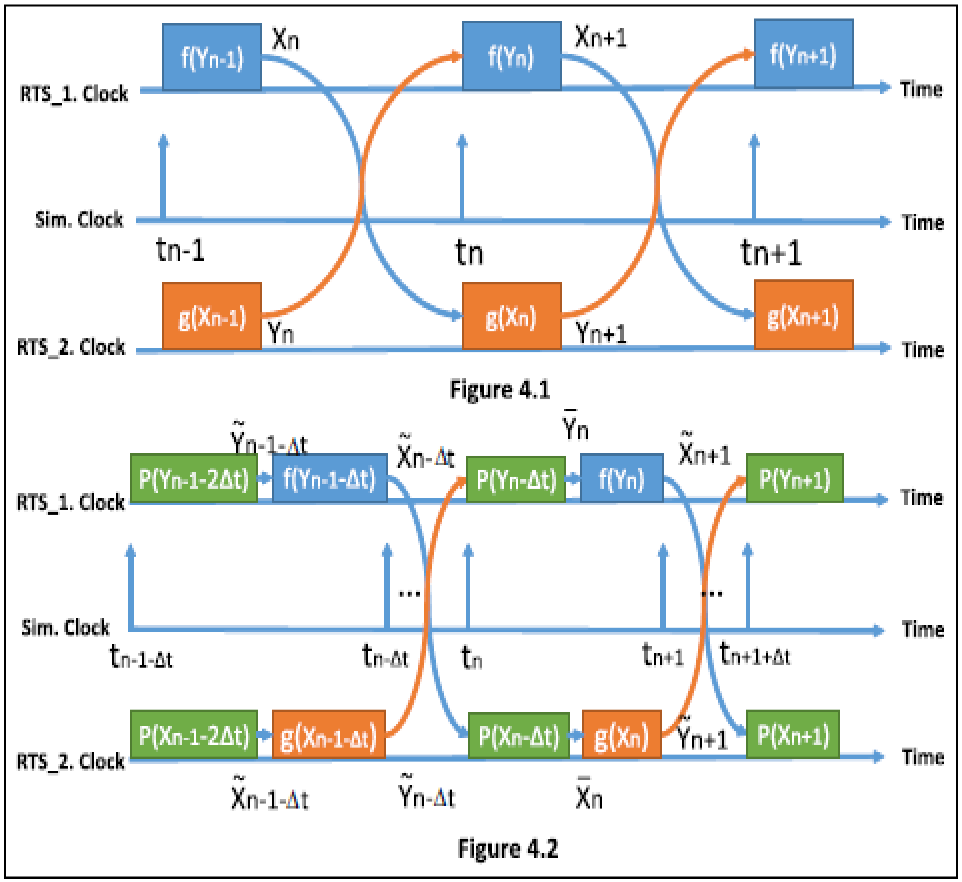
Latency Mitigation Techniques

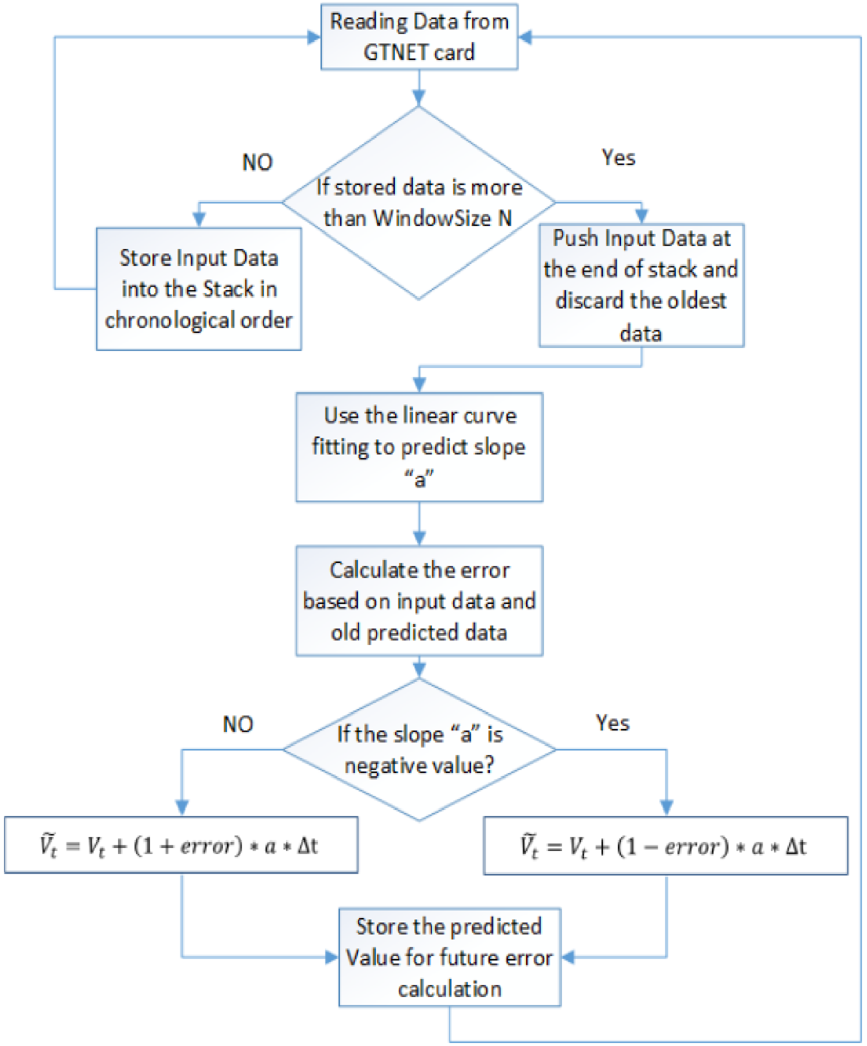
- Geographically distributed experiments between INL and NREL indicate the data latency challenges
  - Latency mitigation techniques are required to ensure simulation fidelity
- Two main research directions within the project to address the latency issue:
  - Real-time implementation of linear prediction method
  - Representation of interface quantities in time-frequency domain: dynamic phasors
    - Application of advanced methods for signal processing, filtering, data compression



