

GRID EMT

SIMULATION INITIATIVE

Benchmark Model for Large Load Integration

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August 2026



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Motivation and Objective

- ❑ EMT benchmark system models are necessary for:
 - Comparing different solvers in EMT.
 - Reproducing test cases for academic and industrial studies, such as grid-strength and stability studies, fault analysis, and protection studies.
 - Understand and demonstrate what capabilities EMT offers.
- ❑ Reviewed most popular open-source standard IEEE and TAMU systems:
 - Limited demonstration of capturing real events.
 - No representation of data centers.
 - Most of them are for phasor, especially models for large-scale systems.
 - Wide range of use cases for small-scale systems but limited for large-scale systems.
- ❑ Objective: [Develop EMT benchmark systems with large data center loads and realistic disturbance scenarios to support large-scale grid studies, parameter standardization, model validation, and emerging technology evaluation.](#)



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Approach

- ❑ Propose 5 systems spanning small, medium, and large sizes .
 - Identify locations and Integrate data center models.
 - Scenario variations: different penetration levels and distances between data centers and generation plants.
 - Improve existing models (add missing dynamics).
 - Allow assessment of frequency and voltage transient stability, oscillations, partial trips, as well as performance of EMT solvers.
- ❑ Identify component and control parameters for the benchmark models.
- ❑ Generate data sets for different scenarios.
- ❑ Provide standardized input data files (e.g., raw, dyr, dss, xml) for each benchmark model to enable consistent evaluation across different simulation platforms.



Five Benchmark Models Developed for EMT Analyses

Category	System	Component information	Studies performed	Large load present?	EMT model available?	TS model available?	Reflecting near future system?
Small	IEEE 9-bus (WECC)	3 generators, 9 buses, 3 loads, 6 lines, and 3 transformers	Power flow, Transient stability	No	Yes	Yes	No
Small	IEEE 39-bus (New England)	10 machines, 19 loads, 34 lines, and 12 transformers	Fast frequency support, partial trip of renewable plants, EMT-phasor benchmarking, ac-dc power flow validation	No	Yes	Yes	No
Medium	240-bus Reduced WECC	109 machines, 37 renewable, 329 lines, 122 transformers, 139 loads	Production cost, Transient stability, Power flow, generation plant and HVDC integration, wide-area oscillations	No	Yes	Yes	Yes (2018 and more)
Medium	Texas 2000-bus synthetic	2751 buses, 1099 generators, 1351 transformers, 2993 lines, 1410 loads (86 GW)	Transient stability	No	No	Yes	Yes (generation and load only)
Large	70k-bus EI synthetic	10390 generators, 38181 loads (595 GW), 71353 lines, 10554 transformers, 2100 3-winding transformers	Transient stability	No	No	Yes	Yes (generation and load only)

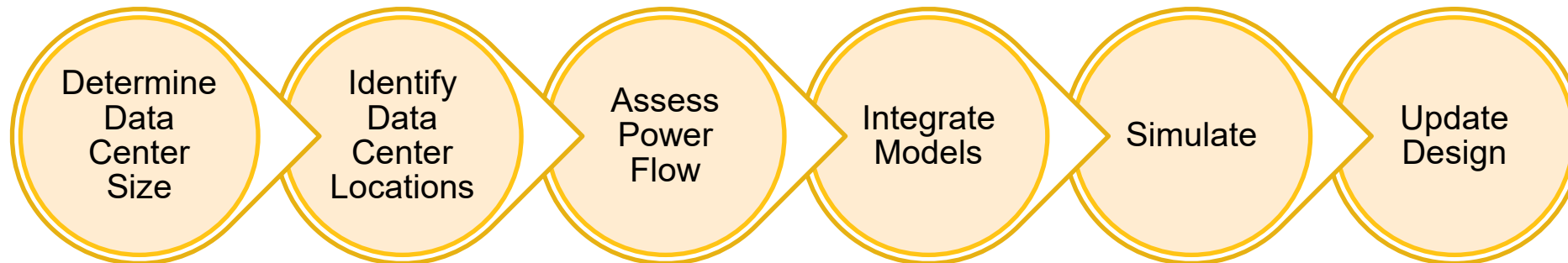


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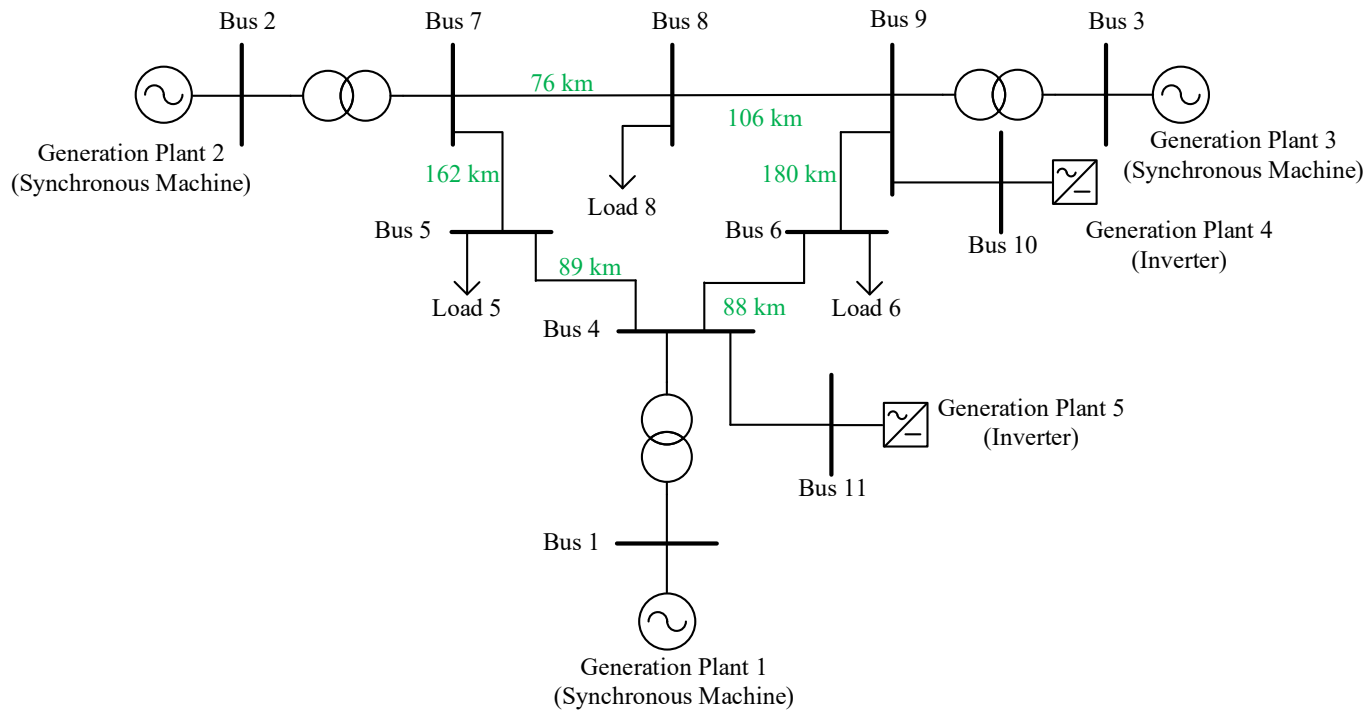
Design Workflow

