Structural Resiliency Assessment of a Single-circuit Overhead Distribution System under Extreme Wind

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INTRODUCTION

A reliable and resilient power grid is crucial for the public safety and economy, especially in regions that suffer from frequent extreme weather conditions. As a essential unit of the electrical power system, overhead distribution lines are the closest related to the end customers and act as "lifeline". However, existing distribution lines suffered extensive damage and the associated failures induced most of the outages during various hazards like hurricanes or winter storms in decades. The high vulnerability of overhead distribution system against such extreme wind hazards highlights the need for reliable hazard induced damage assessment to provide an effective decision-making strategy of pre-storm hardening and post-storm restoration, serving for system resilience purpose. Therefore from physical infrastructure perspective, a structural resiliency assessment framework is proposed overhead distribution system under extreme wind hazard. With the Monte Carlo finite element analysis of a simple pole-wire system, fragility curves of age-degraded poles are generated for both wind load and falling tree load. The Monte Carlo simulations also apply to a relatively realistic single-circuit overhead distribution line model, which is constructed with a parametric finite element model (FEM) based approach interacting with a parameter database integrating the extracted information from several resources including LiDAR data. Based on the probability of failure, the critical poles are located and ranked, serving the development of hardening strategy, as well as planning of post-storm inspection and restoration. This study is a part of both 3-D Imaging for Modernization project and Power Grid Resiliency project.

POWER SYSTEM RESILIENCE

Concept of Critical Infrastructure Resilience

- **Resilience has a broad features and its definitions and metrics are various and still in evolution.**
- **For example, the National Infrastructure Advisory Council (NIAC, USA) defines critical infrastructure resilience as:**

"…the ability to reduce the magnitude and/or duration of disruptive events. The effectiveness of a resilient infrastructure or enterprise depends upon its ability to anticipate, absorb, adapt to, and/or rapidly recover from a potentially disruptive event."

Resilience Main Features by NIAC and Projection to Power System Resilience Cycle

Robustness	• Keep operating or stay standing in the face of disaster • Withstand low-probability but high-consequence events	➡	**Preconditions:** **normal maintenance and hardening**
Resourcefulness	• Effectively manage a disaster as it unfolds • Identify options, prioritize what should be to control and mitigate the damage	➡	**Cascade events resistance:** **Line redundancy, islanding, etc.**
Rapid Recovery	• Get things back to normal as fast as possible after a disaster • Contingency plans and emergency operations	➡	**Restoration:** **Better restoration plan**
Adaptability	• Absorb new lessons from a catastrophe • Introduce of new tools and technologies for boosting robustness, resourcefulness and recovery before the next crisis	➡	**Adaptation:** **Post-outage resilience enhancement**

