2025 Electromagnetic Transient Simulation workshop,

7-9 October 2025, Oak Ridge National Laboratory

Advanced Multi-Rate EMT Emulation Using a Digital Real-Time Simulator for Bulk Transmission Systems: A Case Study of the Western Electricity Coordinating Council

Yash Agalgaonkar

ARIES by NREL

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Overview

Introduction

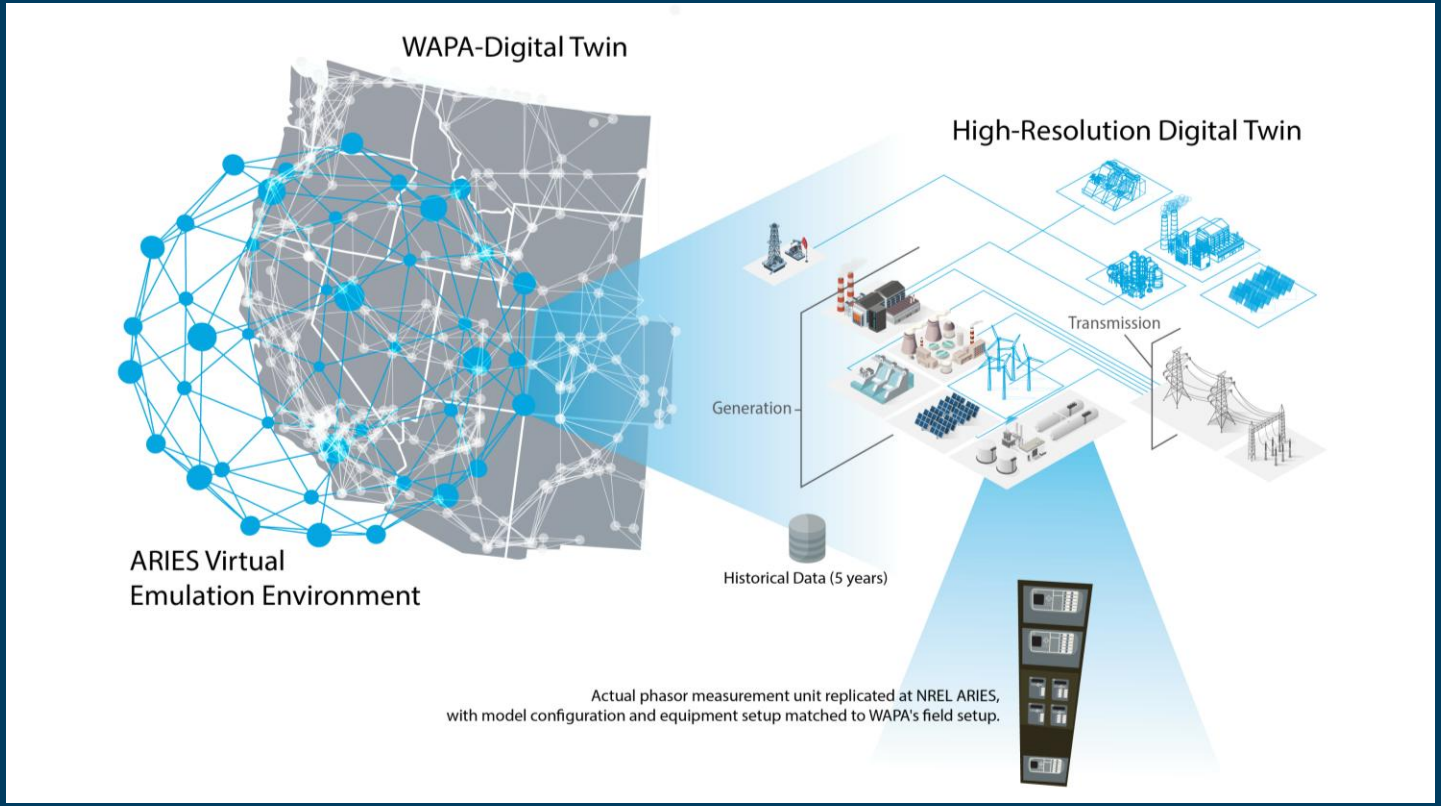
- Western Electricity Coordination Council (WECC)

Demonstration

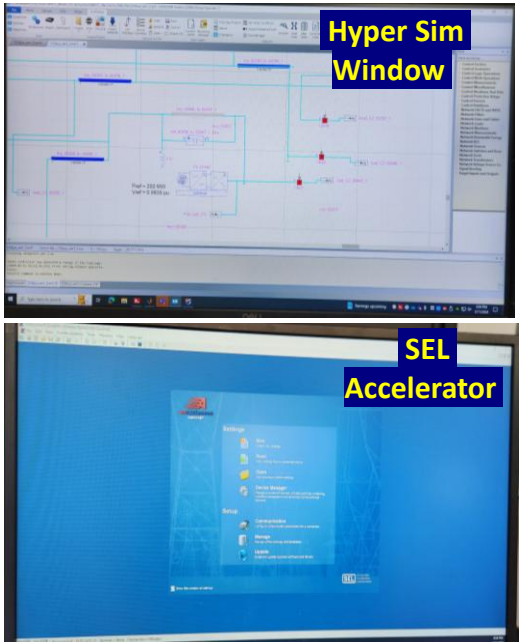
- ARIES Hardware virtual emulation capabilities
- Bulk transmission level digital twin validation
- Data analysis and system stability analysis

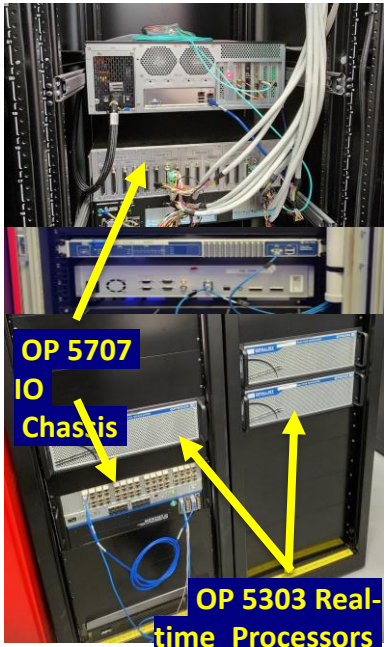
Discussion

WECC and WAPA Digital Twin on the ARIES VEE



WECC and WAPA Digital Twin

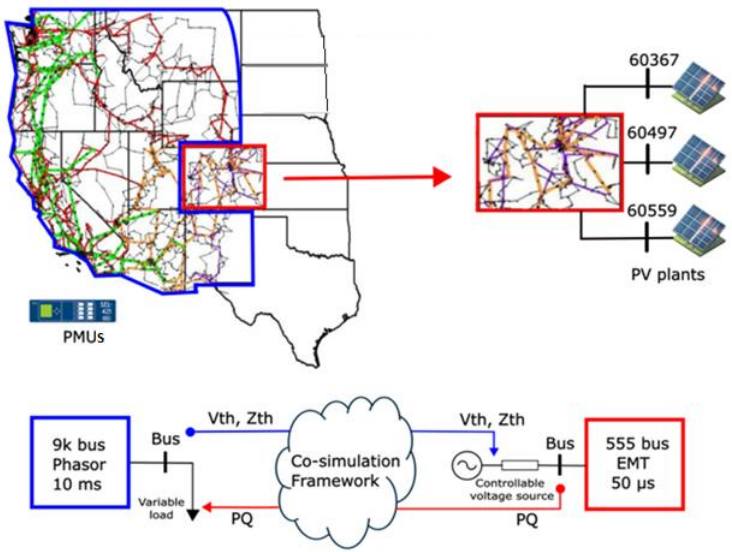




WECC and WAPA digital twin hardware leverages multiple ARIES assets.

