Final Scientific/Technical Report Template

Texas A&M Engineering Experiment Station
Final Scientific/Technical Report
Creation of Synthetic Electric Grids(SPP/MISO) Supporting PERFORM
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Public Executive Summary

Over the course of the project, two "realistic but not real" synthetic transmission-level grid models over the SPP-MISO and ERCOT footprints were created to provide more realistic data and increase the reliability and resiliency of the grids under a variety of scenarios. The datasets are available for download at https://electricgrids.engr.tamu.edu/electric-grid-test-cases/datasets-for-arpa-e-perform-program/ The synthetic ERCOT transmission grid is compatible with the distribution grid developed in collaboration with NREL.

All generators are based on the EIA 860 data and a column with EIA plant code and Gen ID is added to generators of both grids so that they can be easily mapped. The improvements are also made to electric grids including N-1 contingencies with some remedial actions, improving the transmission lines to avoid lines in lakes, including an HVDC line to the SPP-MISO case, providing several generator parameters and their temporal constraints that were not included in EIA 860 form, generators' cost curves, load offer curves, adding phase shifters and tap changers with impedance correction tables, adding reactive power control and partitioning the grids into active and reactive reserve zones and determine different types of the required reserve for each zone. Hourly load time series at the bus level were generated to create scenarios for solving power flow in different loading conditions. Weather measurement information and the models of renewable generators are used to directly include the impact of weather on the grids. Based on a variety of load and weather conditions the grids are improved to accommodate different conditions. The ERCOT 7k-bus grids were also modeled for the year 2030 with predicted improvements in renewable resources. The renewable generation model was also improved with historic weather data included. The impact of electric vehicles on the ERCOT grid is also modeled.

Acknowledgements

The team at the Texas A&M Engineering Experiment Station (TEES) would like to gratefully acknowledge the project funding from the US ARPA-E for enabling this cutting-edge research work. The cases that were developed from this project have enabled significant improvements in the planning and operations of electric power grids.

Also, the TEES team would like to express our gratitude to the team at the University of Wisconsin-Madison, and especially to Dr. Scott Greene. His collaboration was invaluable in completing this project.

Finally, we would like to thank the graduate students and research staff at Texas A&M who assisted with this project including Diana Wallison, Wonhyeok Jang, Yijing Liu, and Seri Kang

Accomplishments and Objectives

We believe all milestones have been fully met with the grids available for public download at https://electricgrids.engr.tamu.edu/electric-grid-test-cases/datasets-for-arpa-e-perform-program/
We also provided support based on requests and questions about the grids from the other PERFORM teams.

Table 1: Key Milestones and Deliverables

Tasks	Milestones and Deliverables
Task 1: Delivery of draft power flow model of SPP-MISO grid 1.1 Delivery of draft power flow model of ERCOT grid	Q2: Delivery of draft power flow model of SPP-MISO grid. **Actual Performance:** (1/31/2021) The initial draft of this grid is now complete Q2: Delivery of draft power flow model of ERCOT grid **Actual Performance:** (1/31/2021) The initial draft of this grid is now complete
Task 2: Delivery of improved model for SPP-MISO grid 2.1 Delivery of improved model for ERCOT grid	Q3: Delivery of improved model for SPP-MISO grid **Actual Performance:** (5/7/2021) This is now complete with the electric grid publicly available at electricgrids.engr.tamu.edu/electricgrid-test-cases/datasets-for-arpa-e-perform-program/ Q3: Delivery of improved model for ERCOT grid **Actual Performance:** (5/7/2021) This is now complete with the electric grid publicly available at electricgrids.engr.tamu.edu/electricgrid-test-cases/datasets-for-arpa-e-perform-program/
Task 3: Delivery of final SPP-MISO grid 3.1 Delivery of final ERCOT grid	Q4: Delivery of final SPP-MISO grid **Actual Performance:** (8/1/2021) The new grid data has been uploaded to our public website at electricgrids.engr.tamu.edu/electricgrid-test-cases/datasets-for-arpa-e-perform-program/ Q4: Delivery of final ERCOT grid **Actual Performance:** (8/1/2021) The new grid data has been uploaded to our public website at electricgrids.engr.tamu.edu/electricgrid-test-cases/datasets-for-arpa-e-perform-program/
Task 4: Support and modification of SPP-MISO grid 4.1 Support and modification of ERCOT grid	Q6: Support and modification of SPP-MISO grid **Actual Performance:** (1/31/2022) This is the official completion of this milestone, but the A&M team continued providing support to the PERFORM teams and updates to the grid models through the duration of the project Q6: Support and modification of ERCOT grid **Actual Performance:** (1/31/2022) This is the official completion of this milestone, but the A&M team continued providing support to the PERFORM teams and updates to the grid models through the duration of the project