- ❑ Multi-step process:
 - ❑ Determine locations and size of data centers w.r.t. existing loads, machines, and generation plants
 - ❑ Assess power flow throughout the system.
 - ❑ Integrate dynamic models and parameters (data centers and generation plants)
 - ❑ Run scenario-based simulation and tune and modify the model if needed

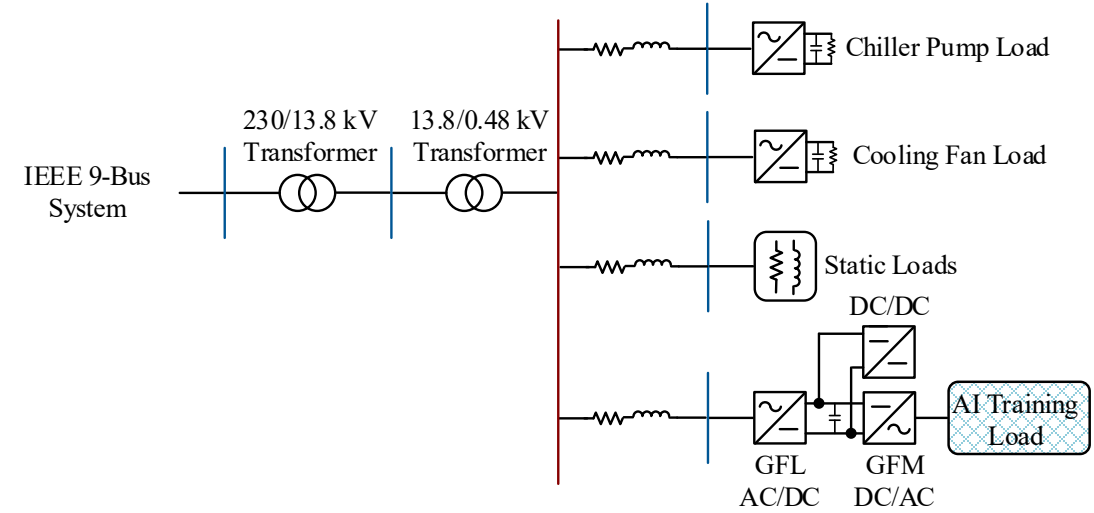


Benchmark Model Development

IEEE 9 Bus System



Data Center Model



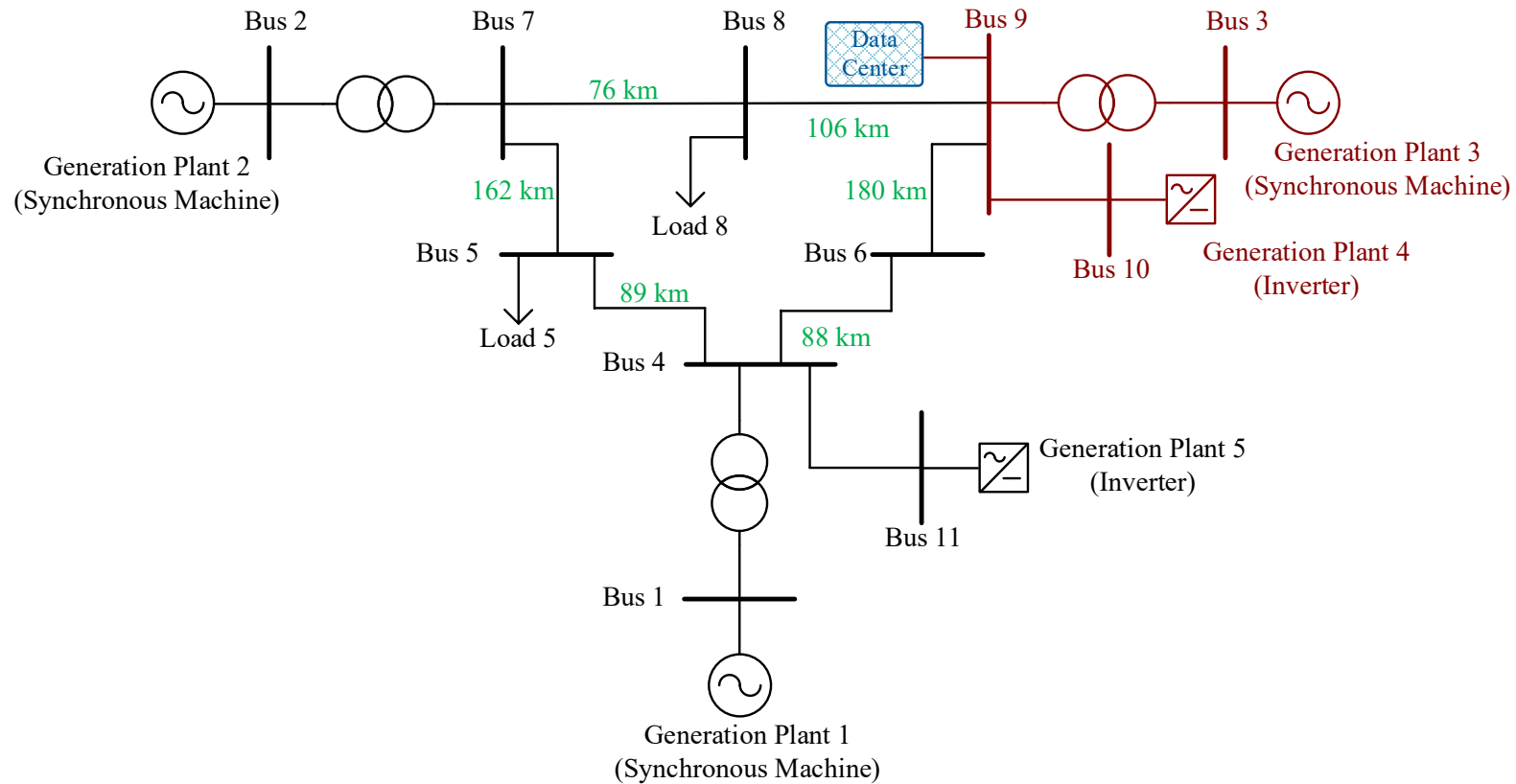
Ross B.A., and J.D. Follum, *Electromagnetic Transient Modeling of Large Data Centers for Grid-Level Studies*, Pacific Northwest National Laboratory, 2026



