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EMT-TS Hybrid Simulation and Cloud-hosted EMT Simulation

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ORNL is managed by UT-Battelle, LLC for the US Department of Energy

U.S. DEPARTMENT OF ENERGY

ISO-NE's Advanced Technology Solutions Dept.

- A unique R&D department

- EMT related R&D efforts in the past two years:
  - Automated IBR Model Verification using DFR data and Playback method
  - EMT-TS Hybrid Simulation
  - Prototype EMT simulation on the Cloud

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EMT-TS Hybrid Simulation

EMT vs. TS Models – What They Are Good For

ElectroMagnetic (EMT)

- Faster Dynamics (μs)
  - Switching actions
  - Protections
  - Controls with smaller time constants
  - Instant values
- 3-Phase
  - Inverter level
- Higher frequencies
  - SSO (SSR/SSCI/SSTI)
- Smaller Systems

ElectroMechanical (TS)

- Slower Dynamics (ms)
  - Turbine/motor movements
  - Exciter and governor controls
  - RMS values
- Positive sequence
  - Fundamental frequency
- Local/Inter-Area Oscillations, Transient Stability
- Larger Systems

EMT vs. TS Models – Model Characteristics

ElectroMagnetic (EMT)

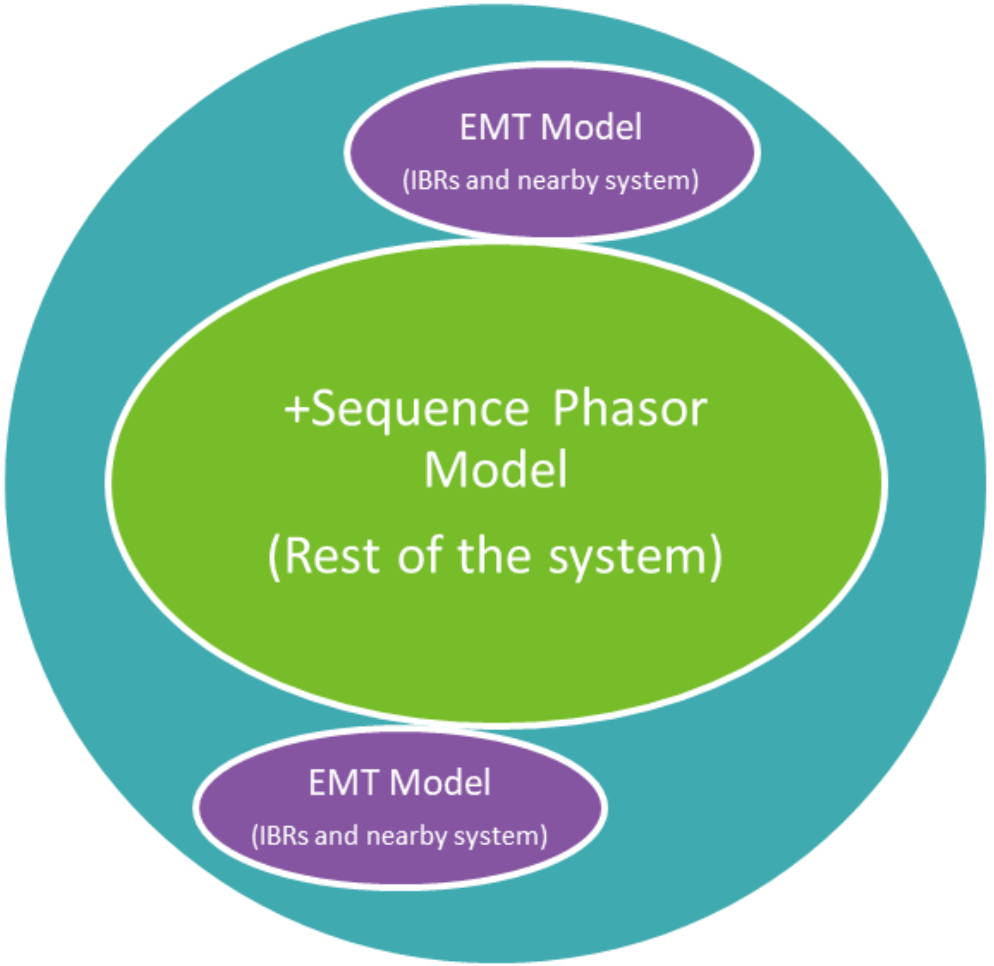
- One-of-a-kind Models
- New and Not Well Documented
- Black- or Gray-Box Models
- Complex and Still Evolving
- Lacks Testing and Validation Procedures

