EMT Simulations for Hawaii Oscillation Events

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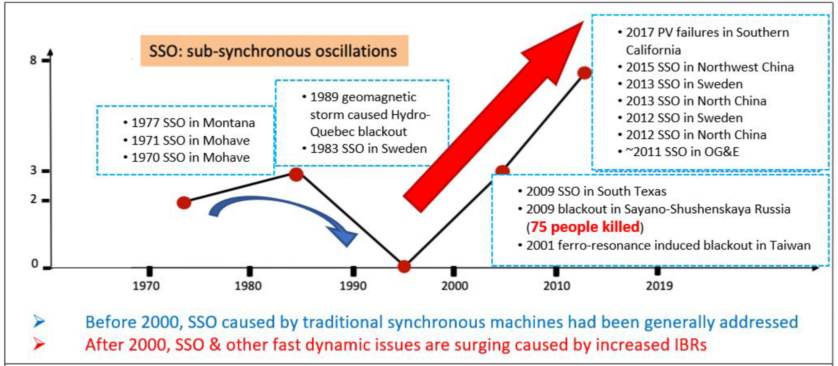
August 18, 2023

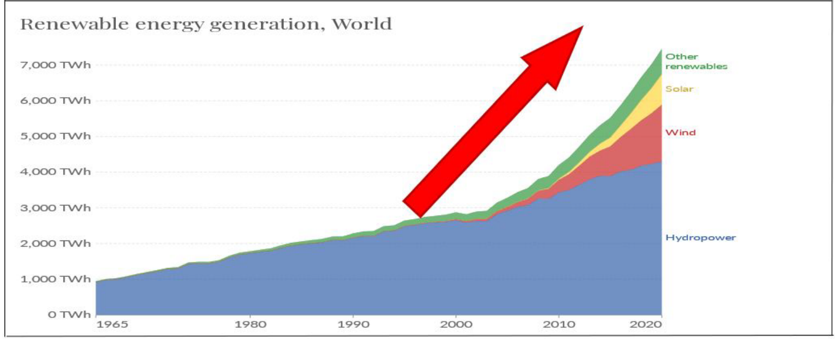
For ONRL-DOE-NERC EMT Workshop

Content

Challenges With High Renewable Penetrations

- **New problem**- New fast dynamics from inverter-based renewables





Examples:

2009 TX sub-synchronous oscillation (SSO) event

Other recent oscillation events

- SSO in UK blackout on Aug. 9, 2019
- 8 Hz oscillations on Aug. 24, 2021, in UK
- 19.5 Hz oscillation on Kauai Island on Nov 21, 2021

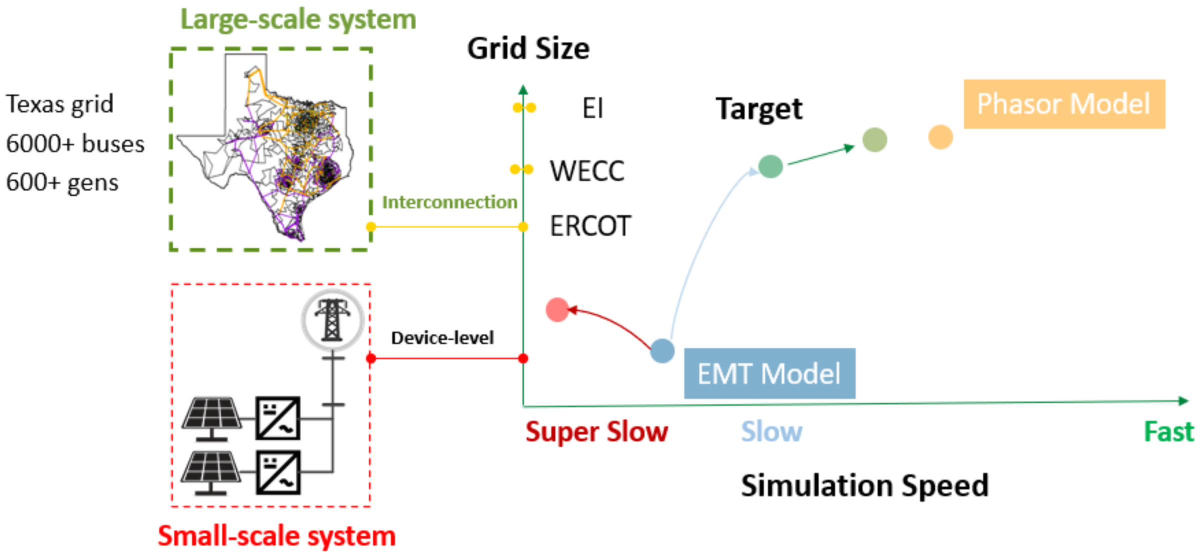
Source: [4] https://www.youtube.com/watch?v=TLWvSoBAjOc