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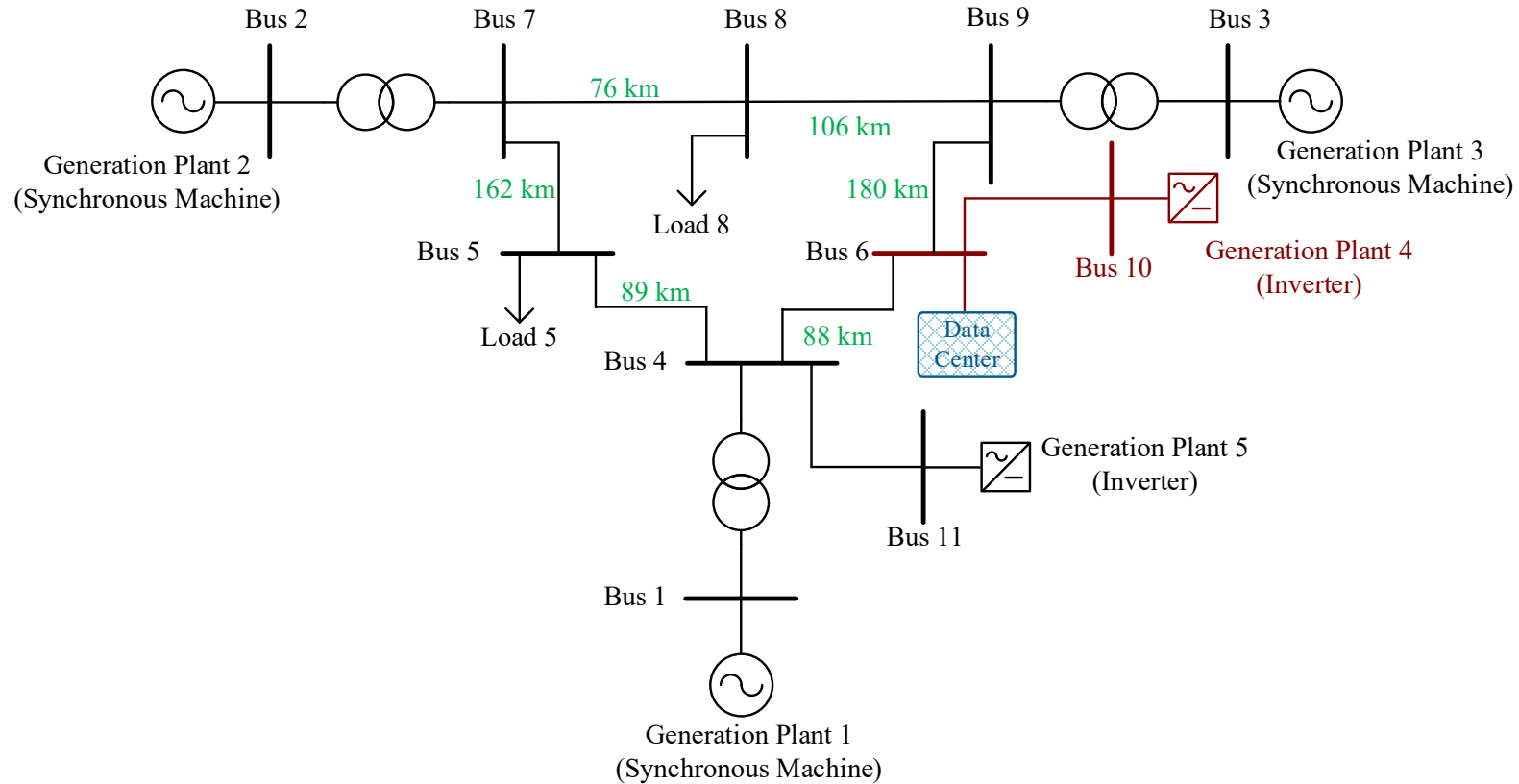
Benchmark Model Development (Cont.)

- Case 1: This case represent data center co-located with two different types of generation plants.



Benchmark Model Development (Cont.)

- Case 2: This case represent data center co-located with power electronics-based generation plant.