The remainder of the document provides a brief description of these two electric grids and the main improvements.

Synthetic Grid on the ERCOT Footprint

The ERCOT footprint case contains 6,717 buses and geographically covers the ERCOT portion of Texas. The transmission network is built using the three nominal transmission voltage levels that exist in the actual grid for this footprint: 345 kV, 138 kV and 69 kV. This report provides a brief description of this case and Table 1 provides a summary of the case. All generators with capacity larger than 8 MW are mapped with EIA-860 data. Table 2 shows a summary of EIA-860 generators and unit types in ERCOT footprint and Figure 1 shows a one-line diagram of the grid.

Table 2: ERCOT Case Statistics

Number of buses	6,717
Number of substations	4,894
Number of areas	17
Number of transmission lines	7,168
Number of transformers	1,967
Number of phase shifters	2
Number of loads	4,856
Number of generators	731
Number of shunts	634
Load range (GW)	30-80

Table 3: Type and Number of Generators in ERCOT 7k Grid

Fuel Type	Number of Units	MW Capacity Total
Natural Gas	472	56,352
Coal	23	14,407
Nuclear	4	4,960
Wind	153	25,702
Solar	36	2,335
Hydro	22	498
Petroleum	2	53
Battery	2	66
Other	17	960.7
Total	731	104,914

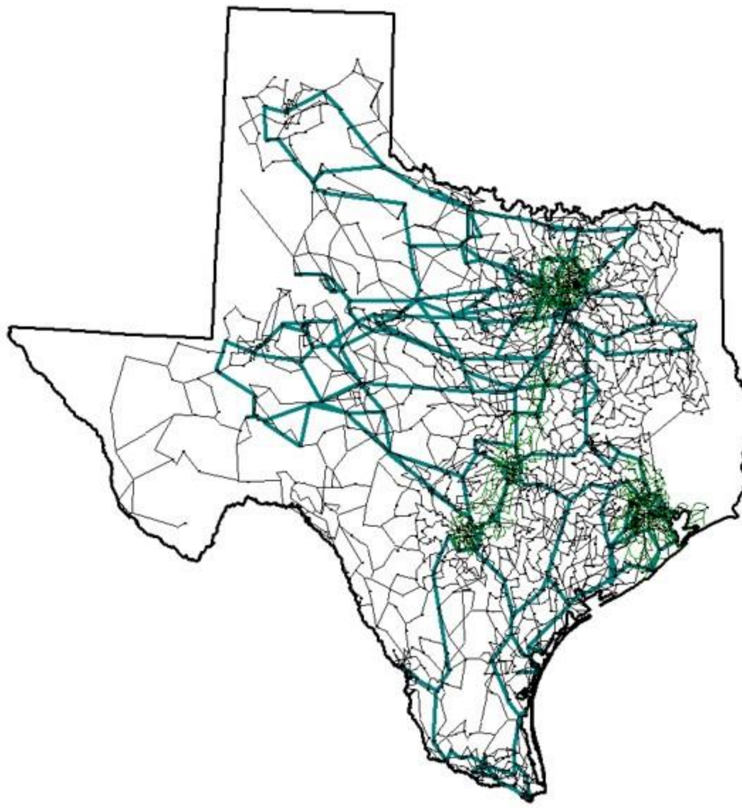

Figure 1: Overview One-line diagram of the ERCOT case

Validation metrics are used to validate the case to the actual presented in [6] and [7].

