Oak Ridge National Laboratory

New York State | Advanced Grid Innovation Laboratory for Energy

A Digital Service of the New York Power Authority

Real-Time EMT Simulations of Large-Scale Power Grids: A Case Study of New York State Power Grid

Advanced Grid Innovation Laboratory for energy (AGILe)

New York Power Authority

U.S. DEPARTMENT OF ENERGY

Introduction/Context

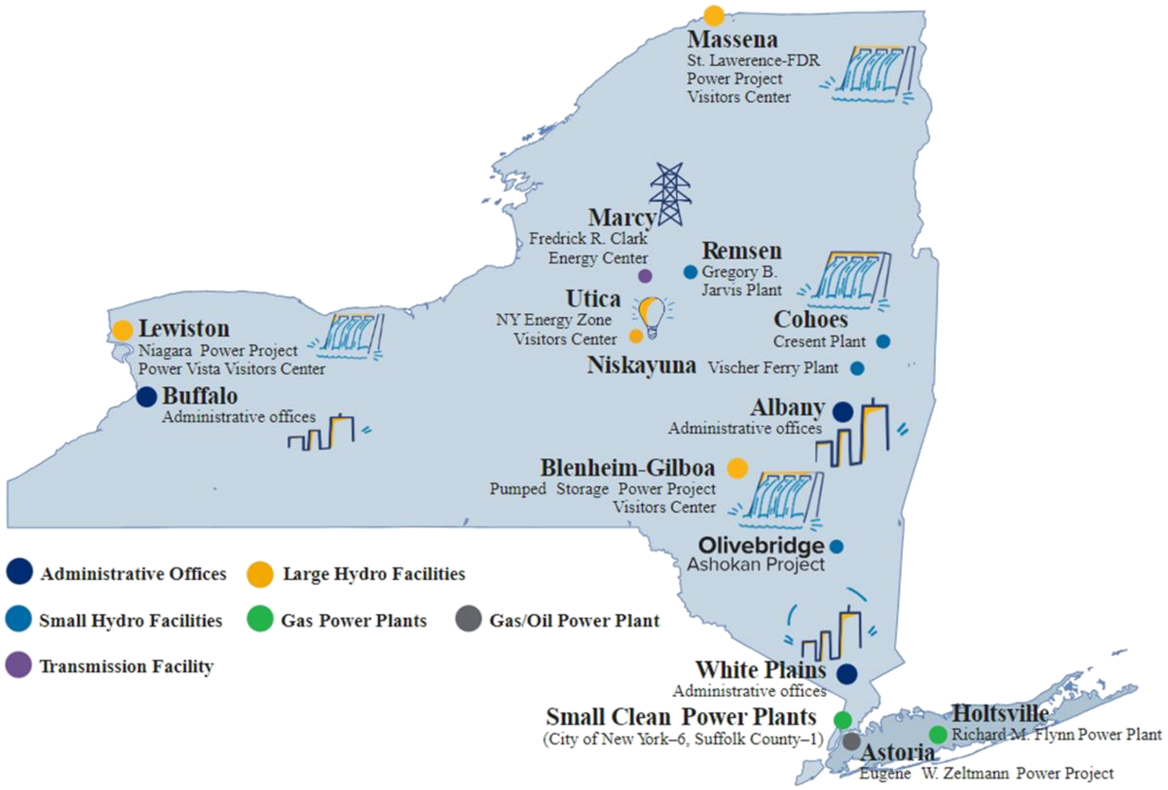
New York Power Authority (NYPA)

Established by the NY State Legislature in 1931, and NY State Canals is a subsidiary since 2017.

NYPA is the largest state public electric utility in the United States.

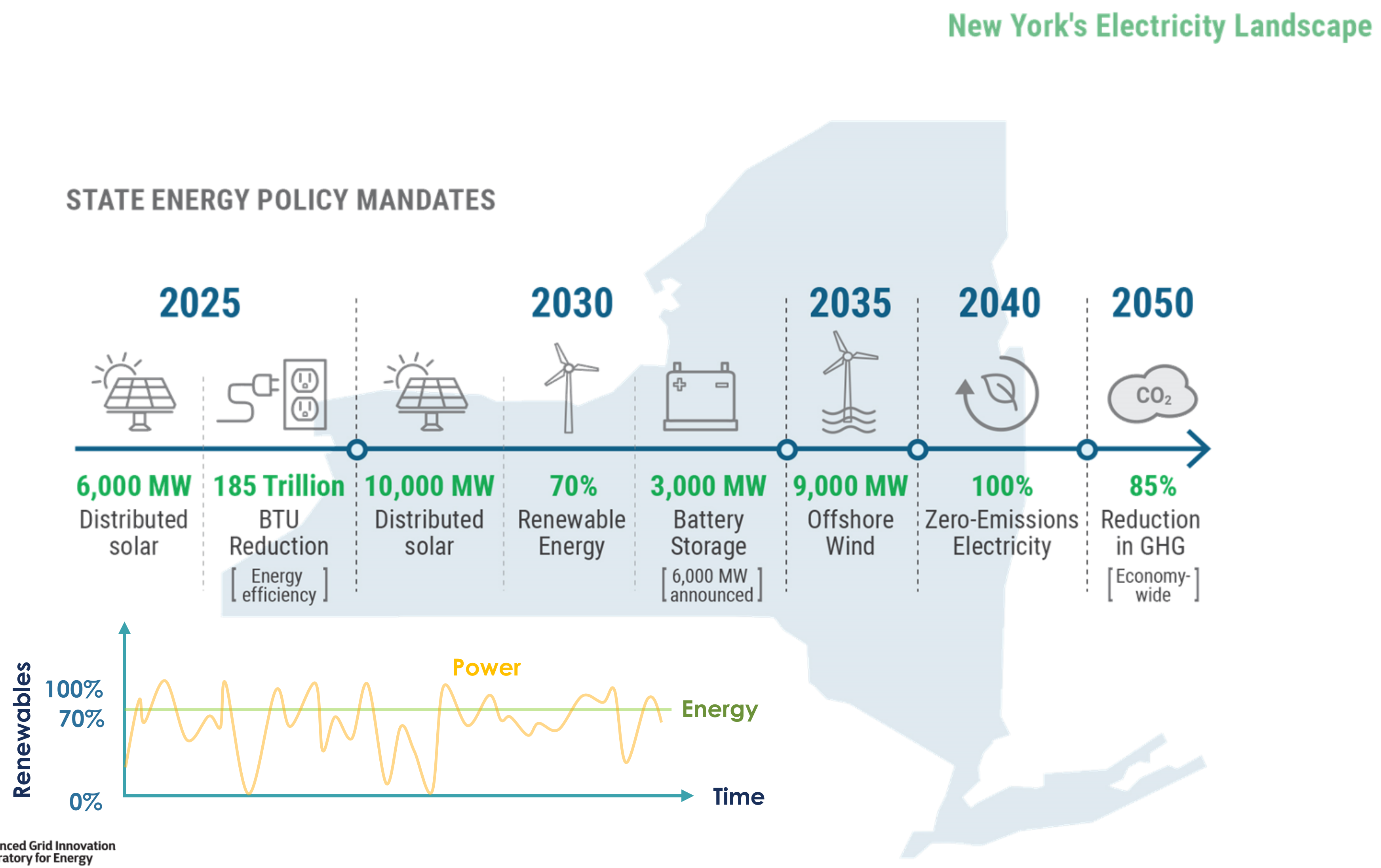
Generation assets: 16 hydro and natural gas generation plants (~6GW, 80% hydro and 20% gas)

Transmission assets: Portion of bulk NYS power grid (115kV ~ 765kV)



