

GRID EMT

SIMULATION INITIATIVE

Large-EMT Dynamic Simulations for Resource Integration: Load Modeling Challenges

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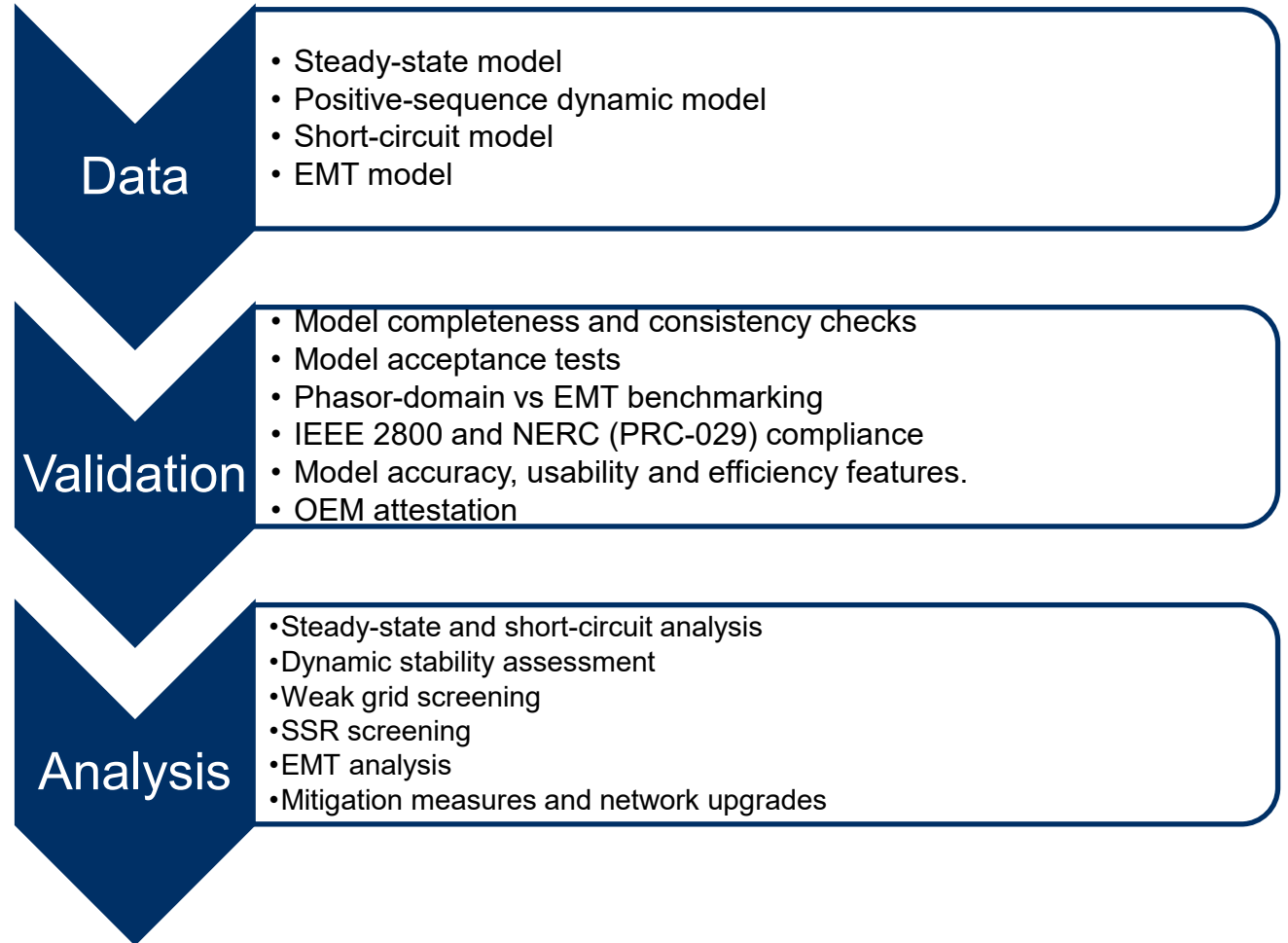
Motivation

- Increasing penetration of inverter-based resources (IBRs) has expanded the use of EMT simulations beyond traditional phasor-domain stability analysis.
- EMT studies are becoming an integral component of the resource interconnection process.
- Dynamic load representation is emerging as a significant challenge in large-scale EMT simulations.
- Emerging large converter-based loads introduce electromagnetic and control interaction phenomena similar to those that originally drove EMT adoption for IBR integration.