The main ERCOT case improvements include mapping generators with EIA 860 form, coordinating this grid with the distribution system, improving reactive power control devices such as switched shunts and adding transformer control devices such as phase shifters and load tap changers with impedance correction tables, creating bus-level load time series, using publicly available resources to determine realistic values for generators and unit commitment parameters and cost of generators, creating scenarios with low/high load and high/low amount of wind, improving the N-1 contingency performance, and including the impact of electric vehicles on the grid. We used a strategy to create synthetic load time series validated by time series from actual power systems. We also improved the performance of the grid by avoiding voltage violations and overload violations in a variety of scenarios. In addition, they included several remedial action schemes to improve the performance of the grid and do corrective action for some significant contingencies. We believe that these improvements will make the ERCOT 7k synthetic grid more resilient.

The hourly time series of bus-level load and renewable generation for a typical year are created based on the strategy explained in [8-9]. For the load time series, the geographic coordinates of each bus are used to determine a unique electricity consumption profile at that location. An iterative aggregation approach is then taken to integrate publicly available building- and facilitylevel load time series to the bus-level. The synthetic load time series were also validated using time series from the actual power systems [9].

For generators' parameters, unit commitment parameters, and cost of generators, we have used publicly available resources to determine realistic values. These parameters include startup cost, shutdown cost, cold startup time, warm/cold startup time, ramp rate up/ down, minimum up/down time, variable O&M cost, fuel cost, and generator cost from bid curves. In addition, load offer curves are included.

We also modeled the impact of electric vehicles on the electric grid and improved it based on the additional demand. We have published [2] for more details.

To increase the reliability and resiliency of the grid and to provide different types of reserves closer to demand, we partitioned the buses into real power and reactive power reserve zones and determined the required reserve.

Also, weather historical measurements of several years have been collected and used to create a variety of scenarios. This data is used to find extreme weather events and improve the reliability and resiliency of the grid. The grid is then improved to solve the power flow in different load and weather scenarios. Reactive power control devices have been managed in a way to avoid voltage issues as the load and generation change.

In the older version of the grid, switched shunts model allowed capacitive and inductive shunts with the same shunt ID so one shunt could change from capacitive to inductive values. However, since this is not realistic, in the latest version of the grid, capacitive and inductive shunts are separated with independent shunt IDs.

The ERCOT grid is created based on the 2030 generation mix upon the request from Princeton University according to predictions by Electric Reliability Council of Texas Long-Term System Assessment [13]. Based on EIA 860 data and ERCOT predictions, the ERCOT grid is updated with the 2030 generation mix and predicted retirements. Proposed plants to be added in Texas by 2023 were selected and added to the synthetic case, while retiring two coal units by 2030. The renewable generation capacity of the ERCOT 7k Synthetic Grid was increased by 26,835 MW of solar and 55,702 MW of wind by 2030. The load was increased by 20%, and the transmission grid was updated to avoid overloaded lines and transformers. This involved adding GSUs and upgrading voltage levels of buses, as well as adding more transmission lines and calculating line parameters. Also, generators' parameters are approximated based on the common current wind and solar plants to be realistic and the inflation rate is added to the cost curves. Then, we updated the transmission grid to avoid overloaded lines and transformers. The overall process was first to split new buses to have a bus per generator. Then we added GSUs to the generators and upgraded the voltage levels of buses with added new generators and we also had to add new transformers to connect the new voltage levels to the previous voltages in the same substation. Then we add more transmission lines to avoid line overloads, calculate line parameters and check the validation metrics. The latest version of the grid is available at [1].