Challenges with State Targets

New York's Low- to No-Carbon Future: State Targets



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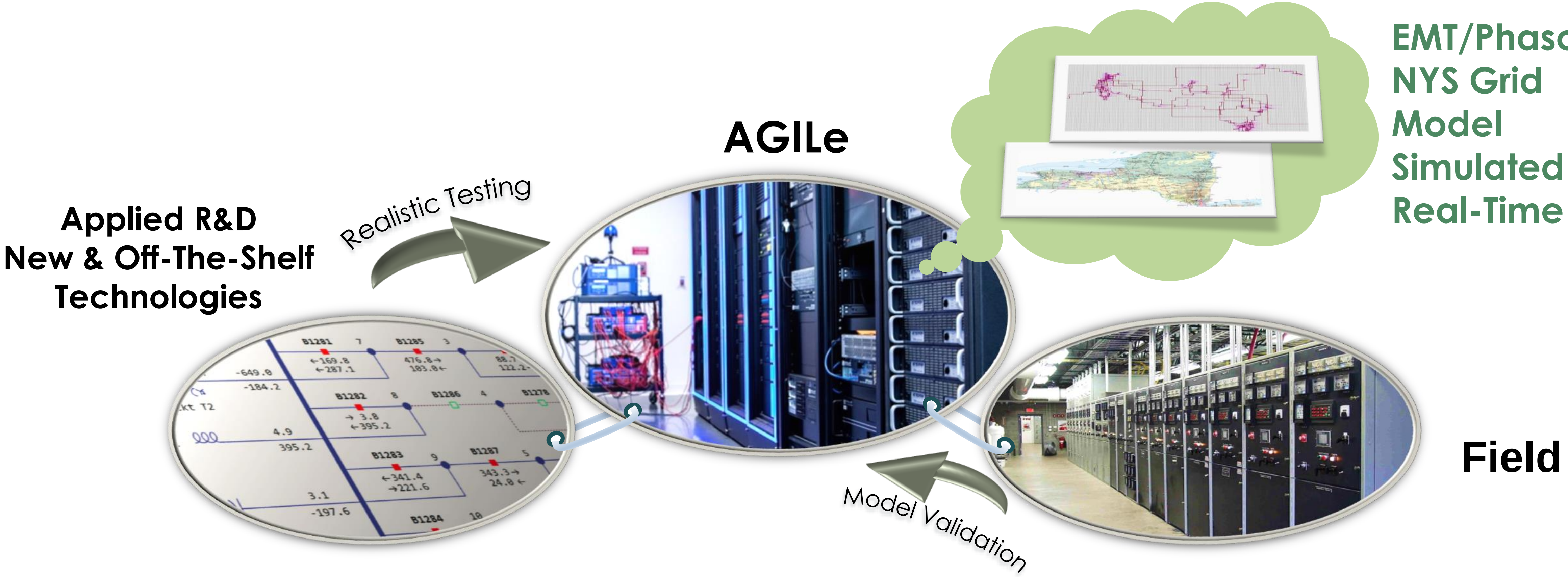
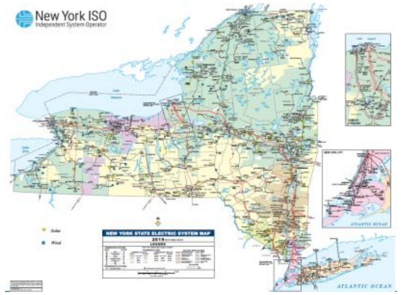
NYPA's AGILe

Enabling an Affordable, Reliable, Low-Carbon Future



Technologies cannot be deployed w/o thorough testing in a close-to-real environment.

NYS Grid Suite of Models in AGILe



2019
- Positive-sequence (PS) model in ePHASORSIM

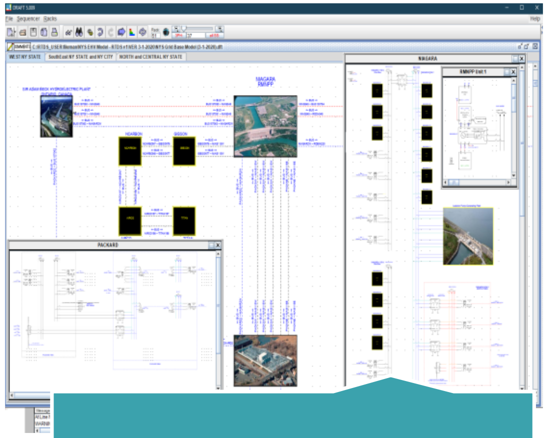
2022
- Multi-regional EMT models of 34.5kV+ power systems

2018
- EMT models of 230kV+ NYS trans. systems in RTDS and HYPERSIM

2021
- Regional EMT models of 34.5kV+ power systems
- Regional EMT-PS hybrid simulation models

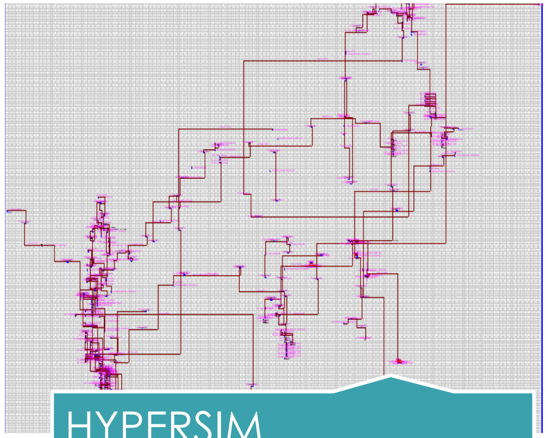
2025
- Digital twin of NYS Power Grid – including full NYS grid EMT model