WECC Digital Twin Setup and large EMT model

At-scale WAPA and WECC Multi-Rate Emulation Setup Using the ARIES VEE



NREL has implemented a multi-rate emulation setup for the WECC bulk transmission system, incorporating multiple renewable and classical generation sources

Graphics inspired by [1] A. B. Birchfield; T. Xu; K. M. Gegner; K. S. Shetye; T. J. Overbye, "Grid Structural Characteristics as Validation Criteria for Synthetic Networks," in *IEEE Transactions on Power Systems,* vol. 32, no. 4, pp. 3258-3265, July 2017. [https://electricgrids.engr.tamu.edu/electric-grid-test-cases/activsg10k/]

Colorado EMT zone: Load flow validation

10k-bus WECC zone

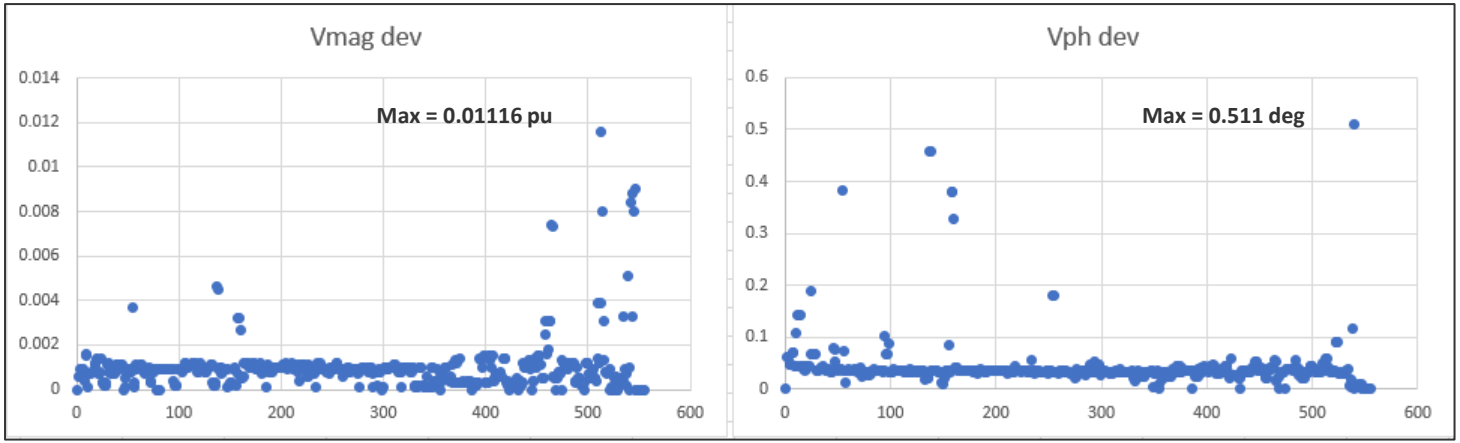
ePhasorsim example

ACTIVSg10k_revOpalRT.raw

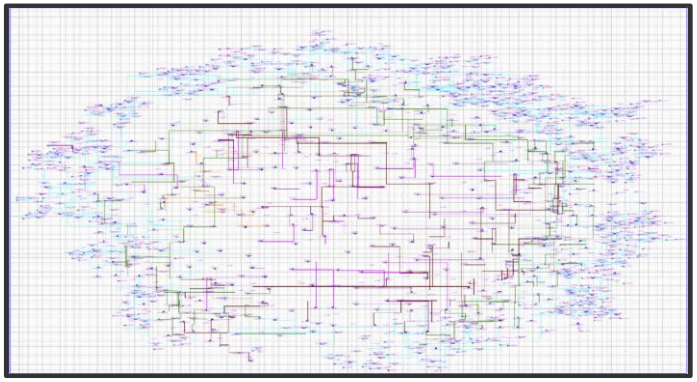
555-bus Colorado

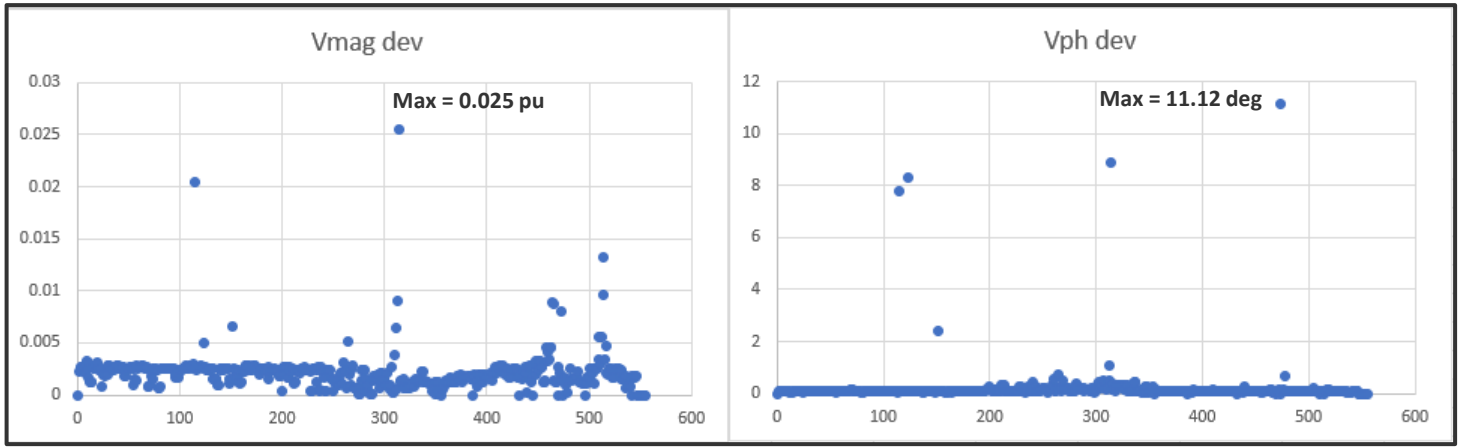
EMT portion

ACTIVSg10k_revOpalRT_555bus.raw



Colorado Digital Twin – Load Flow Validation





Colorado EMT Zone: Load Flow Validation

10k-bus WECC

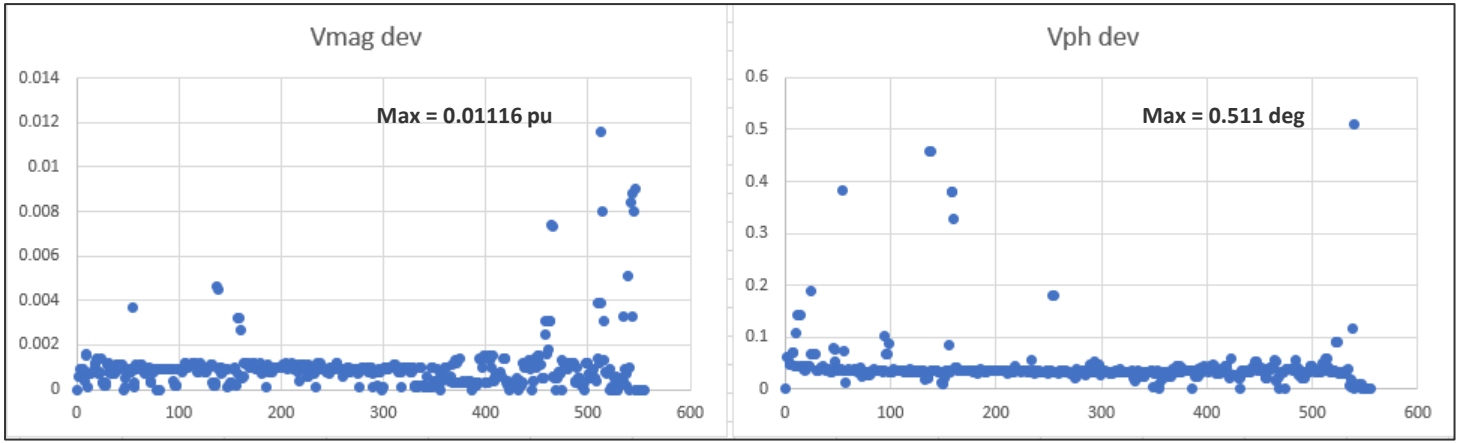
ePhasorsim example

ACTIVSg10k_revOpalRT.raw

555-bus Colorado zone

EMT portion

ACTIVSg10k_revOpalRT_555bus.raw



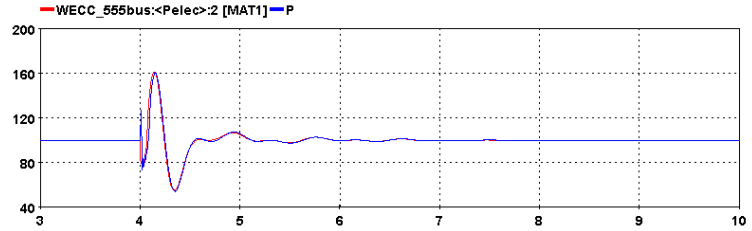
NERC Faults Database

Fault location	MW loss	Date of fault	Time of fault
NERC fault event 1	Approximately 1500	August 2019	Evening
NERC fault event 2	Approximately 700	September 2019	Evening
NERC fault event 3	Approximately 700	November 2019	Evening
NERC fault event 4	Approximately 500	March 2019	Evening

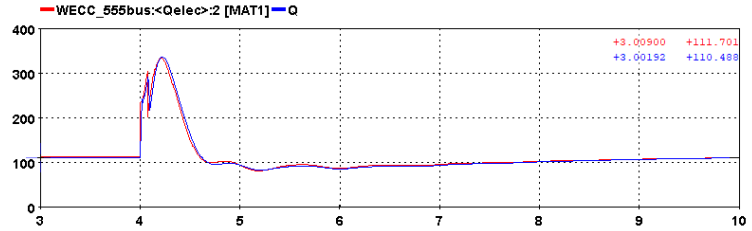
Colorado Plus Region High Precision Zone: Generator Responses

WECC 555-bus model
Measurements at Gen 60688 (GENROU + EXPIC1 + IEEEST + TGOV1)

