2022 AMPS Workshop- May 26, 2022

9:00	Welcome
9:15-9:45	Update on AMPS and Power Grid Opportunities- Lee Jameson & Ali Ghassemian

<u>Presentations are 20 minutes + 5 minutes for questions.</u>

Session 1	*Chair- Yao Xie*
9:45-10:10	Guanqun Cao (in-person) Functional Data Analysis via Deep Neural Network
10:10-10:35	Guang Lin (virtual) On Learning the Dynamic Response of Non-autonomous Nonlinear Systems using Deep Operator Networks
10:35-11:00	Mohsen Zayernouri (virtual) Nonlocal Machine Learning of Micro-Structure Defect Evolusions in Crystalline Materials
11:00-11:25	Georgios Fellouris (in-person) Ultra-Fast Line Outage Detection and Identification
11:25-11:50	Maxim Bichuch (virtual) Identification of Optimal Capacity Expansion and Differentiated Capacity Payments under Risk Aversion

11:50-1:00	Lunch Break

Session 2	*Chair- Stephen Becker*
1:00-1:25	Jie Xu (in-person) Large-scale Simulation-based Optimal Hardening of Power Lines for Improved Power Grid Weather Resilience using Criticality Scores
1:25-1:50	Yao Xie (in-person) Spatio-Temporal Modeling for Power Grid Resilience to Extreme Weather Events
1:50-2:15	Mike Ludkovski (virtual) Hierarchical Correlation Analysis for Simulation of Day-Ahead Renewable Generation
2:15-2:40	Abhishek Halder (virtual)

	Prediction and Optimal Feedback Control of Probability Densities in Power System Dynamics
2:40-3:05	Will Kleiber (virtual) Stochastic Process Models for Space-Time Weather-Driven Renewables
3:05-3:25	Break
Session 3	*Chair Barry Lee*
3:25-3:50	Vassilis Kekatos (virtual) Monitoring and Optimization Solutions for Inter-Area Oscillations
3:50-4:15	Stephen Becker (in-person) High-Probability Bounds for Stochastic Gradient Descent
4:15-4:40	Mark Embree (in-person) Structure-Preserving Data-Driven Modeling for Power Networks

Poster Session (5:10-7:10)

Caitlin Berry	Subordinated Processes for Solar Irradiance Simulation
Mantautas Rimkus	Real-time Power Grid Fault Detection
Tianqiao Zhao	Structure-informed Graph Learning of Networked Dependencies for Online Prediction of Power System Transient Dynamics
Yuzhou Chen	Understanding Power Grid Network Vulnerability through the Stochastic Lens of Network Motif Evolution
Zhiwei Zhen	Anomaly Detection in Critical Infrastructures and Cyber-Physical Systems Using Graph Neural Networks and Extreme Value Theory
Sean Reiter	Power System Event Location via DEIM
Nilton Alan	Dynamic Recovering for Power Networks using DMD
Ignacio Segovia-Dominguez	Time-Aware Zigzags at Graph Convolutional Networks for Cyber-Physical Systems

Presentation Abstracts

Guang Lin- On Learning the Dynamic Response of Non-autonomous Nonlinear Systems using Deep Operator Networks

We propose a Deep Operator Network (DeepONet) framework to learn the dynamic response of non-autonomous nonlinear dynamical systems from data. To this end, we first construct and train a DeepONet that approximates the system's local solution operator. Then, we design a numerical scheme that recursively uses a trained DeepONet to simulate the system's long/medium-term dynamic response for a distribution of initial conditions. We accompany the proposed scheme with an estimate for the error bound of the scheme's cumulative error. Finally, numerical experiments on a (1) continuous control system and (2) generator that interacts with the power grid or numerical solver confirm that our proposed DeepONet scheme can approximate the dynamic response of non-autonomous systems effectively.

Mohsen Zayernouri- Nonlocal Machine Learning of Micro-Structure Defect Evolusions in Crystalline Materials

The presence and evolution of defects that appear in the manufacturing processes play a vital role in the failure mechanisms of engineering materials, particularly in power grid systems. In particular, the collective behavior of dislocation dynamics at the mesoscale leads to avalanche, strain bursts, intermittent energy spikes, and nonlocal interactions producing anomalous features across different time- and length-scales, directly affecting plasticity, void and crack nucleation. Discrete Dislocation Dynamics (DDD) simulations are often used at the meso-level, but the cost and complexity increase dramatically with simulation time. To further understand how the anomalous features propagate to the continuum, we develop a probabilistic model for dislocation motion constructed from the position statistics obtained from DDD simulations. We obtain the fluid-limit of dislocation dynamics through Probability Density Function for the dislocation motion, and propose a nonlocal transport model for the PDF. We develop a machine-learning framework to learn the parameters of the nonlocal operator with a power-law kernel, connecting the anomalous nature of DDD to the origin of its corresponding nonlocal operator at the continuum, facilitating the integration of dislocation dynamics into multi-scale, long-time power grid failure simulations.

Georgios Fellouris- Ultra-Fast Line Outage Detection and Identification

We will talk about the problem of detecting a power system outage and identifying the transmission line that experiences it. The goal will be to perform this joint detection and identification with minimal delay after the outage, using data from only a small number of buses, equipped with phasor measurement units. This will be achieved using a statistical model for the data in the early transient regime after the fault, that is based on the underlying power system equations. Specifically, this model will provide the basis for the application of a CUSUM-type algorithm, which will turn out to be sufficient not only for the detection, but also for the isolation task. A case study will be presented that illustrates the proposed approach.