Developed EMT Models of the NYS Power Grid



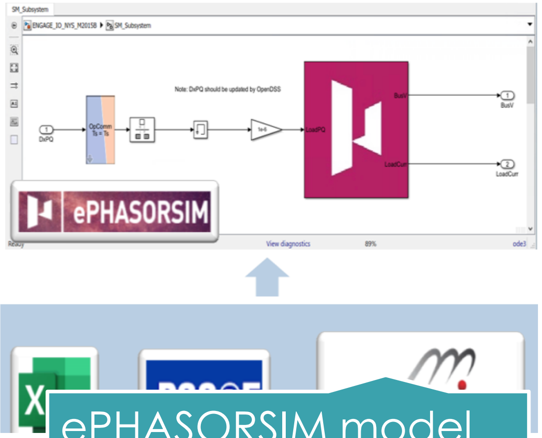
RTDS NYS model

RTDS regional & multi-regional models



HYPERSIM

- Network split on 9 cores

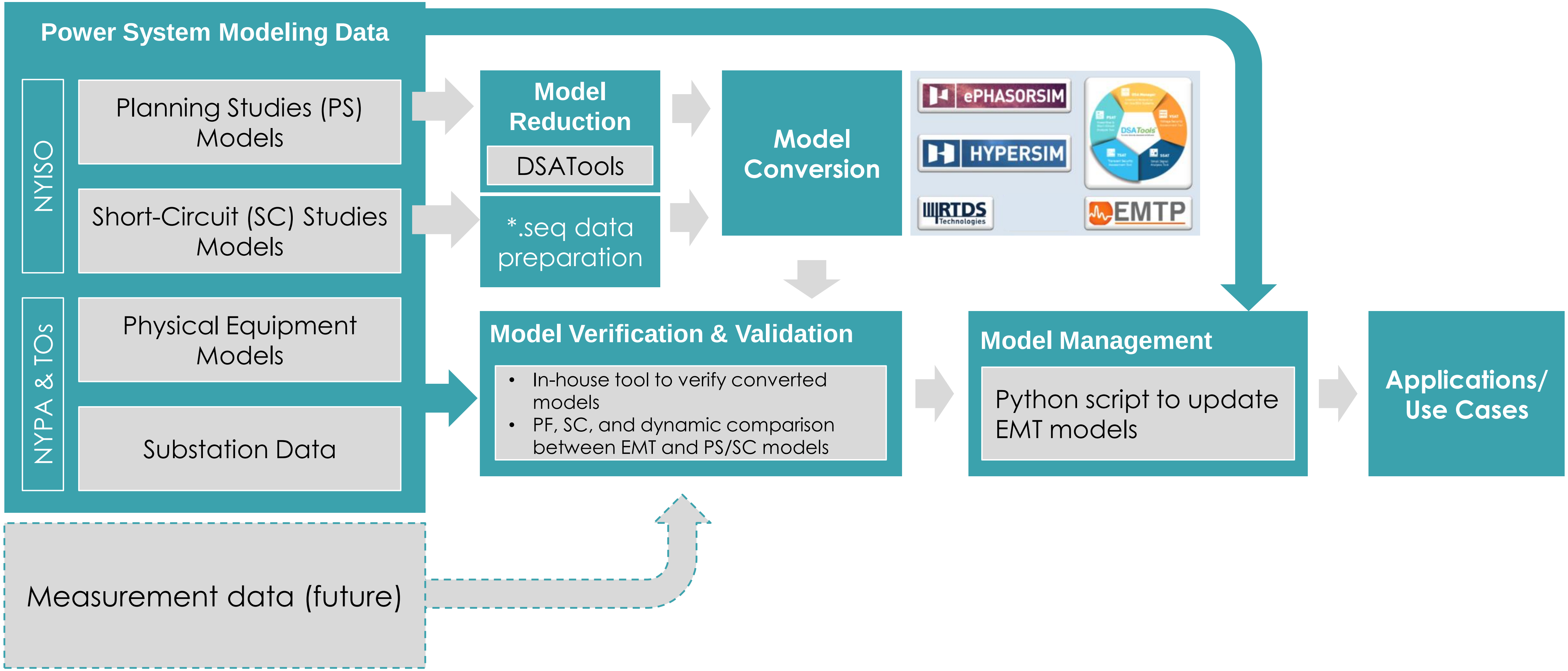


ePHASORSIM model

- Can be used for hybrid sim.

- Use of hierarchy boxes to facilitate component organization
- Utilization of color coding for different voltage levels
- Regional & multi-regional models:
  - cover all voltage levels from 765 kV down to 34.5 kV levels
  - ability to utilize as stand alone “pieces” or in hybrid EMT-PS simulation environment

Process to Develop EMT Models

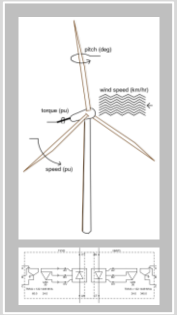


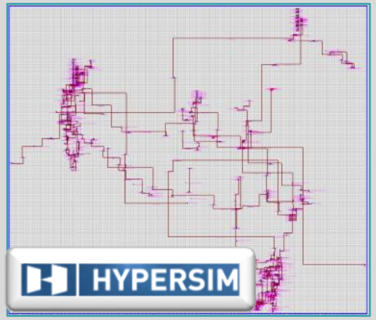
AGILe Technology Stack

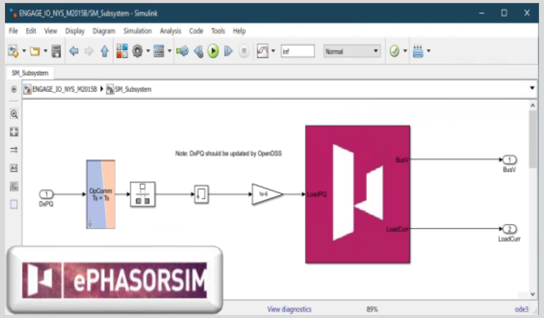
Capabilities Outcomes

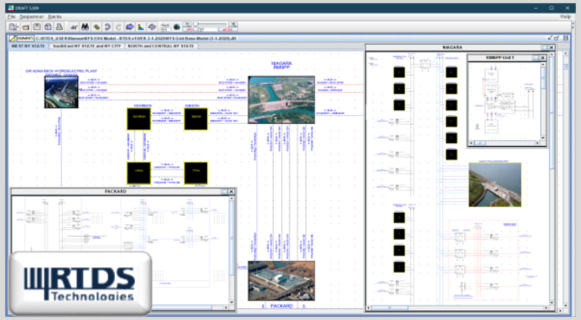
- Grid Modeling and Simulation
- Real-time hardware & software in the loop simulation
- Communication Network Emulation
- Economic Analysis
- Application Development
- Hardware Testing

NYS Grid Models & Data









Apps

OpenDSS	PSCAD	PSSE	EMTP	MatLab	DSATools
CYME	RSCAD	HYPERSIM	ePhasorSim	EXATA	GE-MAPS

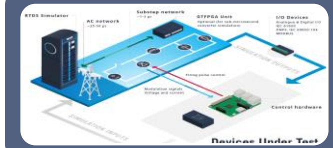
Servers Simulators

RTDS	OPAL-RT	TSAT Server	Communications Emulator	MAPS Server	Work Stations

Hardware Devices

Relays	Intelligent Electronic Devices	Amplifier	GPS Clock	Substation Mockup

AGILe Use Cases and Applications

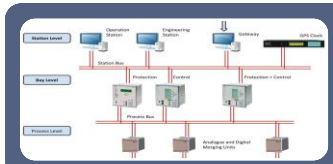


Equipment Configuration and Testing

- Test equipment in realistic field conditions
- Validate the performance of novel technologies

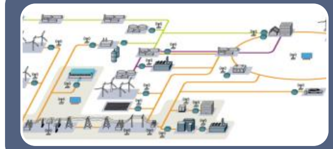
Novel System Protection Schemes

- Validate protective relaying behavior and settings
- De-risk novel protection schemes



Digital Substation and IEC 61850

- Create replicas of substation intelligent electronic devices
- Perform closed-loop testing using communication protocols



Distribution Automation and DERMS

- Simulate the performance of distribution automation system
- Integrate distributed energy resources and storage

Cyber Security

- Create testbeds used for tabletop exercises
- Evaluate and test intrusion detection and mitigation schemes

Economic Analysis and Evaluation of Technical Solutions

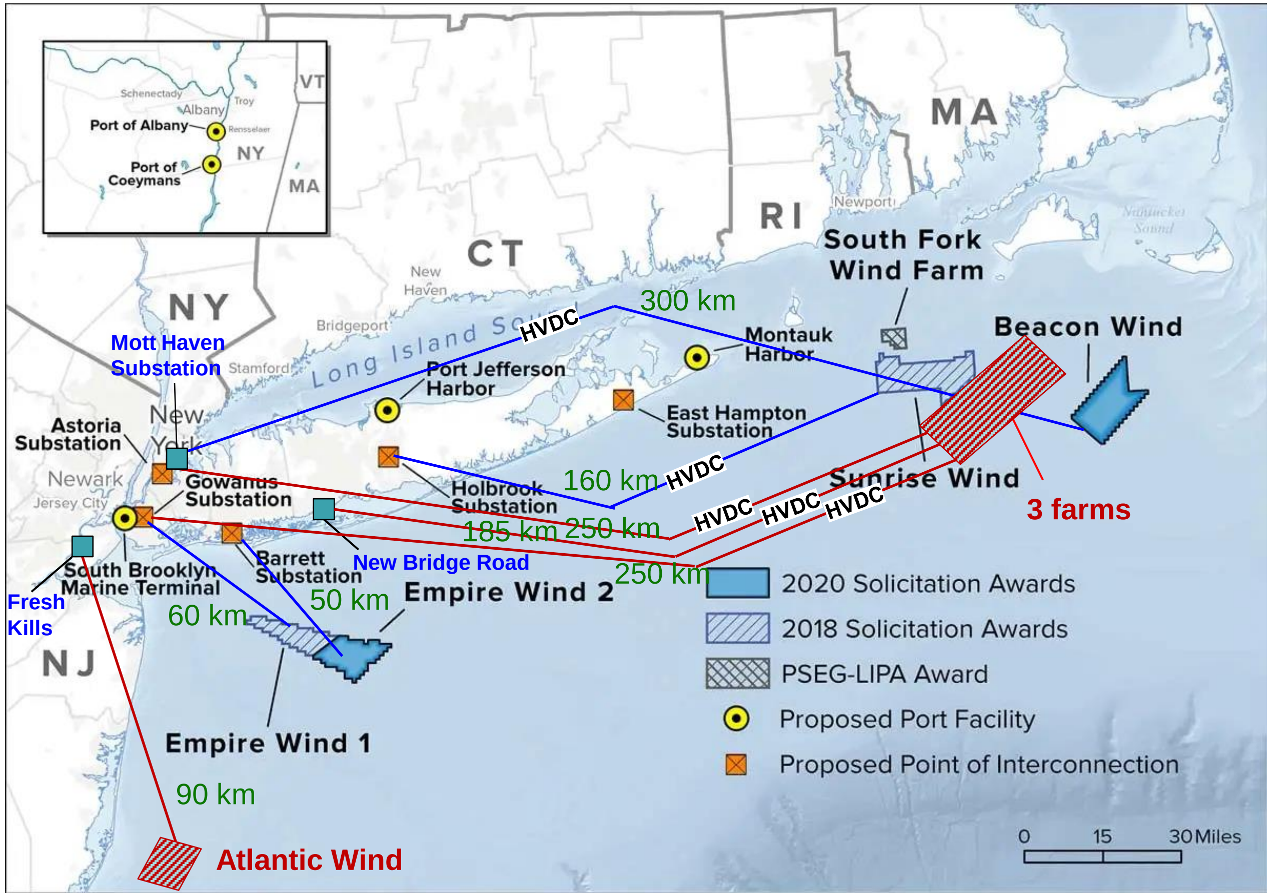
- Production cost modeling
- Economic impacts of upcoming technologies