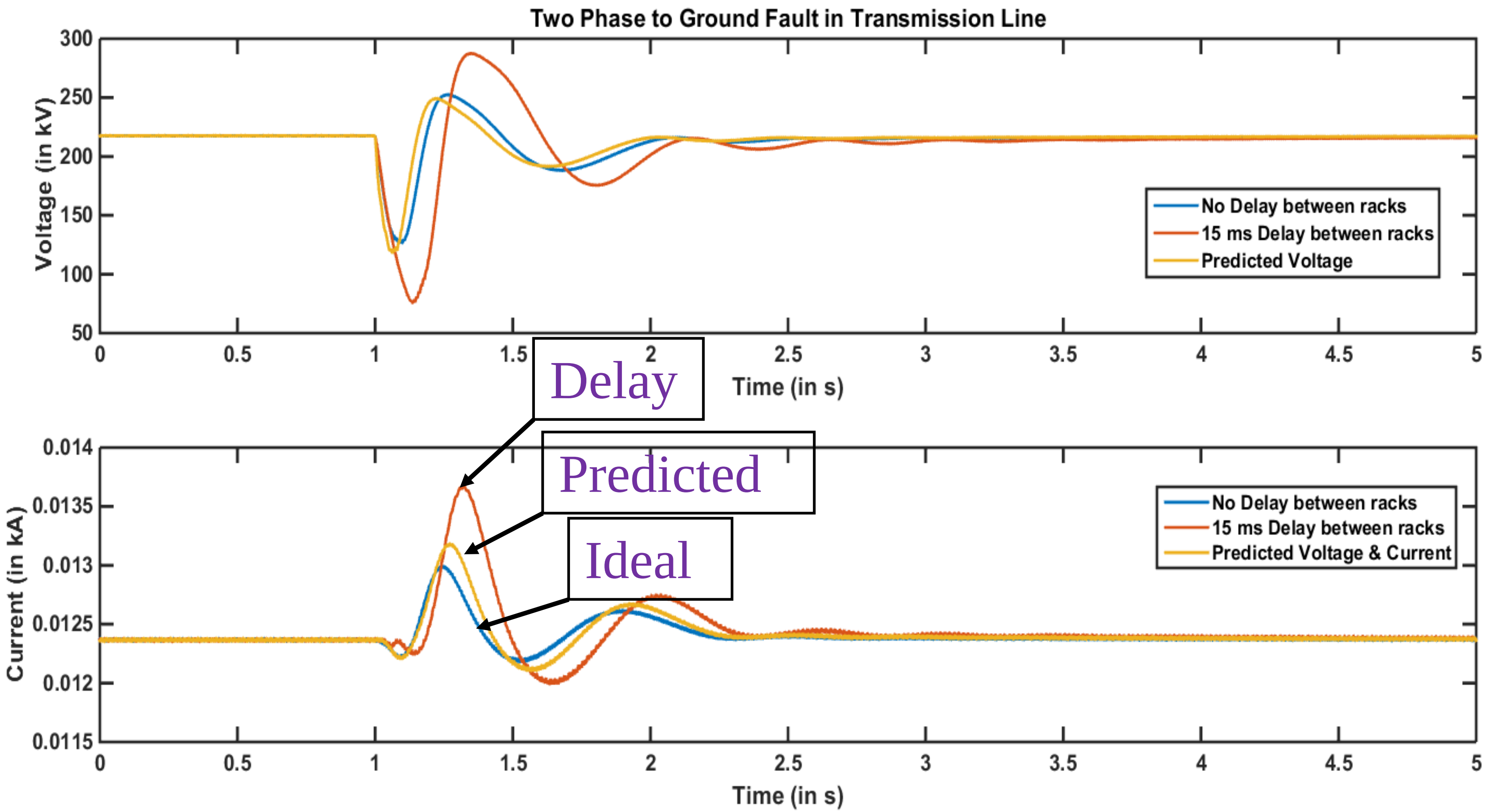
Data latency mitigation is necessary for accurate distributed RTS