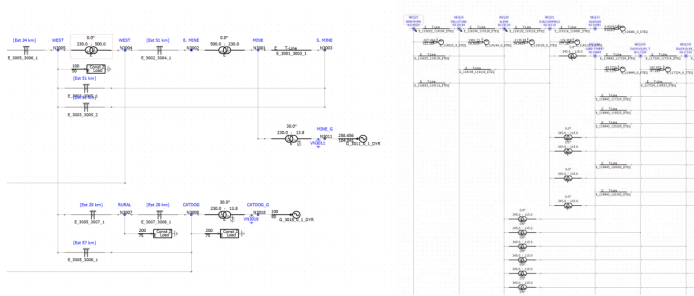
Large-scale EMT Study Framework – Resources Integration

- Resource interconnection studies increasingly use EMT analysis to complement traditional phasor-domain simulations for evaluating fast electromagnetic phenomena, converter control interactions, and performance under weak-grid conditions.
- As EMT model fidelity and study footprint expands, load representation becomes an important source of modeling uncertainty.



Large-scale EMT Study Framework – Relevant Aspects

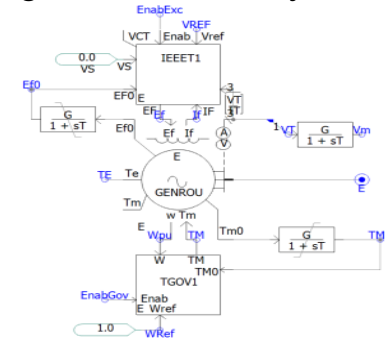
Full positive-sequence system reduced to the retained EMT study area.



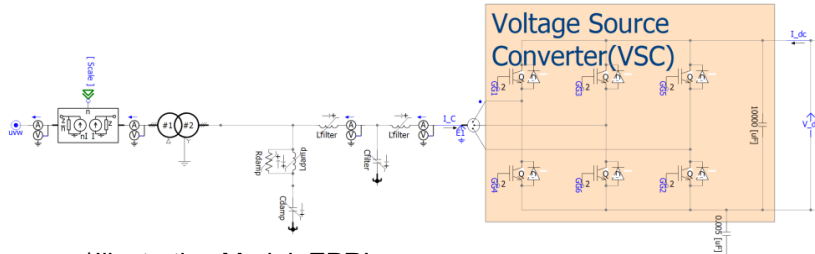
Network Equivalent

Synchronous Generation

Synchronous generation represented using standard library models.



IBR and FACTS represented using detailed OEM-validated EMT models.

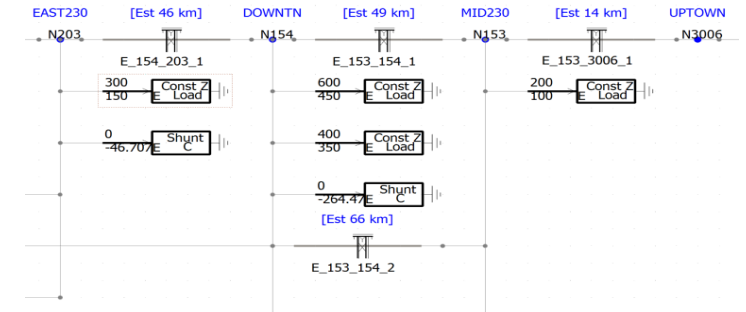


*Illustrative Model: EPRI

Detailed IBRs and FACTS

Simplified Load Representation (ZIP)

Loads represented using simplified static
ZIP characteristics.