Use Cases of Multi-regional EMT Models

Real-Time Interconnection Studies and Control of New York Offshore Wind

- Joint research project by Clarkson University and NYPA, funded by NYSERDA.
- Full EMT modeling and simulation: NYS power grid on RTDS and 9GW offshore wind on Opal-RT
- 9GW offshore wind models in Opal-RT:

No	POI	Capacity (MW)	Transmission line	Length (km)	Turbine Model	Wind Farm Model
1	Mott Haven 345kV	1400	DSW-HVDC	250	AVG	Aggregated
2	New Bridge Road 138kV	1325	DSW-HVDC	185	AVG	Aggregated
3	Astoria West 138 kV	1230	DSW-HVDC	300	AVG	Aggregated
4	Gowanus 345kV	1200	DSW-HVDC	250	AVG	Aggregated
5	Barrett 138 kV Substation	1260	HVAC	50	**DSW**	Aggregated
6	Holbrook 138kV	924	DSW-HVDC	160	AVG	Aggregated
7	Fresh Kills 345kV	880	HVAC	90	**DSW**	Aggregated
8	Gowanus 345kV	816	HVAC	64	DSW	Disaggregated

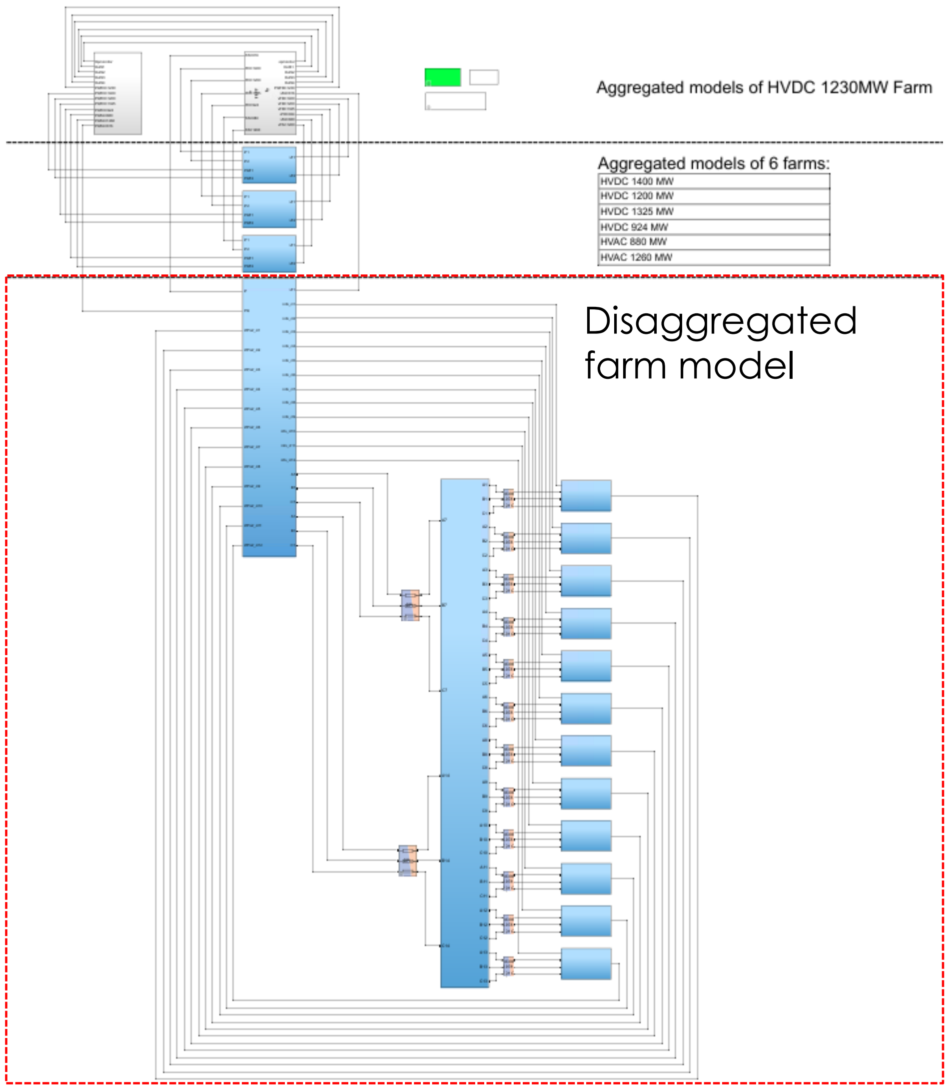


New York Bight Task Force Wind Developer Project Summaries (boem.gov)

Use Cases of Multi-regional EMT Models

Real-Time Interconnection Studies and Control of New York Offshore Wind

- Modeling technique to improve computation:
  - Model reference
  - Multi-time-step simulation
  - Parallelization
- WTG model validation against IEEE 2800 Std. was performed.
- 9GW model requires 18 cores:
  - One disaggregated farm including 68 DSW WTGs uses 14 cores.
  - 7 aggregated farms use 4 cores.

