



# PROGRESS MATRIX: Analytical Methods and Stability Analytics Leveraging WAPA Practical Data using Digital Twin at NREL-ARIES

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October 15, 2024



## Introduction

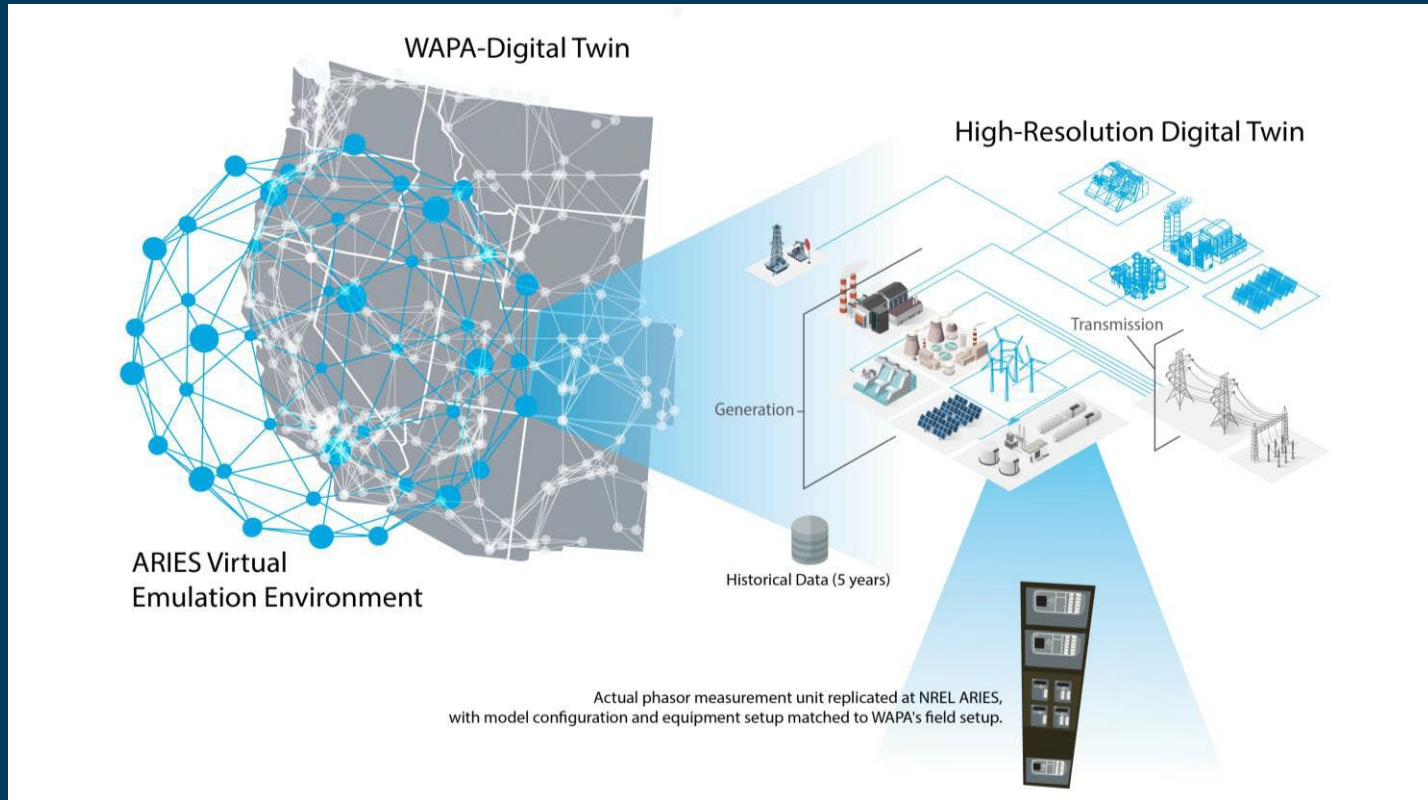
- Western Electricity Coordination Council (WECC)
  - Geographically the largest and most diverse of the six regional entities with delegated authority from the North American Electric Reliability Corporation (NERC) and Federal Energy Regulatory Commission (FERC)
- Western Area Power Administration (WAPA)
  - One of the four power administrations within the U.S. DOE

## 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

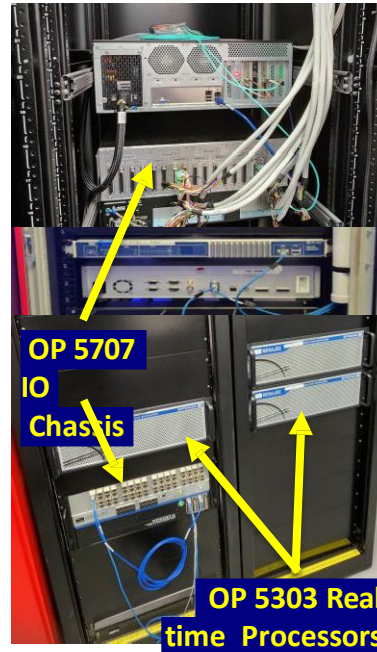
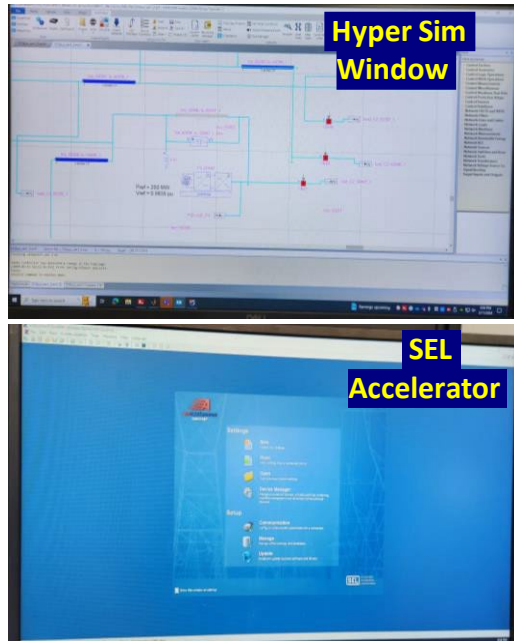