Synthetic Grid on the MISO and SPP Footprints

The MISO and SPP footprint case (MISO-SPP) contains 23,643 buses. The geographic footprint is the US Midwest including the US portion of MISO and SPP, along with smaller parts of other interconnects (mostly to fill in the holes such as the part of PJM in Northern Illinois). The geography is complex and diverse; the grid contains 19 states and for convenience the states form the areas of the system. The transmission network is built using the seven nominal transmission voltage levels that exist in the actual grid for this footprint: 500 kV, 345 kV, 230 kV, 161 kV, 138 kV, 115 kV and 69 kV. Table 5 provides a summary of the case. And Figure 2 shows the online diagram of this case with bolded green lines 345 KV lines, 138 kV lines in black and 69 kv lines in light green.

Table 4: MISO-SPP Case Statistics

Number of buses	23,643
Number of substations	14,069
Number of areas	19
Number of transmission lines	23,787
Number of transformers	9,942
Number of phase shifters	5
Number of loads	11,731
Number of generators	6,274
Number of shunts	1017
Load range (GW)	84-202

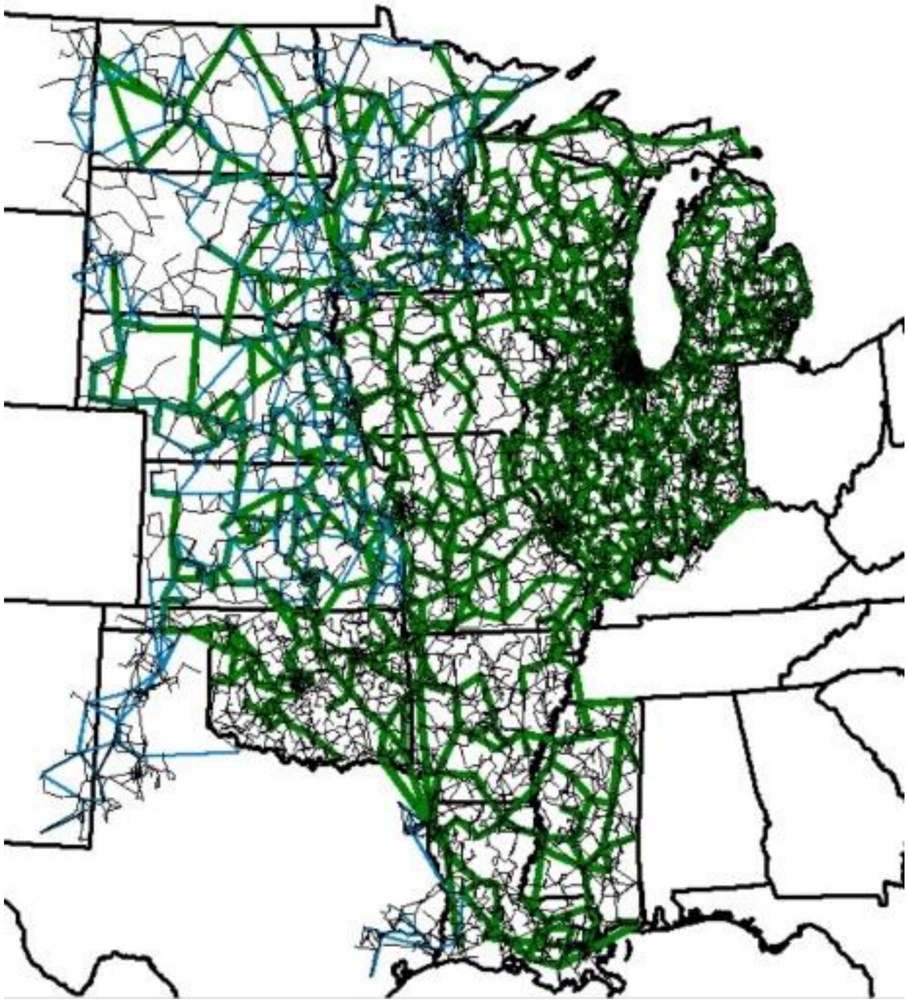

Figure 2: Overview One-line diagram of the MISO_SPP case

This grid includes accurate locations, capacities and characteristics of generators based on EIA-860 generator data and plant data. All generators are mapped with EIA-860 data and a column called “Custom String 1” is added to the generators data that includes plant ID-generator number data from EIA-860 data. Table 6 shows a summary of EIA-860 generators and unit types. Also, the overall load in the base case is 201,815 MW and the overall load of each state is adjusted based on the actual Eastern Interconnection (EI) load. In addition, the N-1 contingency performance of the MISO and SPP grid is evaluated that there is no overload or overvoltage violations for 23,769 contingencies in the base case. Validation metrics presented in [7] and [6] which in turn were based on actual North American electric grid power flow models are used to validate the grid. This case is studied in more details in [12], which provides additional insights into creating large-scale, high quality synthetic grids and specifically explains the improvements of the MISO/SPP case.

Table 5: Type and Number of Generators in MISO-SPP 24k Synthetic Grid

Fuel Type	Number of Units	MW Capacity
Natural Gas	1889	131,863.4
Coal	269	93,788.9
Nuclear	27	27,105.8
Wind	614	46,792.6
Solar	614	1796.8
Hydro	756	8673
Other	2105	11,659.4
Total	6274	321,679.9