ElectroMechanical (TS)

- Standard Generic Models
- Well Documented and Understood
- White-Box Models
- Mature
- MOD-26/27/33

EMT-TS Hybrid Simulation

- The best of both worlds
  - IBR (rich area) or HVDC in EMT
  - Rest system in TS



ISO-NE's Efforts Investigating EMT-TS Hybrid Simulation

- Part of the ISO-NE's Corporate Scorecard in 2021 and 2022

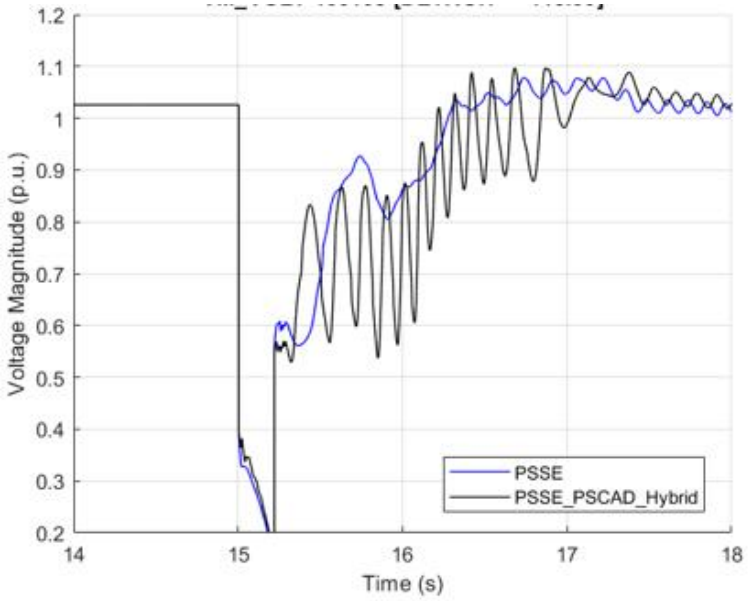
Year 1: Proof-of-concept
- Software platform evaluation
- SMIB case study
- Process development
- Performance testing

Year 2: Dry Run
- Hybrid + EMT parallel simulation
  - Each IBR is modeled as an individual case
  - Network in a separate case
- 3 IBRs and a larger network
- In-depth evaluation

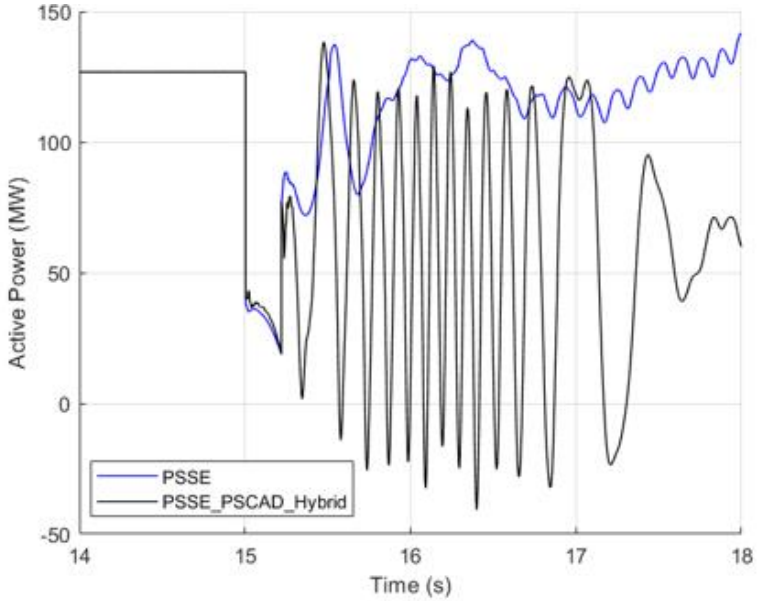
Hybrid Simulation Case Study – SMIB (wind plant)