# ARIES Lab Setup Infrastructure

*Flatirons Campus*

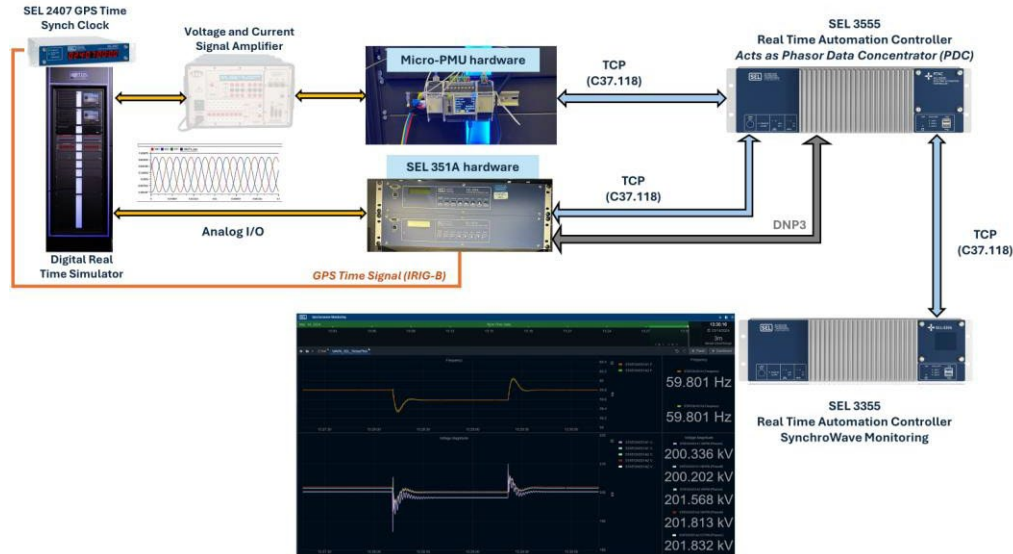


# WECC and WAPA Digital Twin



WECC and WAPA digital twin hardware leverages multiple ARIES assets.

# Real Time Automation Controller

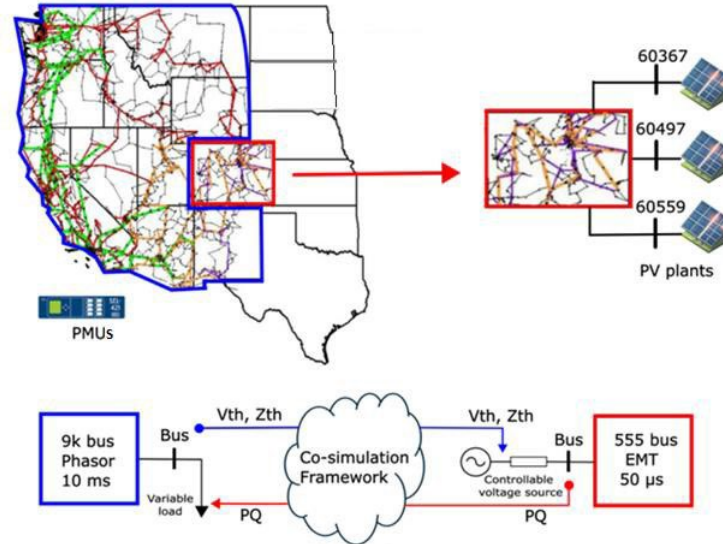


RTAC is used in utility grid for real-time monitoring and control applications

# WECC Digital Twin Setup

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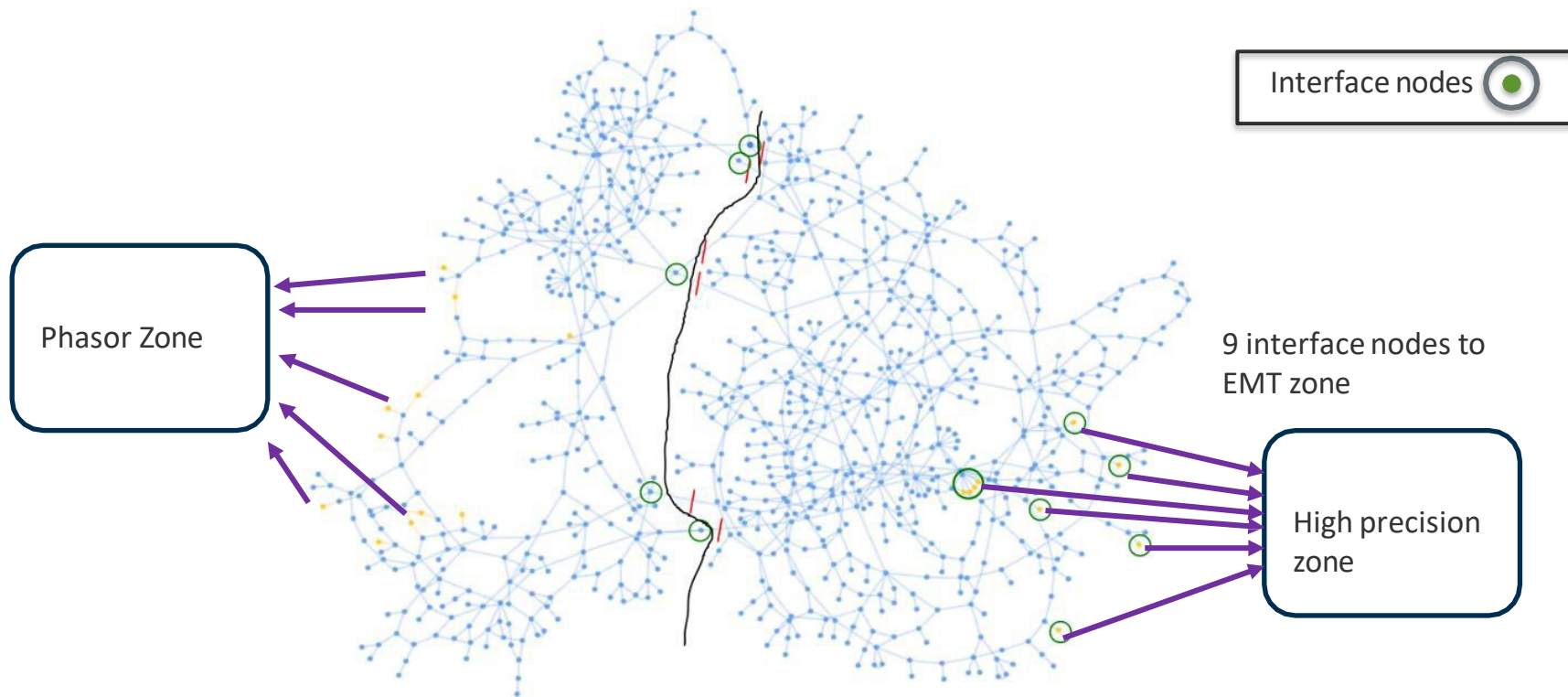
# At-scale WAPA and WECC Multi-Rate Emulation Setup Using the ARIES VEE