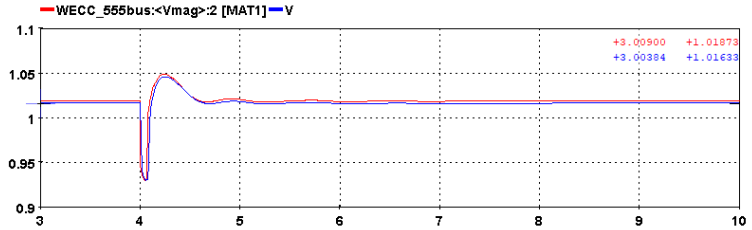
Active power



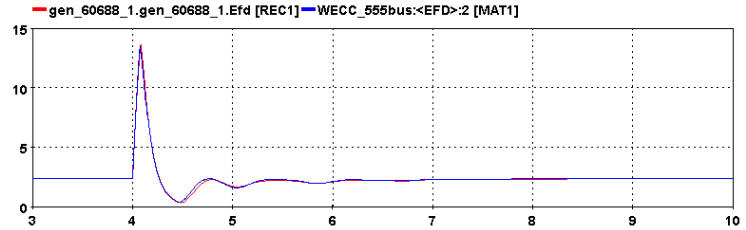
Reactive power



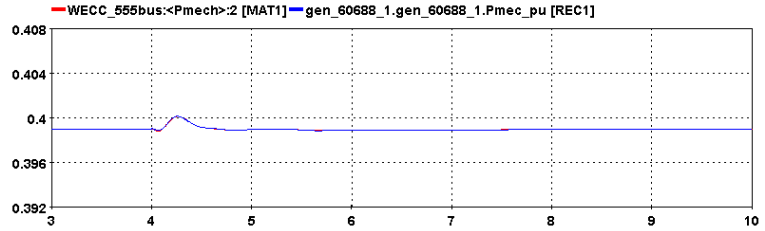
Voltage



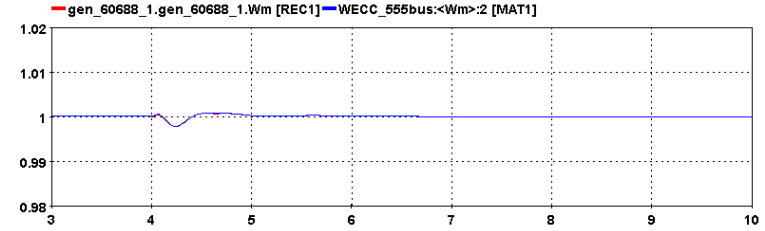
Field voltage



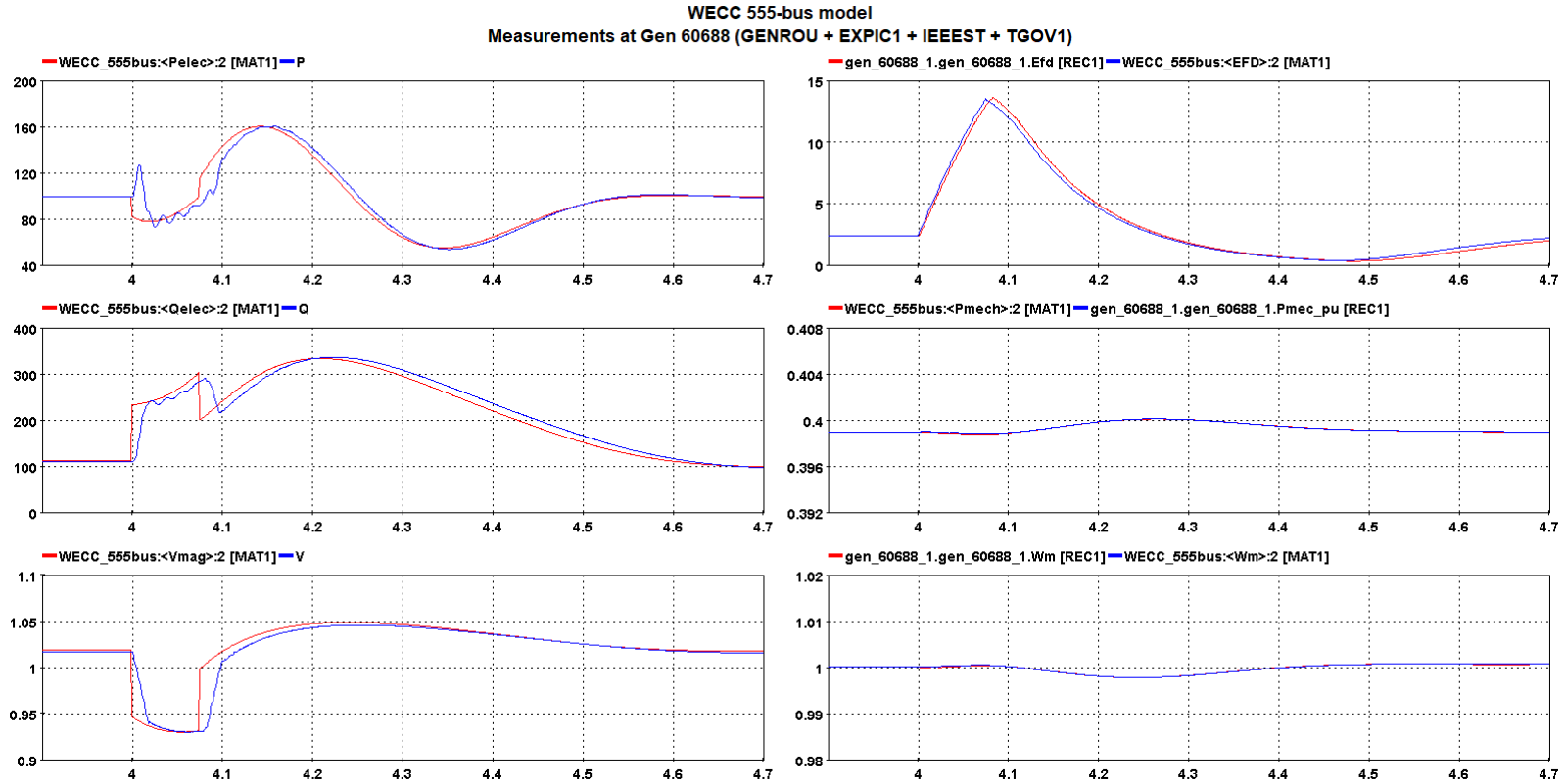
Mechanical power



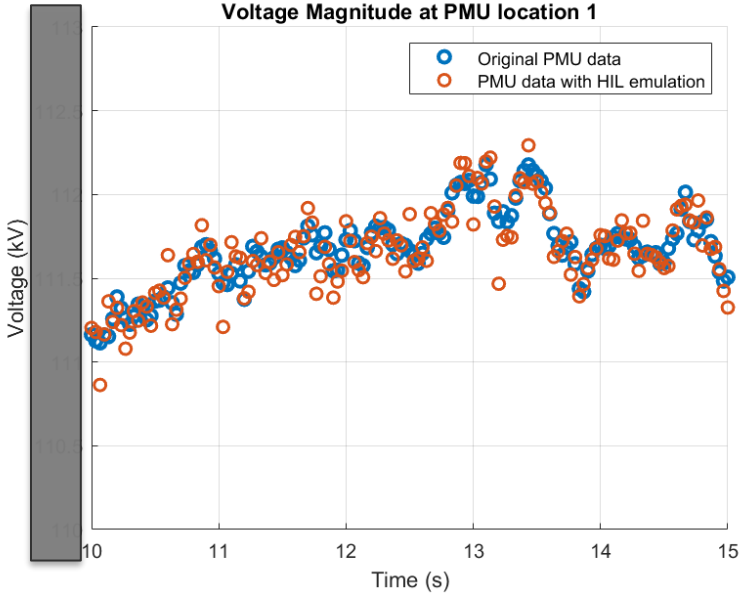
Speed

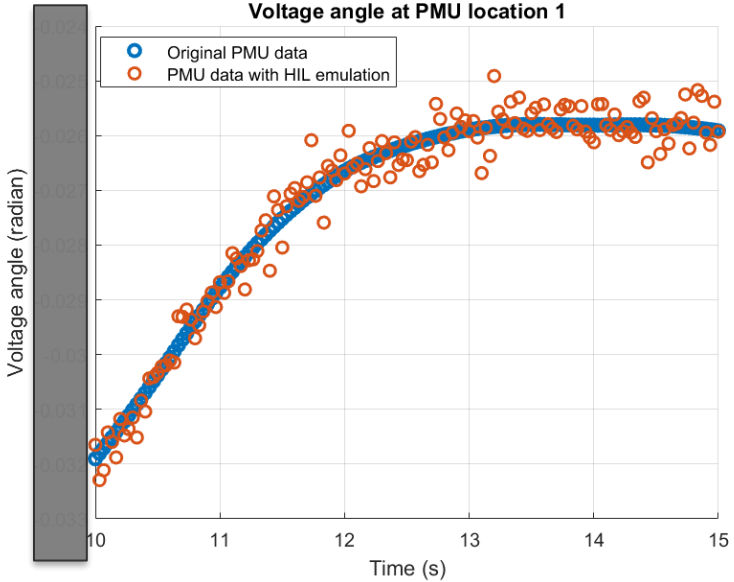