- Disturbance: 3-phase fault at 345kV bus A, cleared after 13 cycles with line A-B tripped.
- Features IBR dynamics

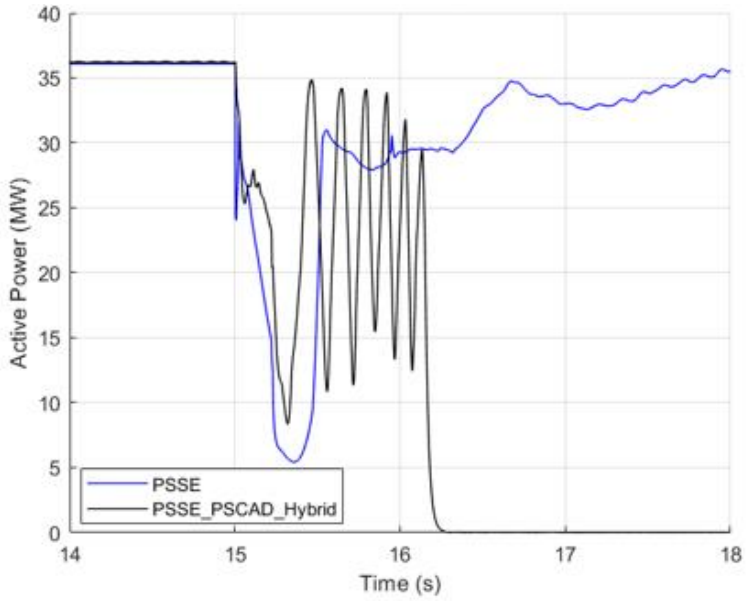
115 kV Bus Voltage (PSS/E side)



115 kV Line Flow (PSS/E side)



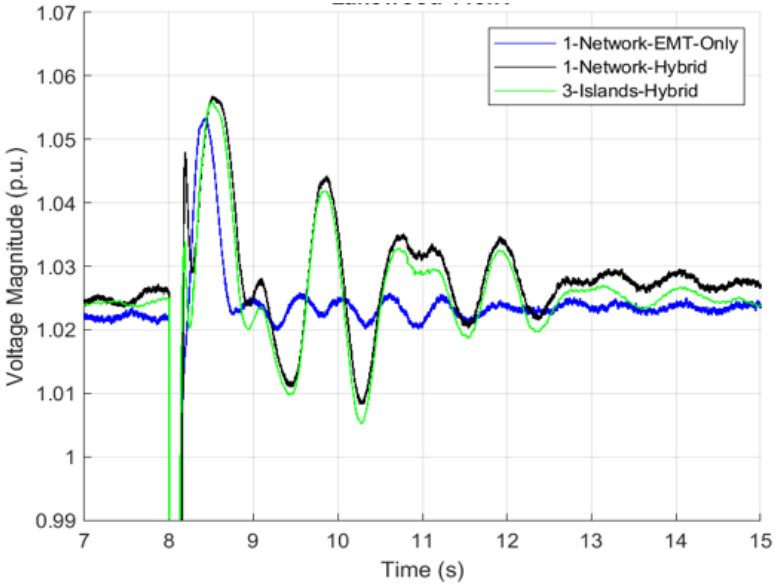
Wind Plant String 1 Flow; Wind plant tripped in hybrid sim