Source for top figure: L. Zhang, B. Wang, et al, "A hierarchical low-rank approximation-based network solver for EMT simulation," IEEE Trans. on Power Del., vol. 36,no. 1, pp. 280–288, 2021
Source for bottom figure: https://ourworldindata.org/renewable-energy

EMT Simulation Needs and Challenges

Features of Morden Power Systems

- Faster and faster; larger and larger; more and more.

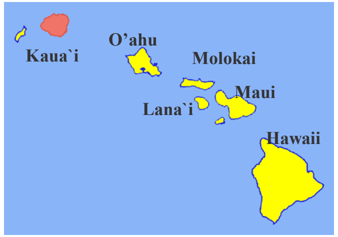


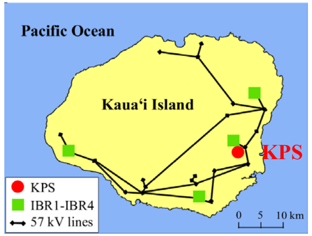
Challenges: How to capture **fast dynamic characteristics** of inverter-based resources for **large-scale** power systems simulation and analysis?

19.5 Hz Oscillation Event on Kauai Island

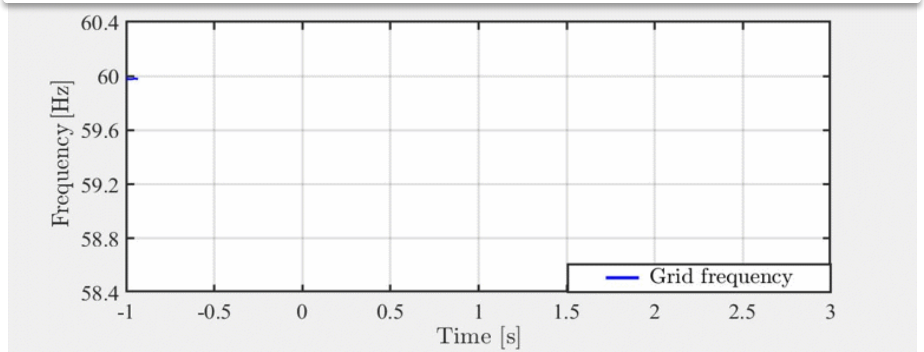
Kauaʻi Island Utility Cooperative (KIUC)

- System Peak: 75.17 MW [1] (in 2021)
- **Time:** Nov. 21, 2021, at 05:30:47 am.
- **Event:** The largest generator (KPS) on Kauai tripped. It had a 26.6 MW output, **60.6%** of power demand.





Grid Frequency of Kauai Island Grid



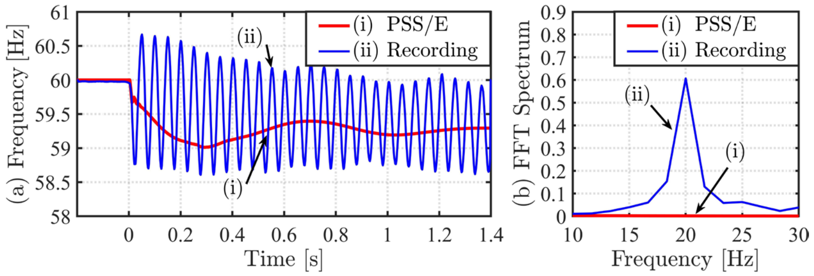
Remark:

- Fast power response from 4 BESSs avoided blackout.
- Significant 19.5 Hz oscillations lasted for about one minute.