Colorado Plus Region High Precision Zone: Generator Responses

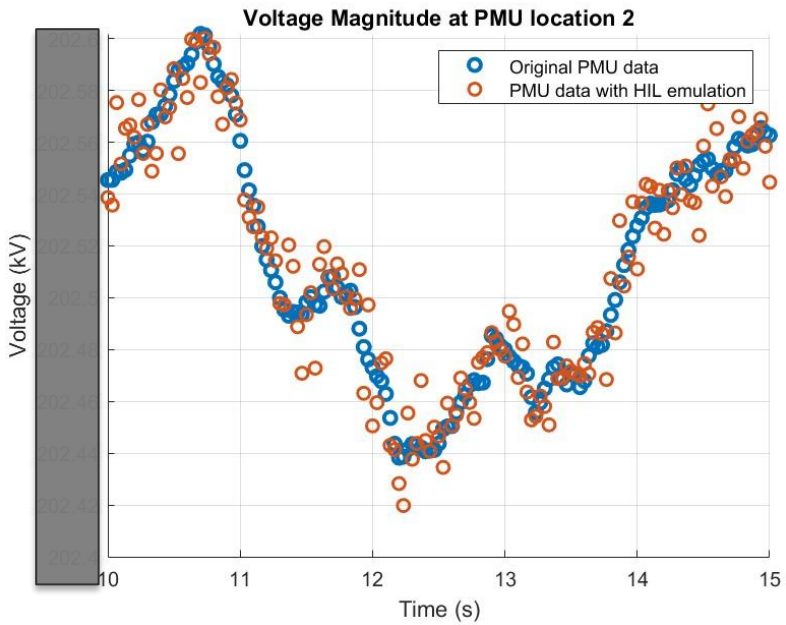


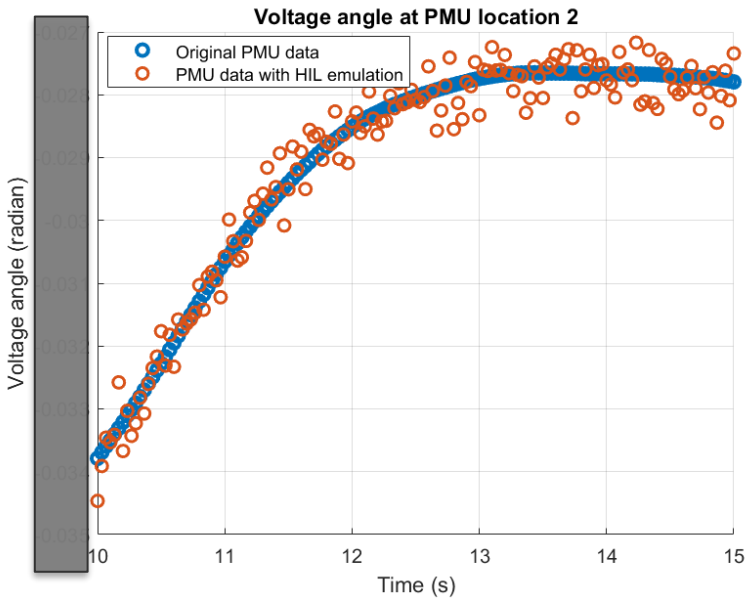
Comparison of Digital Twin Results with Field Measurements



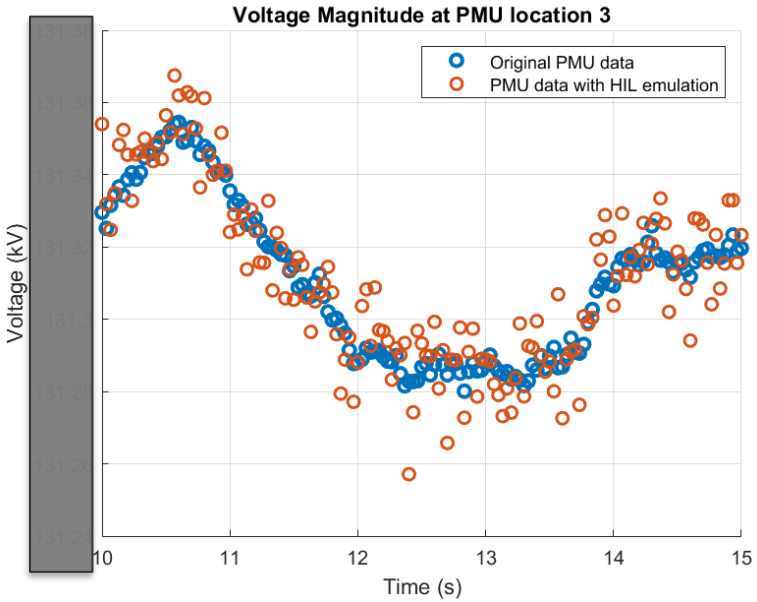


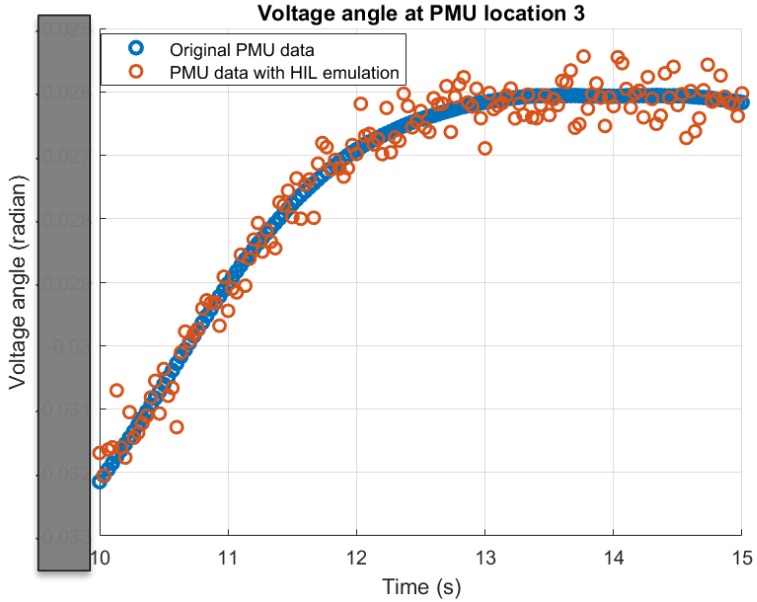
Model Validation : PMU location 2 measurements



