Harnessing the Power of Artificial Intelligence (AI) for Transmission & Distribution Operations

Final Project Report

T-63

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

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Power Systems Engineering Research Center

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Executive Summary

Due to the increasing complexity of operations in transmission and distribution (T/D) grids, a number of scenarios have emerged where traditional decision-making tools have failed to control grid operations in a reliable manner. In this project, we explore if *physically meaningful artificial intelligence methods* can address this problem. We focus on three specific topics:

In Task 1, we perform prediction of equipment failure using several artificial intelligence (AI) techniques, including machine learning (ML) and matrix-based techniques, to assess localized power system asset health and provide prompt detection of asset degradation indicators. Through Task 2, we demonstrate seamless integration of physical laws using AI, which significantly improves the state-of-the-art state estimation and anomaly detection, when the system is unobservable due to the lack of sensor measurements. In Task 3, we move from monitoring to control for distribution grids, where lack of system information, due to unobservability and presence of unknown third-party controllers, is the primary concern. We show that AI can provide generalized power flow equations for robust monitoring and control of distribution grids, unavailable in the past when there are unobservability issue and third-party controllers.

Potential Benefits: Artificial intelligence (AI) and machine learning (ML) often offer solutions to problems that are traditionally considered intractable. In particular, this project demonstrates how novel ML techniques can use diverse sources of data streams to produce probabilistic forecasts of congestion and contingency patterns. The online learning offers several orders of magnitude reduction of computation costs. A framework for successfully integrating physical laws with failure patterns is also developed. Finally, the proposal shows how to draw inferences intelligently and efficiently from limited system information. The successful completion of the project result in the following specific benefits:

Benefits to RTOs/ISOs: Our AI-based learning algorithms helps RTOs/ISOs manage a diverse mix of resources reliably by analyzing a variety of scenarios that were not addressable in the past. The results of this research aids RTOs/ISOs in improving the performance of their state estimators and facilitating the integration of active renewable generation into RTOs/ISOs' system by enhancing situational awareness.

Benefits to utilities: Task 1 not only ensures optimal returns on investments made (e.g., purchasing expensive equipment such as a power transformer), but also keep the utility secure against unforeseen equipment failures, such as [1], by generating alarms in advance. Utilities can use the analysis carried out in Task 2 to model a grid that has limited observability. Additionally, utilities can maximize their control capability in a grid where the third-party controller is deployed without informing the utility in Task 3.

Benefits to vendors: Task 1 is extremely beneficial to vendors, because by generating alarms in advance, it creates an opportunity to run tests on the affected equipment (in coordination with the utility, e.g., during planned shutdowns), and repair/replace equipment parts, at a much lower cost. This also improves relations between vendors and utilities. Task 2 results in a distribution grid state estimator that is robust to missing system information. Task 3 provides controllability with

system unobservability. The three tasks are useful additions to modern distribution management systems. As a PSERC partner, GE shows great interest in the task's control design.

Summary of benefits:

- A method to forecast transformer failure based on phasor measurement unit (PMU) measurements
- A tool to extract system model for state estimation when systems are unobservable
- A control strategy to provide efficient distribution grid management with partial system information

Outcomes: This work leads to the development of data analytic tools that can be used by industry as well as academia. Specifically, the proposal's outcomes will be used for (a) *online monitoring of the health for power transformers*, (b) *distribution grid state estimation and control*. The investigators provided regular report to PSERC.

Industry Engagement: We had calls with our industry advisers to guide the work and discuss critical questions. We also seek out student internship opportunities with industry for more direct collaboration.

Potential Applications: One of the direct outcomes of this project is the creation of a tool that can predict the proximity to a failure of high voltage power transformers in advance. *Electric Power Group (EPG)*, an LLC that specializes in developing and implementing synchrophasor-based solutions and works closely with many PSERC industry members is especially interested in commercializing this tool.

Project Publications:

[1] M. Padhee, R.S. Biswas, A. Pal, K. Basu, and A. Sen, "Identifying unique power system signatures for determining vulnerability of critical power system assets," ACM SIGMETRICS Perform. Eval. Rev., vol. 47, no. 4, pp, 8-11, Apr. 2020.

[2] K. Mestav, J. Luengo-Rozas, and L. Tong, "Bayesian state estimation for unobservable distribution systems via deep learning," IEEE Transactions on Power Systems, vol. 34, no. 6, pp. 4910-4920, Nov. 2019.

[3] K. Mestav and L. Tong, "Learning the Unobservable: High-Resolution State Estimation via Deep Learning," 2019 57th Annual Allerton Conference on Communication, Control, and Computing (Allerton).

[4] K. Mestav and L. Tong, "State Estimation in Smart Distribution Systems with Deep Generative Adversary Networks," 2019 IEEE International Conference on Communications, Control, and Computing Technologies for Smart Grids (SmartGridComm).

[5] K. Mestav and L. Tong, "Universal Data Anomaly Detection via Inverse Generative Adversary Network," IEEE Signal Processing Letters, vol. 27, pp. 511-515, March 2020.

[6] X. Wang and L. Tong, "Innovations Autoencoder and its Application in One-class Anomalous Sequence Detection," submitted to Journal of Machine Learning Research, July 2021. Accessible online on arXiv at https://arxiv.org/abs/2106.12382

[7] K. Mestav, X. Wang, and L. Tong, “A deep learning approach to anomaly sequence detection for high-resolution monitoring of power systems,” submitted for publication. Accessible online on arXiv at https://arxiv.org/abs/2012.05163

[8] J. Yuan and Y. Weng, “Support Matrix Regression for Learning Power Flow in Distribution Grid with Unobservability,” IEEE Transactions on Power Systems, Aug. 2021.

[9] J. Yuan, Y. Weng, and C. Tan, “Quantifying Hosting Capacity for Rooftop PV System in LV Distribution Grids,” International Journal of Electrical Power and Energy Systems, Jul 2021.

Student Theses:

[1] K. Mestav, *A deep learning approach to state estimation and bad data detection, Ph.D. Dissertation*, January 2021.