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

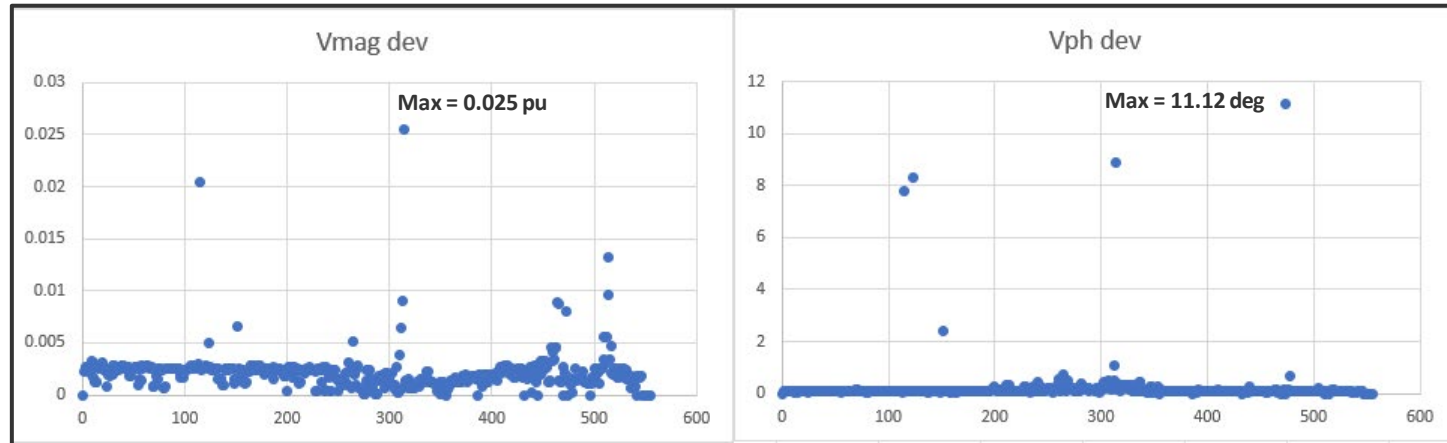
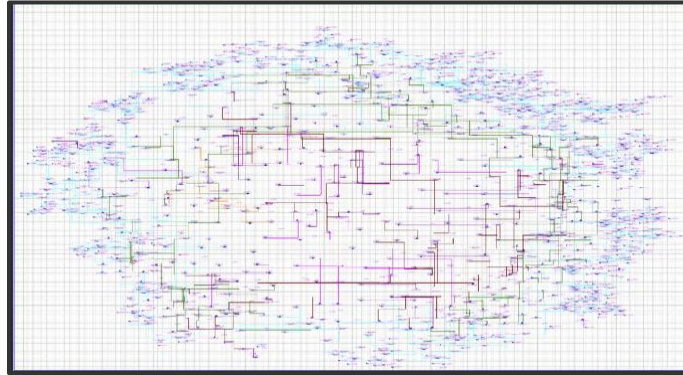