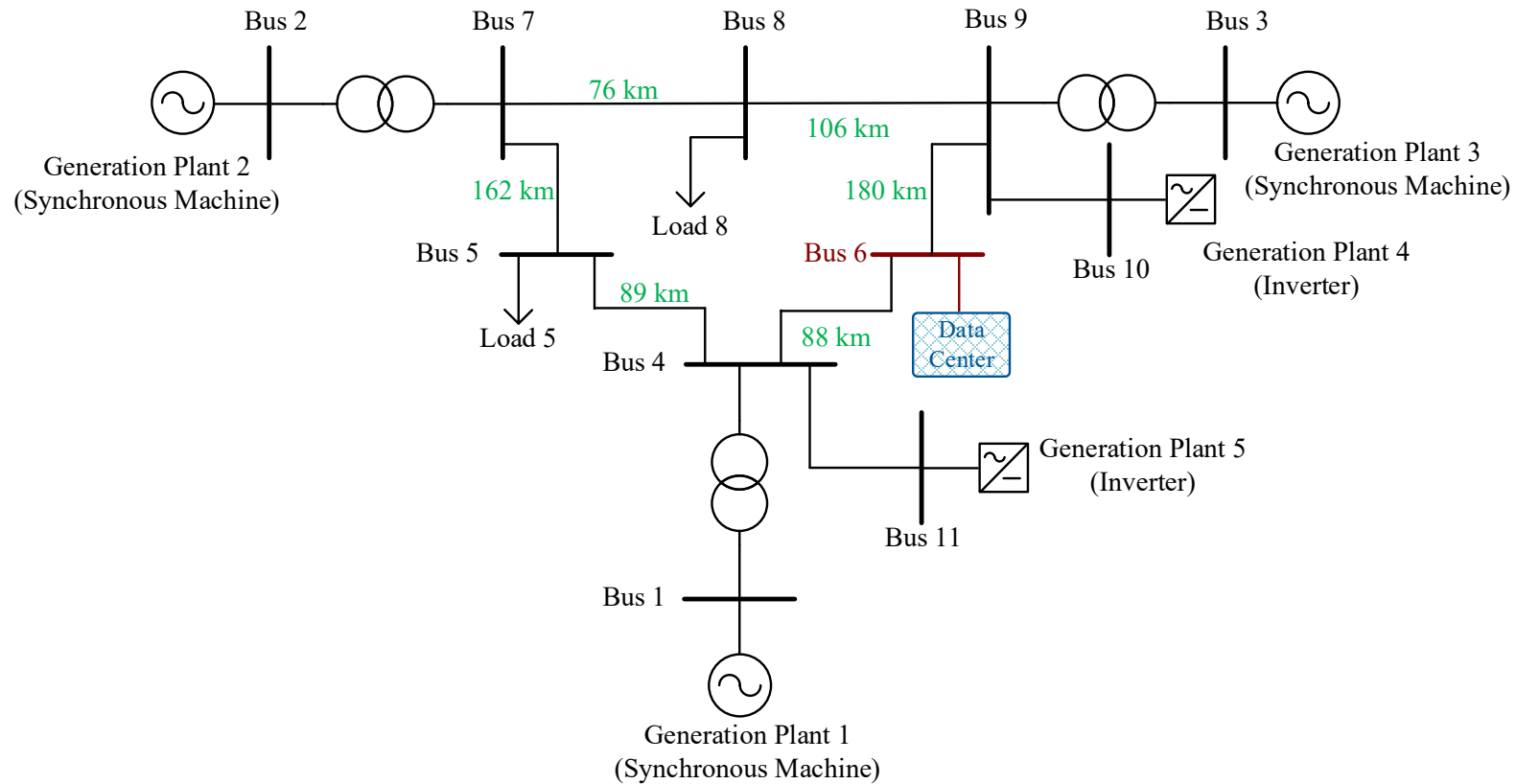


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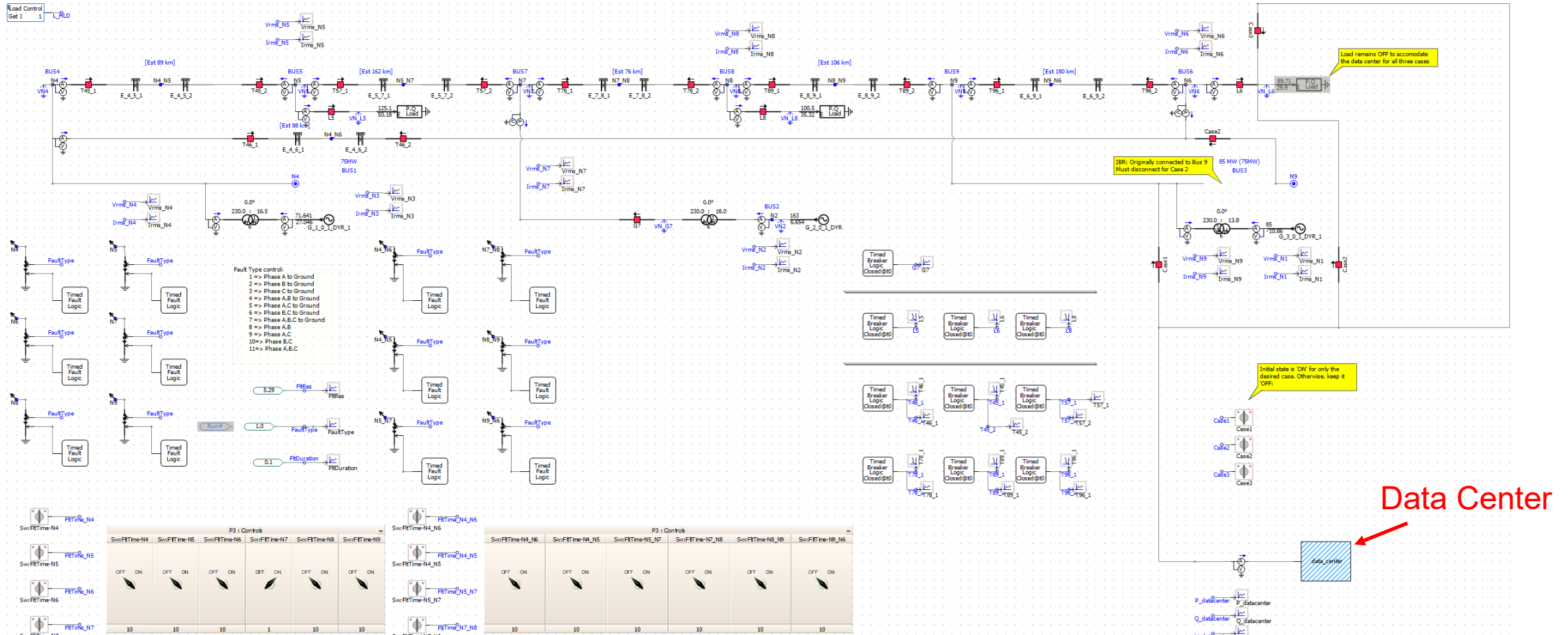
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Benchmark Model Development (Cont.)