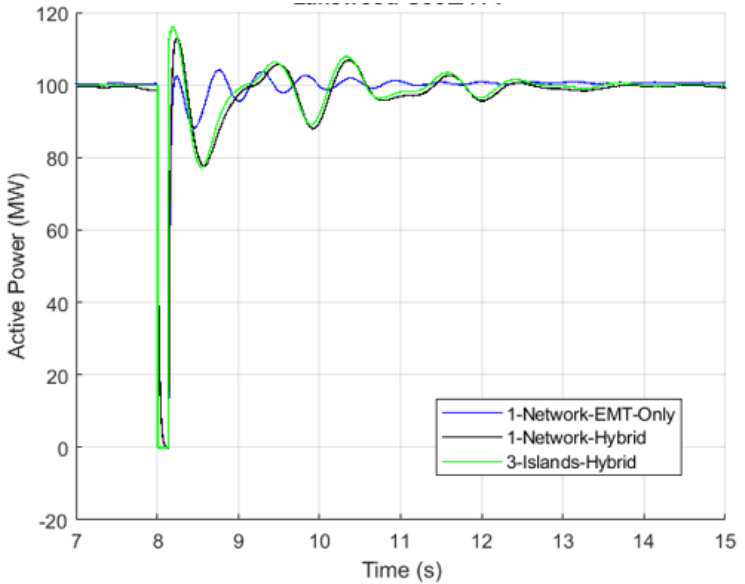
Hybrid Simulation Case Study – 3 IBRs with Network 1

- 3 IBRs: two wind plants and one solar plant
- Disturbance: 3-phase fault at 115kV bus A, cleared after 8 cycles
- 1-network EMT only; 1-network hybrid; 3-island hybrid;
- Features grid dynamics

115 kV Bus A Voltage (PSS/E side)



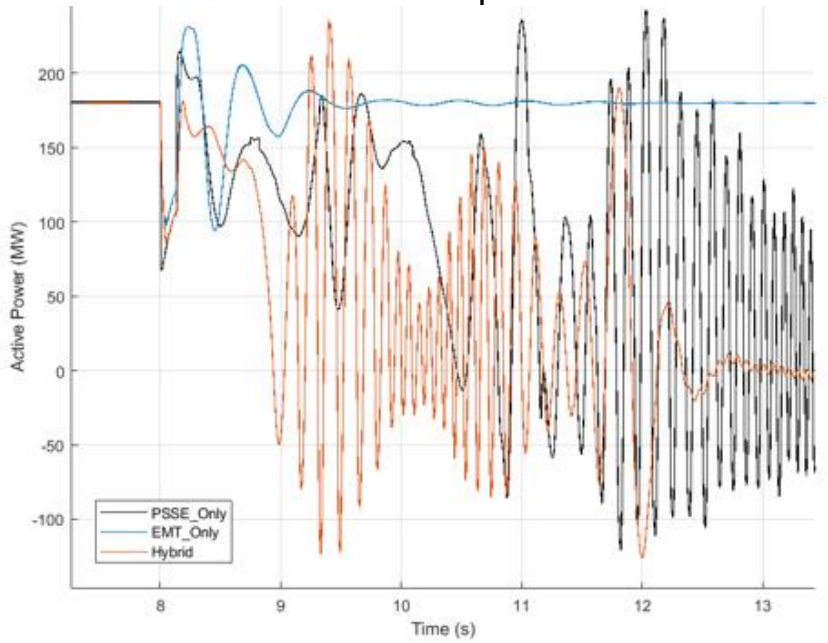
115 kV line A-B Flow (PSS/E side)



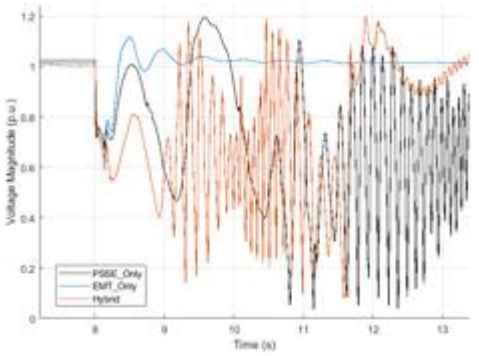
Hybrid Simulation Case Study – 3 IBRs with Network 2

- Topology change: two 345 kV lines out-of-service
- Disturbance: 3-phase fault at 115kV bus B, cleared after 8 cycles with 115kV line B-C tripped
- Features IBR and grid interactions