Linear Predictor Approach





Improvements With Linear Predictor Approach



Impact of data latency is mitigated in several cases using linear prediction

Distributed RTS Accuracy & Stability Evaluation

- A systematic assessment and testing of latency on simulation fidelity is substantial for fundamental research on latency mitigation techniques
- The results obtained based on the theoretical framework
  - Quantify the effect of latency in terms of stability and accuracy regions
  - Serve as a basis to better understand critical issues and further improve latency mitigation techniques

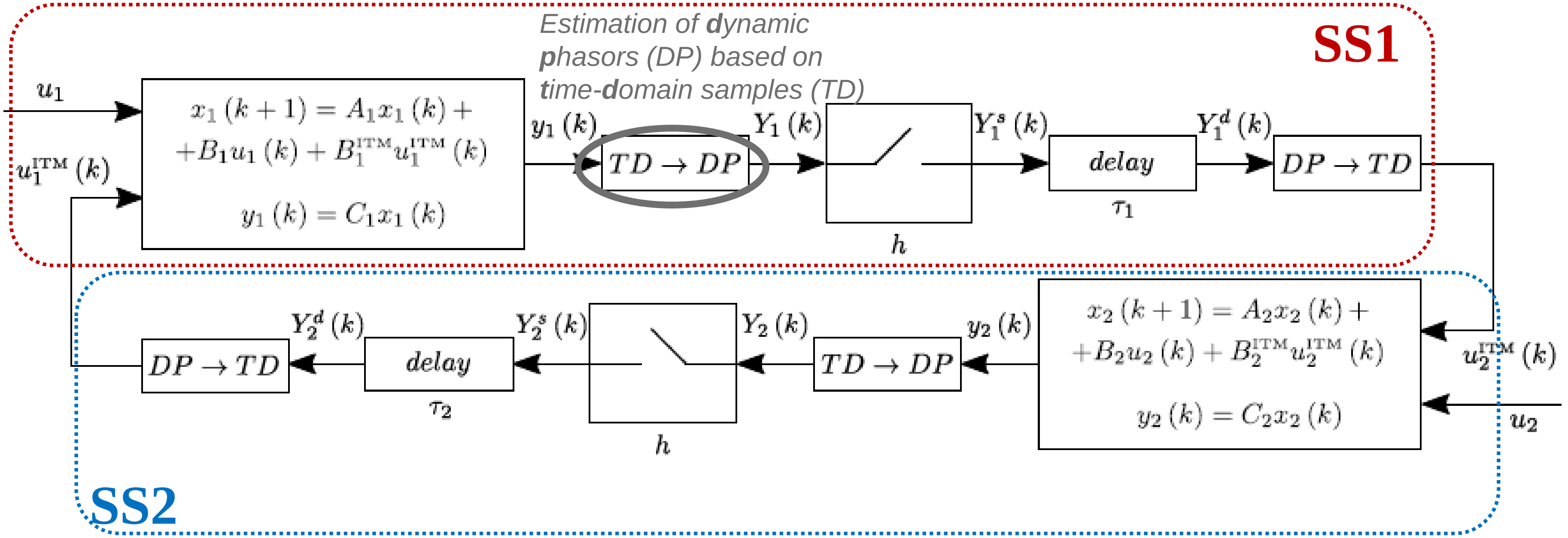
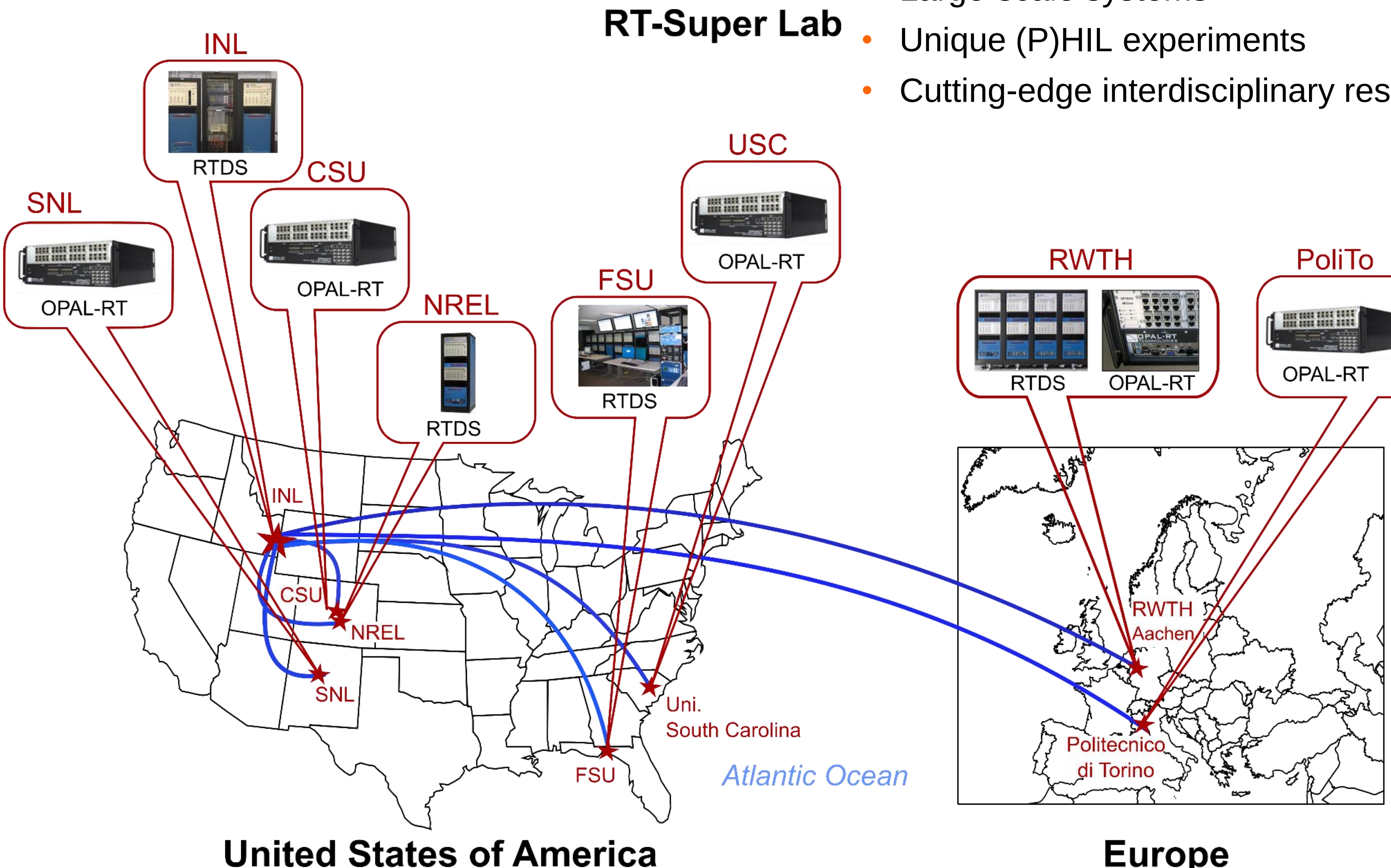