# WECC 10k-bus network – Portioning EMT Zone



WECC emulation can be achieved by creating multiple high-precision zones in DRTS

# Colorado Digital Twin – Load Flow Validation

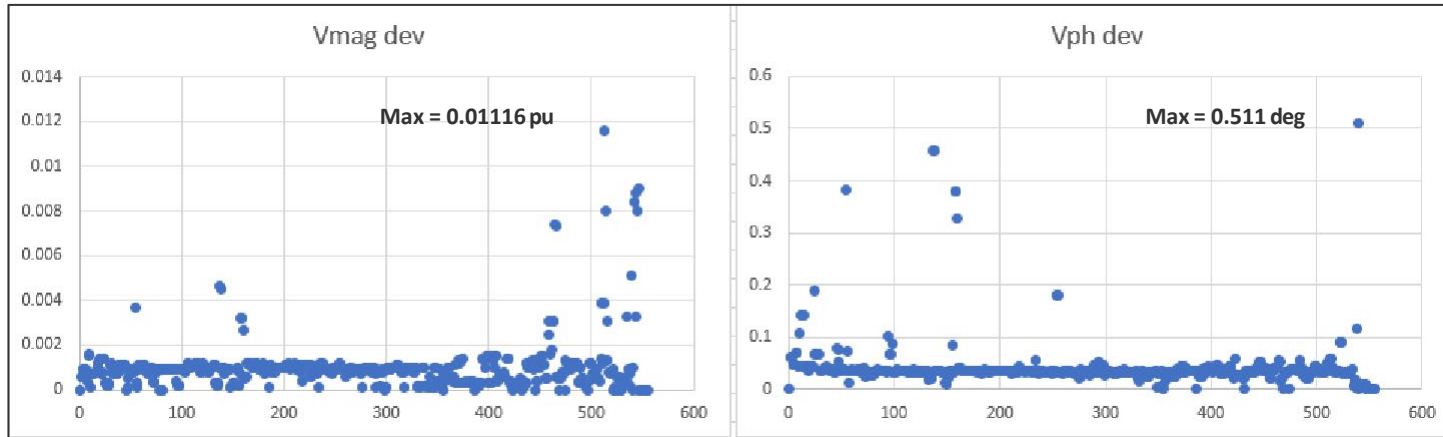


# Colorado EMT Zone: Load Flow Validation

10k-bus WECC  
ePhasorsim example

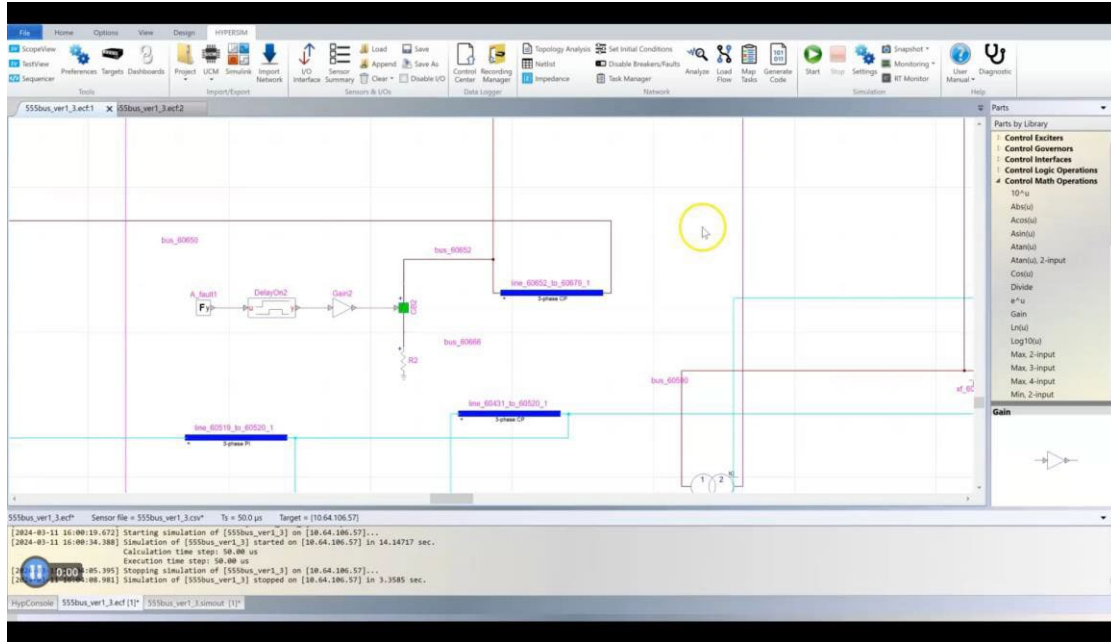


555-bus Colorado zone  
EMT portion



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

# WECC Fault Scenarios



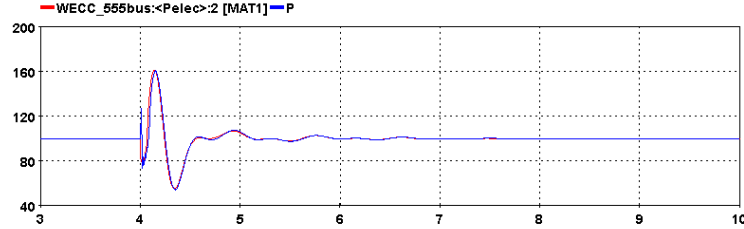
WECC faults (based on NERC reporting) are replicated in the hardware-in-the-loop setup, and PMU data collection is used for validation during anomalous grid operations.

Emulation of faults based on NERC reporting - By validating the digital twin, it will behave dynamically exactly the same as in the field in the laboratory-controlled environment.

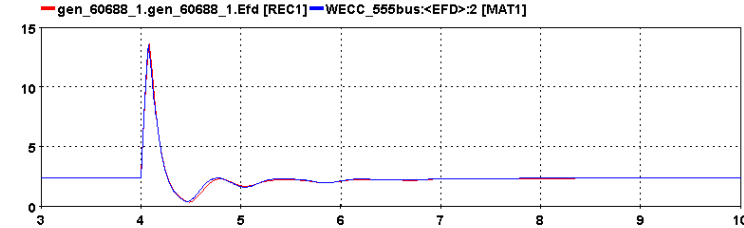
# Colorado Plus Region High Precision Zone: Generator Responses