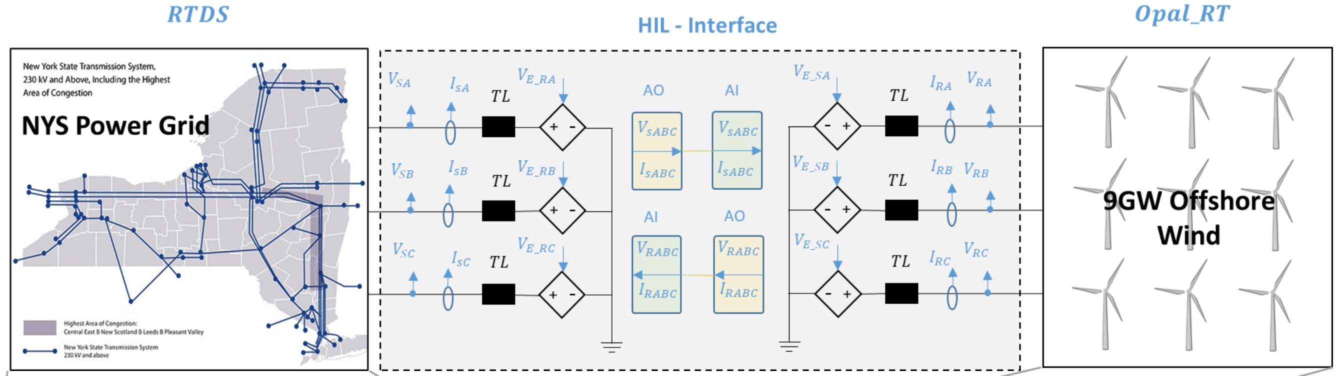


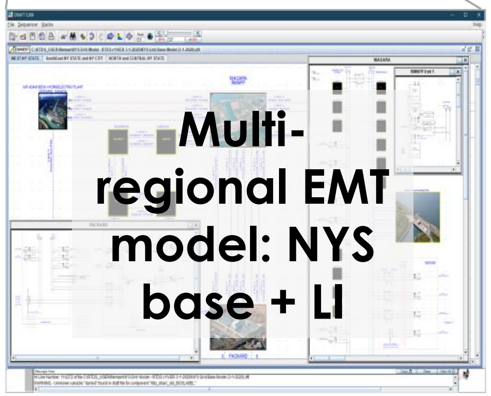
9GW offshore wind model in Opal-RT for RT co-simulation

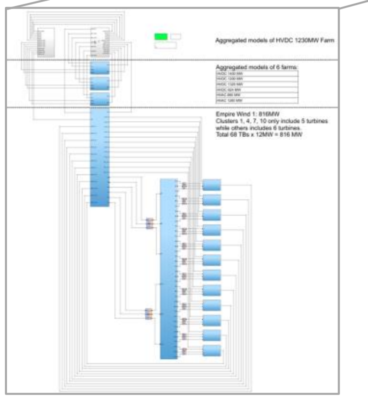
Use Cases of Multi-regional EMT Models

Real-Time Interconnection Studies and Control of New York Offshore Wind

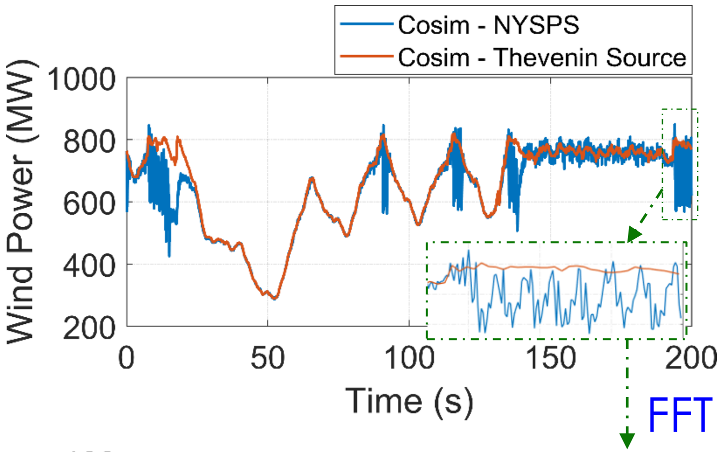
- 50 cores of RTDS are used to run the NYS power grid EMT model: NYS base + Long Island region
- TLM-based HIL interface was developed to conduct real-time EMT co-simulation (Opal-RT & RTDS).
- Reveal SSO risk when performing full EMT simulation (Entire NYS power grid & wind farms).

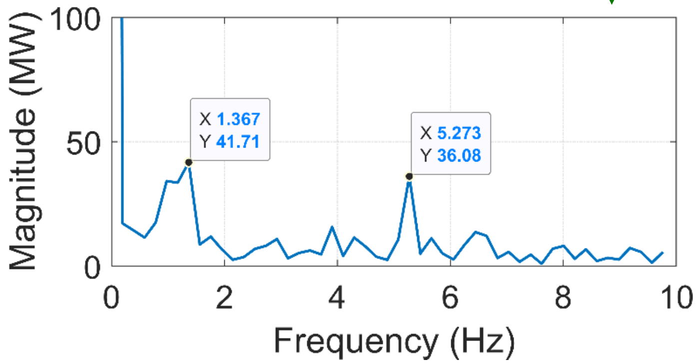






- 8 farms
- Aggregated & dis-aggregated WF models
- AVG & DSW TB models
- HVDC & HVAC connection

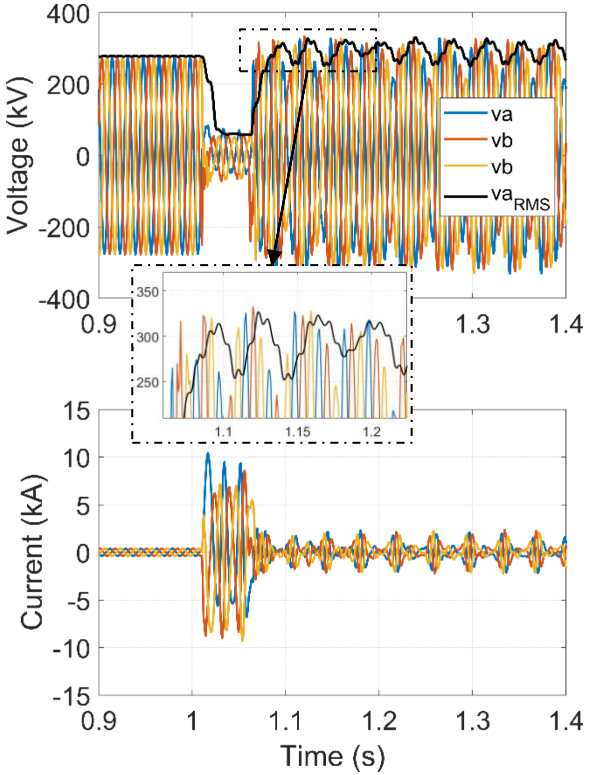




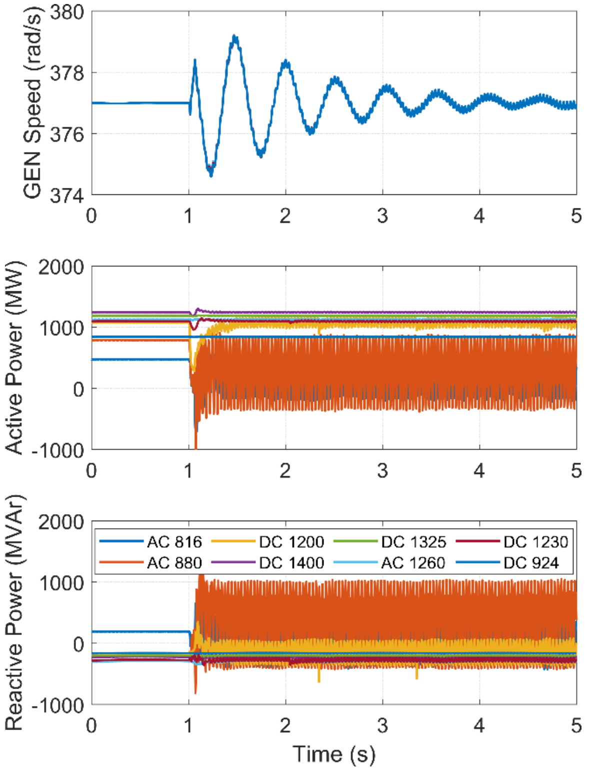
Use Cases of Multi-regional EMT Models

Real-Time Interconnection Studies and Control of New York Offshore Wind

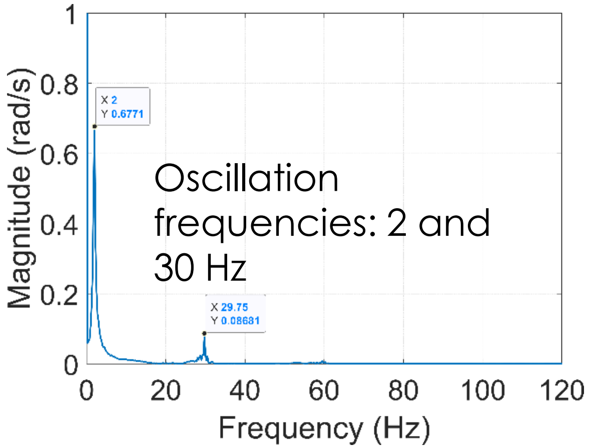
- Three-phase-to-ground fault at bus; fault impedance is 0.1 Ω and fault duration is 3 cycles.
- Significant post-fault oscillation in three farms: AC816, AC880, and DC1200.