Diagram of a simplified geographically distributed simulation system used for theoretical framework

Super Lab for the Futuristic Grids

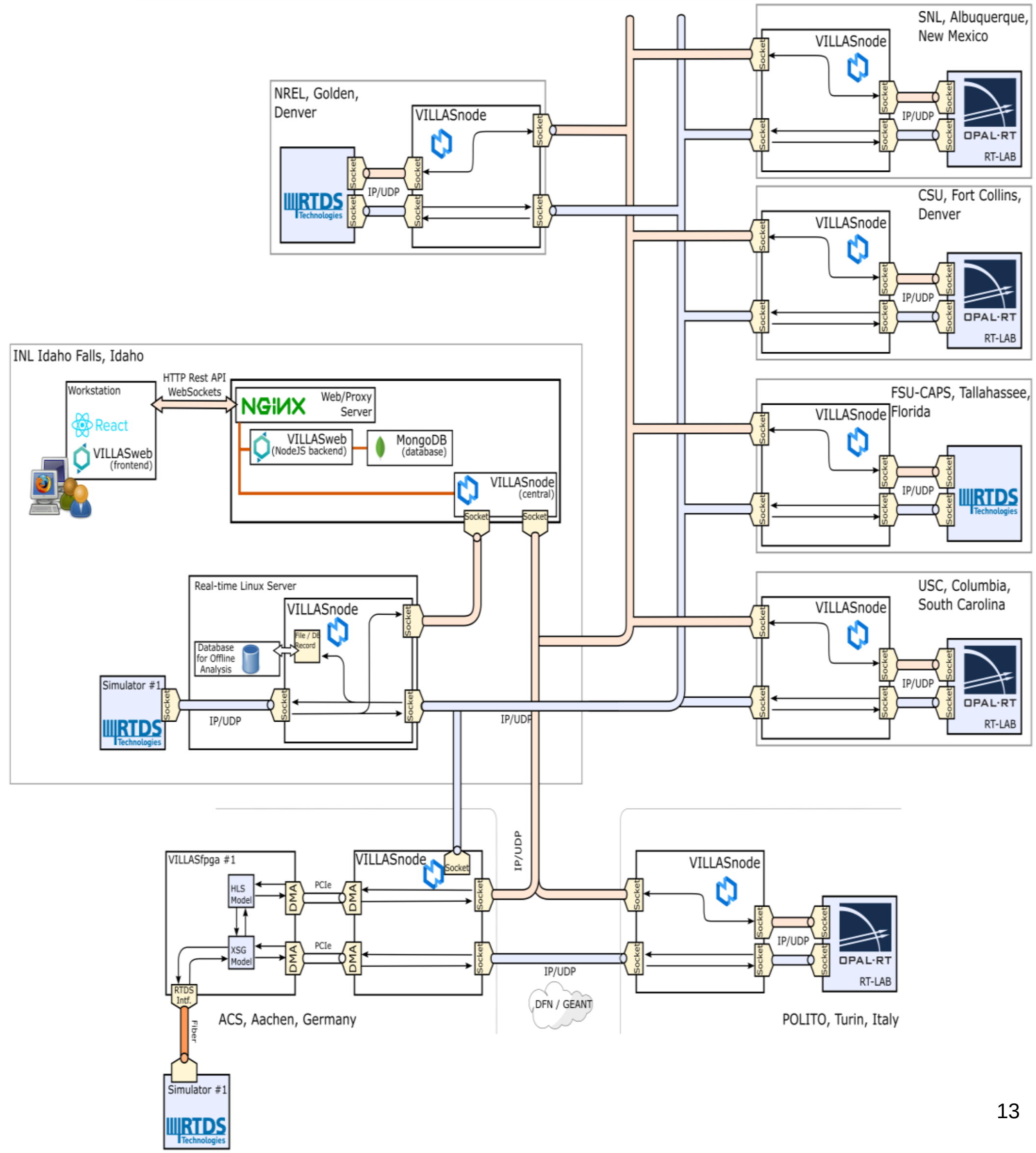
Collaborative research infrastructure for

- Large-scale systems
- Unique (P)HIL experiments
- Cutting-edge interdisciplinary research

