MAE 573 – Project Proposal

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November 20, 2024

Abstract

This research proposal aims to develop a comprehensive framework for optimizing power flow in electrical grids, with a primary focus on enhancing network robustness against external uncertainties and disruptions of two types: demand variability and link disruptions. By leveraging the ERCOT aggregated system, we will explore various techniques to improve grid resilience while maintaining efficiency.

Research Purpose

The objective is to extend beyond traditional economic dispatch and capacity expansion problems to incorporate grid vulnerabilities to external, uncertain events in the optimization framework. This study will explore and compare different approaches to mitigate vulnerabilities:

- Heuristic methods: we will conduct a sensitivity analysis to pinpoint vulnerable links, and test different heuristics to decide on either increasing the capacity of these links (to cope with demand uncertainty) or increasing the redundancy between the nodes involved (to cope with possible disruptions).
- Stochastic optimization: we will generate multiple scenarios with varying demand profiles and disruption levels to optimize network configuration based on transmission capacity expansion and rewiring decisions. We will also implement constraints on the number of allowed switching operations to keep the problem tractable.
- A next interesting step would be to develop ML-driven models to predict grid vulnerabilities in a more performant way than sensitivity analysis, and also explore other types of optimization such as swarm algorithms (Reddy et al., 2023).

Developing performant optimization models that can handle distributed uncertainties is crucial to power systems, as uncertainty is inherent in renewable generation, technical failures, energy storage, and demand response. To perform this analysis we will be using the ERCOT 120-bus 500kV simulated system, a simplified model of the Electric Reliability Council of Texas (ERCOT) power grid. This dataset allows us to focus on the generation and transmission levels, yet maintaining a granular representation of the power grid compared to the zonal models. Hence we can study the effect of variability and uncertainty at demand nodes, transmission links and generators.

There will be two main challenges in this project:

1. Model assumptions: Choices between DC Optimal Power Flow (DCOPF) and other AC approximations, but also choices on energy storage, renewable integration, rewiring or transmission switching limitations, etc. may largely influence outcomes and would require an assessment of their impact on results. However they will probably simply be assumptions of the model. Nonetheless it would be interesting to explore the impact of renewable penetration on the solution found, as it would add a layer of uncertainty, not on links' functionality or on load at nodes, but on the generation itself. It also comes with interesting network optimization problems such as finding optimal locations for renewables and energy storage in a way that minimizes transmission losses and congestion as well as required reserves.

2. Resilience metrics: One question will actually be to find a way of estimating the performance of each solution. The task is to balance performance and resilience under assumed levels of disruptions and demand variability; hence even with a defined cost for elements such as unmet demand, the metric would be dependent on what level of variability we decide to consider. We will need to establish robust metrics for grid resilience under various scenarios, focusing on redundancy in the network and load energy unserved.

One research interest behind the optimization task, is also to estimate how well does the network topology (node connectivity and path redundancy) approximate performance under uncertainty, that is, to what extent can we infer from topological features the network's ability to cope with increased demand or missing links?

References

Conejo, A. J. and Baringo, L. (2018). *Power System Operations*. Power Electronics and Power Systems. Springer International Publishing, Cham.

Khodayar, M., Liu, G., Wang, J., and Khodayar, M. (2020). Deep learning in power systems research: A review. *CSEE JPES*.

Purchala, K., Meeus, L., Van Dommelen, D., and Belmans, R. (2005). Usefulness of DC power flow for active power flow analysis. In *IEEE Power Engineering Society General Meeting, 2005*, pages 2457–2462, San Francisco, CA, USA. IEEE.

Reddy, V. V., Rajalakshmi, B., Boddu, B., Verma, M. K., Thethi, H. P., and Sabah, H. A. (2023). Hybrid Swarm Intelligence Algorithms for Enhanced Optimal Power Flow in Renewable Energy Networks. In *2023 International Conference on Power Energy, Environment & Intelligent Control (PEEIC)*, pages 762–767, Greater Noida, India. IEEE.

Wang, Y., Gao, S., and Wang, F. (2022). Measurement of Power Grid Resilience Based on a Dynamic Inoperability Input–Output Model. *Front. Phys.*, 10:895267.

Xu, L., Feng, K., Lin, N., Perera, A., Poor, H. V., Xie, L., Ji, C., Sun, X. A., Guo, Q., and O'Malley, M. (2024). Resilience of renewable power systems under climate risks. *Nat Rev Electr Eng*, 1(1):53–66.