Voltage and Current



Output power of 8 farms

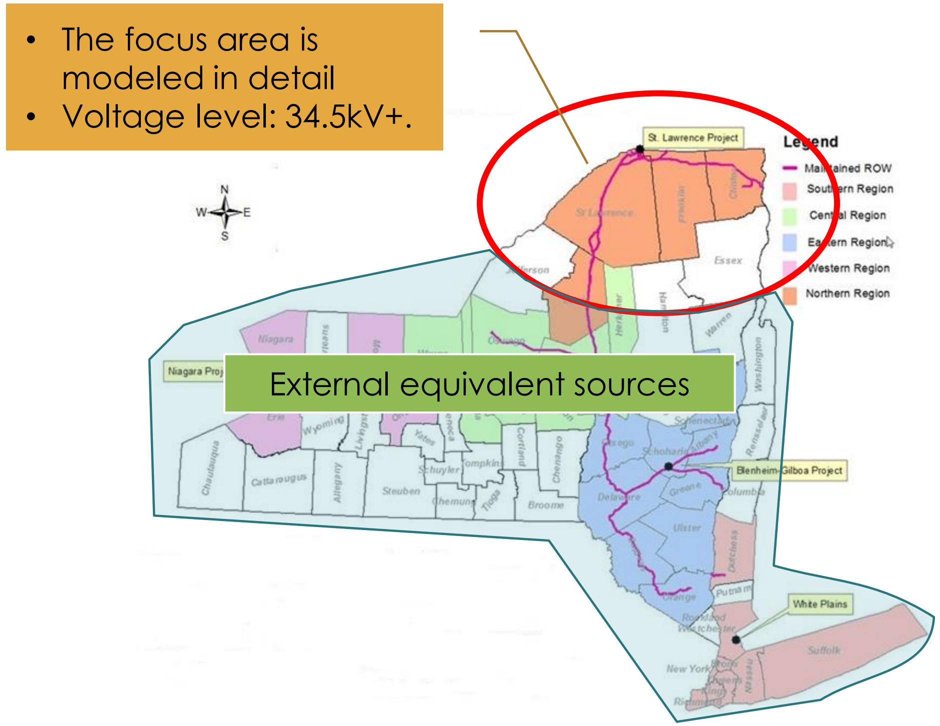


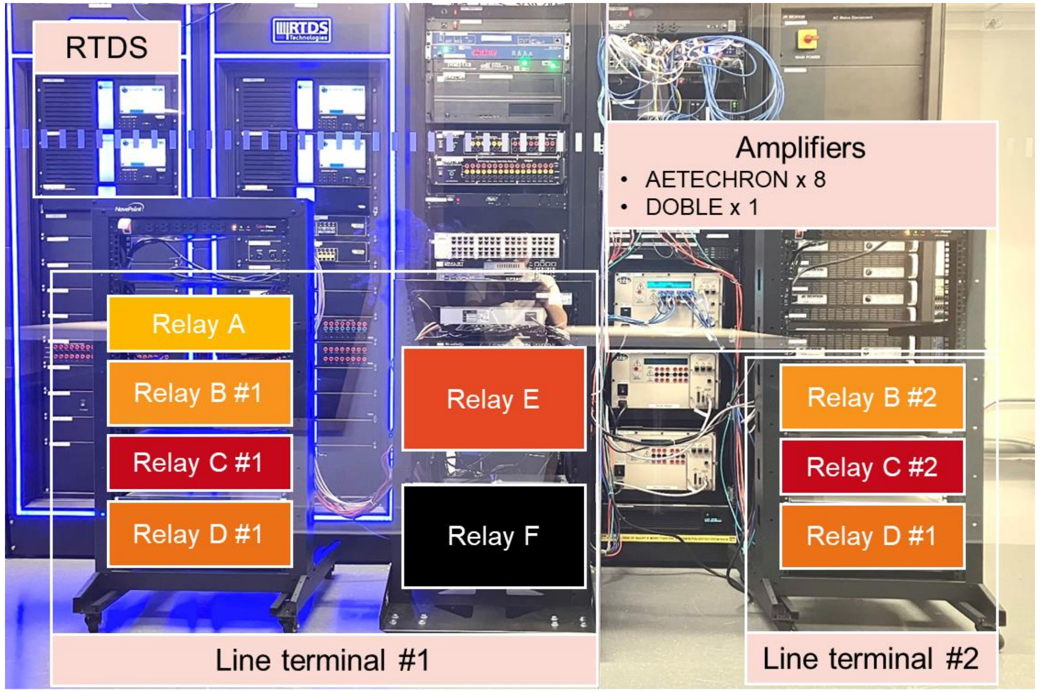
Frequency Spectrum of generator speed

Use Cases of Regional EMT Models

Protective Relaying Solution under High Renewable Penetration in New York State's Electrical Grid

- Joint research project by Quanta Technology and NYPA, funded by NYSERDA.
- Northen area of NYS power grid was selected due to its potential to reach high IBR penetration.
- Regional EMT model of Northen region in RTDS was used, voltage level from 34.5kV and above.
- 9 relays from 6 vendors were tested with the protective relay HIL testbed.





Protective Relay HIL Testbed at AGILe Lab

Use Cases of Regional EMT Models

Protective Relaying Solution under High Renewable Penetration in New York State’s Electrical Grid

- IBR penetration level was increased to test relay performance.
- Number of misoperation varies in the relay vendors
- Revealed the impact of IBR penetration on directional and distance elements
- Reached out to the relay vendors to resolve the issues.
- Mitigation solutions:
    - Revision of relay setting provided by relay vendors
    - Improved fault-type selection logic proposed by Quanta

misoperation

Relay A				IBR Case 2	IBR Case 3
0%	ABC	0.048	0.046	0.048	0.050
0%	AG	0.056	0.052	0.058	
0%	AB	0.051	0.042	0.054	0.076
0%	ABG	0.054	0.050	0.062	0.063
25%	ABC	0.049	0.049	0.051	0.053
25%	AG	0.057	0.053	0.047	
25%	AB	0.054	0.044	0.046	0.063
25%	ABG	0.053	0.051	0.065	0.062
50%	ABC	0.054	0.050	0.058	0.057
50%	AG	0.056	0.054	0.055	
50%	AB	0.050	0.040	0.063	0.067
50%	ABG	0.049	0.054	0.065	
75%	ABC	0.055	0.051	0.060	0.067
75%	AG				
75%	AB	0.054	0.039	0.075	0.082
75%	ABG	0.050	0.054	0.070	
Legend					
	Undesirable			Mis-operation	

Relay B				IBR Case 2	IBR Case 3
0%	ABC	0.034	0.042		
0%	AG	0.033	0.034	0.034	
0%	AB	0.032	0.036	0.039	0.035
0%	ABG	0.035	0.049	0.045	0.048
25%	ABC	0.039	0.043	0.045	0.063
25%	AG	0.037	0.040		
25%	AB	0.038	0.038	0.043	0.036
25%	ABG	0.042	0.048	0.044	0.042
50%	ABC	0.045	0.042	0.039	0.047
50%	AG	0.042	0.041		
50%	AB	0.043	0.040	0.042	0.042
50%	ABG	0.044	0.051	0.049	0.046
75%	ABC	0.054	0.049	0.063	0.046
75%	AG	0.056	0.048		
75%	AB	0.056	0.066	0.070	0.077
75%	ABG	0.057	0.070	0.070	0.050
Legend					
	Undesirable			Mis-operation	