Observations

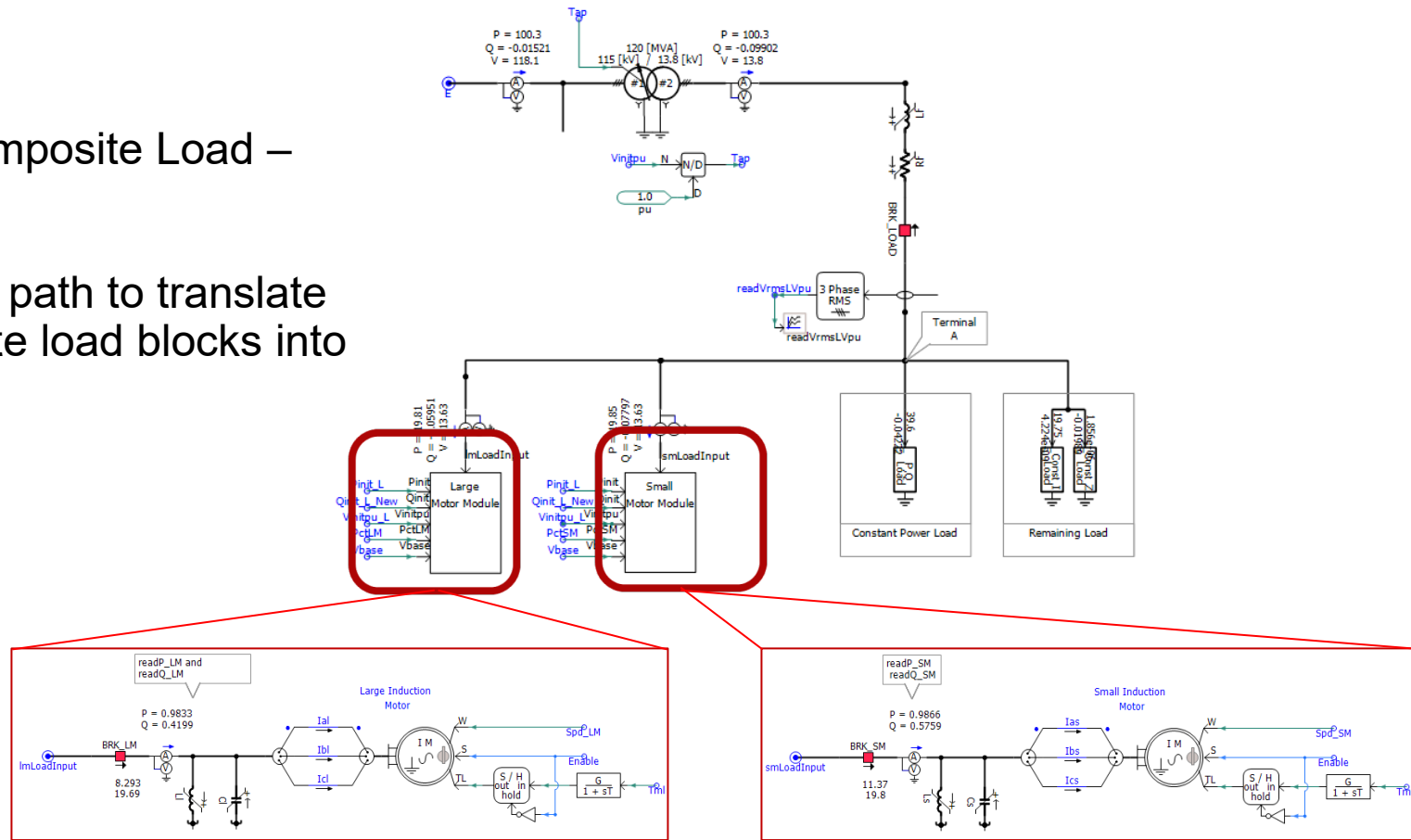
- High EMT modeling fidelity is generally placed on the generating resource and FACTS.
- A significant portion of the network loading is represented with static ZIP equivalents.
- More detailed aggregated load representations exist (e.g., composite load models, induction motor models, electronic load representations); however, their application in large-scale EMT simulations presents several challenges:
 - **SCALE:** Large number of load buses dispersed throughout the retained EMT system.
 - **TRANSLATION:** Composite load models developed for phasor-domain simulations cannot always be efficiently translated into EMT representations.
 - **AUTOMATION:** Limited automated workflow exists in commercial tools to systematically replace load representations with EMT-compatible dynamic load equivalents when creating the EMT cases.



Observations

EMT Composite Load – CLOAD

Practical path to translate composite load blocks into EMT



Load Substitution Options

% of Load as Large Motor:	20	% of Load as Constant Power:	40
% of Load as Small Motor:	20	Kp for Remainder of Load:	1
% of Load as Transformer Exciting Current:	5	Branch R:	0.01
% of Load as Discharge Lighting:	5	Branch X:	0.001

Apply CLOAD Substitution To:

Buses: 913501

Eg - 101(1,2) Load substitution on bus 101 with load IDs 1 and 2. Bus number without IDs will substitute all loads attached to it.

Owners:

Zones:

Areas:

Undervoltage Protection Settings

☒ Enable undervoltage protection

Time to enable (sec): 2

Undervoltage Threshold 1 (pu): 0.5

Undervoltage Threshold 2 (pu): 0.8

Protection Delay 1 (sec): 0.1

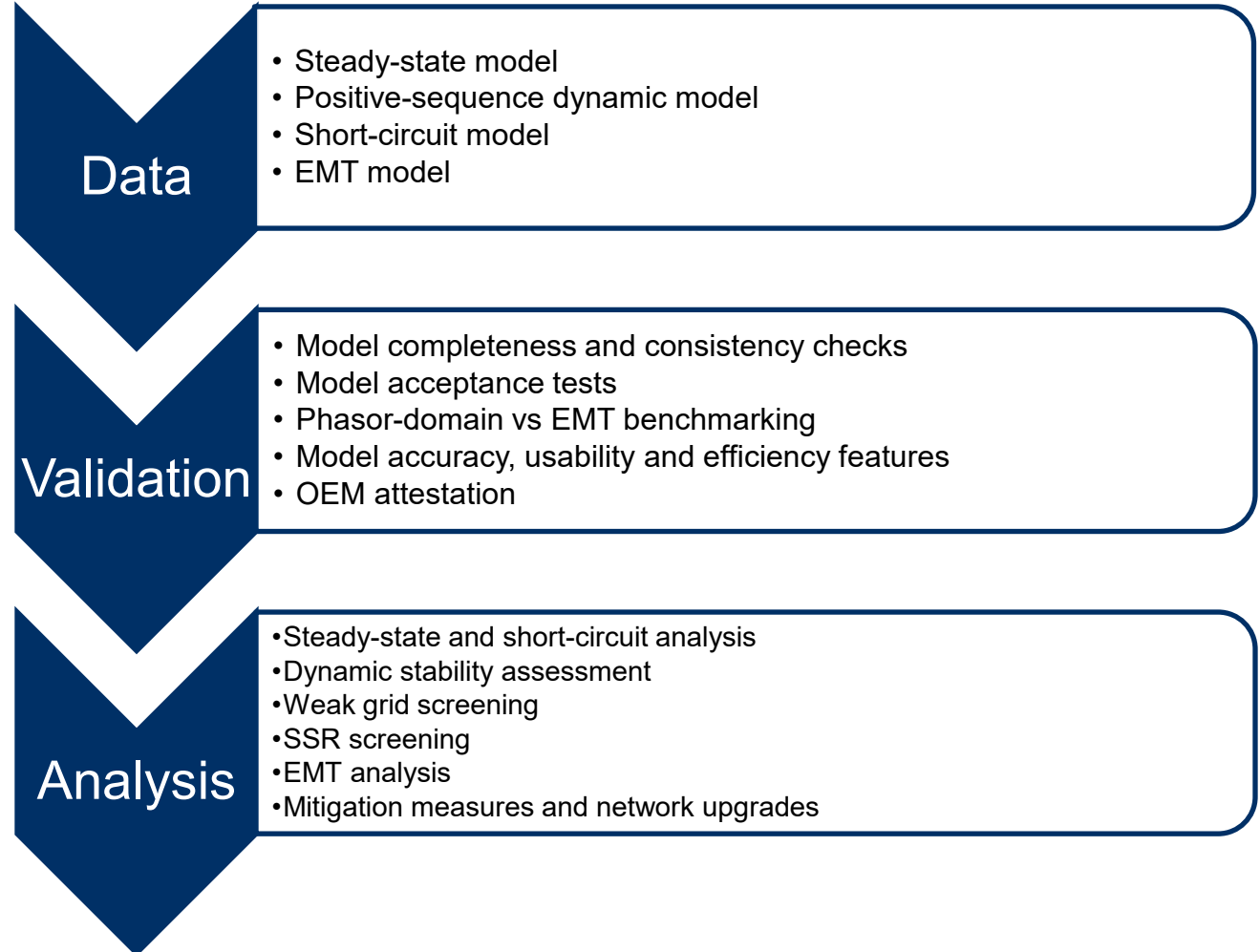
Protection Delay 2 (sec): 1

Save Cancel



New Large Loads Challenges - EMT Study Framework

- Large converter-based loads are introducing EMT modeling challenges similar to those previously encountered with IBR models.
- Phasor-domain models should provide a response consistent with their EMT equivalents around fundamental frequency. Augmented EMT models should therefore be appropriately benchmarked.