- Case 3: This case represent data center positioned away from all the generation plants.



EMT Model of Data Center Integrated IEEE-9 Bus System



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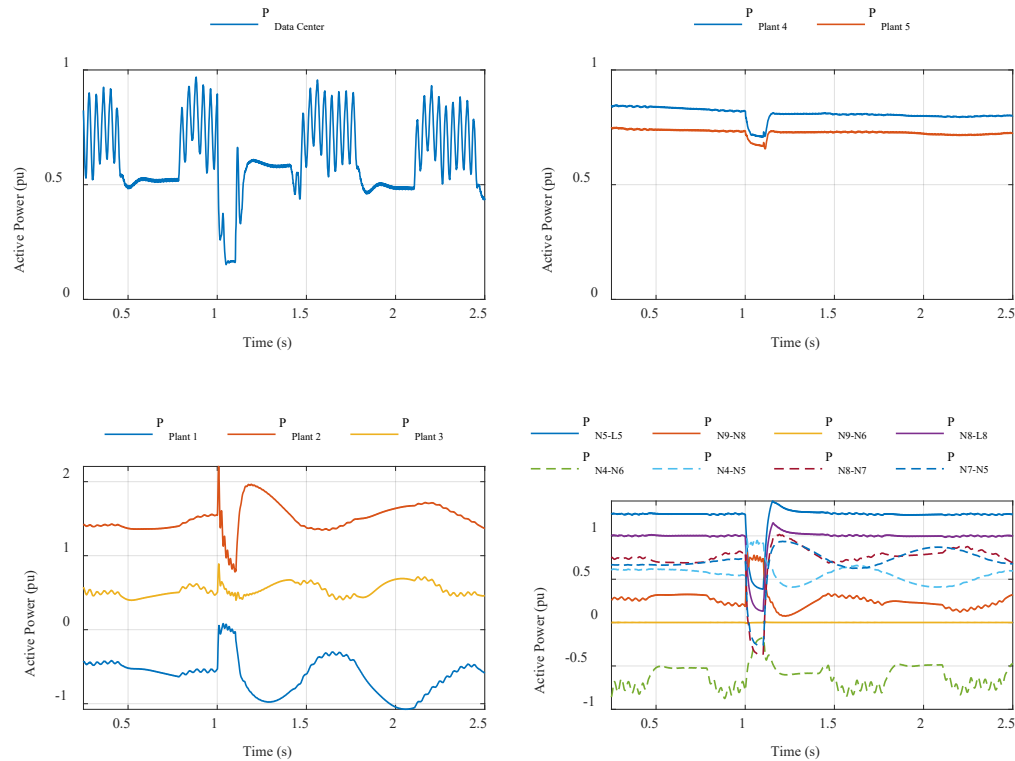
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Simulation Results: Fault Study 1