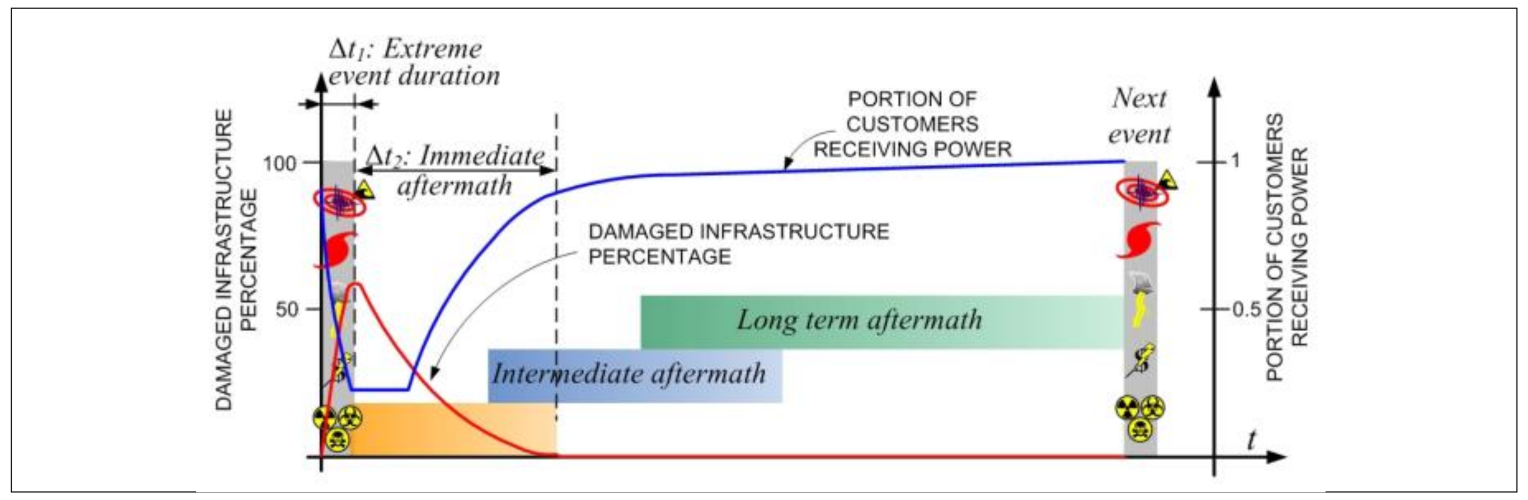


Figure 1. **The schematic representation of resilience of an extreme event of power systems (Rf.1)**

STRUCTURAL RESILIENCE OF POWERLINE

Physical Infrastructure Perspective of Powerline Resilience

- **Since the resilience of power system is focused on the power delivery instead of structural response, the physical infrastructure such as pole-wire system cannot be evaluated alone for resilience.**
- **The damage assessment of physical infrastructure system acts as a link between weather forecast/vegetation condition and power system performance.**
- **The structural assessment of powerline infrastructure under extreme weather conditions can provide the fragility curves to be used in outage prediction model and total system performance model. It can also locate and rank critical components for hardening and restoration plan, serving a resilient purpose.**

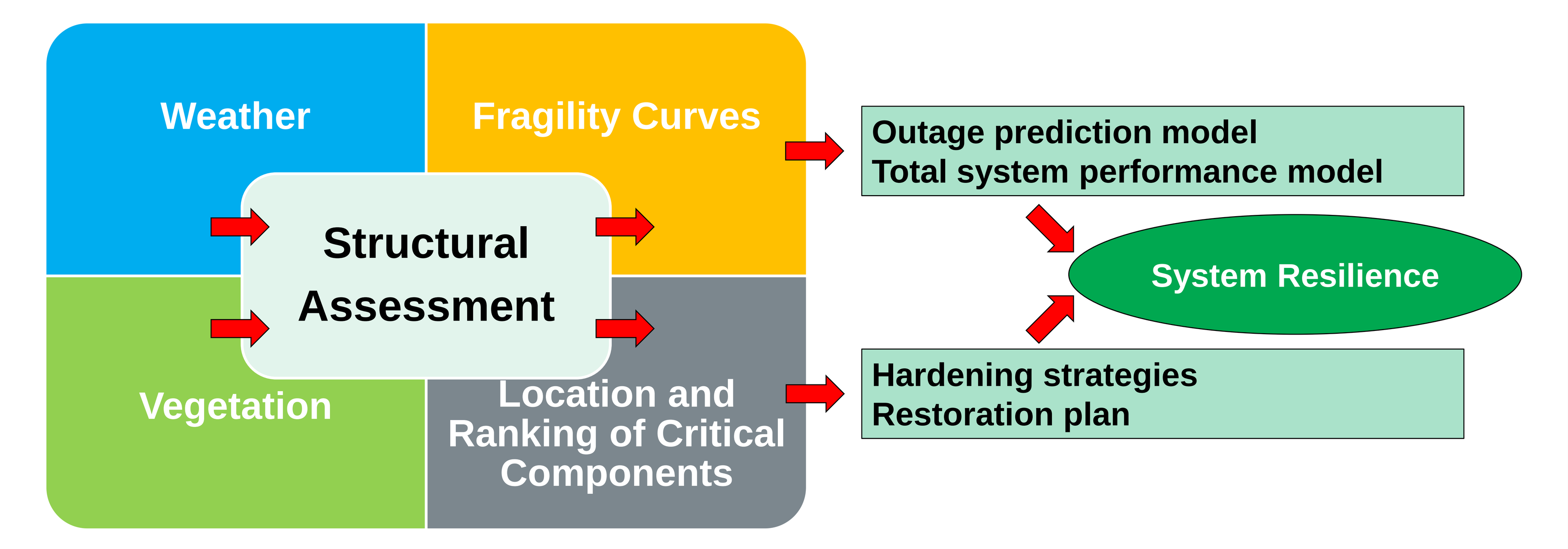


Figure 2. **Input and output of structural assessment module and relation to system resilience**