Relay C				IBR Case 2	IBR Case 3
0%	ABC	0.042	0.043	0.042	0.048
0%	AG	0.043	0.041	0.038	0.034
0%	AB	0.037	0.041	0.034	0.038
0%	ABG	0.050	0.043	0.052	0.044
25%	ABC	0.041	0.042	0.046	0.044
25%	AG	0.042	0.039	0.044	0.032
25%	AB	0.039	0.038	0.035	0.034
25%	ABG	0.044	0.048	0.049	0.046
50%	ABC	0.043	0.044	0.042	0.046
50%	AG	0.042	0.047	0.038	0.041
50%	AB	0.042	0.037	0.042	0.038
50%	ABG	0.041	0.050	0.049	0.043
75%	ABC	0.046	0.051	0.050	0.047
75%	AG	0.038	0.040	0.043	0.038
75%	AB	0.038	0.040	0.042	0.042
75%	ABG	0.043	0.047	0.050	0.049
Legend					
	Undesirable			Mis-operation	

Relay D				IBR Case 2	IBR Case 3
0%	ABC	0.037	0.040	0.040	0.038
0%	AG	0.038	0.037		
0%	AB	0.030	0.036	0.034	
0%	ABG	0.042	0.038	0.047	0.051
25%	ABC	0.041	0.038	0.041	0.045
25%	AG	0.039	0.050		
25%	AB	0.038	0.038	0.034	0.040
25%	ABG	0.077	0.047	0.041	0.044
50%	ABC	0.040	0.046	0.046	0.042
50%	AG	0.042	0.046		
50%	AB	0.038	0.038	0.041	
50%	ABG	0.048	0.054	0.054	0.052
75%	ABC	0.046	0.044	0.048	0.043
75%	AG	0.050			
75%	AB	0.038	0.044	0.041	
75%	ABG	0.049	0.055	0.062	

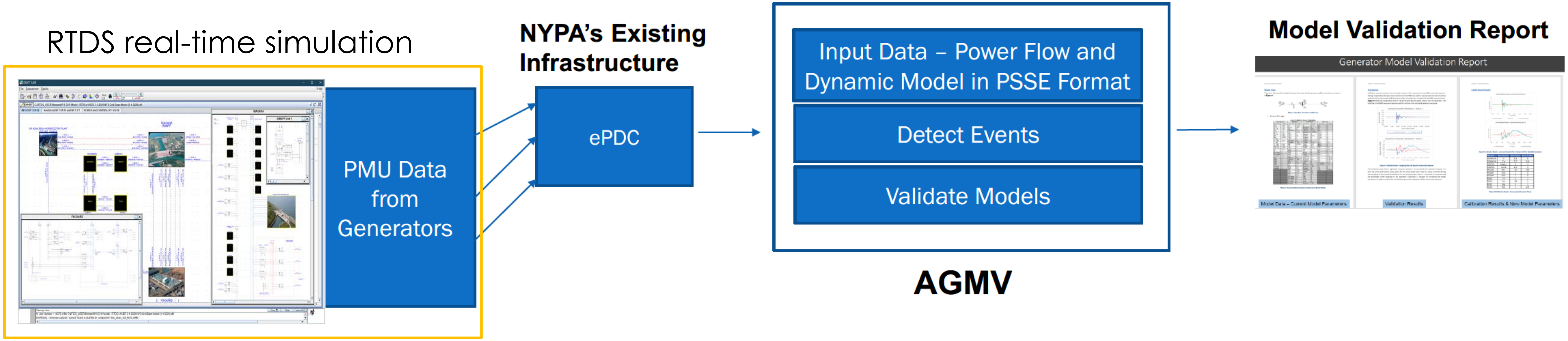
Relay E				IBR Case 2	IBR Case 3
0%	ABC	0.035	0.012	0.013	0.015
0%	AG	0.034	0.014	0.026	0.022
0%	AB	0.031	0.022		0.019
0%	ABG	0.038	0.013	0.015	0.018
25%	ABC	0.035	0.013	0.017	0.014
25%	AG	0.038	0.014	0.015	0.026
25%	AB	0.031	0.022		0.022
25%	ABG	0.036	0.018	0.014	0.014
50%	ABC	0.034	0.017	0.017	0.032
50%	AG	0.043	0.014	0.014	0.029
50%	AB	0.033	0.027	0.014	
50%	ABG	0.038	0.014	0.017	0.015
75%	ABC	0.040	0.026	0.038	0.058
75%	AG	0.049	0.013	0.047	0.054
75%	AB				
75%	ABG		0.053	0.058	0.036
Legend					
	Undesirable			Mis-operation	

Relay F				IBR Case 2	IBR Case 3
0%	ABC	0.032	0.026	0.026	0.037
0%	AG	0.032	0.030	0.041	
0%	AB	0.028	0.025	0.038	0.052
0%	ABG	0.034	0.037	0.044	0.067
25%	ABC	0.031	0.026	0.030	0.036
25%	AG	0.034	0.032	0.048	
25%	AB	0.030	0.030	0.042	0.053
25%	ABG	0.032	0.034	0.055	0.066
50%	ABC	0.031	0.054	0.050	0.055
50%	AG	0.036	0.044	0.046	
50%	AB	0.030	0.043	0.050	0.059
50%	ABG	0.030	0.059	0.064	0.062
75%	ABC	0.050	0.056	0.057	0.056
75%	AG	0.039	0.050	0.053	
75%	AB	0.037	0.057	0.054	0.070
75%	ABG	0.045	0.060	0.067	0.073
Legend					
	Undesirable			Mis-operation	

Use Cases of NYS base EMT Models

Automated Generator Model Validation (AGMV)

- NYPA’s project to validate the AGMV solution provided by a vendor
- Utilize the EMT model of the NYS power grid to create significant events
- Real-time simulation data is streamed to NYPA’s existing infrastructure (ePDC) using PMU
- Verify and tune the vendor solutions



Lessons Learnt

- Lack of sufficient power grid modeling data to develop accurate EMT models
  - Sequence impedance data
  - Transformer-winding configuration
  - Legacy IBR models
  - Missing controller models/parameter data in dynamic PS models
- Inaccuracy in EMT model conversion, e.g. measured signals for control components
- Labor-intensive in organizing components of EMT models for usability

Gaps & Challenges Observed

Challenges	Inconsistency in power grid modeling data in different simulation platforms	Scalability of simulation software/hardware for performing ultra-large-scale EMT simulations	Maintaining EMT models up-to-date is a challenging task.
Solutions	• Data matching script to find which ASPEN bus corresponding to PSS/E bus	• Optimize simulation model • Hybrid EMT-Phasor simulation • Working with vendors to develop software and hardware architecture	• Use single source of truth for model management

Impact

Grid of the Future Needs:

- A platform to evaluate the grid of the future
- A facility to prototype solutions
- A platform to safely and realistically test and demonstrate solutions

Advanced Grid Innovation Lab for Energy (AGILe)

- A state-of-the-art power systems laboratory to enable an affordable, reliable, low-carbon future power grid
- Provide a close-to-real testing environment that facilitates identifying and solving grid related challenges
- A one-stop shop for all NY grid stakeholders for accelerated research, development, and deployment opportunities

