



Generating Value from Detailed, Realistic Synthetic Electric Grids

Final Project Report

S-91

Power Systems Engineering Research Center
*Empowering Minds to Engineer
the Future Electric Energy System*



Generating Value from Detailed, Realistic Synthetic Electric Grids

Final Project Report

Project Team

Thomas Overbye, Project Leader

Katherine Davis

Texas A&M University

Bernie Lesieutre

Line Roald

University of Wisconsin-Madison

Graduate Students

Hanyue Li

Jessica Wert

Seri Kang

Shashwat Tripathi

Texas A&M University

Jonathan Snodgrass

Noah Rhodes

Sofia Taylor

Aditya Rangarajan

University of Wisconsin-Madison

PSERC Publication 22-03

October 2022

For information about this project, contact:

Thomas J. Overbye
Texas A&M University
Department of Electrical and Computer Engineering
308C, Wisenbaker Engineering Building
College Station, Texas 77843-3128
Phone: 979-458-5001
Email: overbye@tamu.edu

Power Systems Engineering Research Center

The Power Systems Engineering Research Center (PSERC) is a multi-university Center conducting research on challenges facing the electric power industry and educating the next generation of power engineers. More information about PSERC can be found at the Center's website: <http://www.pserc.org>.

For additional information, contact:

Power Systems Engineering Research Center
Arizona State University
527 Engineering Research Center
Tempe, Arizona 85287-5706
Phone: 480-965-1643
Fax: 480-727-2052

Notice Concerning Copyright Material

PSERC members are given permission to copy without fee all or part of this publication for internal use if appropriate attribution is given to this document as the source material. This report is available for downloading from the PSERC website.

© 2022 Texas A&M University. All rights reserved.

Acknowledgements

This is the final report for the Power Systems Engineering Research Council (PSERC) research project titled “Generating Value from Detailed, Realistic Synthetic Electric Grids”. We wish to express our appreciation for the support provided by PSERC’s industry advisors:

Harvey Scribner (SPP)
Jim Price (CAISO)
Bryan Palmintier (NREL)
Di Shi (GEIRI)
Evangelos Farantatos (EPRI)
Cho Wang (AEP)
Steven Judd (ISO-NE)
Melvin Schoech (CenterPoint)
Al Engelmann (ComEd)
Yazhou Jiang (GE)
Anil Jampala (GE)
Mahesh Morjaria (First Solar)
Patrick Panciatici (RTE)
Jianzhong Tong (PJM)
Baj Agrawal (APS)
Felicia Ruiz (MISO)
Casey Cathey (SPP)
Atena Darvishi (NYPA)
Paul Myrda (EPRI)

The authors and PSERC industry advisors would like to recognize the research teams at Texas A&M University (Tom Overbye, Kate Davis, Komal Shetye, Jonathan Snodgrass, Hanyue Li, Jess Wert, Seri Kang) and the University of Wisconsin-Madison (Bernie Lesieutre, Line Roald, Noah Rhodes, Sofia Taylor, Jonathan Snodgrass (graduated 2021)) for their research contributions to this project:

Executive Summary

The goal of this research project was to generate value from large-scale detailed and realistic synthetic electric grids. This was accomplished by completing four sub-tasks: 1. Developing customized grids, 2: Developing specific grid scenarios, 3: Exploring decision making with uncertainty, 4: Expanding the scope of synthetic grids for coupling with other infrastructures

Task 1: Developing customized grids

For Task 1 we focused on the development, visualization, and application of large-scale synthetic electric grids, with specific examples are provided in many of the papers given below in the publications section. One of the challenges with doing engineering studies (such as power flow, optimal power flow, contingency analysis and time-domain simulations) on these systems has been maintaining good engineering situational awareness (SA). To address these challenges, we created visualizations that quickly and dynamically reduced an 82,000 bus system to show the overall system flows and the minimum bus voltages. We have also created several new synthetic grids, in some cases extending the complexity of the grids (such as include transformer impedance correction tables). These grids are available at <https://electricgrids.engr.tamu.edu/> with details on a new 27,000 bus grid.

Additionally, we explored the application of wide-area transmission grid operation visual storytelling. The gist of this approach is to apply scientific video visualization approaches that have been developing over the last decade in other fields to power system problems, with the synthetic grids used to demonstrate the approach.

Task 2: Developing specific grid scenarios

In task 2 we extended synthetic grid models to consider potential future scenarios. In particular, we used geolocated electric grid models to associate external data such as wildfire risk to electric grid models. Initially, we focused on the small IEEE RTS-GMLC test case (geo-located in California). However, to obtain more interesting and realistic test cases, we developed a test case based on the actual geographical footprint of the California transmission grid. The development of this test case involved gathering data from multiple publicly available sources, including data on the transmission corridors in California obtained from the California Energy Commission and total load data from CAISO. To create a synthetic topology grid based on the location of the transmission lines, we developed methods to identify logical connection points between lines and added simple substation topology. This synthetic grid topology based on the real transmission corridor data was supplemented with realistic, but not real data on generation, load and transmission line parameters.