* S. Dong, B. Wang, J. Tan, C. J. Kruse, B.W. Rockwell, and A. Hoke, "Analysis of November 21, 2021, Kaua'i Power System 18-20 Hz Oscillations" (to be submitted).

Event Replay: Kaua`i EMT Model Development

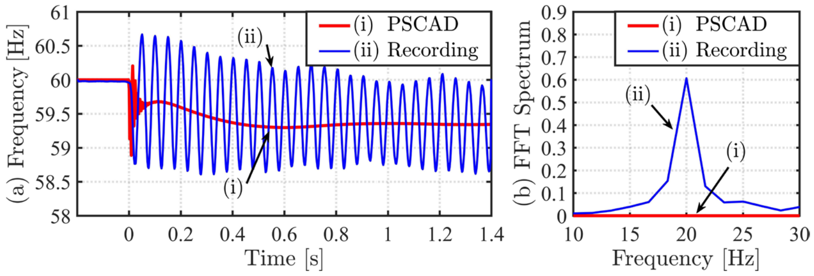
Motivation: Why EMT model?



The phasor-based simulation cannot replay the oscillation event, despite the following efforts:

- Adopting vendor-provided PSS/E models at IBR1 (GFL) and IBR2 (GFL).
- Tuning the KIUC PSS/E model based on KIUC field data.

Importance of vendor-provided IBR EMT models

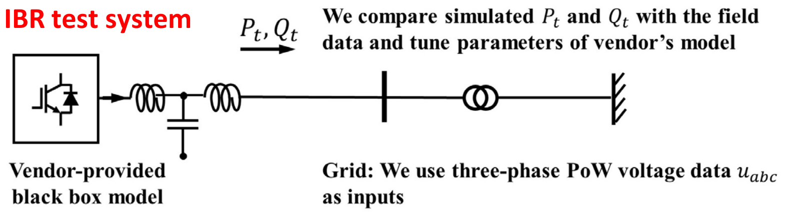


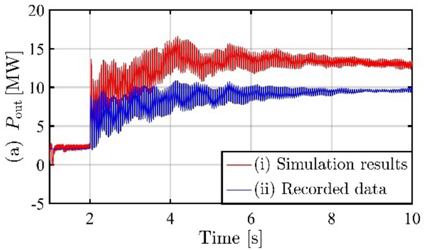
Without vendor-provided IBR EMT models, our developed EMT model (v1) still cannot recreate the event, despite the following effort:

- Developing and tuning KIUC EMT model based on inputs from KIUC (SCADA data, switching diagram, DFR data, etc.)

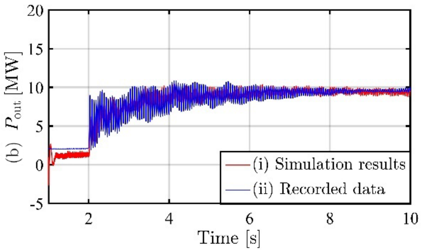
Event Replay: Kaua`i EMT Model Development

Emphasize IBR model validation process





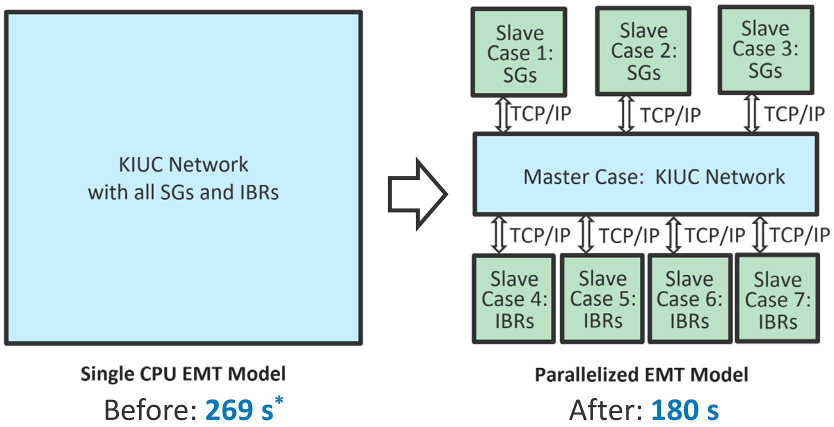
Before parameter tuning



After parameter tuning

The vendor-provided IBR EMT models should be validated against field data before being connected to the whole KIUC model.

