Evolution of Scenario Generation Capabilities in the ExaSGD Project

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EXASCALE COMPUTING PROJECT

Monte Carlo sampling of analog scenarios using WIND dataset

THEN

Linear two-stage stochastic program:

$$\min_{\mathbf{x}} \quad \mathbf{c}^T\mathbf{x} + \mathbb{E}_\xi\left[L\left(\mathbf{x},\xi\right)\right]$$

where,

$$L\left(\mathbf{x},\xi\right) = \min_{\mathbf{y}} \quad {\mathbf{c}_\xi}^{\mathsf{T}}\mathbf{y}$$
$$\text{s. t.} \quad \mathbf{T}_\xi\mathbf{x} + \mathbf{W}_\xi\mathbf{y} = \mathbf{b}_\xi$$
$$\mathbf{y} \geq \mathbf{0}$$

x – first stage variables (generator setpoints)
y – second stage variables (e.g., wind dispatched, slack)
ξ – uncertain variable (wind deviation from persistence)

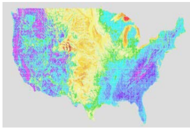
Second stage constraints include power flow constraints, power balance at nodes, constraints on 2nd stage variables.

Sample average approximation

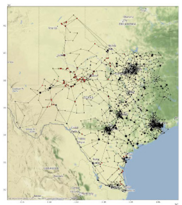
$$\mathbb{E}_\xi\left[L\left(\mathbf{x},\xi\right)\right] \approx \frac{1}{N}\sum_{i=1}^{N} L\left(\mathbf{x},\xi_i\right)$$

Sampling of analog scenarios using Techno Economic subset (2TB) of the full WIND Toolkit dataset (500TB) [1,2].

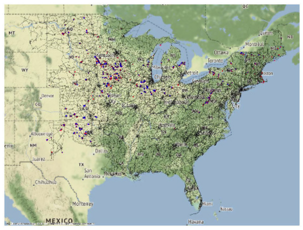
Initially we selected scenarios at random from historical timeseries data. Due to limited scenario budgets, we needed to be more efficient with scenario selection.



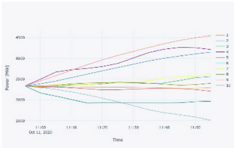
WIND (Wind Integration National Dataset) 7 years of NWP data: 2007-2013 resolution: 2x2km and 5-min



ACTIVSg2000 grid with 2000 buses (black) and 87 wind generators (red)



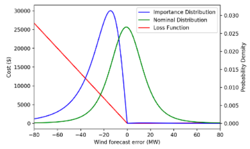
ACTIVSg70k grid with 70,000 buses and 576 wind generators.



Monte Carlo samples of 6-period scenarios on ACTIVSg2000 grid

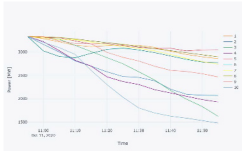
Importance sampling

$$\mathbb{E}_p\left[L\left(\mathbf{x},\xi\right)\right] = \int_\Omega L\left(\mathbf{x},\xi\right)p\left(\xi\right)\mathrm{d}\xi$$
$$= \int_\Omega \frac{L\left(\mathbf{x},\xi\right)p\left(\xi\right)}{q\left(\xi\right)}q\left(\xi\right)\mathrm{d}\xi = \mathbb{E}_q\left[\frac{L\left(\mathbf{x},\xi\right)p\left(\xi\right)}{q\left(\xi\right)}\right]$$

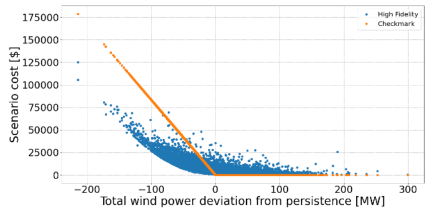


Importance sampling (IS) of analog scenarios using low- and high- fidelity loss functions enables the efficient construction of uncertainty sets, consistently leading to lower operating costs [3]

Importance sampling analog scenarios enabled the efficient characterization of renewable uncertainty. However, more work was required to build contingencies resulting from extreme events

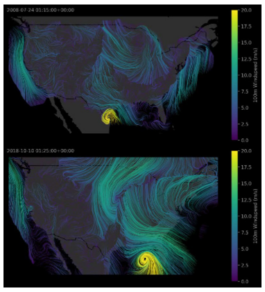


Importance (low-fidelity) samples of 6-period scenarios on ACTIVSg2000 grid



Plot of scenario costs vs. wind power deviation from 5-minute persistence forecast for the ACTIVSg2000 grid vs. lower-fidelity scenario pricing model used earlier in the project. This plot presents a strong case for using higher-fidelity models, e.g, ExaGO, for scenario selection.

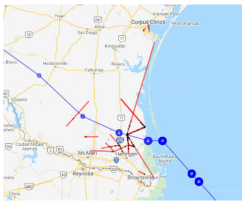
Extreme event scenarios



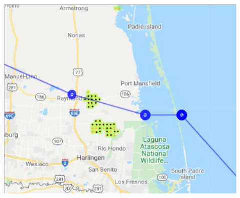
WIND Toolkit 100m velocity field during hurricanes Dolly (top) and Michael (bottom)

Using grid component fragility curves, coupled with hurricane wind speed data from the WIND Toolkit, we model infrastructure damage due to a hurricane strike [4].

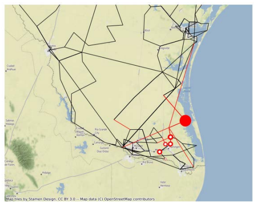
Our damage models enable extreme-event contingency construction, inform emergency asset placement [5], and provide a capability enabling grid planners to use NWP tools such as HWRFx.