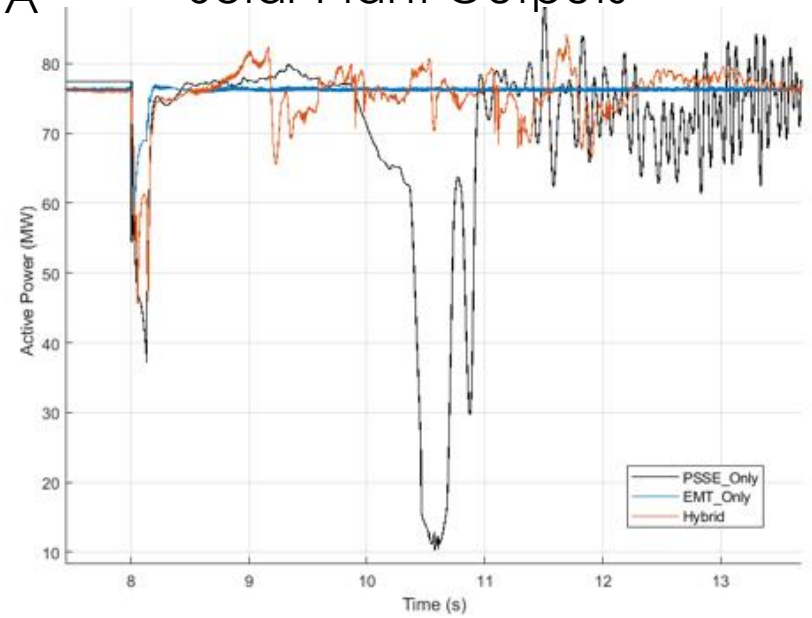
Wind Plant A Outputs



Voltage at Wind Plant A



Solar Plant Outputs



Conclusions

- EMT-TS Hybrid Simulation for large scale power system is feasible and useful
  - Comparing with building and simulating a really large EMT model
- Hybrid simulation can observe both grid and IBR dynamics
- We have developed an internal process manual and a demonstration case to train engineers on hybrid simulation
- Early stage of adoption in our Operations planning study

Challenges

- Mostly on EMT models
  - Non-standard, one-of-a-kind models
  - Off-the-shelf model is not ready-to-use
    - ISO-NE EMTWG has developed an EMT model management process and a packaging standard (substitution library, parallel library and parallel case, etc.)
    - EMT model testing and tuning
  - Limited automation
- Research needs: EMT-TS boundary determination
  - Need a theoretically sound and systematic approach
  - Plan to evaluate impedance scan tool developed by EPRI and NREL
  - Research on grid model partitioning based on participation factors