Accelerate EMT simulation speed



* Simulating KIUC EMT model for 10s in PSCAD

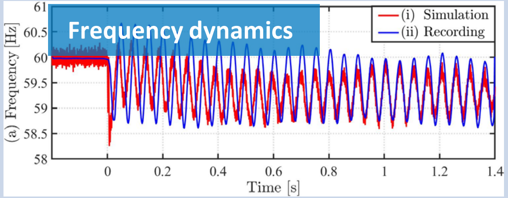
We accelerate the KIUC EMT model simulation speed through parallel simulation.

Event Replay: Validation of KIUC EMT Model

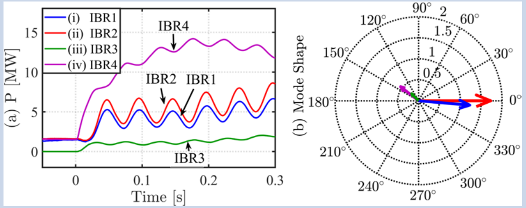
Columns: Time-domain comparison | Mode shape comparison | DEF analysis comparison

EMT simulation

Time-domain comparison

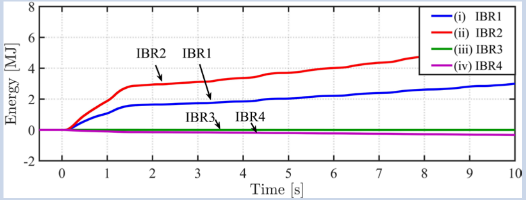


Mode shape comparison



IBR1 (GFL) IBR2 (GFL) IBR3 (GFL) IBR4 (GFM)

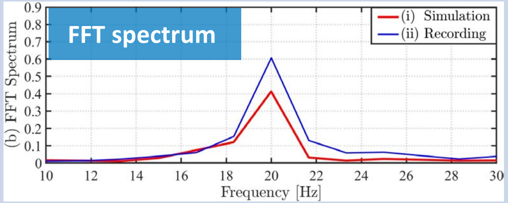
DEF analysis comparison



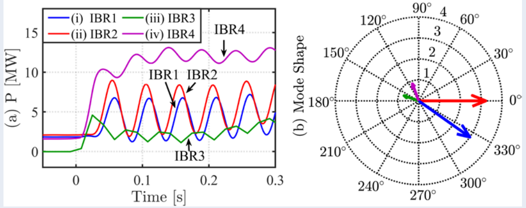
IBR1 (GFL) IBR2 (GFL) IBR3 (GFL) IBR4 (GFM)

Field data

Time-domain comparison

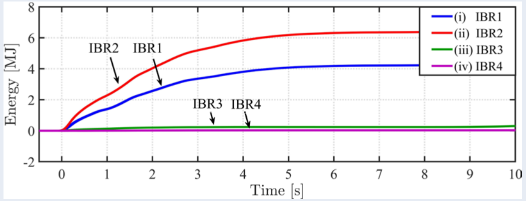


Mode shape comparison



IBR1 (GFL) IBR2 (GFL) IBR3 (GFL) IBR4 (GFM)

DEF analysis comparison

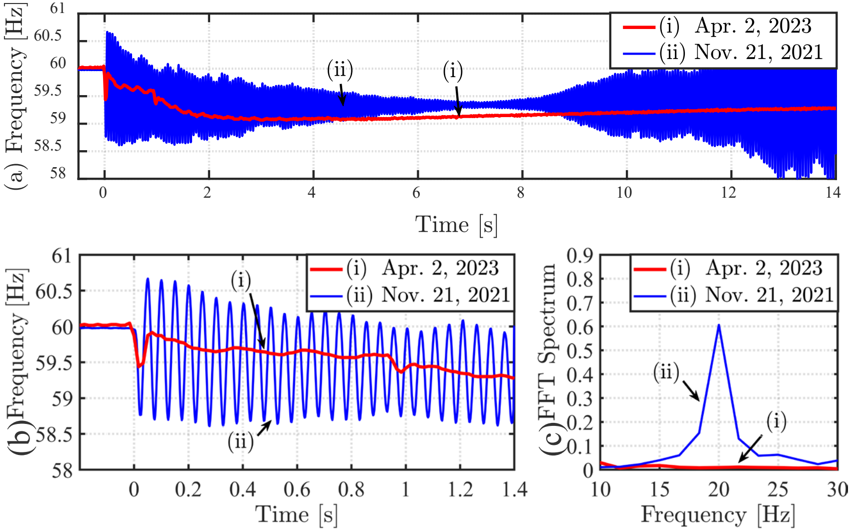


IBR1 (GFL) IBR2 (GFL) IBR3 (GFL) IBR4 (GFM)

