



Machine Learning Approaches for Real-time Integration of Synchrophasor Data

Final Project Report

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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

Recently, the availability of fast time scale synchrophasor data has enabled both researchers and practitioners to tackle challenging and interesting problems related to monitoring, control, and security of power systems. This objective would not have been possible without the significant advancements in machine learning (ML)---specifically, deep learning---in terms of efficiency, reliability, and scalability. The overall goal of this project is to efficiently pre-process large volumes of synchrophasor data and then train suitable ML algorithms to (i) generate synthetic load and voltage data for downstream applications and (ii) detect islanding and events in a power system. Below we outline the key contributions of these two tasks (or parts) and we provide full details in later sections.

Part 1: Generation of synthetic load and voltage data using the state-of-the-art deep learning algorithms

Part 1 of the project considers two problems. The ASU team focused on generating synthetic load data for steady state applications, which can ultimately be used by the industries and practitioners to predict loads and unanticipated attacks. In particular, a framework for the generation of synthetic time-series transmission-level load data is presented. Conditional generative adversarial networks are used to learn the patterns of a real dataset of hourly-sampled week-long load profiles and generate unique synthetic profiles on demand, based on the season and type of load required. Extensive testing of the generative model is performed to verify that the synthetic data fully captures the characteristics of real loads and that it can be used for downstream power system applications, a few of them mentioned above.

The TAMU team focused on generating both synthetic load and voltage data to assess the dynamic (specifically, transient) stability of the power system. In particular, the team creates a massive synthetic eventful data from the given limited real data using the proposed two-stage method that leverages Generative Adversarial Nets (GAN) and Neural Ordinary Differential Equations (NeuralODEs). The key to the success of the proposed idea is to make sure that the synthetic data are realistic and diverse rather than a simple clone of the real data, which is achieved by the proposed PMU data creation algorithm. Finally, the proposed conditional learning framework can be leveraged for the generation of other datasets highlighting different characteristics, such as the level of penetration of renewables or electric vehicle charging.

Part 2: Real time detection, identification, and prediction of oscillatory events and contingencies using synchrophasor data: A machine learning approach

Part 2 of the project considers two problems. PI Pal's group at ASU focused on developing a graph-theoretic approach to detect if a contingency can create a saturated cut set. These potential cutsets, which basically serve as an alarm, can alert operators which geographical region of the power system may be disconnected from the main grid. Identification of such cutsets is important particularly in the presence of extreme weather events where successive contingencies can take place leading to uncontrolled islanding of the power system. To this end, the group proposed a feasibility test algorithm whose inputs are generated by deep neural networks and support vector regression methods that are extensively trained using synchronized bus power injections.

PI Sankar's group at ASU developed a physics-based ML approach for online event (e.g., generation loss and line trips) identification. The proposed approach takes advantage of knowledge of the system dynamics by characterizing event signatures based on their modal information that can be directly extracted from phasor measurement unit (PMU) measurements, and subsequently applying ML techniques to produce a robust classifier from limited but feature-rich training data. However, including all possible measurements channels at each PMU allows exploiting diverse features but also requires learning classification algorithms over a high-dimensional space. To this end, various feature selection methods are implemented in order to choose the best subset of features. Using the obtained subset of features, we investigate the performance of two well-known classification algorithms, namely, logistic regression and support vector machines (SVM) to identify generation loss and line trip events in two different datasets. The first dataset is obtained from simulated generation loss and line trip events in Texas 2000-bus synthetic grid using PSSE software and the second is a proprietary dataset with labeled generation losses and line trip events obtained from a utility in the US, involving measurements from nearly 500 PMUs. Our simulation results indicate that the proposed framework is promising for identifying the two types of events in both real and simulated datasets.

Project Publications:

- [1] A. Pinceti, L. Sankar and O. Kosut, "Generation of Synthetic Multi-Resolution Time Series Load Data" 2021, arXiv:2107.03547 (Submitted to IEEE Transactions on Power Systems).
- [2] A. Pinceti, L. Sankar and O. Kosut, "Synthetic Time-Series Load Data Via Conditional Generative Adversarial Networks", 2021 IEEE Power and Energy Society General Meeting, August 2021
- [3] N. T. Bazargani, L. Sankar and O. Kosut, "Event Identification Framework Based on Modal Analysis of Phasor Measurement Unit Data" 2021, under preparation.
- [4] X. Zheng, B. Wang, D. Kalathil, and L. Xie. "Generative Adversarial Networks-Based Synthetic PMU Data Creation for Improved Event Classification." IEEE Open Access Journal of Power and Energy 8 (2021): 68-76.
- [5] X. Zheng, A. Pinceti, L. Sankar and L. Xie, "Synthetic Eventful Synchrophasor Data Over Time-varying Load Conditions: A Generative Adversarial Netts-based Approach," 2021, under preparation.
- [6] R. S. Biswas, A. Pal, T. Werho, and V. Vittal, "Fast identification of saturated cut-sets using graph search techniques," in *Proc. IEEE Power Eng. Soc. General Meeting*, Montreal, Canada, pp. 1-5, 2-6 Aug. 2020.
- [7] R. S. Biswas, A. Pal, T. Werho, and V. Vittal, "A graph theoretic approach to power system vulnerability identification," *IEEE Trans. Power Syst.*, vol. 36, no. 2, pp. 923-935, Mar. 2021.
- [8] R. S. Biswas, A. Pal, T. Werho, and V. Vittal, "Mitigation of saturated cut-sets during multiple outages to enhance power system security," accepted for publication in *IEEE Transactions on Power Systems*.

Student Theses:

- [1] Andrea Pinceti. Machine Learning for the Analysis of Power System Loads: Cyber-Attack Detection and Generation of Synthetic Datasets. Ph.D. Dissertation, Arizona State University, Tempe, AZ, 2021.

- [2] Reetam Sen Biswas. Power System Security Enhancement for Real-Time Operations during Multiple Outages using Network Science, Ph.D. Dissertation, Arizona State University, Tempe, AZ, 2021.