The main improvements made to the MISO/SPP 24k synthetic grid include mapping generators with EIA 860 form, improving the transmission grid model to avoid long transmission lines over Lake Michigan, including and improving reactive power control devices such as switched shunts and transformer control devices such as phase shifters and load tap changers with impedance correction tables, the creation of bus-level load time series, updating of generators' economic and temporal parameters, improvement of the grid to solve ACPF, N-1 contingency analysis, and clustering the grid into active and reactive power reserve zones. The load offer curves are also updated based on available data, and the grid's performance is studied and visualized under different load and weather scenarios. Finally, the geographic coordinates of each renewable generation are used to map that with the weather stations and based on the historical weather measurements the available capacities of these generators are determined. Most of these improvement strategies are similar to the strategy that was explained for the ERCOT 7k grid.

The updated grid has been improved to be more robust and solve ACPF in different load and weather scenarios. Reactive power control devices have been managed to avoid voltage issues.

The N-1 contingency performance of the grid is improved in a way that there are no overload or overvoltage violations for N-1 contingencies.

Weather measurements of several years are used to simulate historic weather conditions and study grid reliability and resilience under extreme weather scenarios. The importance of considering weather situations in OPF studies is demonstrated by how wind capacity can reduce prices. We also published a paper [14] about the direct inclusion of weather in the simulations.

Also, in older versions of the grid, all switched shunts were continuous, which is not very realistic so the shunts are changed to discrete shunts. Also, capacitive and inductive shunts are added as separate shunt IDs. In the previous model, one shunt could change from capacitive to inductive values.

Finally, a high voltage direct current (HVDC) line was added to replace an alternating current (AC) line that passed over Lake Michigan. The details of the AC line were used to calculate the parameters for the new HVDC line based on [15].

Project Activities

Over the course of the project, two “realistic but not real” synthetic transmission-level grid models over the SPP-MISO and ERCOT footprints were created to provide more realistic data and increase the reliability and resiliency of the grids under a variety of scenarios. To support this development, we also have been working on better ways to visualize the operation of electric grids in general and specifically synthetic grids with accurate geographic coordinates. We have created movies to visualize hourly changes of the grids based on papers published in [2, 3] with improved power system visualization techniques that were partially developed for this project. More detail on visualization tools is given in [4, 5]. These visualization technics as well as validation metrics are used to validate the synthetic grids. Both of these cases were constructed using the approach detailed in [6], which involved a combination of automatic algorithms and manual adjustment.

