SSTDR for Fault Monitoring in Power Systems

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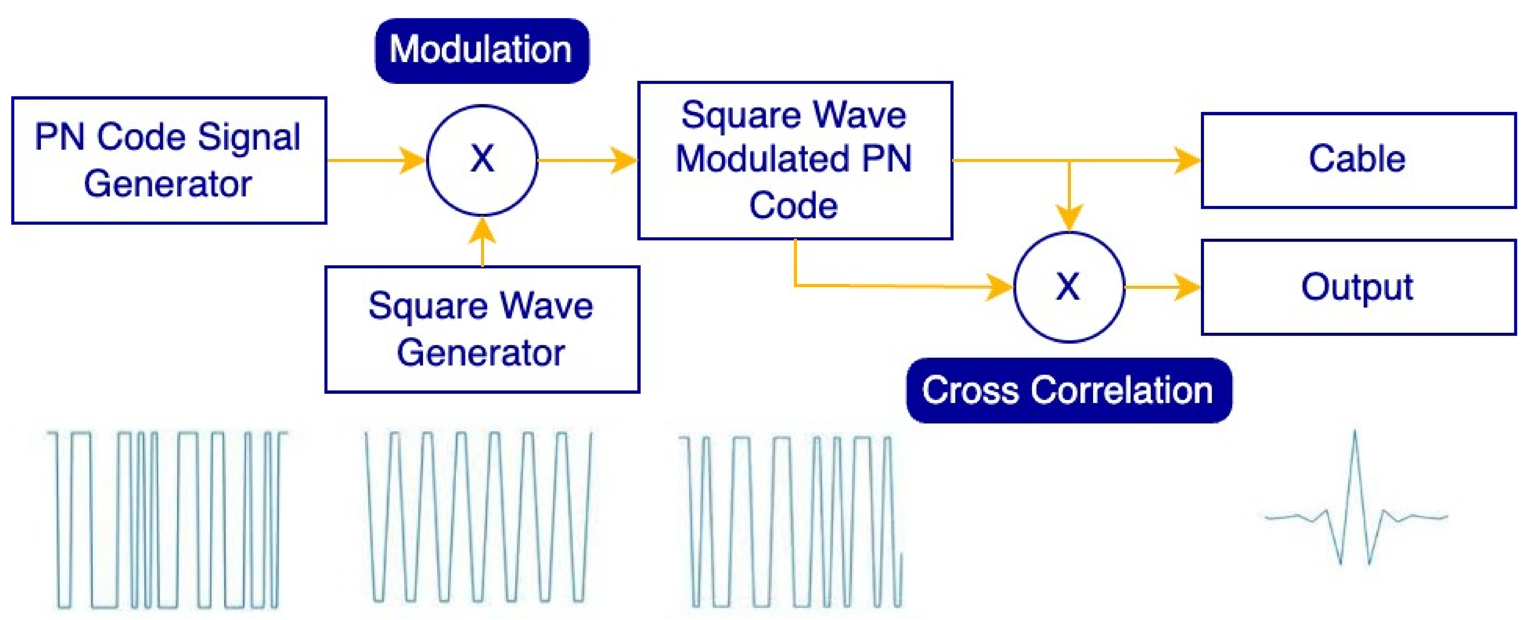
Introduction to Spread Spectrum Time Domain Reflectometry (SSTDR)

- SSTDR can detect, classify, and locate faults on dead or live wires, providing a consistent metric in critically shifting systems.



- Smith et al., "Analysis of SSTDR," IEEE Sensors J 2005.

Literature Review

- SSTDR has been used in aircraft, rail, undersea
  Furse et al, "Fault Diagnosis for Electrical Systems and Power Networks: A Review." IEEE Sensors J, 2021
- Coupling of SSTDR Signals onto HV Lines
  Glass et al, "Evaluation of Clamshell Current Coupler for Online FDR and SSTDR to Detect Anomalies in Energized Cables," 2024
- SSTDR has been used in branching networks before
  Addad et al., "Analysis and Validation of SSTDR for Simultaneous Distributed Diagnosis of Wire Networks," IEEE Sensors J, 2025

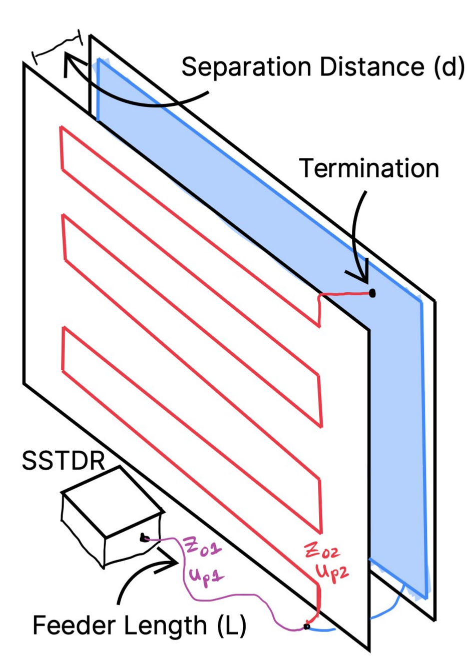
Research Objectives

- This work provides research into SSTDR fault detection applied to power distribution systems, initially targeting fault locating after large scale outages on de-energized cables.
- Our research explores considerations (branching, transmission) and implementation decisions that could guide future work, as well as considering other power applications SSTDR, such as solar/wind.