- Model Accuracy, Usability and efficiency should be validated together with applicable performance requirements including ride-through performance, post-fault recovery, oscillation limits, positive damping.
- User-defined EMT models for large converter-based loads should be incorporated into large-scale studies using an approach similar to that currently applied to IBRs and FACTS devices



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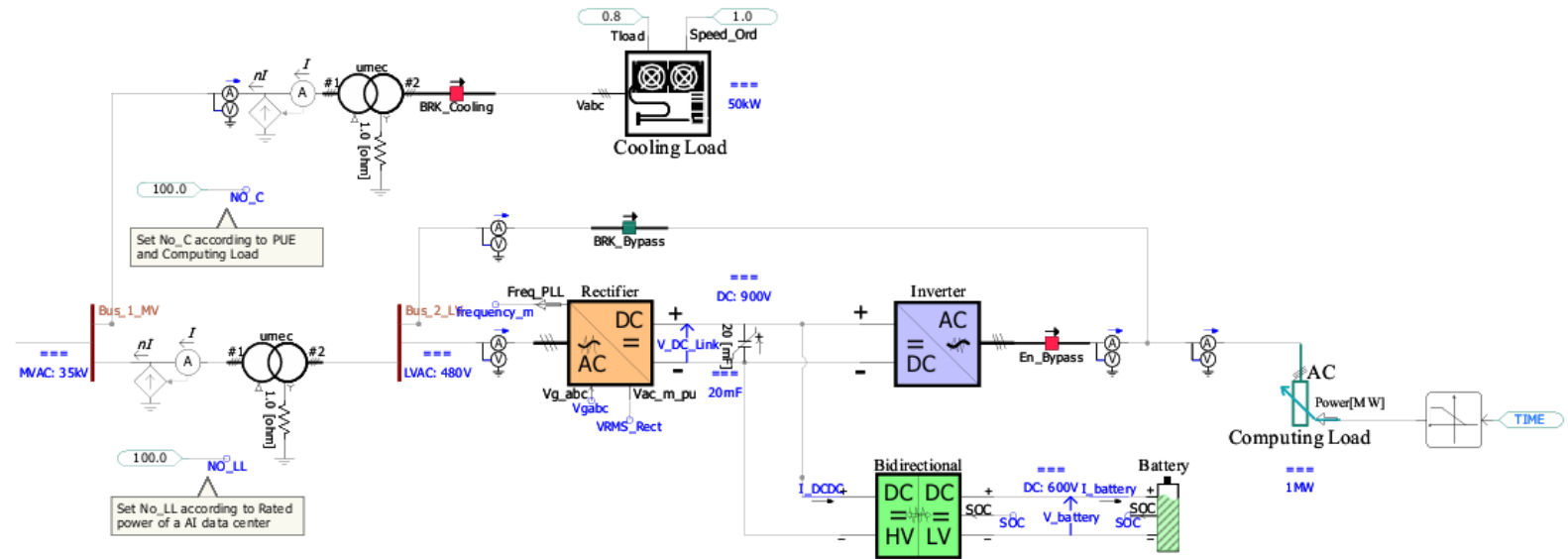
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New Large Loads Challenges - EMT Models