FRAGILITY CURVES OF A POLE-WIRE SYSTEM

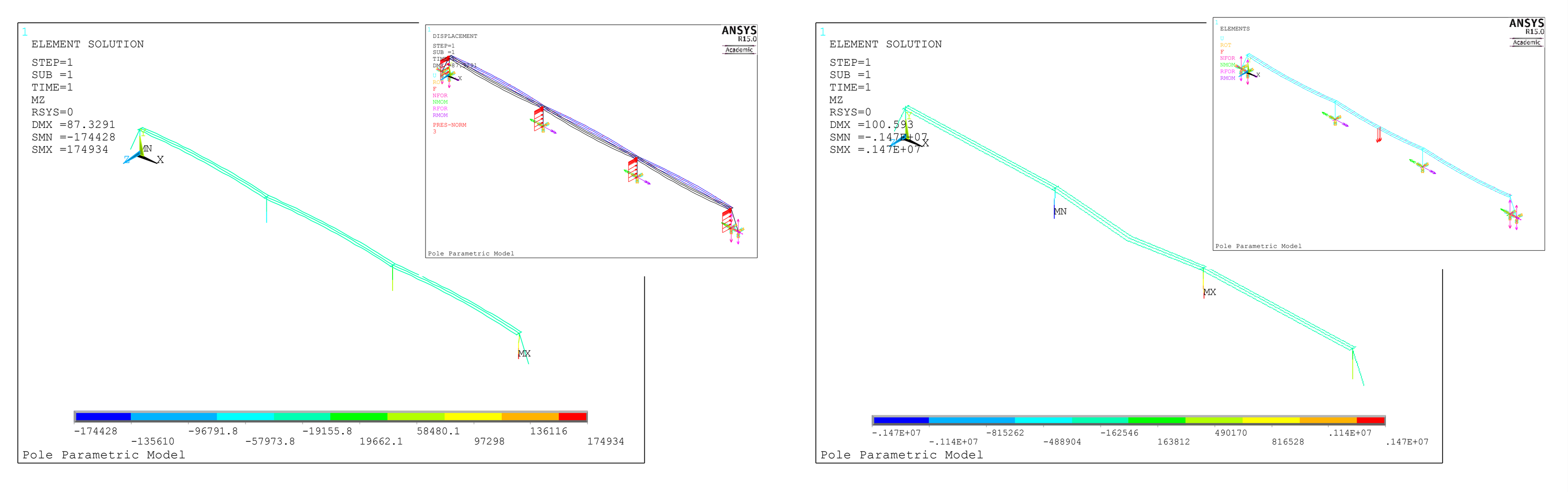


Figure 3. **FEM analysis of a 3-span pole-wire system under direct wind load (left) and falling tree load (right)**

