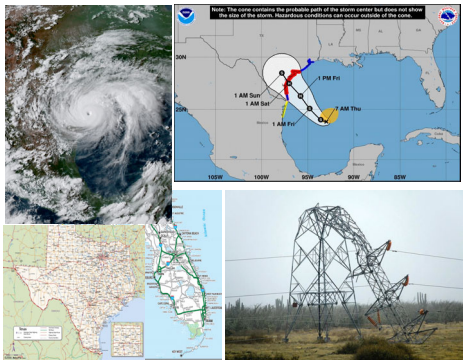
Element: Open Access Data Generation Engine for Bulk Power System under Extreme Windstorms

PI: Ge Ou, Mostafa Sahraei−Ardakani, Zhaoxia Pu

NSF CSSI Award # 2004658

Introduction

Extreme windstorms such as hurricanes and tornadoes often lead to vast and long-lasting blackouts, with severe social and economic consequences. A systematic investigation of power network resilience, appropriate preventive actions, and optimized post-windstorm restoration and repair planning is expected to substantially alleviate such adverse impacts. Unfortunately, due to the disconnection between the physical hazard data and the abstract power system model and the sensitive nature of power system infrastructure, data and tools that represent close to real power system performance during hazards do not exist. This project established a novel data generation engine that enables realistic performance simulation of power systems during extreme windstorms.



Objectives

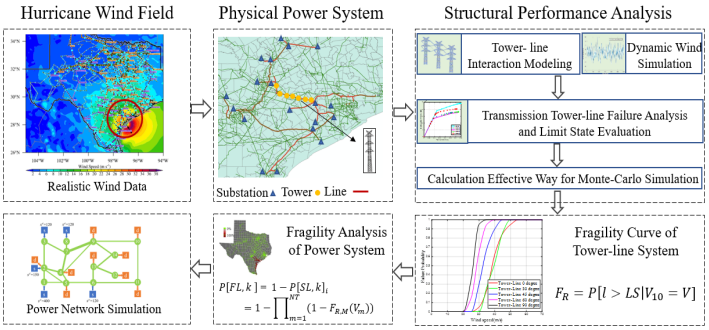
This multi-disciplinary project established a novel data generation engine that developed a new linkage between distributed data sources and computational models to enable realistic performance simulation of power systems during extreme windstorms with the following objectives:

1) Aggregating available resources and developing the missing linkage between the hazard data and power network models.
2) Developing an innovative and high-fidelity data generation engine that fulfills scientific-driven research gaps.
3) Collaborating closely with target users to promote the adoption of the data generation engine.
4) Leveraging existing NSF-supported resources to maintain a sustainable cyberinfrastructure.

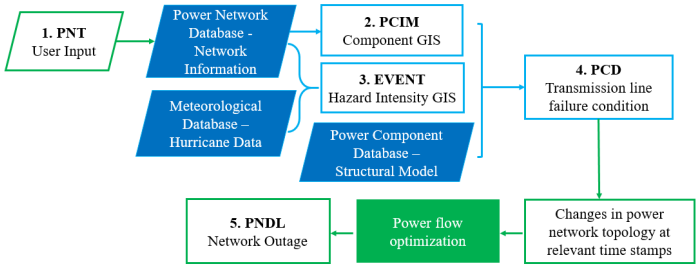
Wind-Impacted Power System and Component Performance Simulator

Power System Simulator during Hurricane

Power outage simulator during hurricane integrates wind field simulation, power network modeling, and structural fragility analysis. Its integration is shown in the following flow chart.

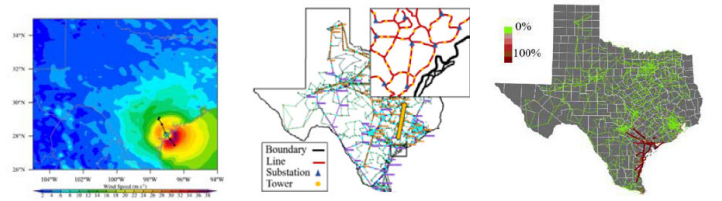


Data Generation Engine Data-Flow Structure



Name	Description	Details
PNT	Power Network Model	The PNT file will describe the power network and can be obtained from either the power network database or a user-defined file.
PCIM	Power Component Information Model	The PCIM file contains information related to each power infrastructural component, including type, material, geometry, design, geographical location, and its probabilistic failure model.
EVENT	Wind Event Data	The EVENT file describes the wind field information at locations of interest, including the vertical profile of mean wind speed and direction. The EVENT file is obtained directly from the hurricane database.
PCD	Power Component Damage Data	The PCD file describes the damage condition (either in probabilistic or deterministic form) of each power infrastructure component in the simulated region.
PNDL	Power Network Damage and Loss	The PNDL file describes the power outage and the economic costs due to the loss of power, given the damage to power system elements.