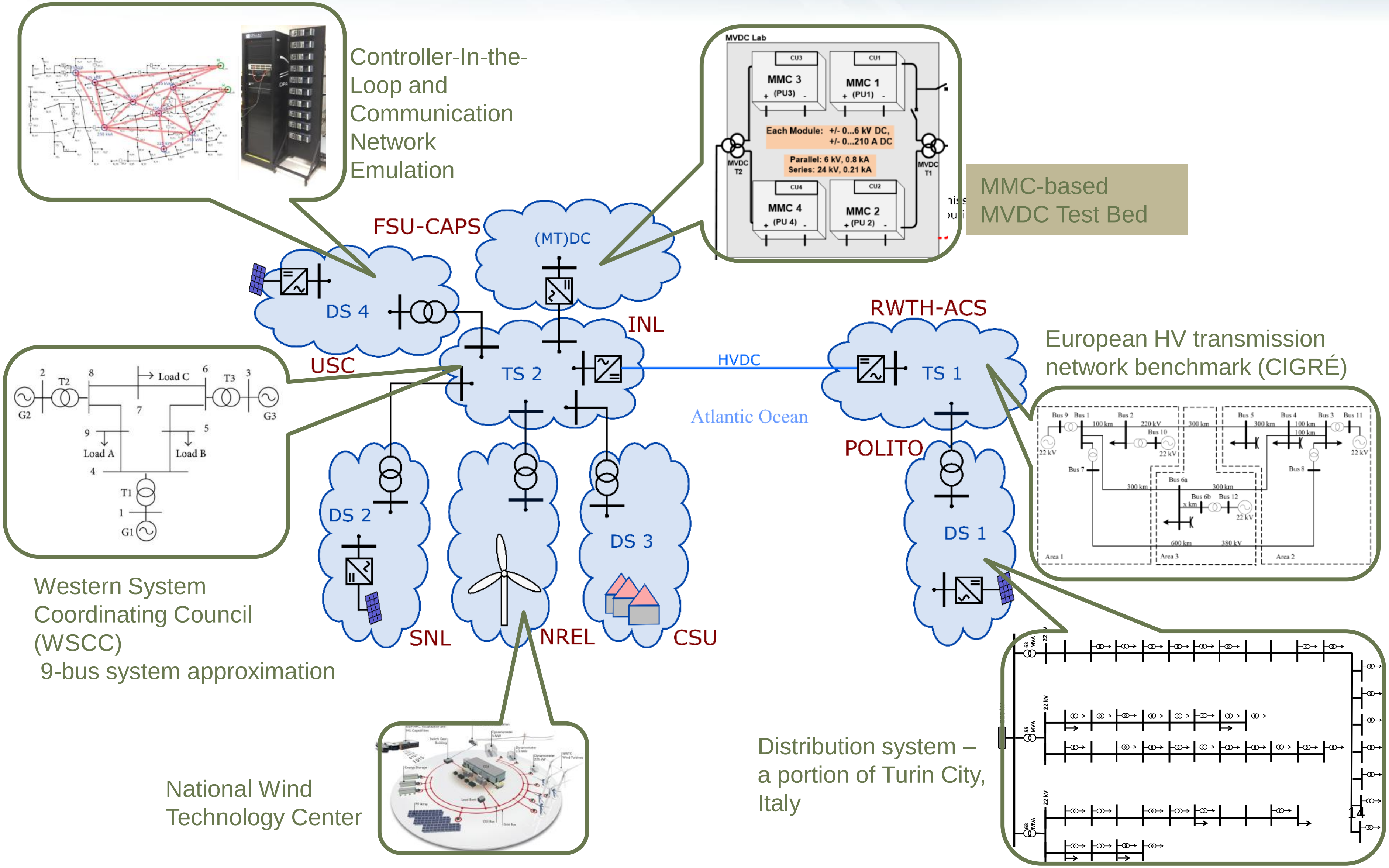


VILLAS framework for RT-Super Lab

- **VILLASnode**
  - Gateway for connecting digital real-time simulators
  - Interface to VILLASweb
  - ACS provides support for deploying VILLASnode instances
  - Distributed under LGPLv2 license
- **VILLASweb**
  - Web interface for consolidated monitoring of the distributed simulation
  - Web Server, Backend and Database hosted at INL for RT-Super Lab Demo
  - Web interface is available within VPN for all participants



RT SuperLab



Controller-In-the-Loop and Communication Network Emulation
MVDC Lab
MMC 3 (PU3)
MMC 1 (PU1)
MMC 4 (PU 4)
MMC 2 (PU 2)
Each Module: +/- 0...6 kV DC, +/- 0...210 A DC
Parallel: 6 kV, 0.8 kA
Series: 24 kV, 0.21 kA
MVDC T2
MVDC T1
MMC-based MVDC Test Bed
FSU-CAPS
(MT)DC
DS 4
INL
USC
TS 2
HVDC
Atlantic Ocean
RWTH-ACS
TS 1
POLITO
European HV transmission network benchmark (CIGRÉ)
Load C
Load A
Load B
G1
G2
G3
T1
T2
T3
Western System Coordinating Council (WSCC) 9-bus system approximation
DS 2
DS 3
DS 1
SNL
NREL
CSU
National Wind Technology Center
Distribution system – a portion of Turin City, Italy

RT SuperLab & Next-Gen Global Grids

- Collaboration between USA and EU institutions enables research groups to jointly investigate innovative solutions such as a direct submarine HVDC cable between USA and EU within the concept of Global Power Grid
- RT-Super Lab environment exploits complementary strengths and knowledge of USA and EU institutions that is particularly beneficial in this research context