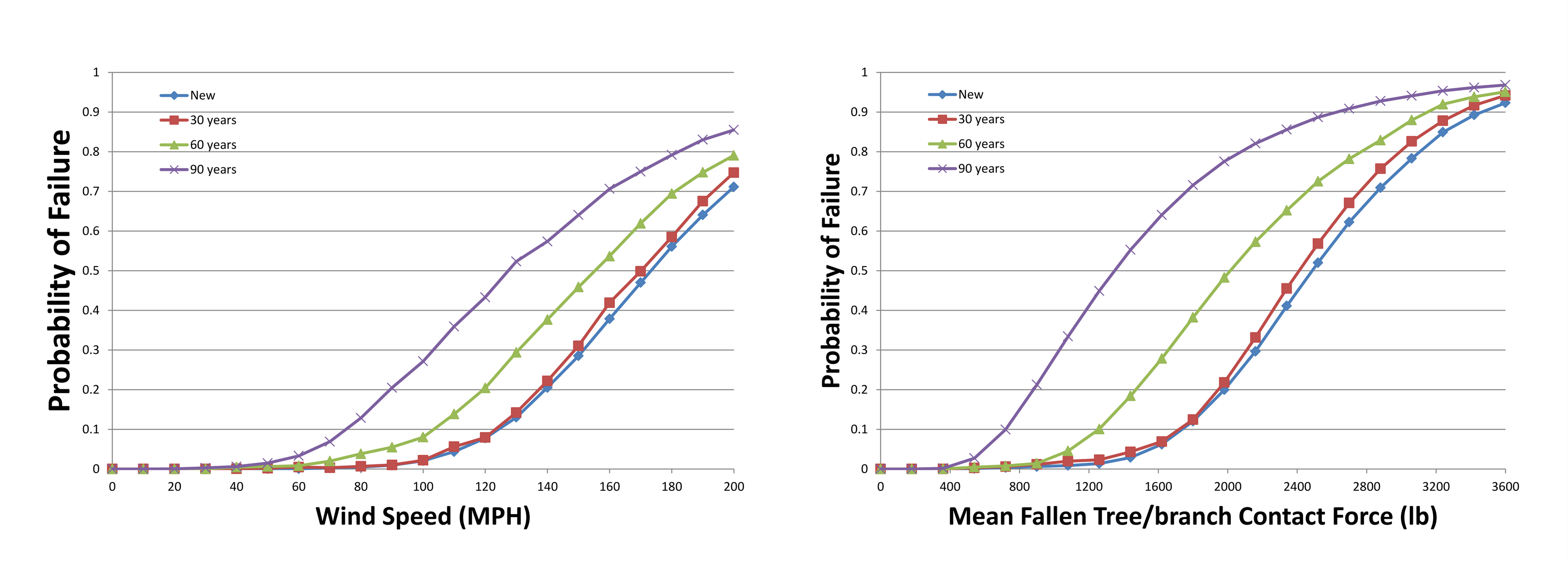
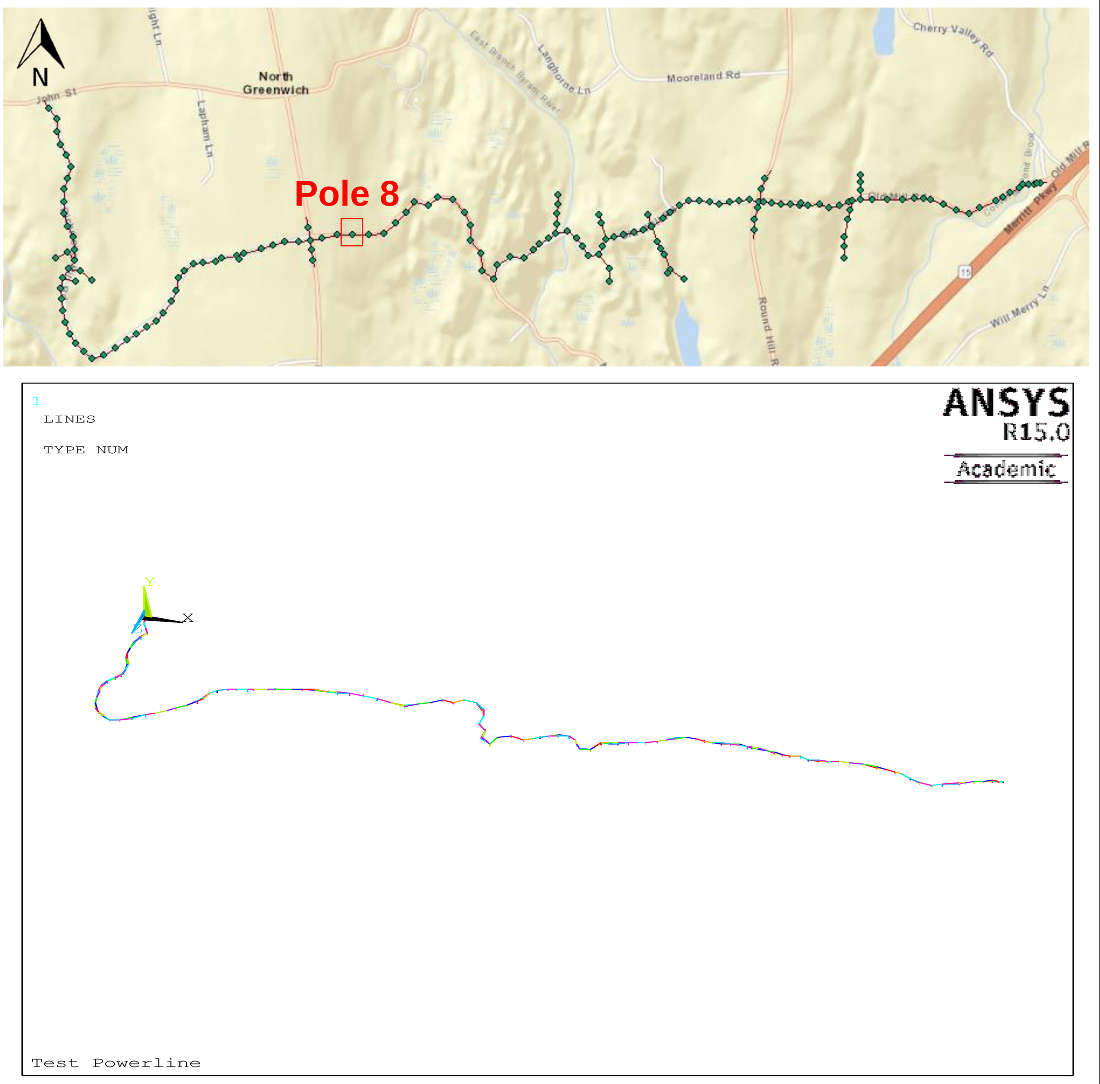