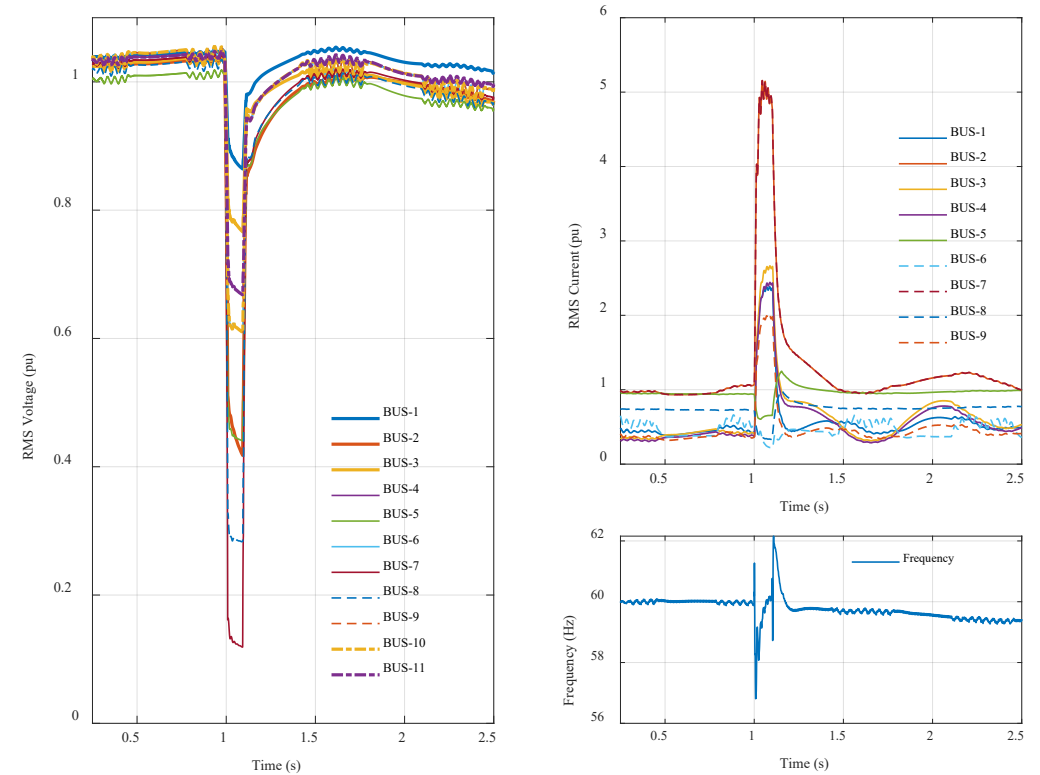
Phase-ABC to Ground Fault: Case 3

Fault Location = N7, Fault Duration = 0.1 s, Fault Resistance = 0.01 pu

Active Power Measurements at IEEE-9



Voltage, Current and Frequency Measurements at IEEE-9



Note: Synchronous machines have more impact of LEL fluctuation compared to power electronics-based generators. Noticeable impact on voltage and frequency.

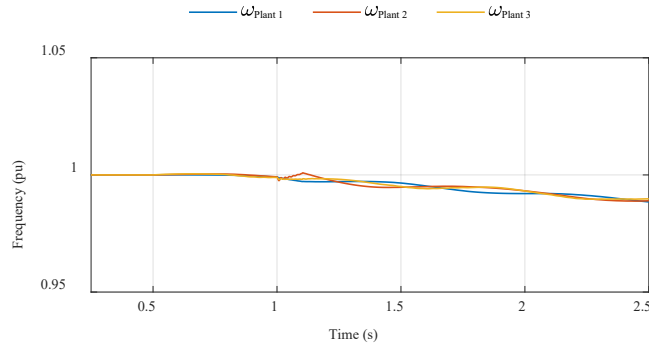
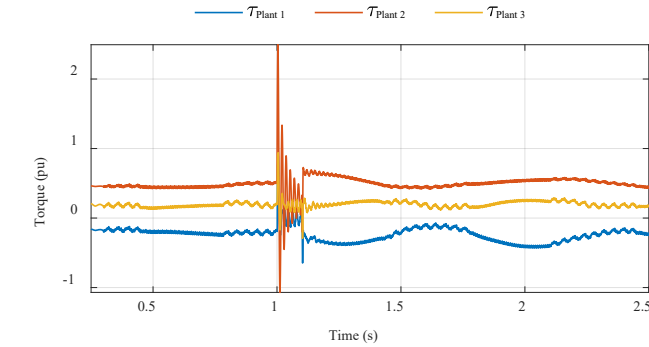


Simulation Results: Fault Study 1 (Cont.)

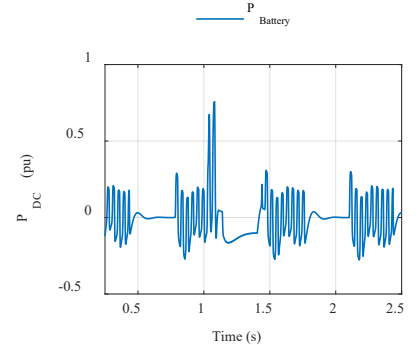
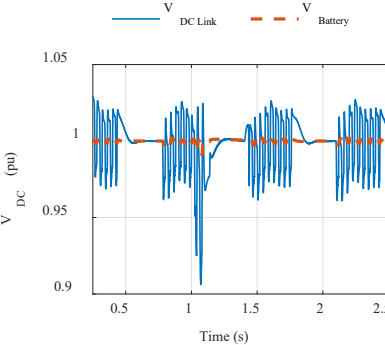
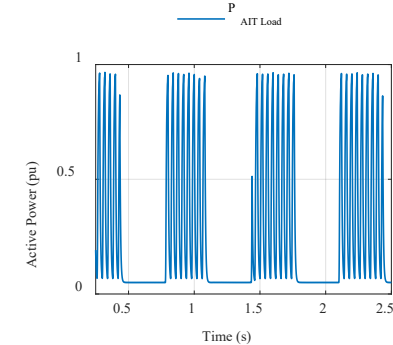
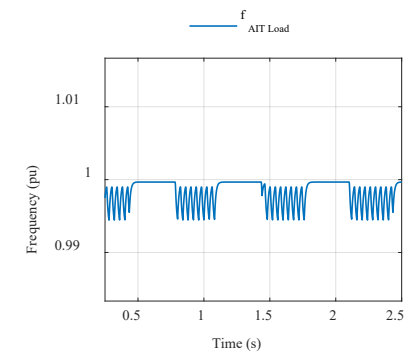
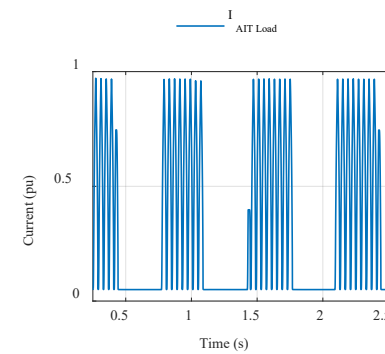
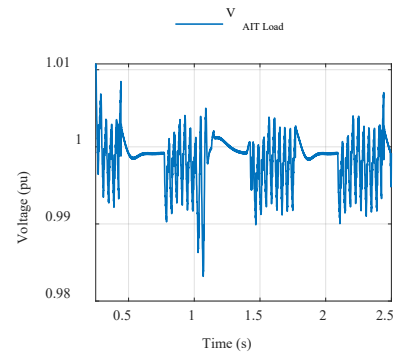
Phase-ABC to Ground Fault: Case 3

Fault Location = N7, Fault Duration = 0.1 s, Fault Resistance = 0.01 pu

Measurements at Synchronous Machines



Measurements at AI Training Branch



Note: Impact of LEL on sync. machines' torque

Note: DC/DC converter support activated during fault to maintain DC voltage to ensure continuous AIT operation