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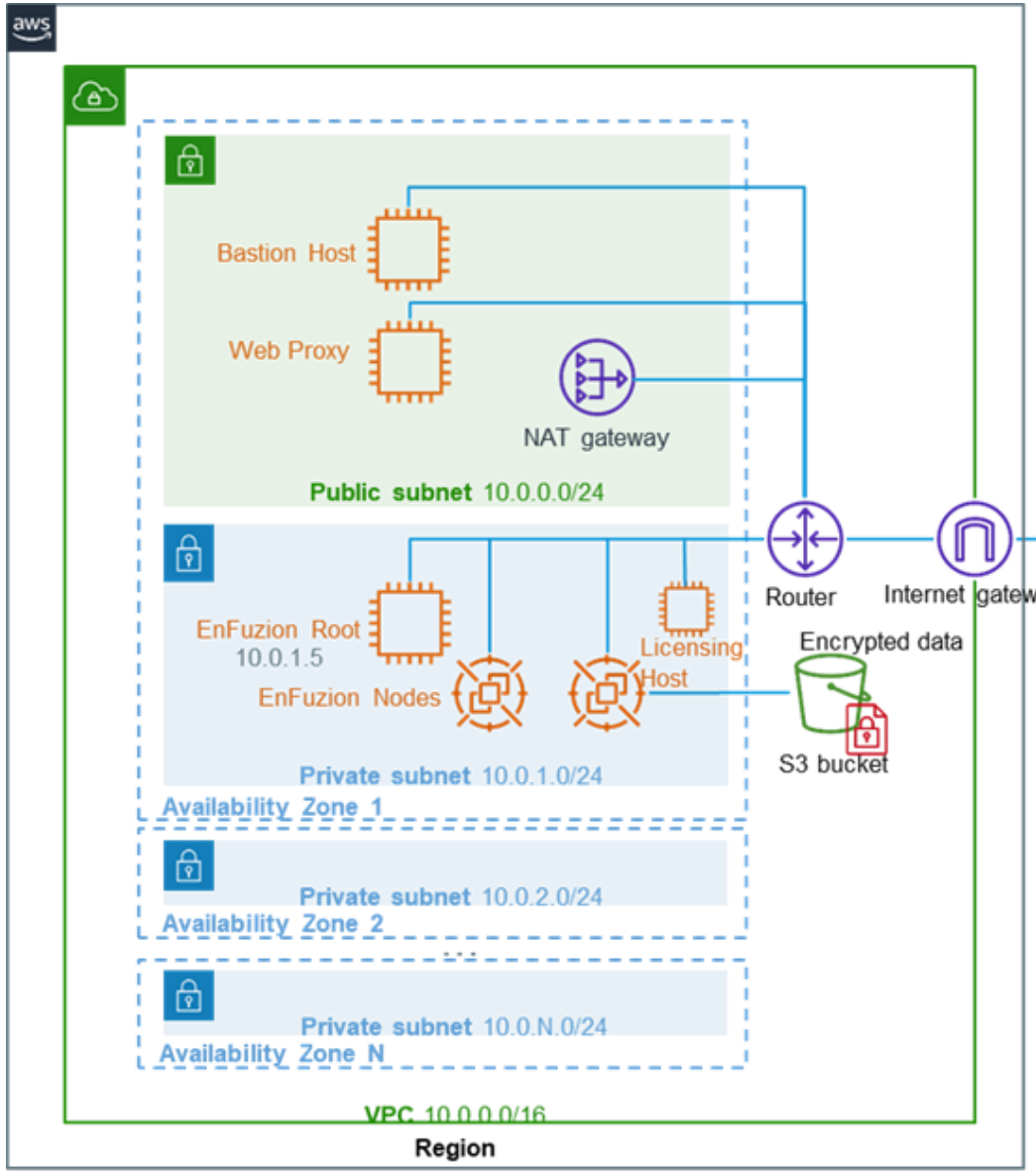
Cloud-hosted EMT Simulation

ISO-NE's Cloud-hosted HPC Platform

Applications:
- PSS/E
- TARA
- GE MARS



Root Instance
- Brain of the platform
- Run 24 x 7
- Cloud Job Scheduler
- Cloud Instance Manager
- S3, EBS and local storage support

Scalable Compute Instances
- EC2 Spot or On-Demand
- S3, EBS and ephemeral storage support

Job Submission Computers
- Job submission web interface
- S3 access

Cloud-hosted EMT Simulation

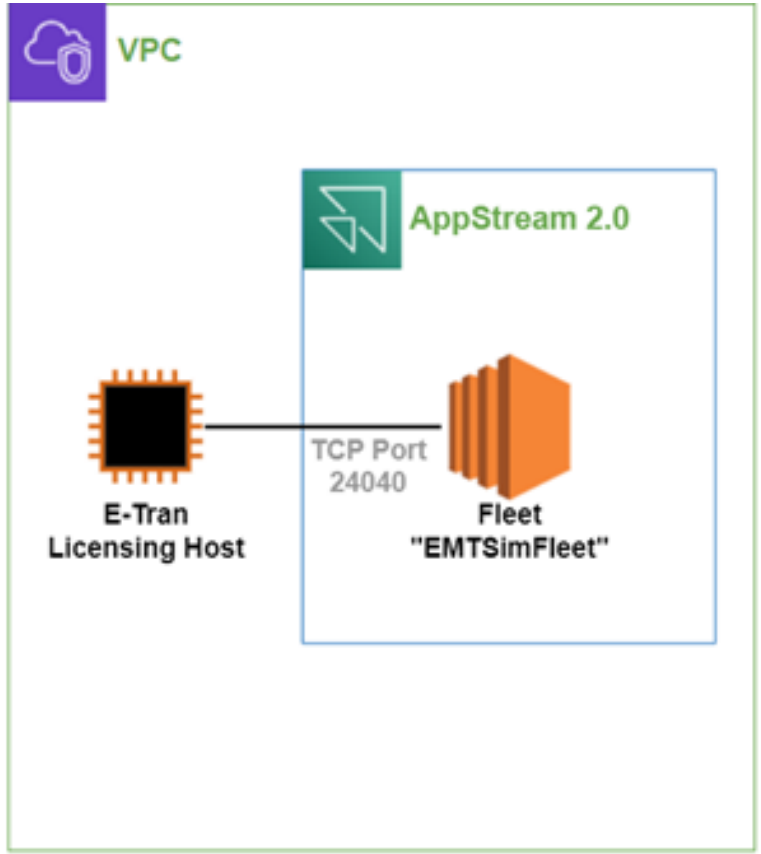
- In 2021, ISO-NE tested various on-premises hardware configuration for running large-scale EMT simulations
- In 2022, ISO-NE tested PSCAD cloud deployment on AWS
- The objectives of the PoC project include:
  - Design the cloud architecture and deploy E-TRAN and PSCAD on AWS
  - Compare cloud performance vs. on–premises hardware for large scale PSCAD simulation
  - Identify any constraints and limitations on cloud deployment

