Motivation and Project Objective

- Power system simulation engines are essential tools for power grid operation and planning.
- Simulations are computationally expensive for large networks and utility model accuracy can be limited.

Project Objective

- Develop deep learning framework for learning 3-phase unbalanced power flow simulation outputs.
- Analyze how knowledge about network characteristics improves performance.

Datasets and Features

Dataset:
- Generate data for each power network with GridLAB-D simulator [1].
- 82,080 samples training, 2,880 samples validation, 2,880 samples testing.
- Calibrate power networks to be in nonlinear power flow regime.

Features:
- Inputs: Real power injections at nominal voltage at each bus
- Outputs: Voltage magnitude at each bus in power network
- Other information: adjacency matrix of power network and phase of power injections

Power network case studies
- IEEE 123 bus power network topology

Models

Baseline models:
- Fully connected network (L=1,2,3)
- Linear regression

Convolutional NN:
- Incorporate knowledge of the phase of the power injections using channels and apply convolutions to learn dependencies between the three phases of power distribution.

Graph Convolutional Network [1]:
- Utilize information about network topology/sparsity
- Poor preliminary results due to (1) model not capturing spatial differences and (2) large # of layers needed to propagate information for large power networks.

Model Training:
- Adam optimization, mean squared error loss
- Hyperparameters: activation (tanh and ReLU), L2 regularization, # of FC layers, # of hidden units

Performance Metrics

- Normalized voltage magnitude error: worst case voltage prediction over all buses for sample $i$
  \[ \epsilon_{i} = \| v - v' \| / \| v \| \]
- Mean over m samples:
  \[ \mu = \frac{1}{m} \sum_{i=1}^{m} \epsilon_{i} \]

References


Results

- Convolutional model outperforms other models in almost all cases.
- Tanh activation most reliably produces best results.
- Training data requirements scale with power network size.

Conclusions and Future Work

- Convolutional model significantly improves performance by accounting for the phase of the power injections and is scalable.
- Error rate of convolutional model ($\mu_{ey}<0.0005$) is appropriate for many power system simulation applications.
- Future work: Complex-valued neural networks, incorporate voltage regulators and capacitors into deep learning model.