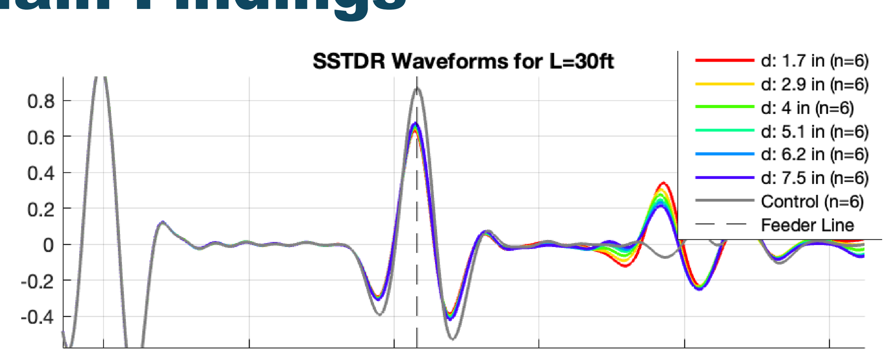
Signal Transmission

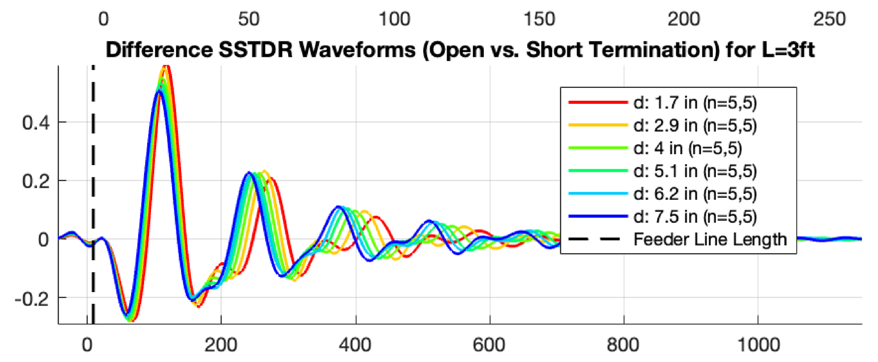
Methodology

- To measure changes in SSTDR responses due to ground coupling, we used the setup shown.
- We varied the feeder length and separation distance to and took 95% confidence intervals for the data.



Main Findings





- Results demonstrate range of variability in both impedance and propagation velocity

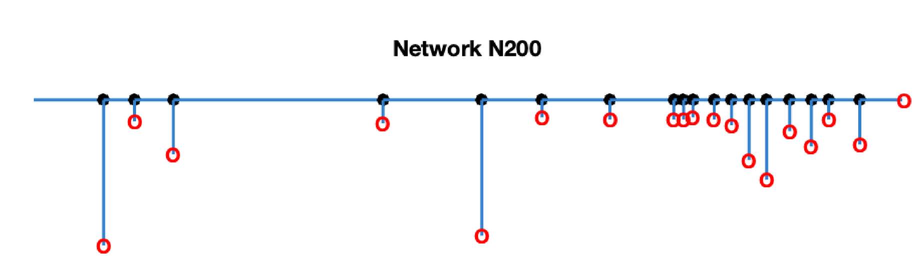
Implications

- These findings provide useful metrics for predicting types and measure of variability present in real distribution systems.
- Uncertainty in propagation velocity and impedances reduce reliability of SSTDR.
- Additional utility is found in other power systems, such as photovoltaics and lightning protection systems, where EM coupling can vary wildly.
- *LaFlamme et al., "Ground Faults in Photovoltaics: SSTDR for Characterization, Detection, and Location," ASME 2022.*