ERCOT

Open-Source AI Data Center Model

- Average and switching bridge models
- UPS
- Battery interface
- VFDs
- Rectified-load
- VRT and FRT at UPS level
- Slow and fast reconnection schemes
- Fluctuating load

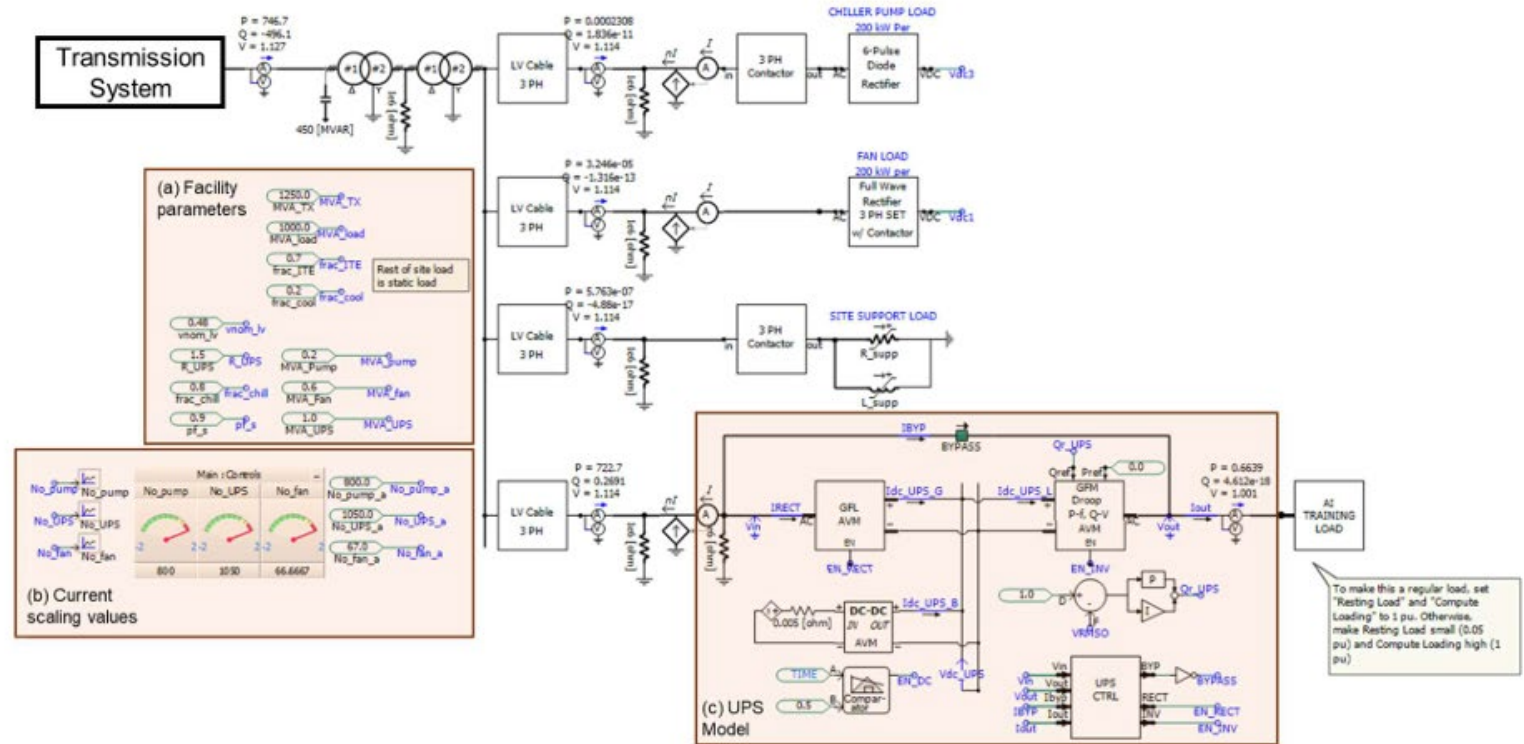


New Large Loads Challenges - EMT Models

PNNL

Open-Source AI Data Center Model

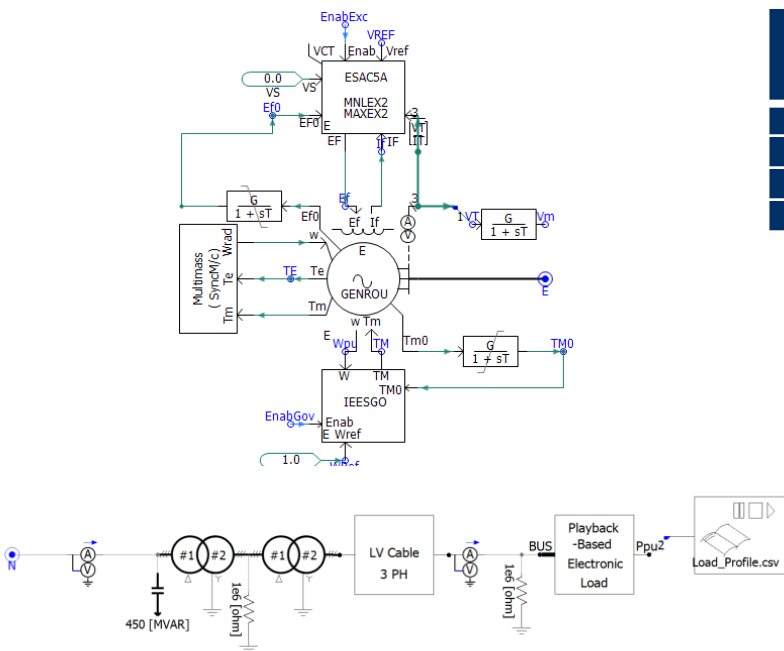
- Average and switching bridge models
- UPS
- Battery interface
- VFDs
- Rectified-load
- VRT and FRT at rectifier side
- Limited delayed reconnection functionality
- Fluctuating load



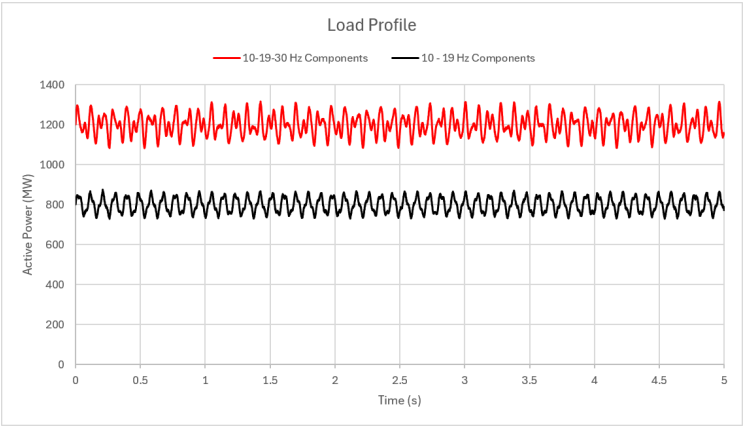
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EMT System Studies - Oscillatory Interactions Due to Large Loads Integration



Mode (i)	Modal Torsional Frequency [Hz]	Modal Damping No Load (D_{mi_NL}) [pu]	Modal Damping Full Load (D_{mi_FL}) [pu]
1	0.00	--	--
2	11	0.15	0.8
3	19	0.2	1.1
4	30	500	2000



UIF

Determine electrical proximity and relevant topology

Transfer Function (EMT)

Evaluate different load profiles and identify negative damping

Detailed Torque Analysis (EMT)