The benefit of a geographically accurate test case with detailed transmission corridor data is the ability to intersect the grid data with other interesting data sources describing the environmental and social context of the grid. In our case, we again considered integration of wildfire risk data (further described in Task 3), and are currently looking into extending this to account for additional environmental hazards including flooding and sea level rise, as well socio-economic data on population resiliency to disasters.

Task 3: Exploring decision making with uncertainty

To demonstrate the usefulness of the geographically accurate grid scenarios developed in Task 2, we leveraged the same grid data towards the Task 3 objectives on decision making under uncertainty. Specifically, we considered how to integrate electric grid and wildfire data to optimize the response of electric grid operators to increased wildfire risk. Specifically, we developed a model that uses the synthetic grid test case based on realistic geographical locations of transmission lines in California along with data on wildfire risk across an entire wildfire season. We overlapped publicly available GIS data from the actual California grid with the Wind-Enhanced Fire Potential Index (WFPI) published daily by the US Geological Survey and developed several different wildfire risk metrics for each line. We then solved an optimization problem to identify the lines that are most promising candidates for moving underground, i.e., which lines are likely to have the largest impact on risk reduction if they are moved underground.

Further, the use of synthetic grids in our testbed allows us to explore user actions taken by different roles (i.e., operators) in a “sandbox” environment. Using our cyber-physical testbed, we explored ways to model and mimic operator actions, i.e., using deep reinforcement learning. We also used our cyber-physical testbed capabilities to help develop a sharable/remotely accessible platform for testing and comparison of these types of approaches for the community.

Task 4: Expanding the scope of synthetic grids for coupling with other infrastructures

For Task 4 we leveraged work done on a separate ARPA-E project (involving IAB partner NREL) to develop synthetic electric grids that combine both transmission and distribution models down to the parcel level with models of other infrastructures such as transportation now being included. One example examined the impact of electric vehicle (EV) charging on the grid. Both the Texas 2000-bus and 7000-bus synthetic networks with their detailed distribution network topology were used extensively for this. The charging load profile by the hour and location was generated using dynamic traffic assignment simulations of transportation networks, incorporating parameters such as time of day, trip characteristics, and drivers’ range anxiety. This spatio-temporal EV load was then mapped to distribution or transmission nodes (as available) in the synthetic power grid network by determining which substation service areas the transportation nodes lie in using graph-theory techniques such as Voronoi tessellation. Detailed EV profiles and studies have been completed for the Austin and Houston regions in Texas using passenger, light duty vehicle (LDV) models. Charging impacts examined system/equipment loading and generator emissions. Our research has also shown the importance of using large, regional, transmission system models in performing multi-city EV load grid impact studies from the point of view of generation dispatch and emissions.

Publications Fully or Partially Supported by the Project:

All publications are available online at either

Tom Overbye’s website, <https://overbye.engr.tamu.edu/publications/>

Kate Davis’s website, <https://katedavis.engr.tamu.edu/publications/>

Arxiv (Line Roald) <https://arxiv.org/search/eess?searchtype=author&query=Roald%2C+L>

Or by emailing the authors

- [1] N. Rhodes, L.A. Roald, “Balancing Wildfire Risk and Power Outages Through Optimized Power Shut-Offs”, IEEE Transactions on Power Systems, vol. 36, July 2021, pp. 3118-3128
- [2] S. Taylor, and L. A. Roald, “A framework for risk assessment and optimal line upgrade selection to mitigate wildfire risk,” Electric Power Systems Research, vol. 213, pp. 108592, 2022.
- [3] N. Rhodes, and L. Roald, “Co-optimization of power line shutoff and restoration for electric grids under high wildfire ignition risk,” arXiv preprint <https://arxiv.org/abs/2204.02507>, 2022.
- [4] J.L. Wert, K.S. Shetye, H. Li, J.H. Yeo, X. Xu, A. Meitiv, Y. Xu, T.J. Overbye, “Coupled Infrastructure Simulation of Electric Grid and Transportation Networks,” 2021 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT), February 2021, Washington DC, USA.
- [5] T.J. Overbye, J.L. Wert, K.S. Shetye, F. Safdarian, A.B. Birchfield, “The Use of Geographic Data Views to Help With Wide-Area Electric Grid Situational Awareness,” 2021 IEEE Texas Power and Energy Conference, College Station, TX, Feb. 2021.
- [6] T.J. Overbye, K.S. Shetye, J.L. Wert, W. Trinh, and A. Birchfield, “Techniques for Maintaining Situational Awareness During Large-Scale Electric Grid Simulations,” IEEE Power and Energy Conference at Illinois (PECI), Champaign, IL, April 2021.
- [7] K.S. Shetye, T.J. Overbye, H. Li, and J. Thekkemathiote, “Considerations for Interconnection of Large Power Grid Networks,” Peci, Champaign, IL, April 2021.
- [8] C. Haseltine and L. Roald, “The Effect of Blocking Automatic Reclosing on Wildfire Risk and Outage Times”, 52nd North American Power Symposium (NAPS), Tempe, AZ, April 2021.
- [9] Y. Liu, M. Gaskamp, Z. Mao, D. Wallison, K. Shetye, K. Davis and T.J. Overbye, “Evaluation of Performance Metrics for Electric Grid Operational Scenarios,” 52nd NAPS, Tempe, AZ, April 2021.
- [10] W. Trinh, Z. Mao, T. J. Overbye, J. D. Weber, and D. J. Morrow, “Considerations in the Initialization of Power Flow Solutions from Dynamic Simulation Snapshots”, 52nd NAPS, Tempe AZ, April 2021.
- [11] D. Wallison, M. Gaskamp, Z. Mao, Y. Liu, K. S. Shetye, and T. Overbye, “Design Considerations for Operational Power Systems Scenarios,” 52nd NAPS, Tempe, AZ, April 2021.
- [12] B. Allison, T. Overbye and J. Weber, “Improved Generator Voltage Control in Power Flow Solutions”, 52nd NAPS, Tempe, AZ, April 2021.
- [13] P. Dehghanian, J.H. Yeo, J. Wert, H. Li, K. Shetye, and T. Overbye, “Application of Transformer Impedance Correction Tables in Power Flow Studies,” 52nd NAPS, Tempe, AZ, April 2021.
- [14] T.J. Overbye, J. Wert, K.S. Shetye, F. Safdarian, A.B. Birchfield, “Delaunay Triangulation Based Wide-Area Visualization of Electric Transmission Grids,” Kansas Power and Energy Conference, Manhattan, KS, April 2021.