Maxim Bichuch- Identification of Optimal Capacity Expansion and Differentiated Capacity Payments under Risk Aversion

We investigate how capacity payments in combination with scarcity pricing of energy can ensure resource adequacy in electricity markets, defined as the ability of supply and other resources to provide enough energy and capacity to meet demand under steady-state operating conditions. This work generalizes models for determining capacity payments by deriving second-best discriminatory payments by resource type that account not only for the ``missing money'' market failure that arises from energy price caps, but also for market power in the capacity market and differences in risk tolerance among resource types that can arise from failures in risk and capital markets. A bi-level equilibrium-constrained optimization model is proposed to define second-best capacity payments in a static long-run setting, considering the impacts of those payments on the mix and cost of generation investment and energy outputs. The lower-level suppliers play a Nash game to determine the generation mix under a capacity payment scheme, while the upper-level regulator considers consumer welfare and resource adequacy. We introduce an equivalent formulation via a variational inequality approach, and find conditions for the solution to exist. Discriminatory payments are found to be second-best when there is market power in the investment game, price caps in energy markets and imperfections in risk markets that lead to diverse risk attitudes.

Jie Xu- Large-scale Simulation-based Optimal Hardening of Power Lines for Improved Power Grid Weather Resilience using Criticality Scores

We present a new integrated statistical learning and simulation-based optimization approach to determine the optimal hardening plans for power lines to improve power grid weather resilience. The new approach builds upon a recently developed model-free dimension reduction method to analyze a large amount of power grid cascading simulation data and rank the criticality of power lines using cascading outage simulation data. The criticality scores are then used to specify a “hot-start” multinomial sampling distribution for a globally convergent model-based stochastic search method to perform efficient simulation-based optimization and identify the optimal hardening plan in response to an incoming severe weather event. The proposed multinomial sampling distribution exploits the specific constraint format of the budget-constrained hardening problem formulation and reduces the number of model parameters by orders of magnitudes. Numerical experiments with both synthetic test function and a large-scale power grid test case demonstrates promising numerical performance of the proposed research.

Yao Xie- Spatio-Temporal Modeling for Power Grid Resilience to Extreme Weather Event

In recent years, extreme weather events frequently cause large-scale power outages, affecting millions of customers for extended duration. Resilience, the capability of withstanding, adapting to, and recovering from a large-scale disruption, has becomes a top priority for power sector, in addition to economics and sustainability. However, a good understanding on the power grid resilience is still lacking, as most approaches still either stay on the conceptual level, yielding no actionable results, or focus on a particular technical issue, revealing little insights on the system level. In this study, we take a quantitative approach to understanding power system resilience by directly exploring real power outage data. We first give a qualitative analysis on power system resilience and large-scale power outage process, identifying key elements and developing conceptual models to describe grid resilience. Then we propose a spatio-temporal random process model, with parameters representing the identified resilience capabilities and interdependence between service areas. We perform analyse using our model on a set of large-scale customer-level quarter-hourly historical power outage data and corresponding weather records from three major service territories on the east-coast of the United States under normal daily operations and three major extreme weather events. It has shown that weather only directly cause a small portion of power outages, and the peak of power outages usually lag the weather events. Planning vulnerability and excessively accumulation of weather effects play a key role in causing sustained local outages to the power system in a short time. The local outages caused by weather events will later propagate to broader regions through the power grid, which subsequently lead to a much larger number of non-local power outages.

Will Kleiber-Stochastic Process Models for Space-Time Weather-Driven Renewables

As the power grid moves to a more renewable future, energy sources from weather-driven phenomena such as solar, wind and hydroelectric power will form an increasingly large portion of generation. Although, in principle, limitless, the uncertainty and variability of these resources challenge current grid operation paradigms. Our research program focuses on quantifying and understanding this variability using modern space-time stochastic process models with particular focus on application to high frequency solar irradiance scenarios. We review some recent efforts in this area from the group including work on subordinated Gaussian processes and deep Levy processes for heavy-tailed and highly non-Gaussian data as well as a new diagnostic tool for assessing spatial dependence in spatially-distributed time series processes.

Stephen Becker- High-Probability Bounds for Stochastic Gradient Descent

In our previous updates, we reported on deriving an optimal method for time-varying optimization. Since then, we have extended our investigation to stochastic methods, focusing on low-probability events. In particular, most stochastic optimization analyses take the form of bounding the error by a factor of 1/delta for a given probability of failure delta. This is unsatisfactory since if we desire to take rare events into account, i.e., delta -> 0, then the bound quickly becomes useless. Our improved analysis gives bounds that involve a factor of log(1/delta), which is a much milder dependence on delta and is appropriate for bounding rare events; our assumptions also allow for heavier-tailed noise than is standard for such types of results.

Mark Embree- Structure-Preserving Data-Driven Modeling for Power Networks

When modeling a dynamical system from data, it is important to retain the inherent physical structures of the underlying system so that the learned model can be used as a physically meaningful surrogate. This is the framework we consider in this talk for modeling power networks from data where the structure to preserve naturally results from nonlinear (and linearized) swing equations. Using the time-domain state-snapshot data, we develop approaches to constructing structured surrogates for linear and nonlinear swing equations. In both cases, we fit the data using a least-squares measure while at the time enforcing the underlying second-order structure. Moreover, for the real-time power system event analysis, we introduce a selection procedure for locating power system events from real-time data based on the Discrete Empirical Interpolation Method (DEIM).