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

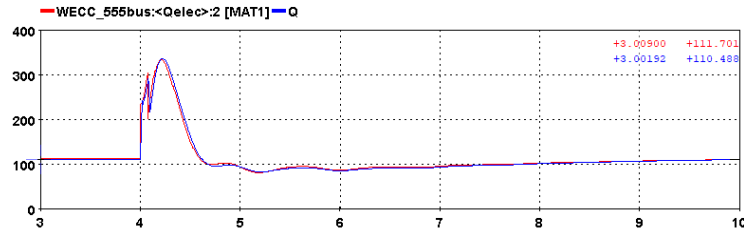
Active power



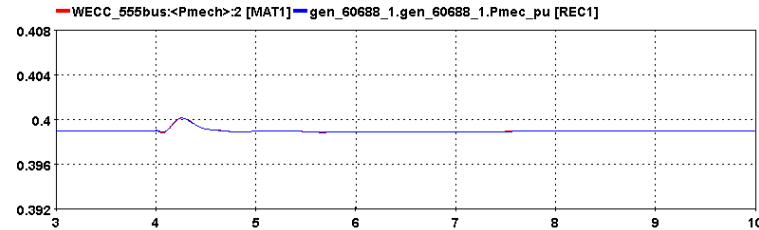
Field voltage



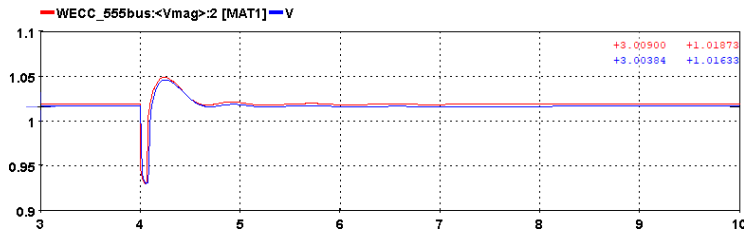
Reactive power



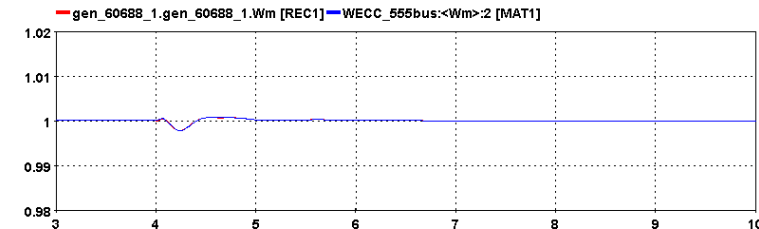
Mechanical power



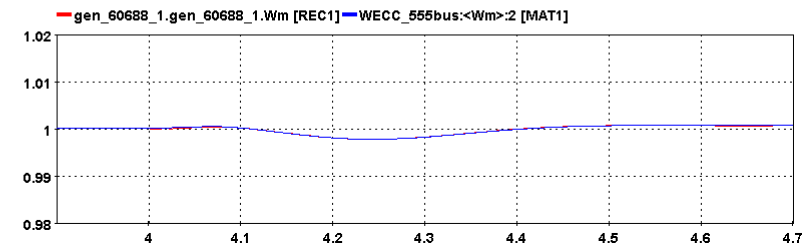
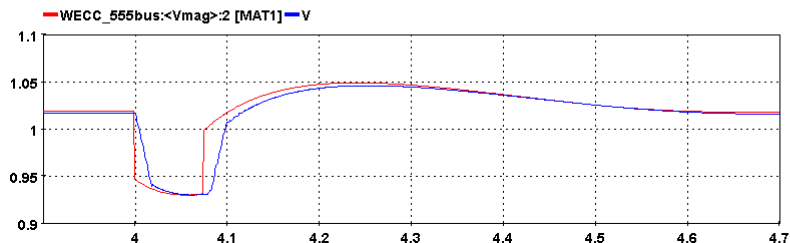
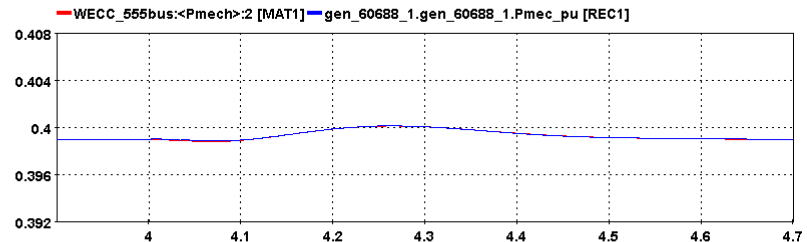
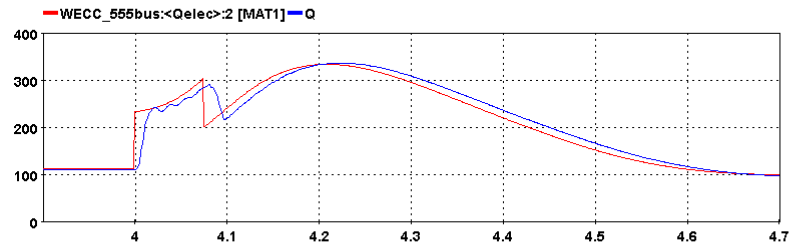
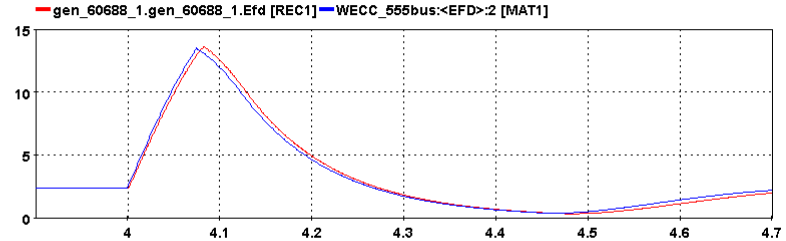
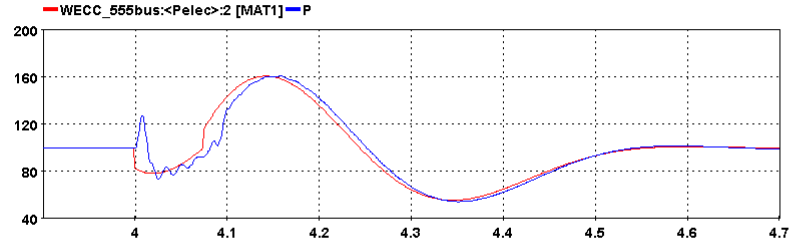
Voltage