Project Outputs

A. Journal Articles

None

B. Papers

1. T.J. Overbye, J.L. Wert, K.S. Shetye, F. Safdarian, and 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
2. T.J. Overbye, J. Wert, K. Shetye, F. Safdarian, and A. Birchfield, “Delaunay Triangulation Based Wide-Area Visualization of Electric Transmission Grids,” Kansas Power and Energy Conference (KPEC), Apr. 2021
3. F. Safdarian, A. Birchfield, K. Shetye, and T.J. Overbye, “Additional Insights in Creating Large-Scale, High-Quality Synthetic Grids: A Case Study,” Kansas Power and Energy Conference (KPEC), Apr. 2021
4. J.L. Wert, J. Yeo, F. Safdarian, and T.J. Overbye, “Situational Awareness for Reactive Power Management in Large-Scale Electric Grids,” in the IEEE Texas Power and Energy Conference (TPEC), College Station, TX, February 2022
5. F. Safdarian, J. Wert, Y. Liu, A. Birchfield, K. S. Shetye, H. Chang, and T. J. Overbye, “Reactive Power and Voltage Control Issues Associated with Large Penetration of Distributed Energy Resources in Power Systems,” Power and Energy Conference at Illinois, Urbana, IL, March 2022.
6. J.L. Wert, F. Safdarian, T.J. Overbye, and D.J. Morrow, “Case Study on Design Considerations for Wide-Area Transmission Grid Operation Visual Storytelling,” in the IEEE Kansas Power and Energy Conference (KPEC), Manhattan, KS, April 2022.
7. T. J. Overbye, F. Safdarian, W. Trinh, Z. Mao, J. Snodgrass, and J. Yeo, “An Approach for the Direct Inclusion of Weather Information in the Power Flow,” Proc. 56th Hawaii International Conference on System Sciences (HICSS), January 2023.

C. Status Reports

Quarterly reports sent to ARPA-E as required

D. Media Reports
None

E. Invention Disclosures
None

F. Patent Applications/Issued Patents
None

G. Licensed Technologies
None

H. Networks/Collaborations Fostered
Collaborations with other dataset team (University of Wisconsin-Madison) and the PERFORM teams (Lehigh, Princeton, NREL, etc)

I. Websites Featuring Project Work Results
https://electricgrids.engr.tamu.edu/electric-grid-test-cases/datasets-for-arpa-e-perform-program/

J. Other Products (e.g. Databases, Physical Collections, Audio/Video, Software, Models, Educational Aids or Curricula, Equipment or Instruments)
Two electrical grid models were created and are available at https://electricgrids.engr.tamu.edu/texas-am-perform-cases/

K. Awards, Prizes, and Recognition
None

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[2] J.L. Wert, H. Chang, F. Safdarian, T.J. Overbye, Y. Xu, "The Economic and Technical Impacts of Houston's Electric Vehicles on the Texas Transmission System: A Case Study," in the IEEE Kansas Power and Energy Conference (KPEC), Manhattan, KS, April 2022.

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[4] 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 (TPEC), College Station, TX, USA, Feb. 2021.

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[13] Electric Reliability Council of Texas Long-Term System Assessment [Online] Available: http://www.ercot.com/content/wcm/key_documents_lists/189719/2020_LTSA_Update_May2020_v3.pdf

[14] Overbye, T. J., Safdarian, F., Trinh, W., Mao, Z., Snodgrass, J., & Yeo, J. (2023, January). An approach for the direct inclusion of weather information in the power flow. In Proc. 56th Hawaii International Conference on System Sciences (HICSS).

[15] T. Whitmore, "HVDC Modelling in Synthetic Power Systems", December 2018, unpublished.