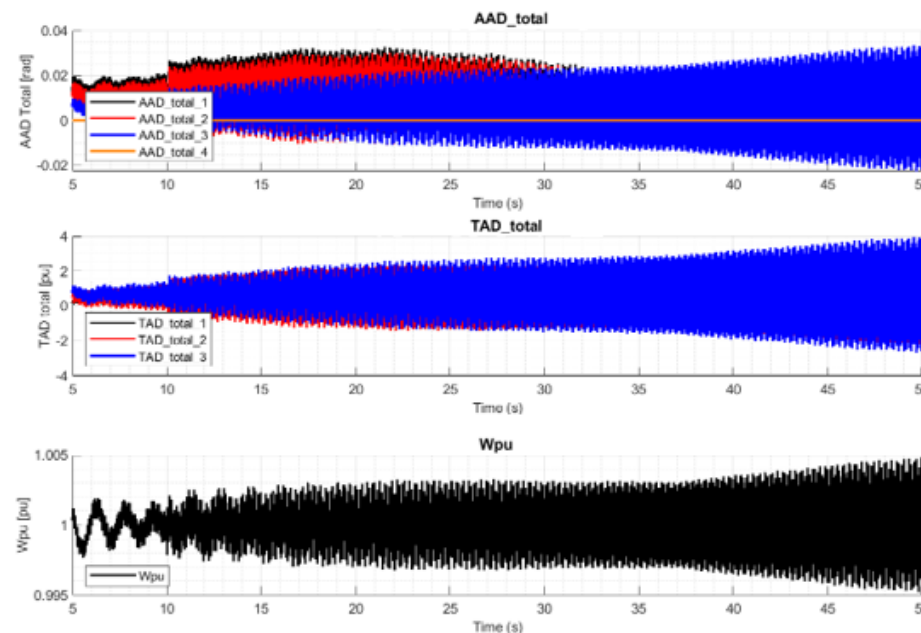
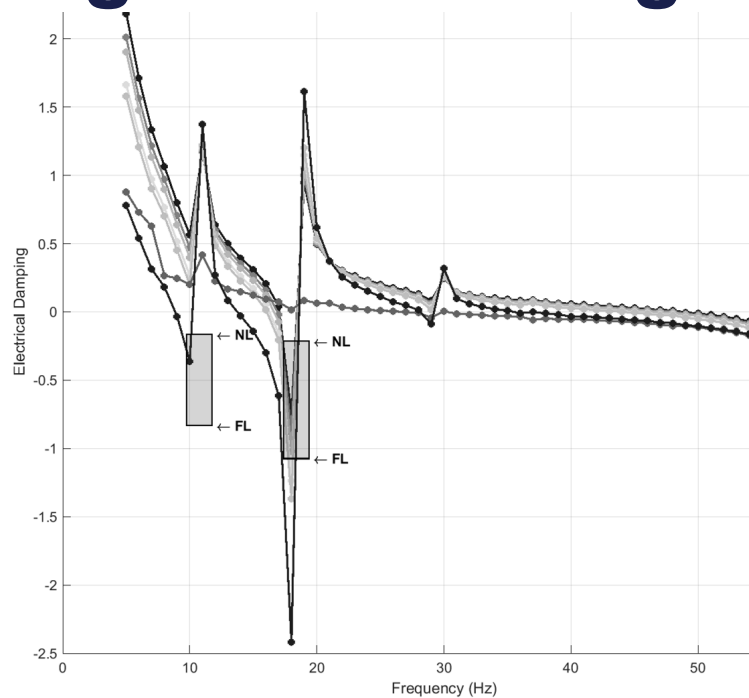
Confirm torsional response and evaluate shaft fatigue