Hurricane Harvey Case Study and Result Validation

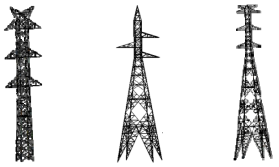


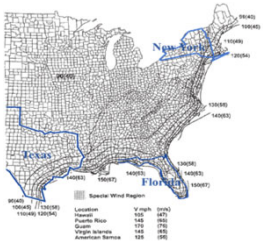
(a) Hurricane Harvey Wind Field (b) Mapping of the Physical Components (c) Transmission Line Failure in Texas 2000 System

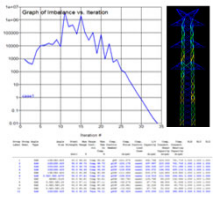
- 70 transmission line are estimated as damaged with a probability larger than 50%, which is 2.1% of the total transmission lines in the system.
- From Department of Energy (DOE), around 200 transmission lines were damaged by Hurricane Harvey. The realistic Texas system has 7800 lines, the reported damage ratio is 2.5%.

Structural Element Design and Modeling

Transmission Tower Design

	Tower 1	Tower 2	Tower 3
Height(ft)	103.5	143.9	264
Steel	A36	A36	A572-50
Total element	716	1537	2747
Total node	1081	1090	1970
Finite element model			



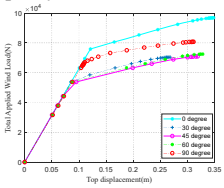


Transmission towers are calculated based on ASCE Manual and Reports on Engineering Practice No. 74: Guidelines for Electrical Transmission Line Structural Loading. Primary environment load, wind load is calculated:

$$F = \gamma_w Q K_z K_{zt} (V_{50})^2 G C_f A$$

All towers are designed by PLS-Tower.

Capacity Curve of Transmission Tower

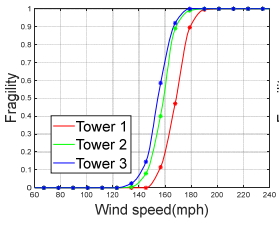


Capacity Curve for Tower 2 designed for 120mph

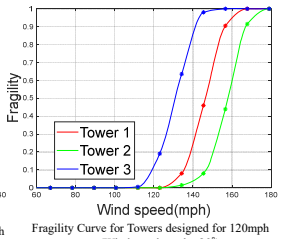
Capacity curves are developed to evaluate the transmission towers' static performance and provide failure criteria for fragility analysis. By monotonically increasing the wind load, the curves are obtained. Five wind attack angles are considered. When the solution to the numerical model does not converge, the tower reaches its maximum capacity. Therefore, 1.5% drift is chosen as the limit state in the fragility analysis.

Fragility Curve of Transmission Tower

Fragility curve shows the likelihood damage and failure of a structure under different loading intensity.



Fragility Curve for Towers designed for 120mph (Wind attack angle: 0°)



Fragility Curve for Towers designed for 120mph (Wind attack angle: 90°)

Contribution of the Project

This project developed a novel data generation engine and scientific workflow to simulate the failure and outage of a regional power network under a hurricane. Through this framework, the vulnerable structural components in the bulk power system during a storm, the transmission tower-line system, are modeled. We considered the transmission tower-line interaction and studied its impact on the power system performance during a hurricane. The synthetic 2000-bus Texas power grid under Hurricane Harvey is analyzed to verify the logistic rationality and feasibility.

With the input loading requirements to model the transmission tower failure condition, the raw hurricane numerical model is processed to extract only needed information so that the files transferred in the workflow are significantly smaller. The smaller intermediate hurricane loading file size greatly improved the computational efficiency. Another heavy computational part is assigning the tower with the associated wind profile in the hurricane in each time step. The nearest neighbor search algorithm is utilized to reduce the computational cost.