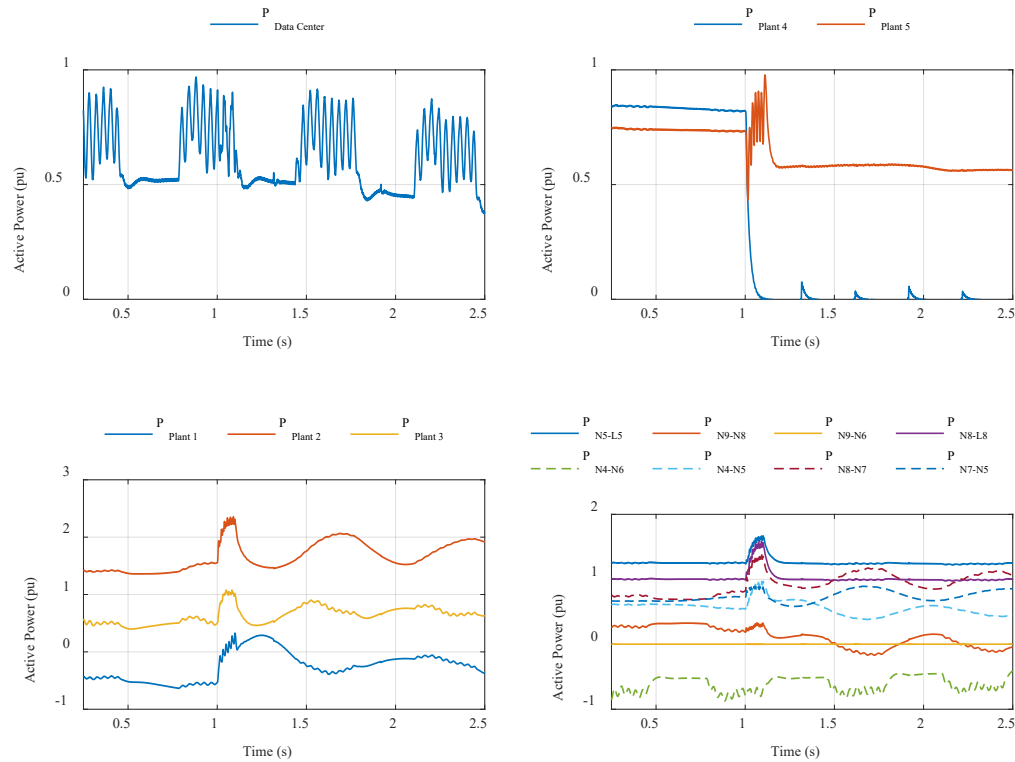


Simulation Results: Fault Study 2

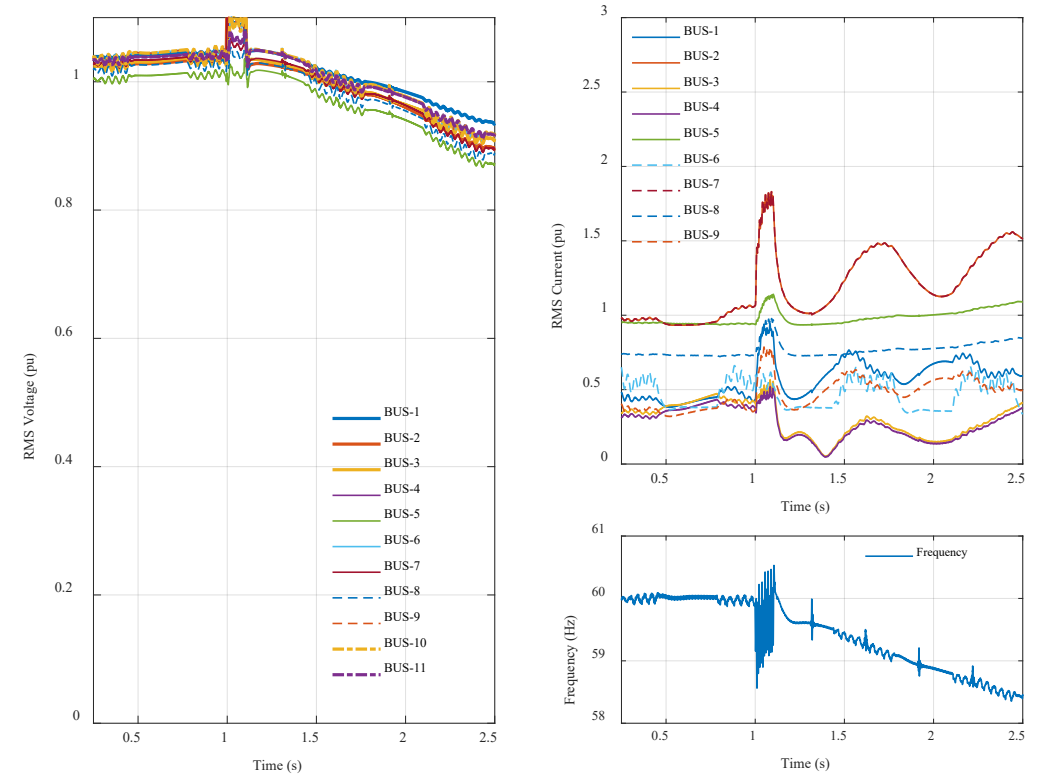
Phase-A to Ground Fault: Case 2

Fault Location = N7, Fault Duration = 0.1 s, Fault Resistance = 0.01 pu

Active Power Measurements at IEEE-9



Voltage, Current and Frequency Measurements at IEEE-9



Note: Complete/partial trip of power electronics-based generators due to unbalanced fault.