Cloud Configuration

- Three potential configurations:
  - EC2 instance with RDP connection
  - Full desktop-as-a-Service (DaaS) by using AWS WorkSpaces
  - Application Streaming Service by using AWS AppStream
- Appstream is more suitable to move existing legacy application to AWS; It also offers more choices of instance types characterized by CPU, memory or GPU inside an Amazon Virtual Private Cloud (VPC).

AWS Environment Setup

- Virtual Private Cloud (VPC)
- Etran Licensing Manager
  - On-demand EC2 instance (t2.small) with port 24040 opened
- Appstream Image
  - PSCAD v4.6.3 with Certificate License
  - Microsoft Visual Studio 2010 Express
  - E-Tran Plus for PSCAD
  - Intel Fortran Compiler XE 13 (not installed due to license)
- AppStream Fleet and Stack
  - Instance type
  - Control user access and permission (Appstream login URL, user name and password)



AWS Environment Setup

- Tested three streaming instance types

Instance type	Instance family	vCPU	Memory (GB)	Hourly price
stream.compute.4xlarge	Compute optimized	16 Intel Xeon E5-2666	30	$2
stream.compute.8xlarge	Compute optimized	32 Intel Xeon E5-2666	60	$4
stream.memory.z1d.12xlarge	Memory optimized	48 Intel Xeon Platinum 8151	384	$10.80