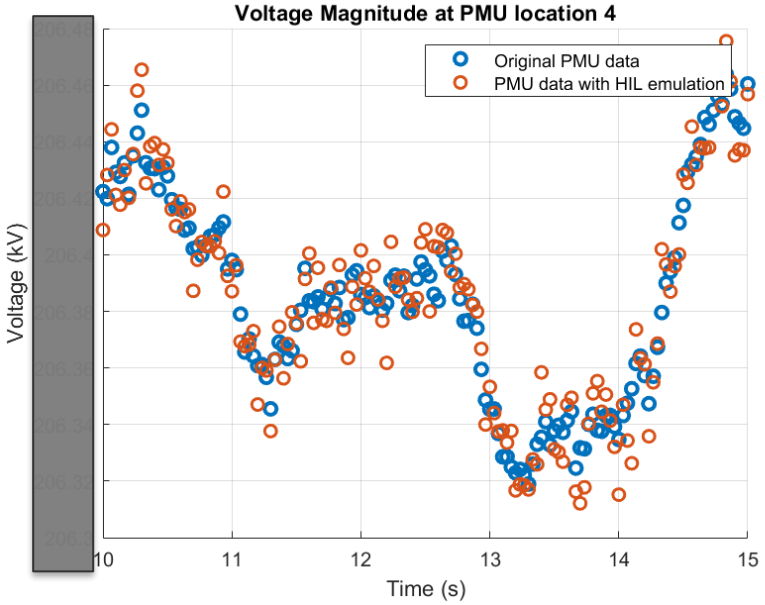


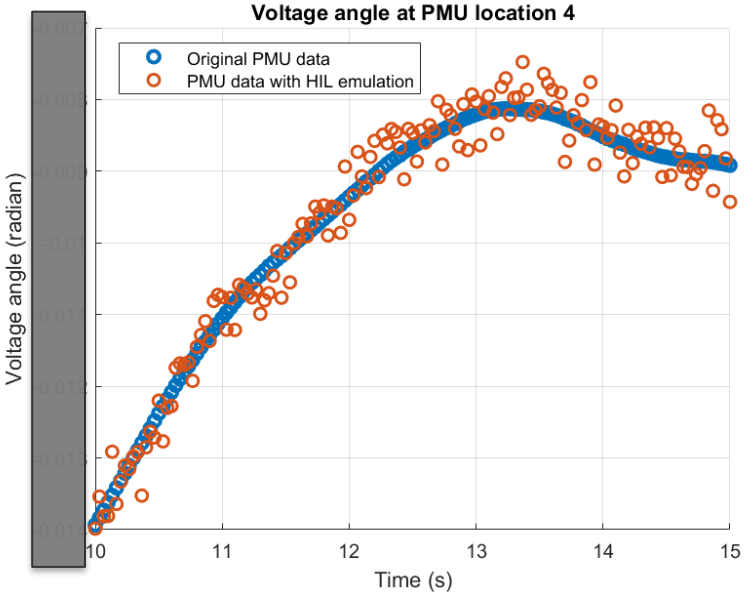
Model Validation : PMU location 3 measurements



