



Incorporating climate impacts into electricity system planning models: review and case study

Final Project Report

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



Incorporating climate impacts into electricity system planning models: review and case study

Project Report

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Power Systems Engineering Research Center

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Executive Summary

Changes in the climate affect the supply, demand, and transmission of electricity in every season and for all types of technologies. While variations in weather like temperature, wind speed, and solar irradiance are already a part of electric power system planning, the models used to plan future power systems now need to address increasing weather dependencies (due to variable renewable generation like wind and solar), changes in weather dependencies of demand (electrification of heating and transportation), and new and more extreme climate conditions. This project was motivated by the need to understand how to incorporate climate change in electric power system planning models. Recognizing the magnitude of this challenge to the industry, this project began with a review of the current state of the industry and academic work and then selectively addressed modeling methods in three areas.

The research began with a summary of current utility planning practices for climate change and a survey of literature on incorporating climate uncertainty from an academic perspective. This review occurred at a time of significant industry attention in this area, and the project leverages efforts by the Electric Power Research Institute (EPRI) and the Energy Systems Integration Group (ESIG), as well as completing our own new review of recent utility climate vulnerability studies. One of the take-aways from this review is that although climate vulnerabilities are recognized, addressing the magnitude and impact of each supply and demand vulnerability begins with first understanding the sensitivity to weather. It is also clear that given the dependence of future supply, demand, and transmission on multiple correlated weather variables along with need to capture climate uncertainty, planning models are challenged to address complexity while remaining practical for industry to leverage in real applications. Several of the potential research and applied directions identified are:

- Development of new stochastic optimization models that are able to capture new types of uncertainty introduced by climate change and capture both chronic and acute stressors.
- Test long term planning model sensitivity to climate stressors to prioritize their impacts; test common mode events (wildfire smoke plus extreme heat) to understand their combined impact.
- Integrate stochastic planning models with integrated assessment models to capture feedbacks between electricity systems and other parts of the built environment (transportation, land management, urban and rural migration) or natural systems (forests, water availability).

The project provided three new contributions to incorporating weather and climate in electricity models. First, we highlighted the need for including weather and other resiliency hazards to electric power systems, i.e. environmental impacts, into power flow modeling. A framework for incorporating environmental impacts into power flow modeling was created, and we used ERA5 and more detailed resources such as High-Resolution Rapid Refresh (HRRR) data over North America and added power flow weather models to the electric grid to include and validate the impact of several historical weather or environmental events. This work resulted in publicly available datasets for building historical weather scenarios in power flow models. The next steps for this research to move towards application may include:

- Development of additional models to incorporate other types of environmental impacts or increasing the model detail for existing impacts.
- Validating environmental impact models with additional historical events.
- Applying machine learning to search for outliers.
- Optimizing computational time for multiple environmental impacts.
- Investigating potential convergence issues with environmental impacts in power flow modeling.

Second, we focused on modeling generation-side mechanisms for supply vulnerability. This report considers the resource adequacy implications of snow on solar photovoltaics (PV), specifically estimating the seasonal capacity credit of solar in a northern climate without snow as a measure of the system's reliance on seasonal PV capacity. The result of these analyses is that although winter PV capacity is not critical, shoulder-season snow events in Fall and Spring may matter to the provision of adequate capacity resources, and warrant further study. We also modeled snow losses from fixed-tilt and single-axis tracking PV systems. We found that different system design choices could affect snow losses (on the order of several more days of snow losses), which motivates more work to better empirically support snow loss models for new types of PV technology including tracking systems and bifacial systems. Next steps in this research area include:

- Estimate the impacts of historical snow events on solar PV over the Eastern Interconnection (and/or other systems that include significant PV development in northern latitudes). These energy production estimates can be used to quantify the resource adequacy implications of snow.
- Link climate change models to the energy models that estimate PV snow losses. This work is necessary to understand what the likelihood is of impactful snow losses are considering changes in precipitation patterns (overall more precipitation falling as rain rather than snow) and uncertainties around regional impacts (lake-effect snow).
- Improve snow loss modeling using observations from more geographically and technologically diverse PV systems. (Today's models rely on observations of fixed-tilt, monofacial PV from a limited number of sites. With the proliferation of PV in northern latitudes, predictive modeling and forecasting at the generator level can be improved with observations of modern systems.)

Third, we developed a new type of stochastic optimization model to capture both normal operation and system response to extreme events, specifically in the context of generation expansion planning for extreme temperatures. Our proposed approach improves the modeling of high-impact, low-frequency events through the use of a bi-objective stochastic integer optimization model. This bi-objective model finds solutions with different trade-offs between efficiency in normal conditions and risk to extreme events. We further propose to leverage conditional sampling paired with a risk measure to address the inherent challenge in approximating the risk of low-frequency events within a sampling-based approach. We present a model for spatially correlated, county-specific temperatures and a method to generate both unconditional and conditionally extreme temperature samples from this model efficiently. These models are investigated within an extensive case study with realistic data that demonstrates the effectiveness of the bi-objective approach and the conditional sampling technique. We find that spatial correlations in the

temperature samples are essential to finding good solutions and that modeling generator temperature dependence is an important consideration for finding efficient, low-risk solutions. Next steps for this research include the following:

- Explore whether the proposed bi-objective modeling framework and conditional sampling approach can be used for other types of extreme event scenarios representing different climate stressors, or combinations of climate stressors.
- Investigate the impact of using climate projected temperature scenarios (rather than historical data) when developing the sampling approach.
- Extend the modeling of the grid to become more realistic, e.g. by including transmission constraints and additional constraints on generation.