Realization when max number of branches were damaged. Damaged lines (red lines) and damaged poles (black dots)



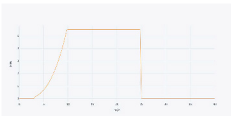
Path of Hurricane Dolly and interaction with synthetic wind farms on ACTIVSg2000. Black dots represent damaged wind sites, red dots indicate undamaged.



Placement of emergency assets, e.g., storage or portable turbines, to counteract loss of load due to damaged infrastructure. White circles denote small battery capacity, large red circle denotes larger battery capacity.

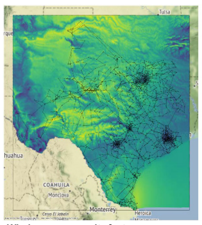
Buildouts: actuals and scenarios using full WIND dataset

NOW

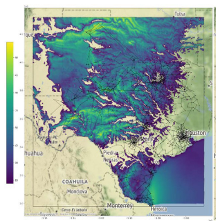


Power curve of user-selected technology: ATB 2030 moderate innovation onshore wind turbine
- *Rating: 5.5 MW*
- *Rotor diameter: 175 m*
- *Hub height: 120 m*
- *etc.*

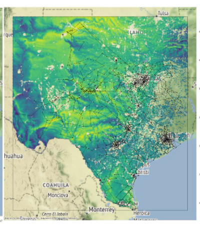
The Techno Economic subset of the WIND Toolkit has a limited number of wind sites and technologies. Sampling of analog scenarios using Full WIND toolkit dataset (500TB) enables more informed placement of renewable energy infrastructure and user-specified renewable energy technologies.



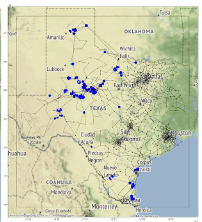
Wind energy capacity factors over ACTIVSg2000 transmission grid representing ERCOT



Capacity factors above 35 %

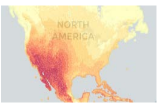


Capacity factors without excluded areas, e.g., protected areas, urbanized areas, etc.



Possible wind sites matching ACTIVSg2000 wind generation

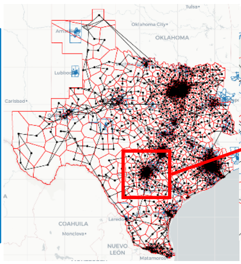
Rooftop PV buildouts: load scenarios



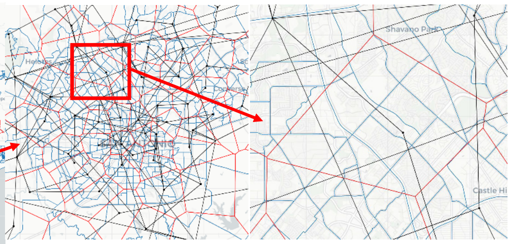
National Solar Radiation Database (NSRDB)

Google Project Sunroof suitable RTPV area data: https://sunroof.withgoogle.com

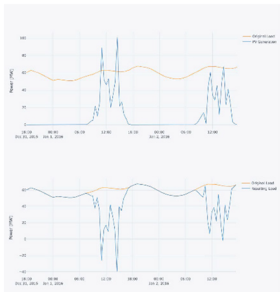
Using NSRDB irradiation data together with Google Sunroof Project's [6] publicly available rooftop data containing suitable area for PV installation we can estimate potential RTPV generation in urban areas of the transmission/distribution grid and modify existing loads.
Resulting time series can be used for stochastic load scenario generation.



Synthetic ACTIVSg2000 transmission grid (ERCOT) partitioned by load bus using Voronoi diagram.



City of San Antonio (left) and its load bus 6150 polygon (right). Red boundaries denote Voronoi polygons of load buses, blue boundaries denote census tracts (finest areas of publicly available data from Google Project Sunroof [6] estimating rooftop area available for PV installation).



Load profile and potential rooftop generation at bus 6150 (top) and resulting load given all rooftops in Voronoi polygon have installed PV panels. Notice negative load on Jan 1st around midday, i.e., RTPV generation is higher than existing load.

References

[1] Powerscenarios: realistic data-driven renewable energy scenarios for stochastic grid operation problems. https://github.com/nrel/powerscenarios

[2] M. Reynolds, I. Satkauskas, J. Maack, D. Sigler and W. Jones, "Scenario creation and power-conditioning strategies for operating power grids with two-stage stochastic economic dispatch," *2020 IEEE Power & Energy Society General Meeting (PESGM)*, 2020, pp. 1-5

[3] K. Panda, I. Satkauskas, J. Maack, D. Sigler, M. Reynolds and W. Jones, "A Data-Driven Multi-Period Importance Sampling Strategy for Stochastic Economic Dispatch," *2021 IEEE Power & Energy Society General Meeting (PESGM)*, 2021, pp. 1-5,

[4] I. Satkauskas, J. Maack, M. Reynolds, D. Sigler, K. Panda, and W. Jones, "Simulating Impacts of Extreme Events on Grids with High Penetrations of Wind Power Resources." *2022 IEEE/PES Transmission and Distribution Conference & Exposition (T&D).*

[5]] I. Satkauskas, J. Maack, M. Reynolds, D. Sigler, K. Panda, and W. Jones, "Emergency Generation Asset Positioning for Resilient Transmission Grid Operation." *Submitted to 2023 IEEE Power & Energy Society General Meeting (PESGM).*

[6] Source: Google Sunroof Project data explorer (Jan 2023)

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