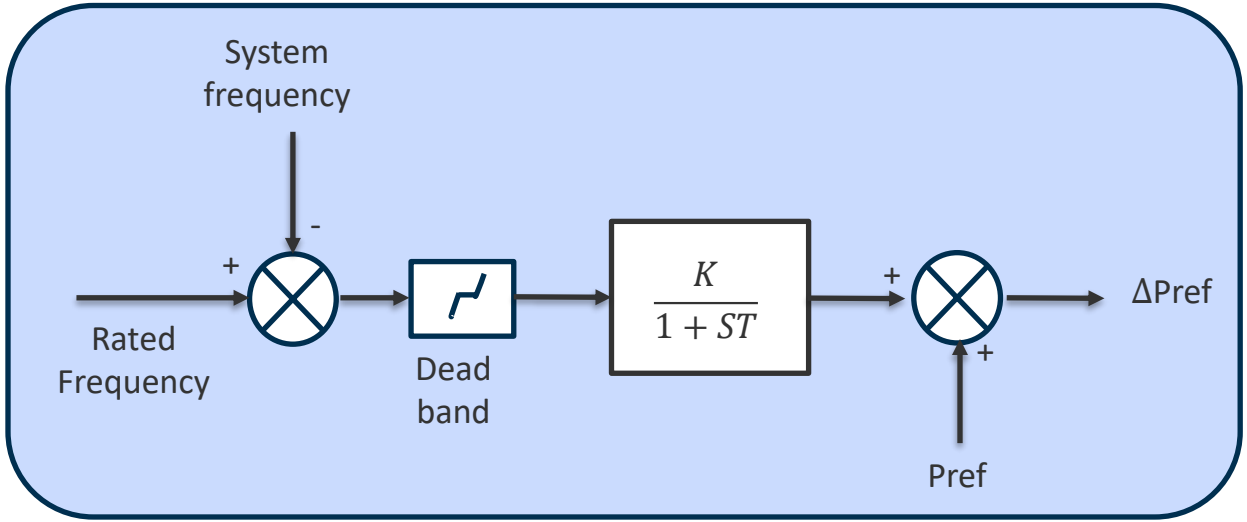


Model Validation : PMU location 4 measurements



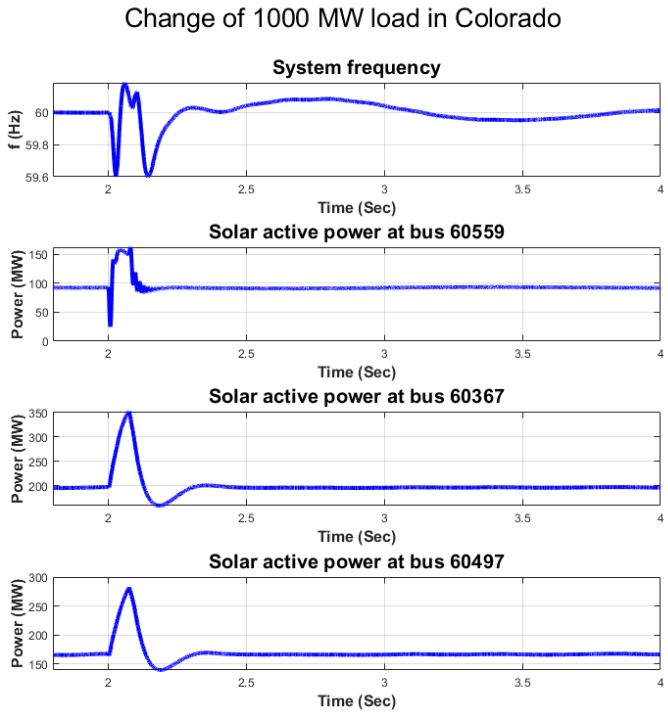


Frequency Control Using Droop PV

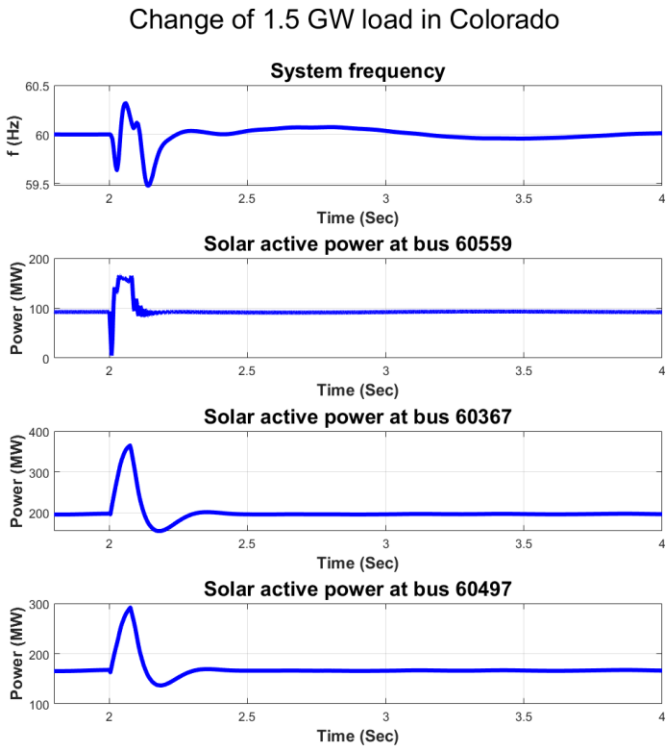


Droop control diagram

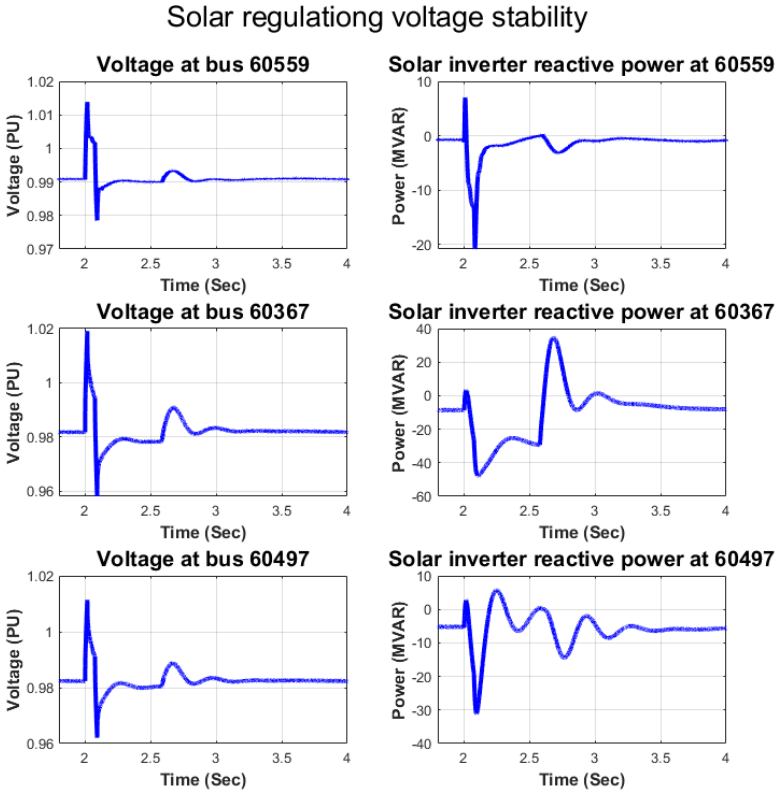
Frequency Response with 1000 MW Load Change



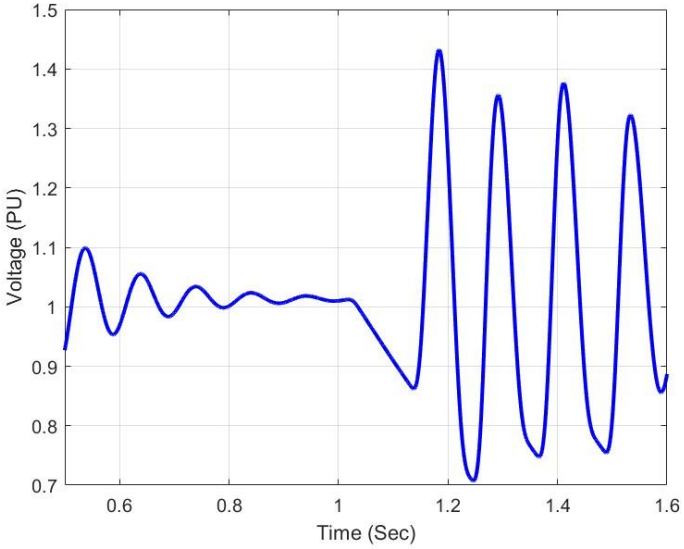