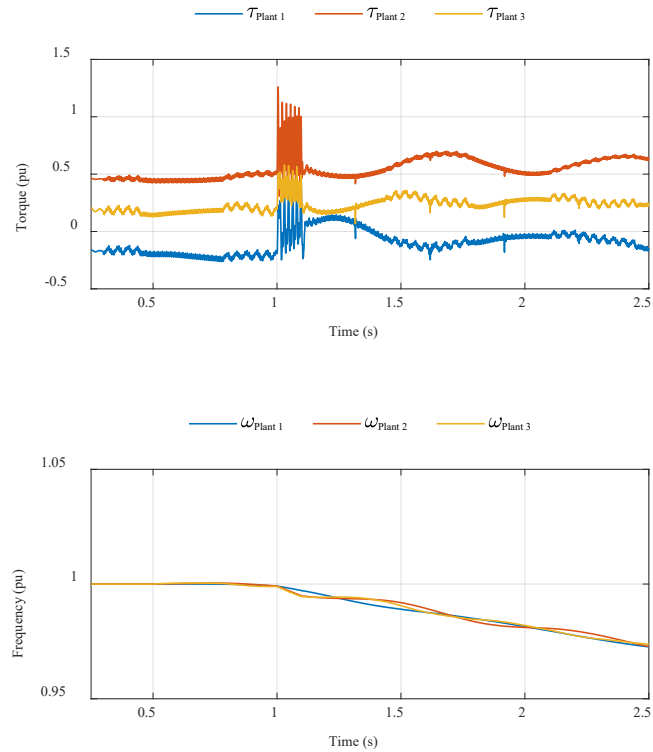


Simulation Results: Fault Study 2 (Cont.)

Phase-A to Ground Fault: Case 2

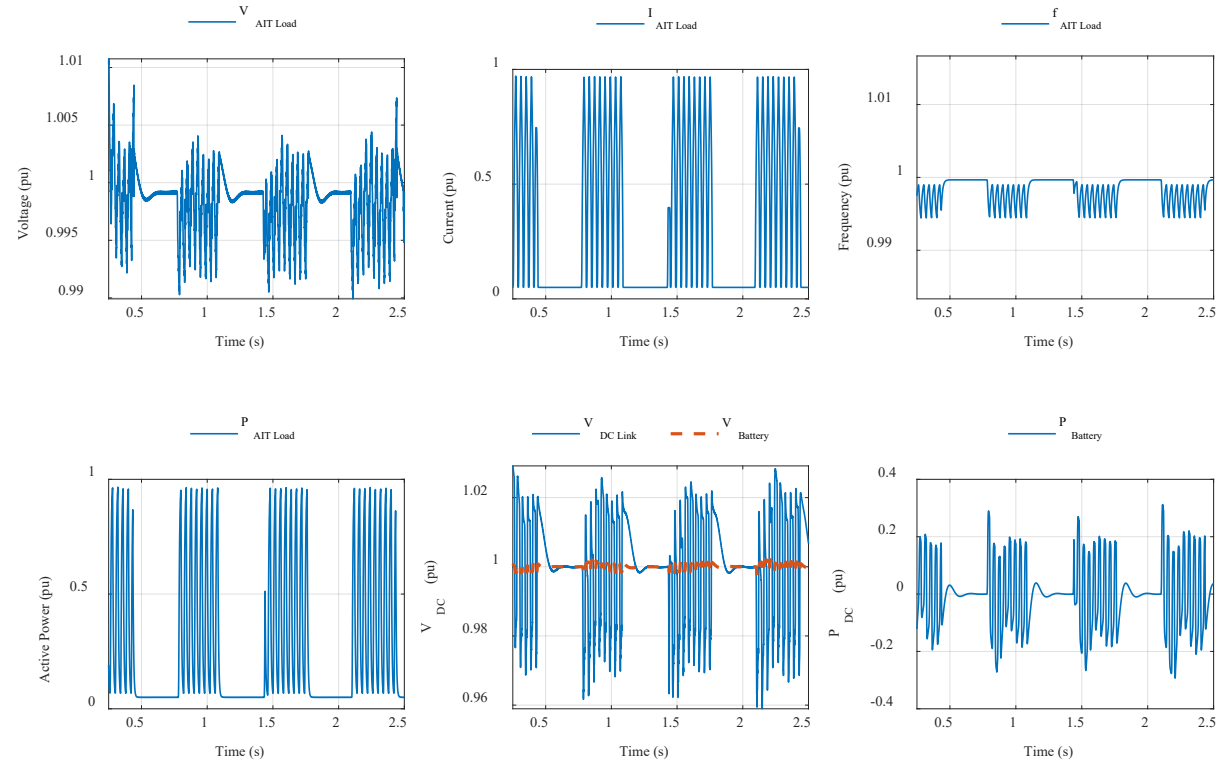
Fault Location = N7, Fault Duration = 0.1 s, Fault Resistance = 0.01 pu

Measurements at Synchronous Machines



Note: Impact of LEL on sync. machines' torque

Measurements at AI Training Branch



Note: AIT branch is not impacted by the applied fault.



Key Takeaways from Case Studies

- ☐ Rapid fluctuations of large load can cause more oscillation on synchronous machine compared to power electronics-based generation plants.
- ☐ Power electronics-based converters are more prone to trip compared to machine-based converters.
- ☐ Data center must be equipped with fault-ride through capability



Conclusion and Future Works

- ❑ A benchmark model consists of IEEE-9 bus system and large electric load (data center model) has been developed.
- ❑ Balanced and unbalanced fault scenarios at different locations.
- ❑ Potential Application of IEEE-9 bus benchmark model:
 - Fault analysis, dynamic/transient-response analysis, small-signal stability analysis, power electronics-based converter integration, control evaluation, protection studies, etc.

Future Works:

- ❑ Documentations
- ❑ Prepare larger benchmark models and study.



Thank You

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Acknowledgement: The authors thank U.S. Department of Energy (DOE) Office of Electricity (OE) Advanced Grid Modeling (AGM) and the EMT initiative for their invaluable guidance and kind support in this work!

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