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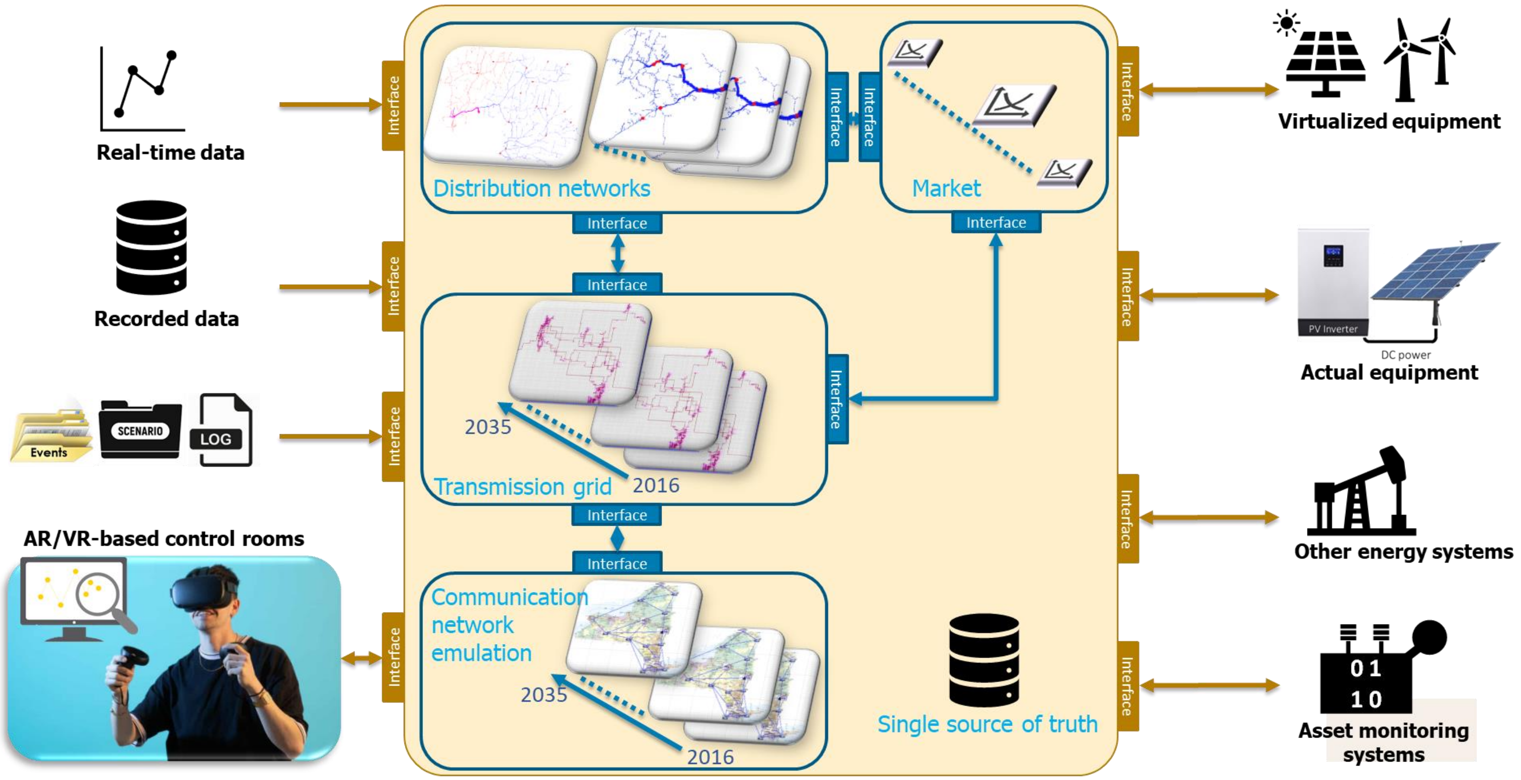
Next Step

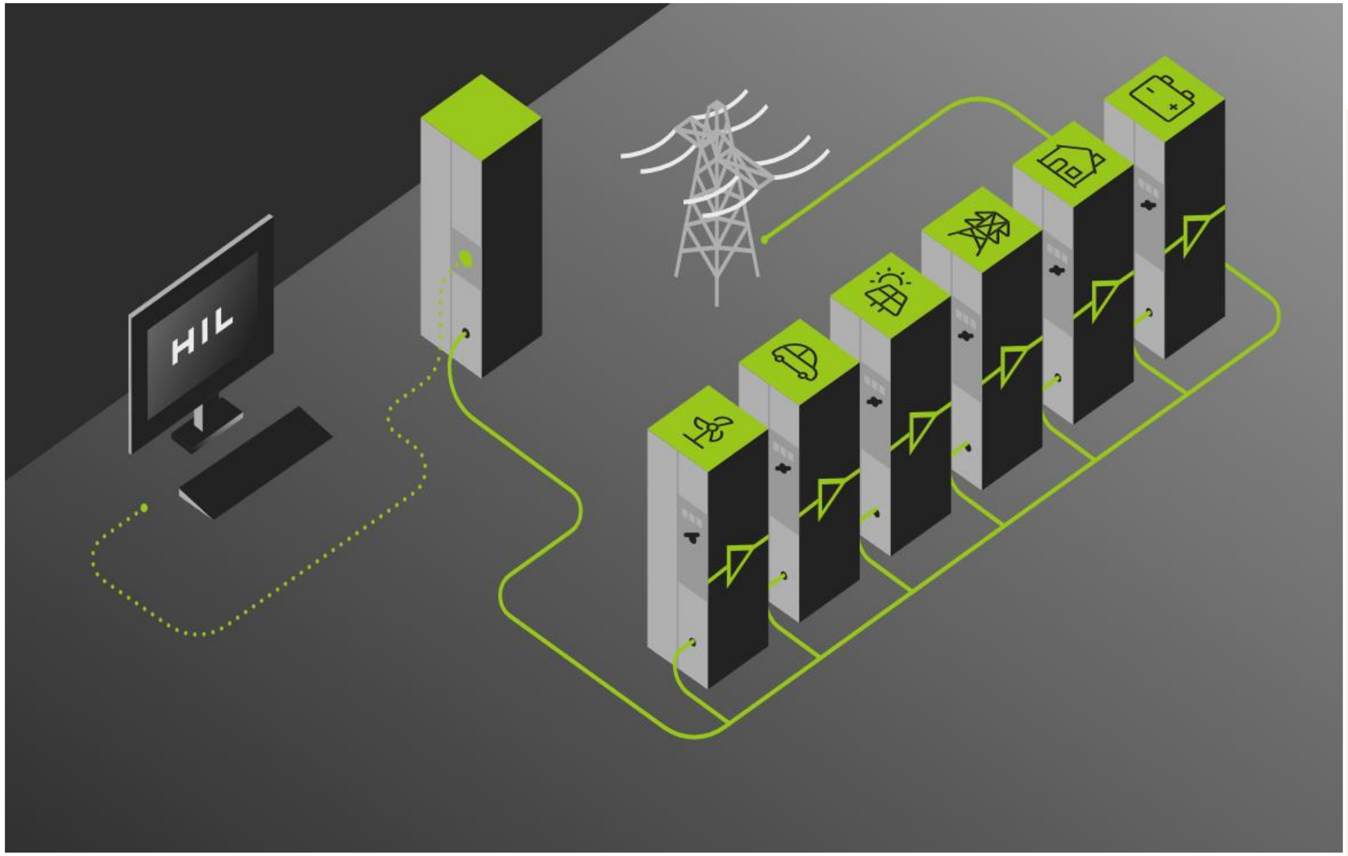
NYS Digital Twin

- NYPA's project to develop the digital twin of the NYS power grid
- Full NYS grid EMT model
- NYS Digital Twin Vision
    - A live digital copy of the grid (TX, DX, Comm)
    - Ability to move in time and replay events
    - Ability to interface with control/protection/power equipment
    - Includes replicas of TOs/NYISO SCADA/EMS functions in the VR-based control room



Next Step

Power Hardware In The Loop (PHIL) Test Setup



PHIL

- Sized for 300 – 600 kW PHIL interface
- Supports 4-quadrant bi-directional power
- Applies realistic grid level voltage/current steady state values and transients on the DUT (Device Under Test).
- DUT reacts as if it is energized by the real grid.

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QUESTION

Thank you!