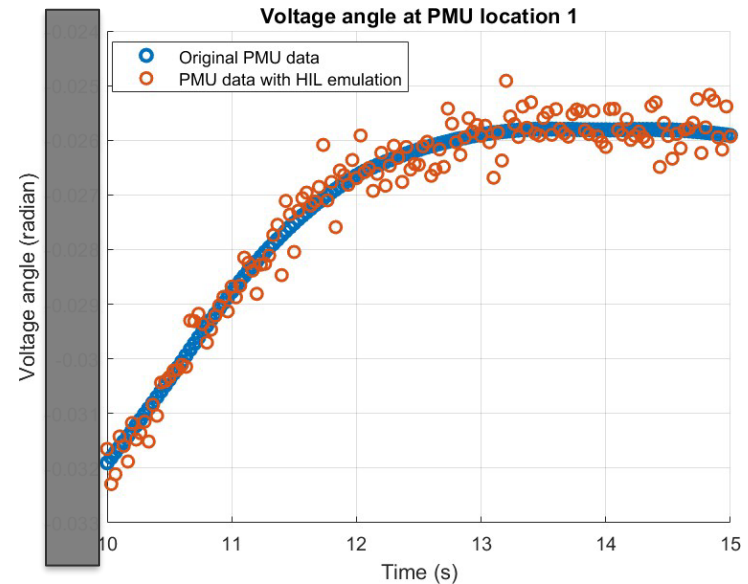
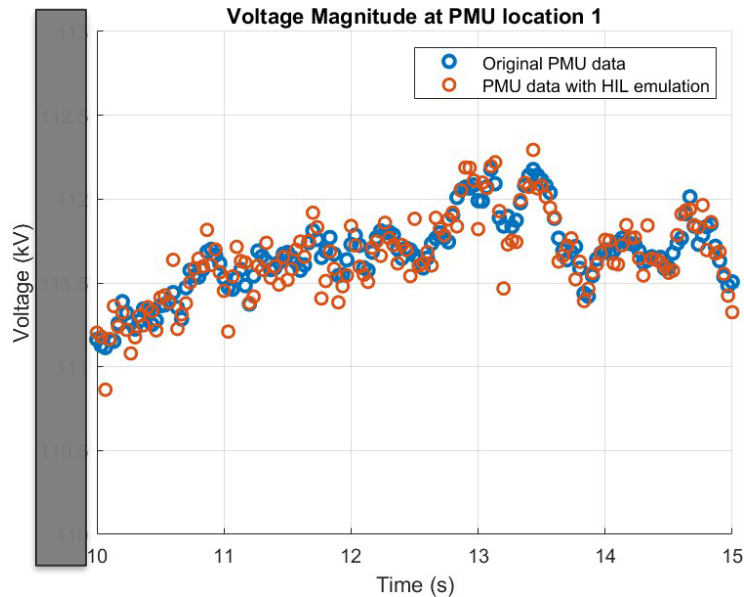
Speed



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



# Comparison of Digital Twin Results with Field Measurements



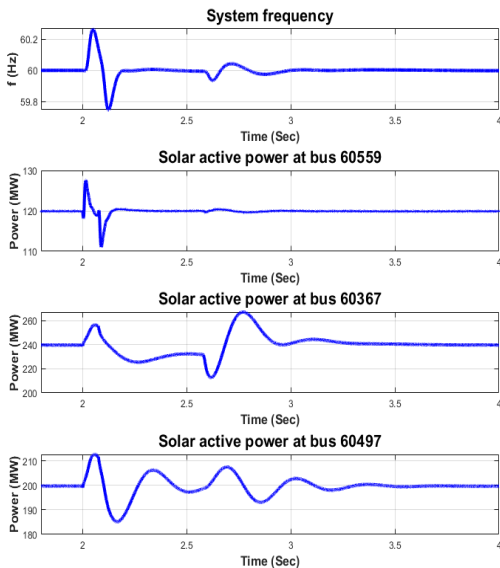


# Stability Analysis Using the DRTS Digital Twin

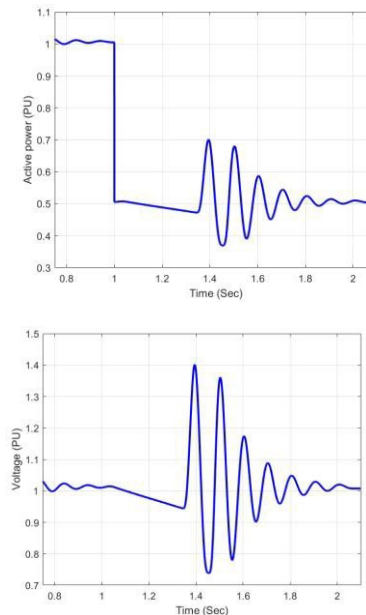
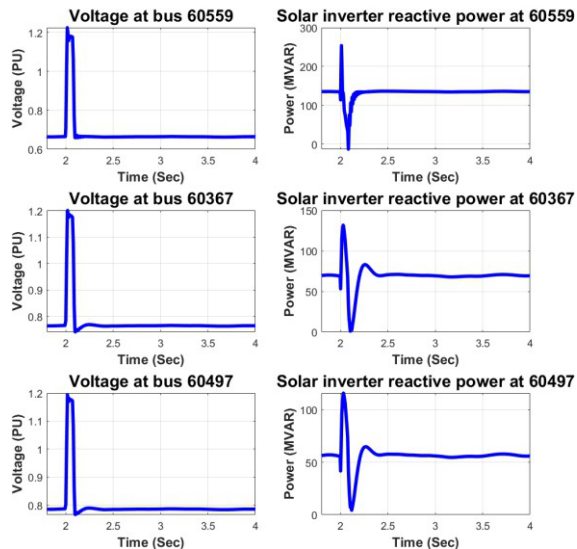
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## Using Digital Twin