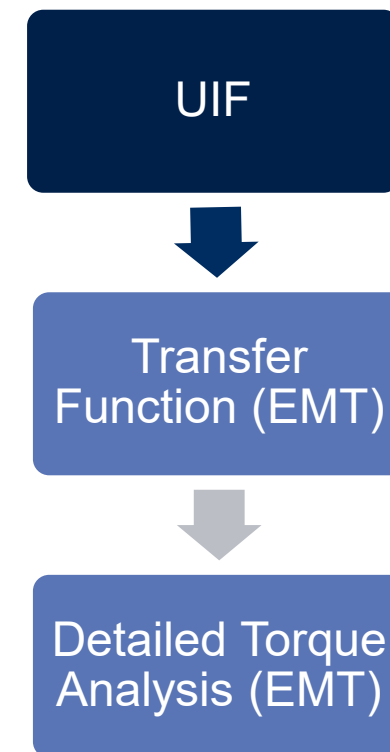
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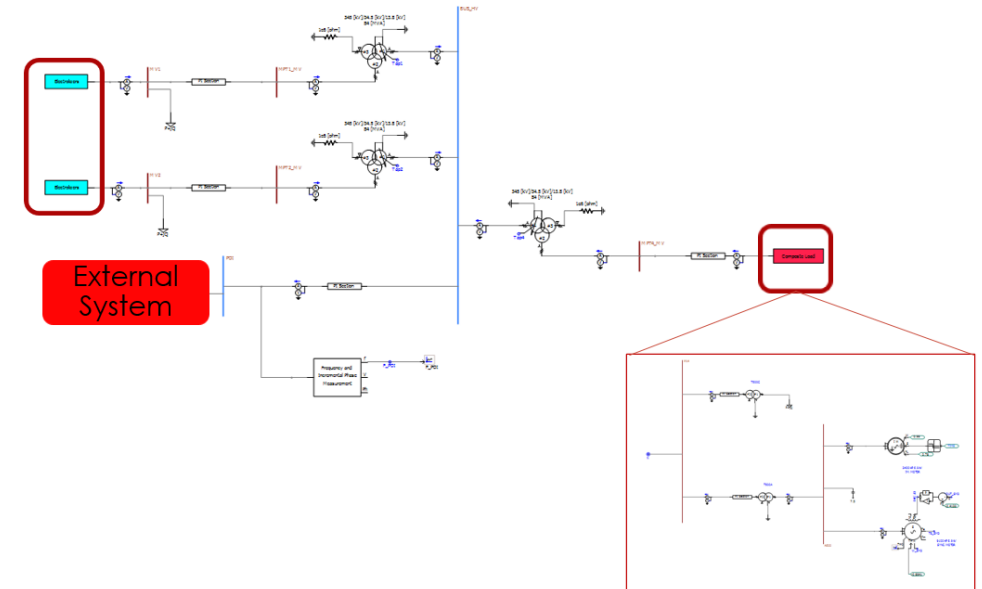
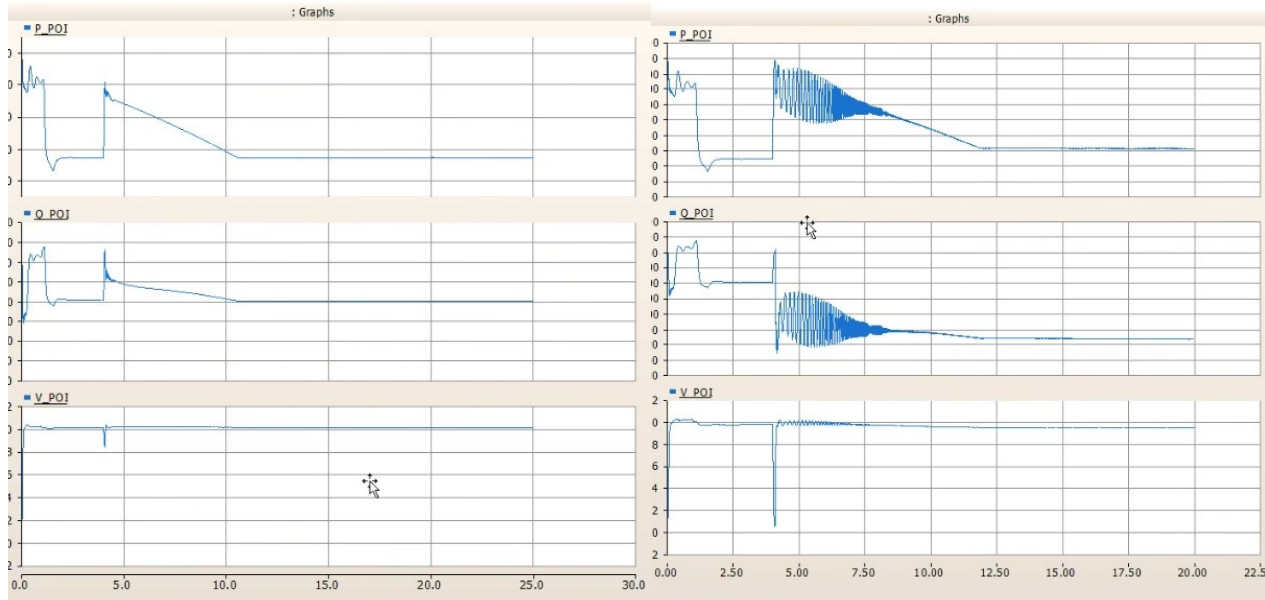
EMT System Studies - Oscillatory Interactions Due to Large Loads Integration



Rather than assessing a specific data center load profile, the study focused on identifying the magnitude and frequency thresholds to avoid SSTI excitation.



EMT System Studies – Dynamic Stability Analysis Including Large Loads



Capture the ride-through performance of converters in combination with the voltage impact of large induction machines to confirm the actual ride-through capability of the entire plant at the POI through a full-system analysis.



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Conclusions

- Large-scale EMT simulations are becoming integral to IBR interconnection studies.
- IBR EMT modeling has advanced significantly whereas load representation often remains simplified.
- As EMT study footprints expand, load dynamics influence system response, resource performance, and control interactions. Consequently, the accuracy of EMT simulation results is increasingly dependent on the load-model fidelity.
- Limited standardized and automated workflows currently exist for translating planning load representations into scalable EMT-compatible equivalents.



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Next Steps

- Develop scalable and computationally efficient representations of composite load dynamic models for EMT simulations.
- Establish practical frameworks for translating transmission planning and composite load models into EMT-compatible equivalents.
- Develop modeling requirements for large converter-based loads building on those applied to IBRs.
- Define criteria for requiring user-defined EMT models for large converter-based loads, enabling their explicit representation in system-wide EMT studies alongside IBRs, FACTS devices, HVDC systems, and conventional generation.

The next challenge for large-scale EMT simulation may not be the modeling of generation resources, but the accurate representation of the loads interacting with them.



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