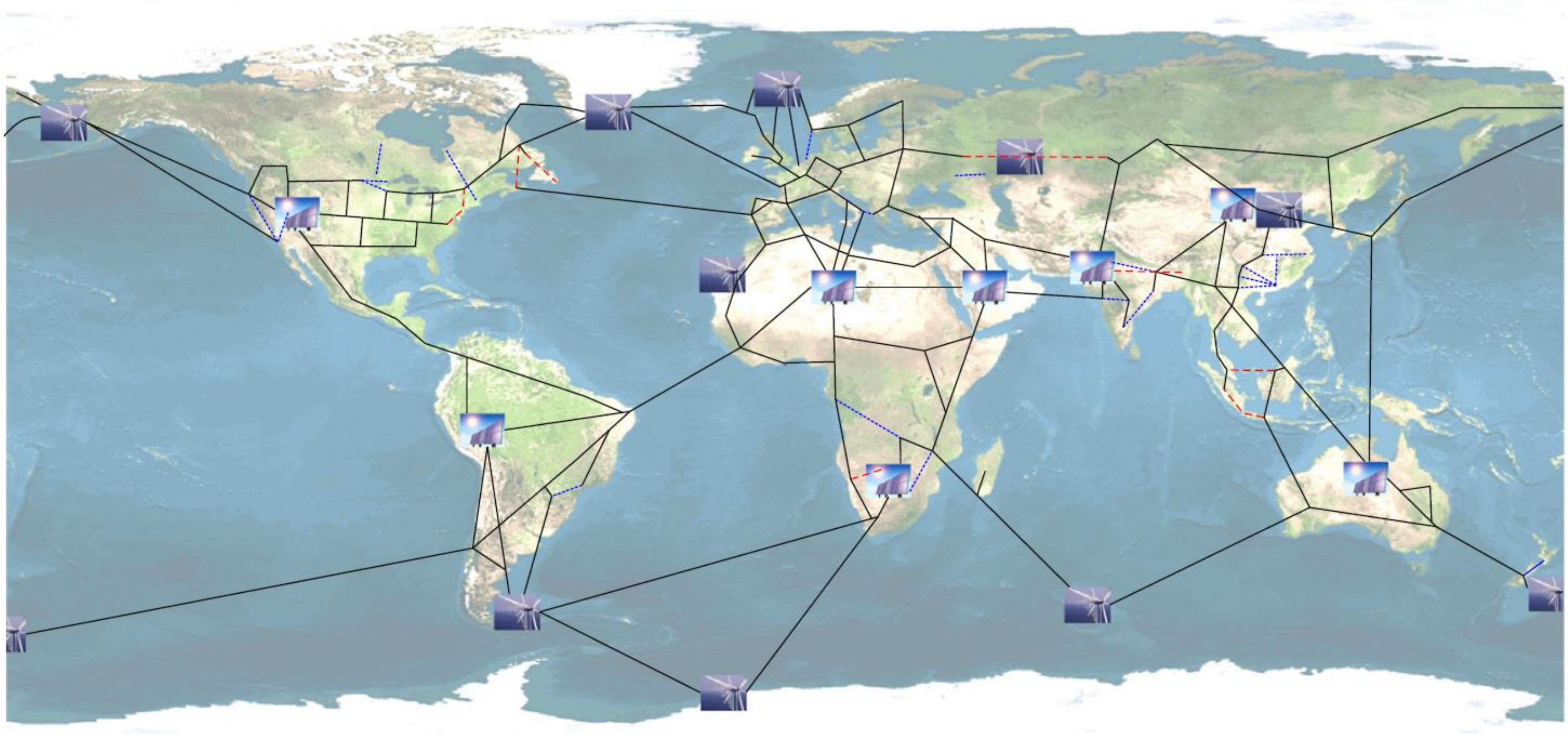


Illustration of a possible Global Grid

Jones, Lawrence E. *Renewable Energy Integration: Practical Management of Variability, Uncertainty and Flexibility In Power Grids.* Burlington: Academic Press, 2014.

Concluding Remarks

- Two main outcomes achieved:
  - Utilization of DOE and academic research assets based on a unique experimental methodology
  - Creation of simulation capabilities that can assess and analyze next generation power grids
- Distributed Real-Time Simulation between INL and NREL was successfully demonstrated
- Impact of data latency was studied via two approaches i.e., heuristic and formal method based
- Linear prediction method was utilized to increase the accuracy of distributed Real-Time Simulation
- Formal method of assessing the accuracy and stability of distributed Real-Time Simulation will be completed
- A RT Super Lab demonstration of including several DOE labs and academic research centers is under development

Acknowledgements & Project Personnel

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- INL colleagues
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- NREL colleagues
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- Colorado State University
  - Prof. Sid Suryanarayanan (co-PI); Mayank Panwar* (Ph.D. intern)
- RWTH Aachen University
  - Prof. Antonello Monti; Ms. Marija Stevic* (Ph.D. intern)
- *2 Ph.D. dissertations generated from this LDRD
  - Mayank Panwar – Operation of electric microgrids under uncertainty
  - Marija Stevic - Advanced methods for geographically distributed RTS of power systems

Publications

Book Chapters

1. M. Mohanpurkar, M. Panwar, S. Chanda, M. Stevic, R. Hovsapian, V. Gevorgian, S. Suryanarayanan, and A. Monti, **“Distributed real-time simulations for electric power engineering,”** Cyber-physical social systems and constructs in electric power engineering, The Institution of Engineering and Technology (IET), London, UK (October 2016)