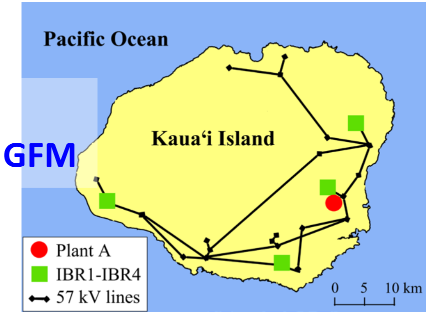
Conclusion: We validate the accuracy of our developed KIUC EMT model, since our EMT simulation results capture the actual time-domain dynamics, exhibit similar system mode shapes, and point to same oscillation sources.

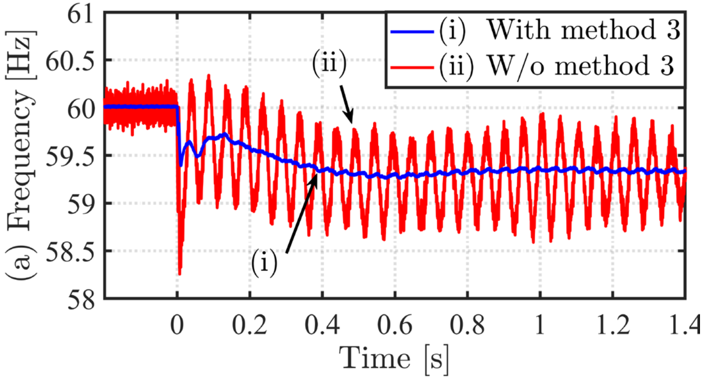
Mitigation Methods Method and EMT Validation

Method 1: Make the P/f droop constant less aggressive.
Method 2: reduce PLL proportional gains.
Method 3: Convert existing GFL to GFM inverters.