Project Journal Publications:

- [1] R. Rossmann, M. Anitescu, J. Bessac, M. Ferris, M. Krock, J. Luedtke, and L. Roald, “A Framework for Balancing Power Grid Efficiency and Risk with Bi-objective Stochastic Integer Optimization”, submitted to *Optimization and Engineering*.
- [2] H. Yang, H. Yang, N. Rhodes, L. Roald and L. Ntamo, “ Multi-period Power System Risk Minimization under Wildfire Disruptions”, *IEEE Transactions on Power Systems*, January 2024.

Project Conference Presentations and Posters (not including PSERC posters):

- [3] A. Chutani, A. Dyreson, S. Wickett., “Snow shedding from single-axis tracking PV systems: observations from the Michigan Regional Test Center and implications for modeling widespread snow events”, Photovoltaic Performance Modeling Collaborative Workshop, Salt Lake City, Utah, May 2024.
- [4] F. Safdarian, J. Cook, S. J. Lee, T. J. Overbye, “Calculation and Validation of Weather-Informed Renewable Generation in the US based on ERA5 Hourly Weather Measurements”, IEEE Power and Energy Conference at Illinois (PECI) 2024, Urbana, IL, April 2024.
- [5] F. Safdarian, M. Stevens, J. Snodgrass, T. J. Overbye, “Detailed Hourly Weather Measurements for Power System Applications”, 2024 IEEE Texas Power and Energy Conference (TPEC), College Station, TX, Feb. 2024.
- [6] J.S. Cook, F. Safdarian, J. Snodgrass, and T.J. Overbye, “Using Power Flow Application Capabilities to Visualize and Analyze US Energy Information Administration Generation Data”, 2024 IEEE Texas Power and Energy Conference (TPEC), College Station, TX, Feb. 2024.
- [7] E. Haag, N. Rhodes and L. Roald, “Long Solution Times or Low Solution Quality: On Trade-Offs in Choosing a Power Flow Formulation for the Optimal Power Shutoff Problem”, Power System Computation Conference (PSCC), 2024 (accepted).

- [8] H. Yang, H. Yang, N. Rhodes, L. Roald and L. Ntamo, “Multistage Stochastic Program for Mitigating Power System Risks under Wildfire Disruptions”, Power System Computation Conference (PSCC), 2024 (accepted).
- [9] Y. Zhou, K. Sundar, D. Deka, and H. Zhu, "Optimal power system topology control under uncertain wildfire risk,” 18th International Conference on Probabilistic Methods Applied to Power Systems, PMAPS 2024 (accepted).
- [10] A. Dyreson, S. Wickett, “Is snow cover on solar panels a blind spot in planning future winter-peaking power systems in the north?”(Poster), American Geophysical Union Fall Meeting, December 2023.
- [11] R. Rossmann, M. Anitescu, J. Bessac, M. C. Ferris, M. Krock, J.R. Luedtke and L. Roald, “A Framework for Balancing Power Grid Resiliency And Efficiency With Bi-Objective Stochastic Integer Optimization”, presentation at the INFORMS Annual Meeting, Phoenix, AZ, 2023.
- [12] A. Dyreson, “Energy transitions in cold climates: regional technical characteristics and uncertainties for electric power systems” (Poster), MultiSector Dynamics Community of Practice Annual Meeting, Davis, California, October 2023.
- [13] J. L. Wert, T. Chen, F. Safdarian, J. Snodgrass, and T. J. Overbye, “Calculation and Validation of Weather-Informed Renewable Generator Capacities in the Identification of Renewable Resource Droughts,” IEEE PowerTech 2023, Belgrade, Serbia, June 2023 (a prepublication copy of this paper is available at <https://overbye.engr.tamu.edu/publications/>).

Industry report (contributor):

- [14] Energy Systems Integration Group. (2023). “Weather Dataset Needs for Planning and Analyzing Modern Power Systems” (Full Report). <https://www.esig.energy/weather-data-for-power-system-planning>

Student Theses:

- [15] Wert, J. L. . *Extracting Value from Electric Grid Information Towards a Resilient Grid Amidst Decarbonization Efforts* (Doctoral dissertation). Texas A&M University, July 2023
- [16] Jung, J. K. . *A Methodology of Utilizing Electric Vehicles to Improve the Reliability and Resiliency of the Power System in Extreme Weather* (Master thesis). Texas A&M University, June 2023
- [17] Wickett, S. , *Assessing the resource adequacy impacts of snow on solar photovoltaics* (PhD), Michigan Technological University, Expected May 2026. (In Prep).