Frequency Response with 1500 MW Load Change

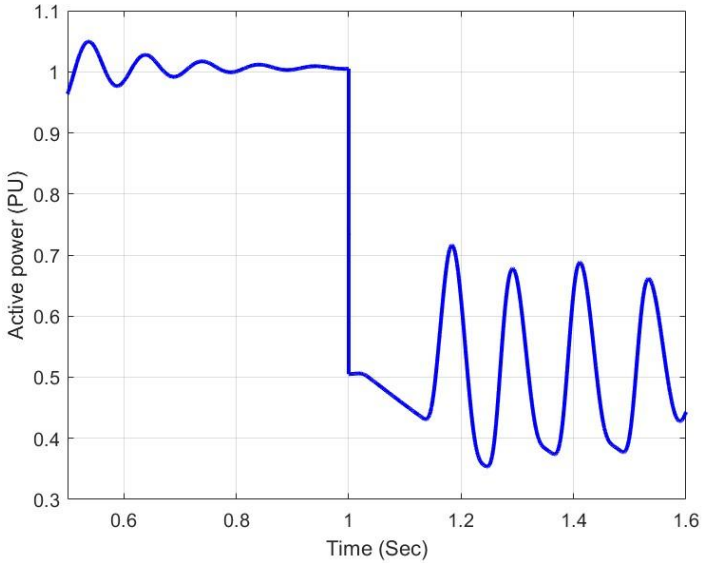


Voltage Control Using PV Reactive Power



Oscillations

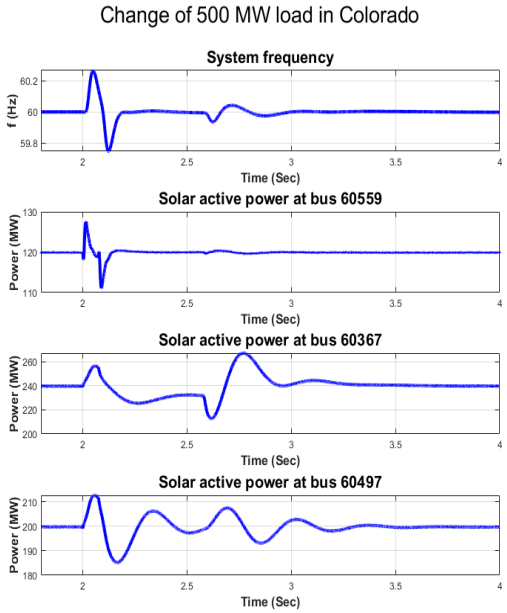


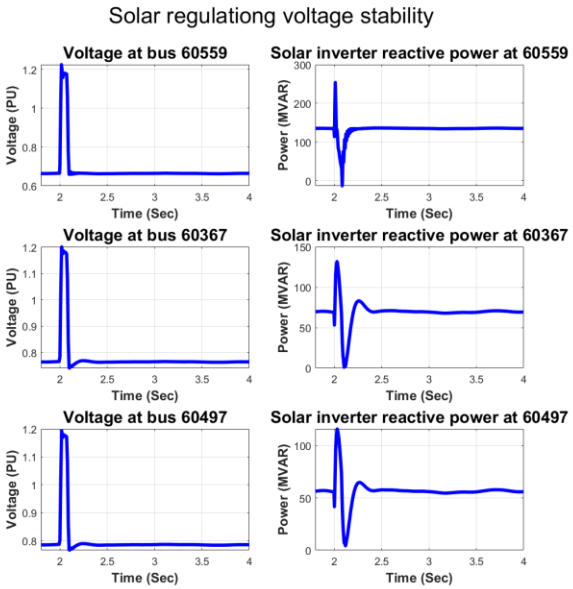


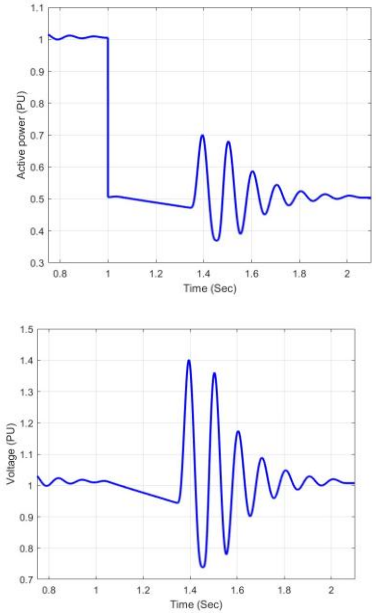
Oscillations during power grid has weak strength during PV ramp down event