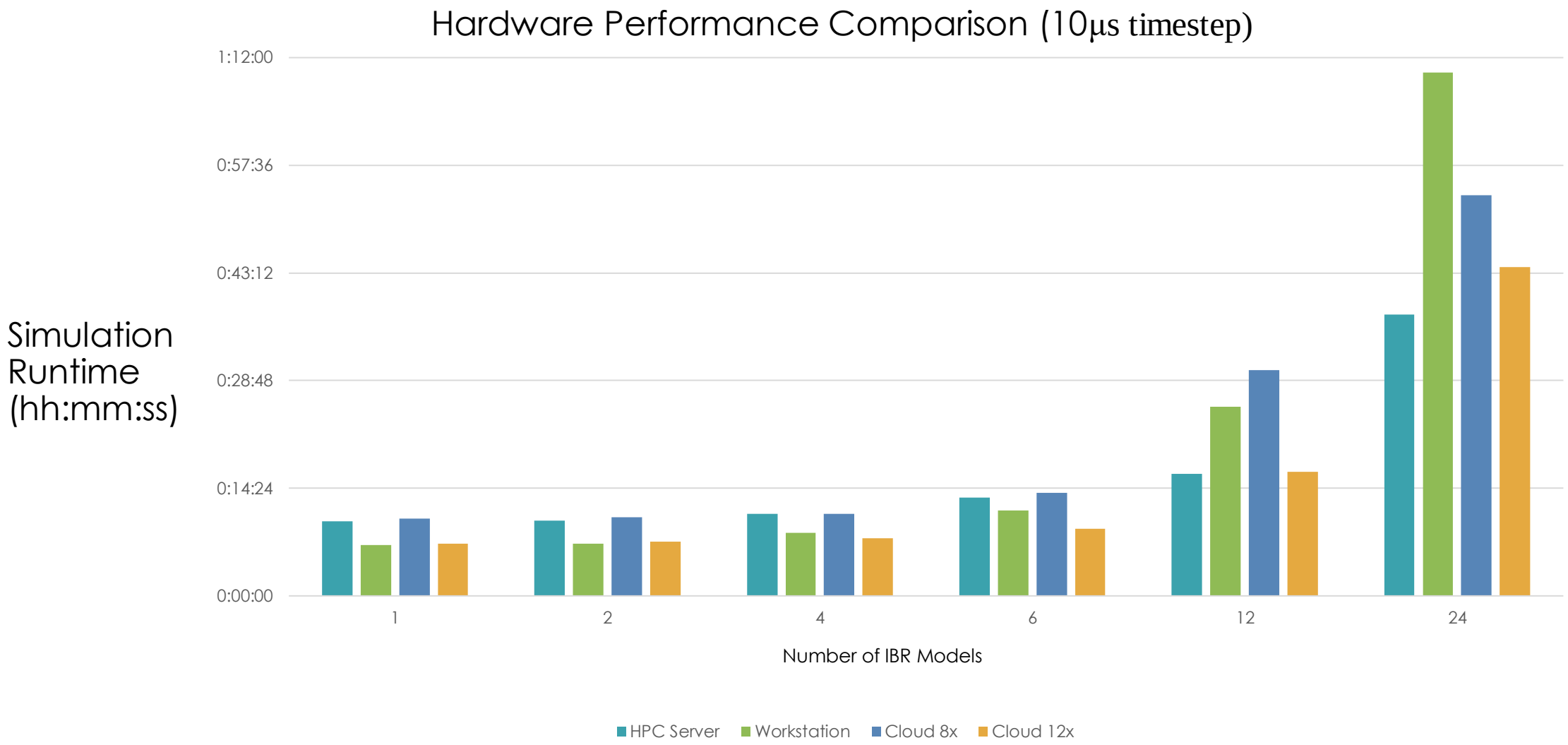
- Appstream storage system
  - Default is S3 Bucket; the read/write speed is too slow for PSCAD, throwing an error and then crashing the PSCAD simulation
  - Change to FSx file management system with SSD storage type and 32 MB/s throughput capacity

Performance Comparison

- Results from the cloud instances were compared against internal hardware that had already been tested
- The same testing suite was throughout all testing
- Tested 1, 2, 4, 6, 12 and 24 inverter cases, all of which were parallelized

	Premium Mini-Workstation	HPC Dual CPU Server	8x Large	12x Large
CPU Model	Intel i7-10700	Intel Xeon Platinum 8176 server	Intel Xeon E5-2666	Intel Xeon Platinum 8151*
CPU Cores/Threads	8/16	2*28/56	10/20	12/24
Thermal Design Power (TDP)	65 W	2*165 W	135 W	240 W
CPU Base/Boost Frequency (GHz)	2.9/4.8	2.1/3.8	2.9/3.5	3/3.7
* This CPU is custom for AWS and spec numbers may be incorrect				

Performance Comparison (Con't)



Benefits of Cloud-hosted EMT Simulation

- Scaling to a higher core count for intensive projects is easy
- User's choice of instance types characterized by CPU, memory or GPU, and can always use the latest hardware
- Only need to update the image with Etran/PSCAD version changes
- Easy to add new users; each user has its own dedicated space without worrying about port conflict like dept. server or on-premises HPC servers

Future Work

- The corporate AWS Foundation Project established Direct Connect with AWS
- We need to re-evaluate the architecture design of the PoC:
  - Choice between Appstream vs. EC2 Instance with RDP
  - Etran and PSCAD license with on-premises license server
  - Storage gateway to bridge PSCAD simulation results
  - Intel Fortran Compiler
- ISO-NE and AWS Strategic Partnership

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Questions