Figure 4. **Fragility curves of age-degraded poles under direct wind load (left) and falling tree load (right)**

ASSESSMENT OF A REALISTIC POWERLINE

A powerline sample is taken along:
Richmond Hill Rd., N Porchuck Rd., Old Mill Rd. in Greenwich, CT.

Analysis is performed for different wind directions assuming all poles are 30 year old.



Probability of Failure of Pole 8 under 90 mph wind

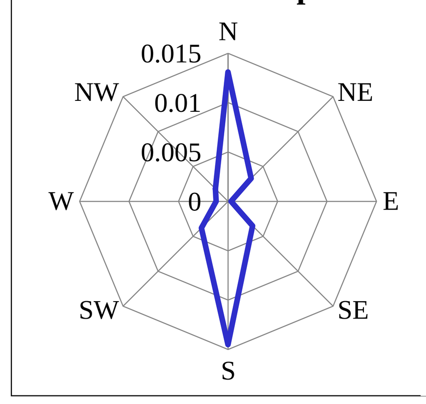
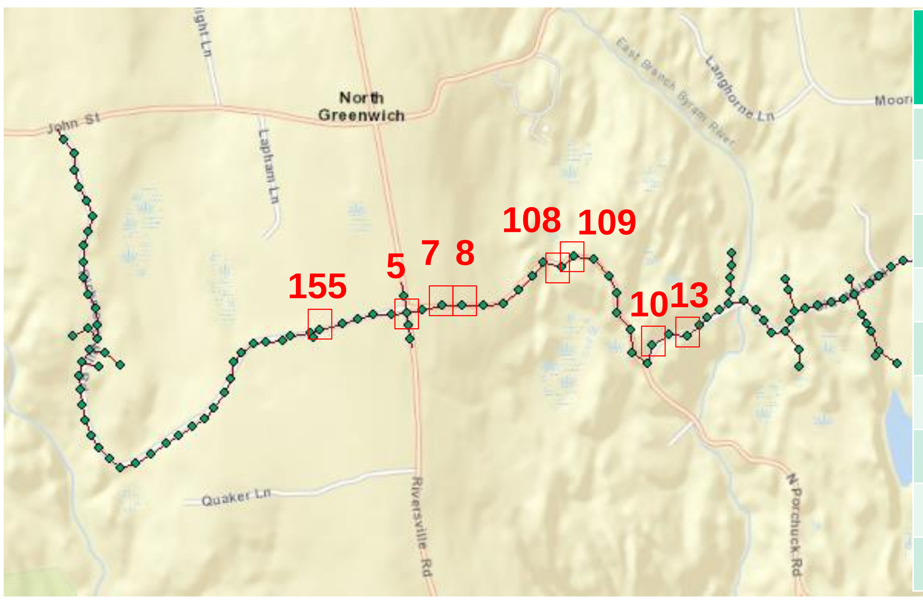


Figure 5. **GIS representation and FEM of a realistic powerline under extreme wind**



Rank	Pole ID	Probability of Failure
1	8	0.0131
2	7	0.0114
3	108	0.0101
4	5	0.0096
5	109	0.0093
6	10	0.0085
7	13	0.0084
8	155	0.0079
…	…	…

Figure 6. **Critical pole location and ranking under 90 mph north wind**

SUMMARY

- **Power grid resilience and structural perspective understanding is presented.**
- **Fragility curves of age-degraded poles are generated for both wind load and falling tree load for a simple pole-wire system.**
- **Monte Carlo simulation on a relatively realistic single-circuit overhead distribution line finite element model provide the failure rate ranking and locations of critical poles.**

ACKNOWLEDGEMENTS & REFERENCES

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- Rf.1 Kwasinski, A. (2016). Quantitative Model and Metrics of Electrical Grids' Resilience Evaluated at a Power Distribution Level. *Energies*, 9(2), 93.

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