Change of 500 MW load in Colorado



Solar regulation voltage stability

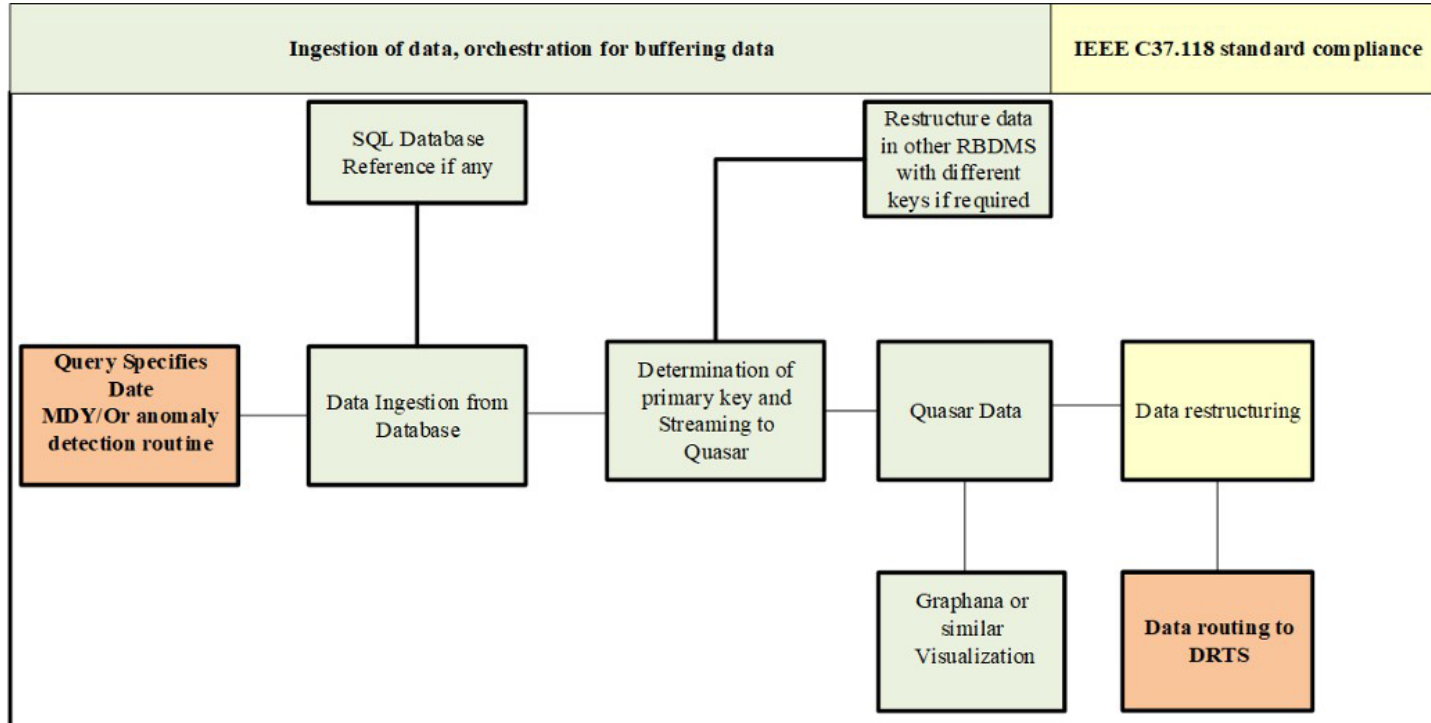


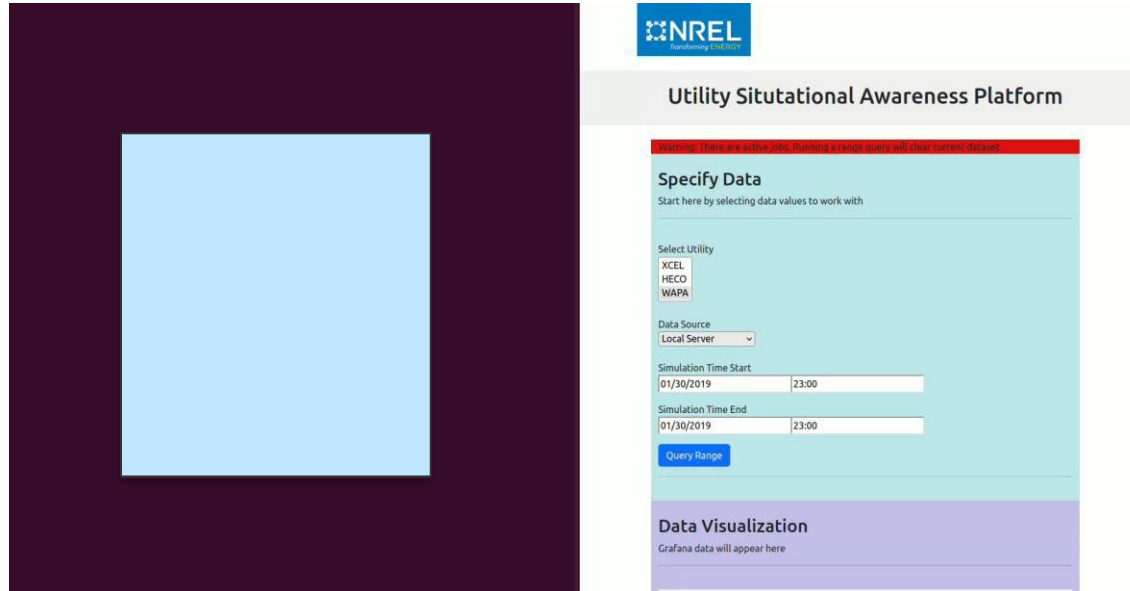
We can emulate multiple what-if scenarios, such as wildfires or scenarios similar to the 2021 ERCOT blackout. The digital twin will mimic the system and emulate field conditions.