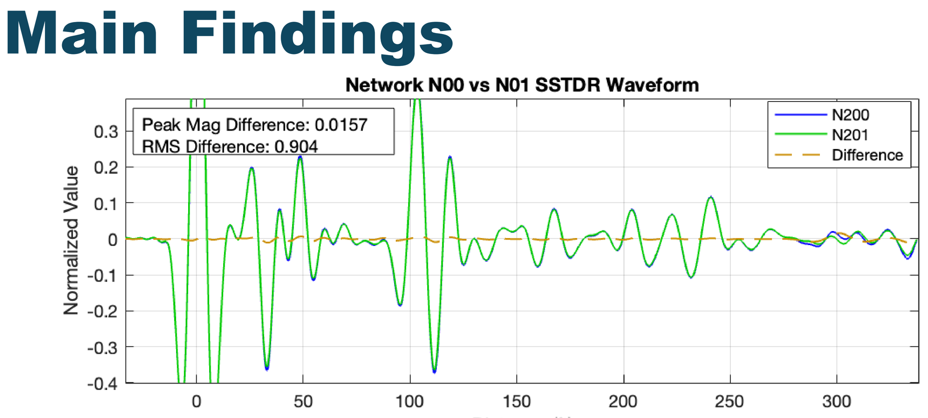
Branching Networks

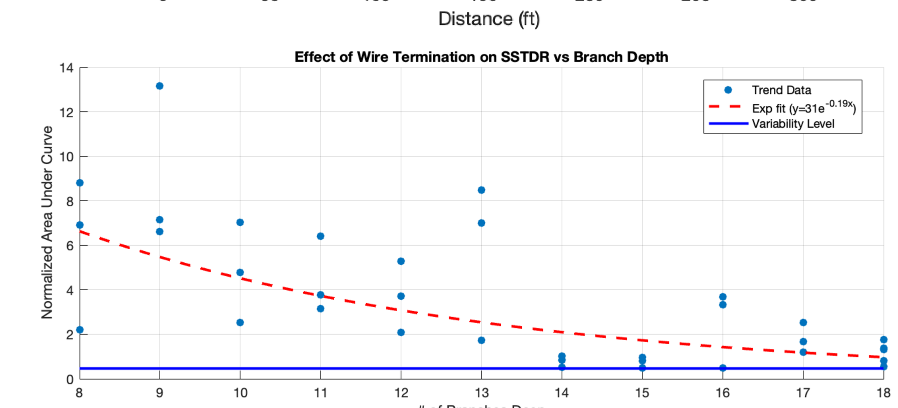
Methodology

- We assembled BNC cable networks to simulate distribution lines. We then probed the network using SSTDR to produce a signature.
- Taking the difference between signatures via RMS quantifies the detectable change between two networks. For example, terminating a branch with open vs short.



Main Findings





- These charts point to detectable changes on cables at least 18 branches away in the network.

Implications

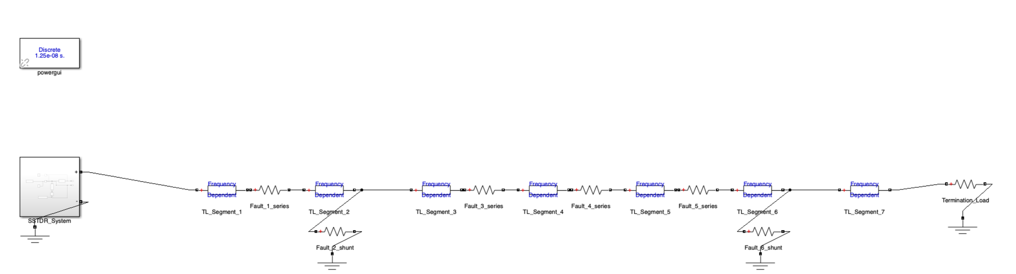
- These findings were more promising than expected, pointing to SSTDR as a valid approach for diagnosing branching networks as well as single conductors.
- Applications involve monitoring energized OR de-energized systems at the neighborhood level.

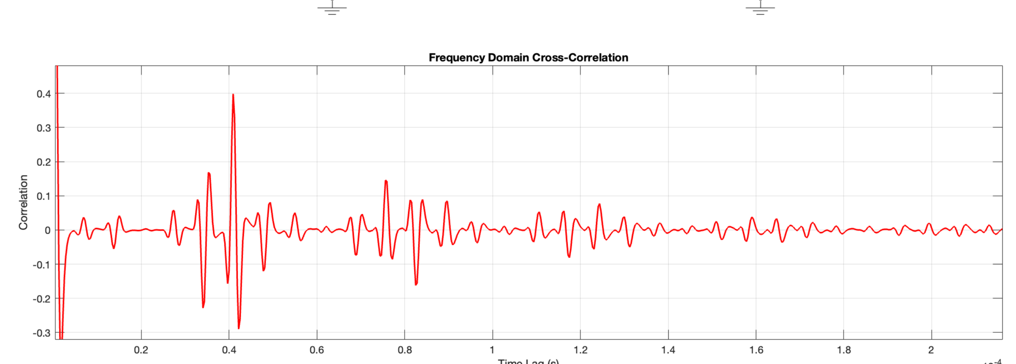
Data Generation for Machine Learning

Methodology

- Turning SSTDR into fault location is difficult when there are multiple impedance changes and branches on the network.
- Machine Learning is a promising approach to map these domains, but requires large amounts of data and proper architecture.

Main Findings





- Our system randomly generates network system and provides realistic simulation with full reflection and attenuation measures included.

Implications

- This simulated training set should provide an estimate of the efficacy of neural network approaches and capabilities using very clean synthetic data.

Future Work

- Using this data generation pipeline, we are entirely ready to start training a machine learning network.
- Several architectures have been considered, including 1D convolution neural networks for the SSTDR waveform, paired with graph neural networks connecting a discretized version of the network layout and impedance faults.

Disclosure

Dr. C.M. Furse is a co-founder of LiveWire Innovation/Viper Innovation which is commercializing SSTDR technology, and therefore she is disclosing a financial conflict of interest with this company.

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