IBR1:
GFL -> GFM



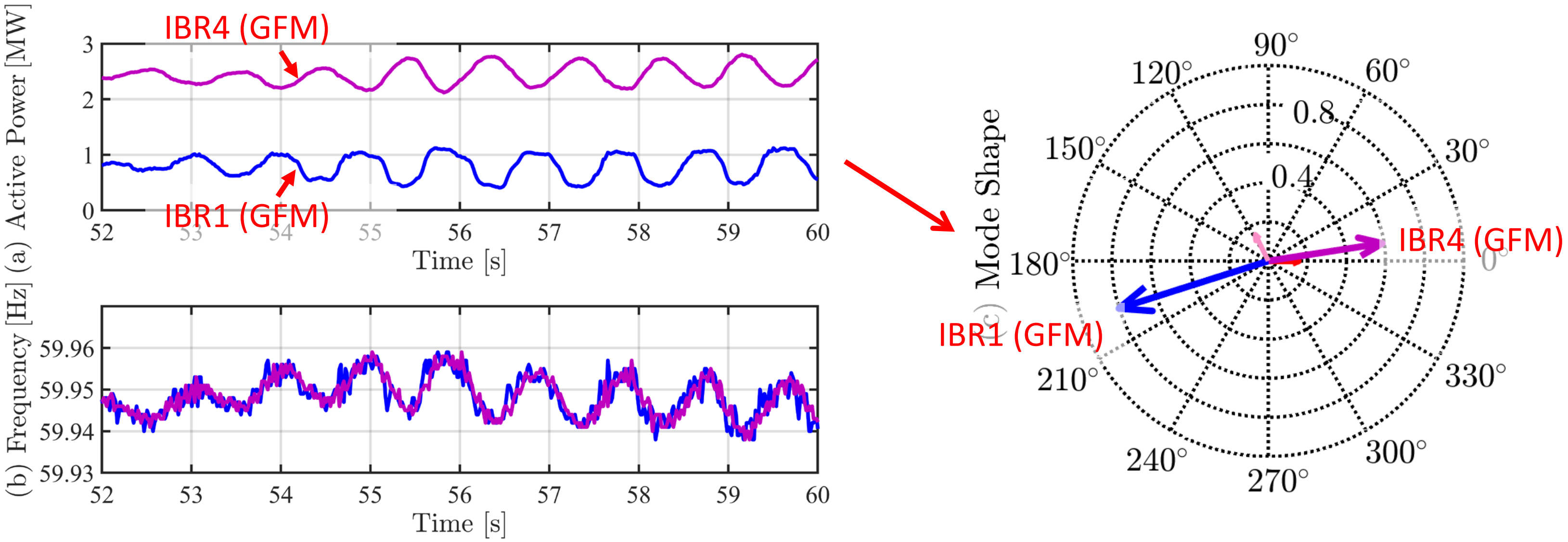


Findings:

- More than one mitigation method could be proposed. GFM is an effective one.

Low-Frequency Oscillation Risks Arising From GFMs

- Event: On Apr. 30th, 2023, two GFMs, IBR1 and IBR4, oscillate against each other for about 5 minutes, and the oscillation frequency is ~1 Hz.



Conclusion: GFM may bring stability challenges within the low-frequency range.

Lessons Learned

Modeling Perspective

- The phasor-based simulation cannot replay the 19.5 Hz oscillation event. EMT simulation is recommended for capturing similar oscillations.
- Vendor model v.s. Generic model
  - Vendor model reflects the real control of the field deployed inverters; however, it is a black box model.
  - Site-specific vendor model and validation is critical for capturing the interaction between the grid and converters. Good for post-event analysis.
  - Generic model can be useful to understand the control impact in general. Good for future planning study.

Simulation Perspective

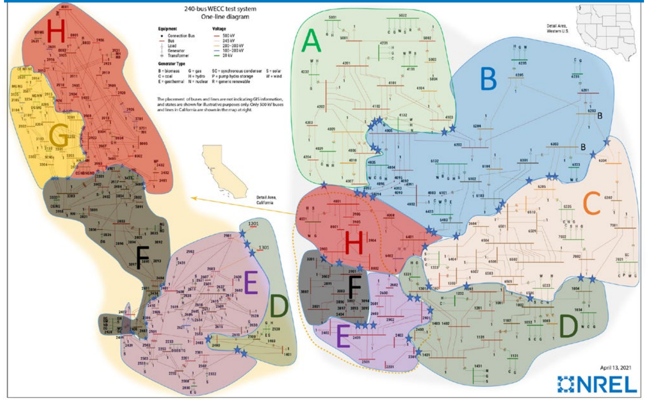
- EMT simulation acceleration is important for large-scale power system simulation.
- System-wide EMT simulation will be needed for analyzing control interaction among different inverters from different locations.

Needs of a testbed for large-scale bulk power systems: Example: EMT Model of 240-bus WECC Test System

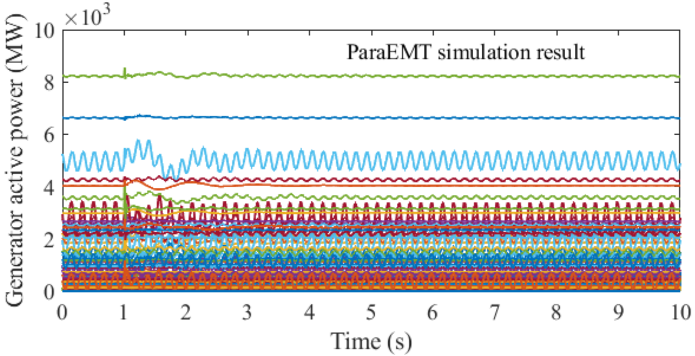
Feature

- One-on-one matched scheduling and dynamic model (MIDAS[1], PSSE[2], PSCAD[3], ParaEMT[4])
- Capture the main dynamic characteristics of the WECC system[2].
- High renewable cases for WECC and a 100% renewable case in the California region.