- [15] F. Safdarian, A. B. Birchfield, K.S. Shetye, “Additional Insights in Creating Large-Scale, High Quality Synthetic Grids: A Case Study,” Kansas Power and Energy Conference, Manhattan, KS, April 2021.
- [16] A. Birchfield, T. J. Overbye, “Graph Crossings in Electric Transmission Grids,” 2021 North American Power Symposium, College Station, TX, November 2021.
- [17] K. Shetye, H. Li, J. Wert, X. Xu, A. Meitiv, Y. Xu and T. J. Overbye, “Generation Dispatch and Power Grid Emission Impacts of Transportation Electrification,” 2021 North American Power Symposium, College Station, TX, November 2021.
- [18] K. Shetye, B. Yancey and T. J. Overbye, “Benchmarking Standard Library and User Defined Models of Renewable Generation,” 2021 North American Power Symposium, College Station, TX, November 2021.
- [19] I. Idehen, K. Shetye, T.J. Overbye and D. Morrow, “Large-Scale Electric System Research Center at Texas A&M – Description and Associated Research Activities,” 2021 North American Power Symposium, College Station, TX, November 2021.
- [20] T.J. Overbye, K. Shetye, J. Wert, H. Li, C. Cathey, H. Scribner, “Stability Considerations for a Synchronous Interconnection of the North American Eastern and Western Electric Grids,” Proc. 55th Hawaii International Conference on System Sciences (HICSS), virtual, January 2022.
- [21] W. Trinh, S. Kunkolienkar, Y. Liu, T. J. Overbye, “On the Sensitivity of Ring-Down Observed Inter-Area Modes in Large-Scale Electric Grids Using a Simulation Approach,” IEEE. Power and Energy Conference at Illinois (PECI), Champaign, IL, March 2022.
- [22] L. Liu, T.J. Overbye, W. Wang, X. Fang, J. Wang, H. Cui, F. Li, “Transmission-Distribution Dynamic Co-simulation of Electric Vehicles Providing Grid Frequency Response,” IEEE Power & Energy Society General Meeting (PESGM), Denver, CO, July 2022
- [23] T. J. Overbye, J. Snodgrass, A. Birchfield, M. Stevens, “Towards Developing Implementable High Altitude Electromagnetic Pulse E3 Mitigation Strategies for Large-Scale Electric Grids,” IEEE. Texas Power and Energy Conference (TPEC), College Station, TX, March 2022.
- [24] J. Snodgrass, S. Kunkolienkar, U. Habiba, Y. Liu, M. Stevens, F. Safdarian, T. Overbye, R. Korab, “Case Study of Enhancing the MATPOWER Polish Electric Grid,” IEEE Texas Power and Energy Conference, College Station, TX, College Station, TX, March 2022.
- [25] J.L. Wert, J. Yeo, F. Safdarian, T.J. Overbye, “Situational Awareness for Reactive Power Management in Large-Scale Electric Grids,” IEEE Texas Power and Energy Conference (TPEC), College Station, TX, College Station, TX, March 2022.
- [26] J. Wert, F. Safdarian, T.J. Overbye, D.J. Morrow, “Case Study on Design Considerations for Wide-Area Transmission Grid Operation Visual Storytelling,” IEEE Kansas Power and Energy Conference (KPEC), virtual, April 2022.
- [27] S. Tripathi, “A study of cyber-attack resilience in a DER-integrated synthetic grid based on industry standards and practices,” MS, Texas A&M, May 2022 (this thesis isn’t currently available online, but IAB members can obtain it by emailing Kate Davis at katedavis@tamu.edu).