Stability Analysis Using the DRTS Digital Twin

Analysis of Multiple What-if Scenarios and Control Design Using Digital Twin





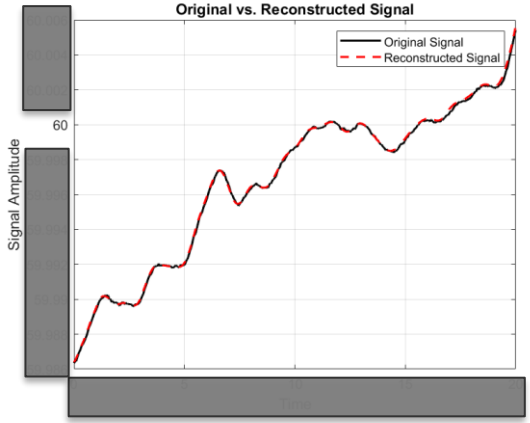


We can model multiple what-if scenarios, such as wildfires or scenarios similar to the 2021 ERCOT blackout. The digital twin will mimic the system and emulate field conditions.

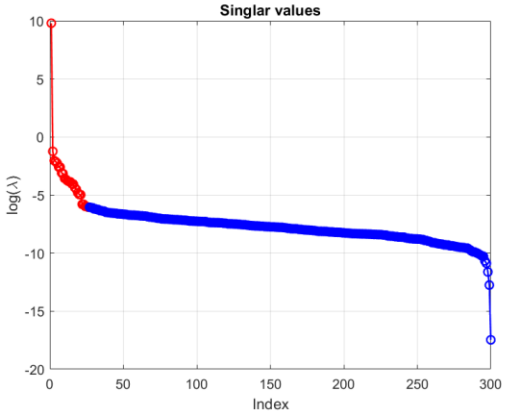
Data Visualization and Disturbance Monitoring

PMU Location 1 Signal

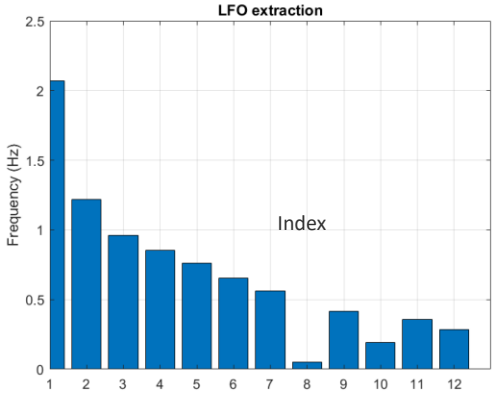
Event Year: 2019 Event Length: 20 Seconds



Signal reconstruction



Dominant singular values

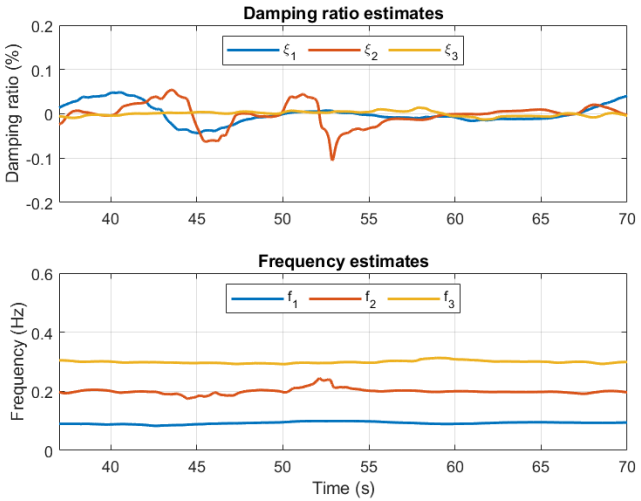


Frequency components

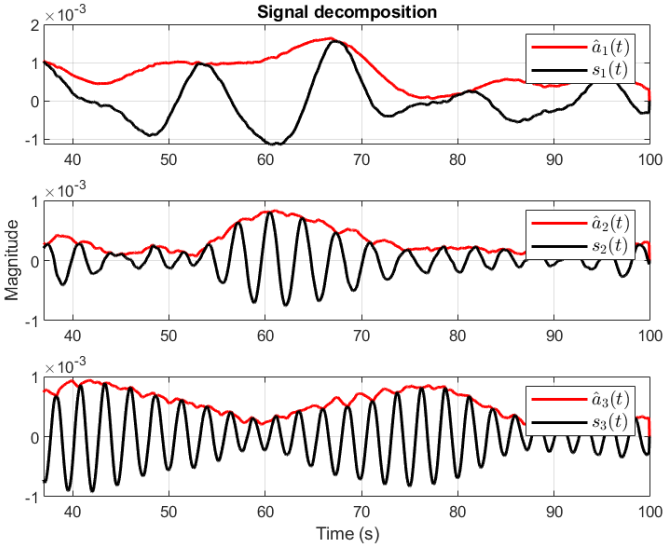
We have five years of WAPA historical data. Big data analytics can be used to capture system anomalies through fault signature detection.

PMU Location 5 Signal

Event Year: 2019 Event Length: 20 Seconds



Frequency and Damping Estimation



Signal Decomposition

We have five years of WAPA historical data. Big data analytics can be used to capture system anomalies through fault signature detection.

Conclusion

NREL has initiated the development of a digital twin of the WAPA/WECC network. NREL focused on emulating the entire WECC network, with a specific emphasis on the WAPA network, using DRTS assets at ARIES.

- Grid Optimization: Digital Twins emulate the behavior of the grid under various conditions, such as blackouts, wildfires, etc.
- Grid Planning and Design: Digital Twins can emulate the impact of new infrastructure, such as renewable energy sources, and the grid's design control architecture, enhancing reliability and efficiency. Capex analysis
- Derisking: Digital twins help derisk the deployment of new technologies, and enhance resiliency of power systems
- Training: Digital Twins can be used to train operators and engineers in a safe and controlled environment, reducing the risk of grid anomalies and improving overall grid system reliability.

Thank You

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Special thanks to Western Area Power Administrator Team