# Data Visualization and Disturbance Monitoring

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# Data Ingestion Platform





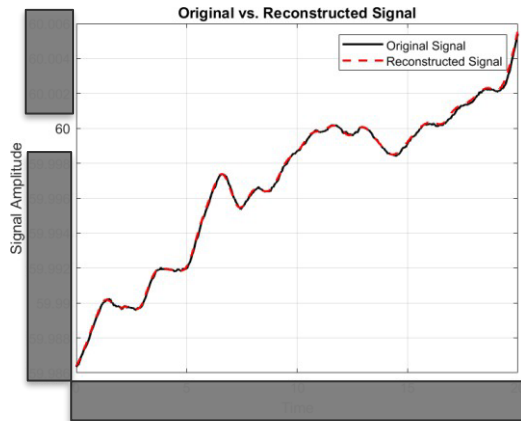
## Demonstration of the data ingestion platform

We have five years WAPA historical data. We can stream it to Digital Twin. This can be done for any large regional level utility.

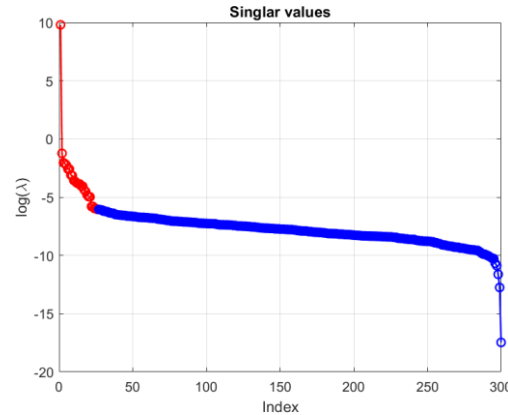
# PMU Location 1 Signal

Event Year: 2019

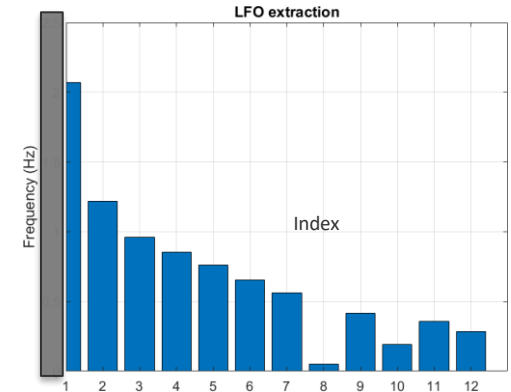
Event Length: 20 Seconds



Signal reconstruction



Dominant singular values



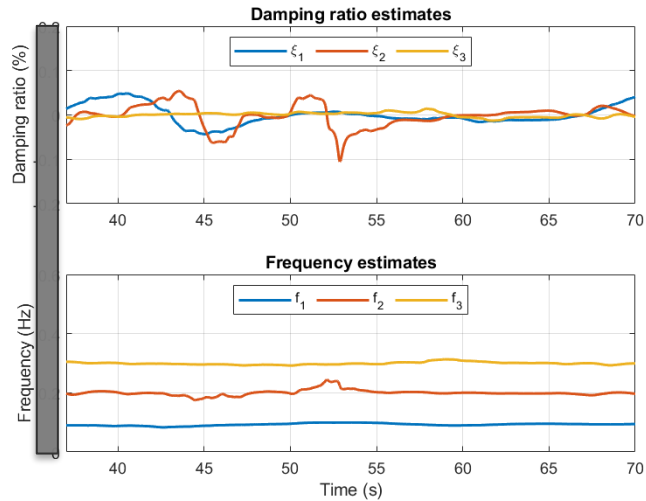
Frequency components

Big data analytics can be used to capture system anomalies through fault signature detection.

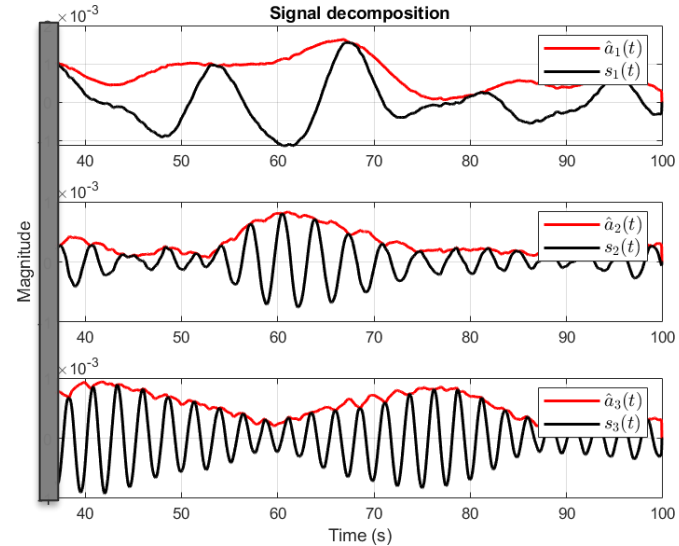
# PMU Location 5 Signal

Event Year: 2019

Event Length: 20 Seconds



Frequency and Damping Estimation



Signal Decomposition

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, focusing on emulating the entire WECC network with a specific emphasis on the WAPA network. This is being done using DRTS assets at ARIES.

- **Grid Resiliency and 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 renewable energy sources and support the design of grid control architecture, enhancing the grid's reliability and efficiency. They can also support the capex analysis of grid infrastructure.
- **Derisking:** Digital twins help derisk the deployment of new technologies.
- **Training:** Digital Twins can be used to train operators and engineers in a safe and controlled environment to reduce the risk of grid anomalies and hence can improve the overall grid system reliability.







*Special thanks to US DOE Solar Energy Technology Office,  
Office of Electricity.*

*Special thanks to Western Area Power Administrator Team*