240-bus WECC Test System



Oscillations induced by IBR controllers[4]



Application

- Provide various oscillation scenarios for the 2021 IEEE-NASPI OSL Contest[5].
- GFM integration study. (GE, ongoing)
- Impact of GFMs on grid stability (NERC & NREL, ongoing)

1. J. Tan and et al, "Final technical report: Multi-Timescale Integrated Dynamics and Scheduling for Solar (MIDAS-Solar)," NREL/TP-5D00-85679, Apr. 2023
2. H. Yuan, R. Sen biswas, J. Tan, Y. Zhang, "Developing a Reduced 240-Bus WECC Dynamic Model for Frequency Response Study of High Renewable Integration," 2020 T&D
3. B. Wang, R. W. Kenyon, J. Tan, "Developing a PSCAD Model of the Reduced 240-Bus WECC Test System," 2022 KPEC.
4. M. Xiong, B. Wang, D. Vaidhynathan, J. Maack, M. S. Reynolds, A. Hoke, K. Sun and J. Tan, "An Open Source, Parallelizable, and HPC-Compatible EMT Simulator for Large-Scale IBR-Rich Power Grids," (under review).

How could we achieve a faster EMT simulation? (Example: ParaEMT)

Feature

- Open source, Python-based, HPC Compatible EMT simulator called ParaEMT[1,2].
- ParaEMT GitHub repository: http://github.com/NREL/ParaEMT_public
- Dynamic model library
  - ➢ Compatible with IEEE/CIGRE DLL std
  - ➢ Generic IBR models
- Parallelizable network solution
- Available test cases
  - ➢ 9-bus, 39-bus, 179-bus, 240-bus.

Application

- I PEP (NREL)
- OEDI (NREL & ORNL, ongoing effort)

Performance

- A large synthetic 10,206-bus case (time step= 50 us)

HPC test of 10k-bus case

20-25x speedup with 20-30 MPI ranks

[1] B. Wang, J. Maack, D. Vaidhynathan, J. Tan, M. Reynolds, “Parallelizable Large-Scale Power System Electro-Magnetic Transient Simulator,” NREL SWR-22-16, Dec. 2021.
[2] M. Xiong, B. Wang, D. Vaidhynathan, J. Maack, M. S. Reynolds, A. Hoke, K. Sun and J. Tan, “An Open Source, Parallelizable, and HPC-Compatible EMT Simulator for Large-Scale IBR-Rich Power Grids,” under review.
[3] J. Tan, B. Wang, “Parallelizable Large-Scale Power System Electro-Magnetic Transient Simulation Capability for Evaluating High Inverter-Based Systems,” 2023 PESGM Panel – High-Performance Electromagnetic Transients Simulation for Power Electronics Dominated Power Systems, July 17, 2023.

Path Forward

Simulation and Analysis Perspective

- Need a better understanding of many questions such as when do we need EMT? Which region do we need EMT? How could we run it faster? How could we run it for a large-scale system?

Modeling perspective

- **Advanced power electronics modeling:** Enable high-performance EMT simulation.
- **Enhanced EMT solver**: Innovations in EMT solver algorithms can lead to substantial speed improvements.
- **Leveraging Parallel Computing:** Harnessing the capabilities of advanced parallel computing technologies
- **Handling DERs in EMT:** Methods for integrating a high volume of DERs within EMT simulations.
- **Phasor + EMT Integration**
  - **Co-simulation Interface technology**
  - **Boundary Definition**
- **Improved phasor model for IBR**

The need for EMT studies is inevitable, and the key question is when, where, and how to run it more efficiently.

Acknowledgments

"Teamwork divides the task and multiplies the success." — Unknown

EMT-based Oscillation analysis

NREL

- Jin Tan
- Shuan Dong
- Andy Hoke
- Jiangkai Peng

KIUC

- Brad W. Rockwell **(Lead)**
- Cameron Kruse

AES

- Kelsey Horowitz
- Mike Simpson
- Sam Ley

ParaEMT

- Bin Wang
- Min Xiong
- Deepthi Vaidhynathan
- Andy Hoke
- Jonathan Maack
- Matthew Reynolds
- Jin Tan

Thank you!

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Publication Number

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office(#37772). The views expressed in the presentation do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work or allow others to do so, for the U.S. Government purposes.

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