Peer-Reviewed Journals/Transactions/Conferences

1. Ren Liu, Manish Mohanpurkar, Mayank Panwar, Rob Hovsapian, Anurag Srivastava, Sid Suryanarayanan, **“Geographically distributed real-time digital simulations using linear prediction,”** International Journal of Electrical Power & Energy Systems, Volume 84, January 2017, Pages 308-317, ISSN 0142-0615
2. Mayank Panwar, Sid Suryanarayanan, Rob Hovsapian, "**A multi-criteria decision analysis-based approach for dispatch of electric microgrids**," International Journal of Electrical Power & Energy Systems*, Vol. 88, Pages 99-107, 2017.*
3. Yusheng Luo, Mayank Panwar, Manish Mohanpurkar, and Rob Hovsapian, “**Real Time Optimal Control of Supercapacitor Operation for Frequency Response**,” *2016 IEEE Power and Energy Society General Meeting* (PESGM), Boston, Massachusetts, pp. 1–5, 2016 (doi: 10.1109/ PESGM.2016.7742036).
4. S. Chanda, M. Mohanpurkar, R. Hovsapian, A. Srivastava, “**Quantifying Power Distribution System Resiliency Using Code Based Metric**," IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES), pp. 6, December 14-17, 2016.

Presentations / Posters

1. R. Hovsapian, “DRTS-DRTS Link for Distributed Real Time Simulation,” Presentation, *Workshop on cyber-physical systems application to power grid*, Boston, MA, July 16-17, 2016.
2. R. Hovsapian, “DRTS-DRTS Link for Distributed Real Time Simulation,” Presentation as part of U.S. Delegation visit, *Aalborg Symposium on Microgrids*, Aalborg, Denmark, August 27-28, 2015.
3. M. Panwar, S. Suryanarayanan, R. Hovsapian, “Performance Metrics-Based Design and Dispatch for Electric Microgrids,” Poster, *IEEE Power and Energy Society General Meeting 2015*, Denver, CO, July 25-30, 2015.
4. R. Hovsapian, LDRD review, BEA Board of Science and Technology Committee Meeting, July 21, 2015.
5. R. Hovsapian, “Laboratory of the Future,” for project – Dynamic Modeling and Validation of Electrolyzers in Real Time Grid Simulation, *Demonstration during Dr. David Danielson’s INL visit*, Idaho Falls, ID, June 30, 2015. [Online], Available: https://vimeo.com/131928051.
6. M. Mohanpurkar, “Distributed Real Time Simulations Using RTDS®,” *RTDS User General Meeting*, San Francisco, CA, May 5-7, 2015.
7. R. Hovsapian, “Dynamic Simulations for Large Scale Electric Power Networks in Real Time Environment using Multiple RTDS,” DOE-NE Review Germantown Meeting, September 22, 2015

Press Releases and Media Coverage

1. https://www.inl.gov/article/inl-and-nrel-demonstrate-power-grid-simulation-at-a-distance/
2. http://www.nrel.gov/news/press/2015/17498
3. http://www.eurekalert.org/pub_releases/2015-05/drel-ian050515.php
4. http://www.southwestclimatechange.org/news/feed/item/inl-nrel-demonstrate-power-grid-simulation-distance
5. https://www.hdiac.org/node/1567
6. Energy Systems Integration Facility (ESIF) NREL, 2015 MID-YEAR REPORT
7. http://www.smartgridnews.com/story/nrel-and-inl-connect-power-grid-technology-over-internet/2015-05-06
8. https://fcw.com/articles/2015/05/06/news-in-brief-may-6.aspx?m=1
9. http://www.realestaterama.com/2015/05/04/inl-and-nrel-demonstrate-power-grid-simulation-at-a-distance-ID026850.html
10. http://phys.org/news/2015-05-inl-nrel-power-grid-simulation.html
11. http://www.brunchnews.com/phys/technology/inl-and-nrel-demonstrate-power-grid-simulation-at-a-distance-2831379
12. http://www.pvbuzz.com/nrel-demonstrates-the-capability-to-connect-grid-simulations-via-the-internet-why-should-we-care/
13. http://news.thomasnet.com/companystory/inl-nrel-successfully-demonstrate-remote-power-grid-simulation-20044059
14. http://www.pressreleasepoint.com/inl-and-nrel-power-grid-simulation-distance
15. Science News http://esciencenews.com/sources/physorg/2015/05/05/inl.and.nrel.demonstrate.power.grid.simulation.a.distance
16. WorldOfRenewables http://worldofrenewables.net/inl-and-nrel-demonstrate-power-grid-simulation-at-a-distance/
17. ExecutiveGov http://www.executivegov.com/2015/05/energy-department-demos-inter-lab-power-grid-simulations/

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THANK YOU & QUESTIONS