Hurricane Resilience Assessment for Power Distribution System Considering Tree Failure Risk and Topology

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- Power distribution systems and communities relying on their services are vulnerable to climatic shocks, especially hurricanes.
- **Resilience assessment** of power distribution system subjected to wind and tree hazards is conducted using data-driven, physics-based, and hybrid methods

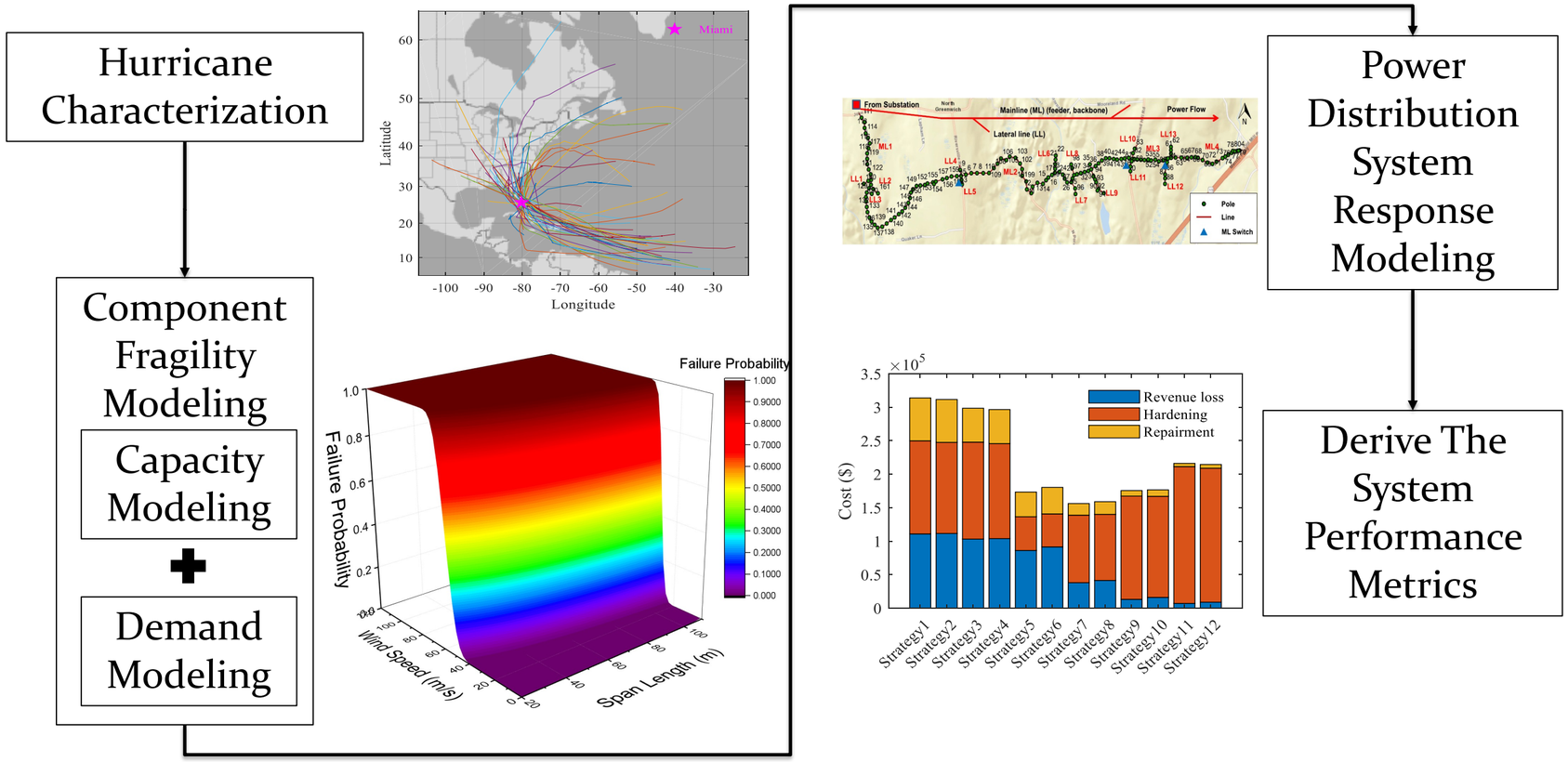

Fig .1: Flow chart describing schematically the process for the proposed resilience assessment methodology

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Tree Identification and Fragility Assessment

- CNN image classifier trained from Google Maps using sliding window technique
- Given the tree height, other tree parameters can be determined by allometric relations
- Tree fragility curves of several common key species (Ash, Maple, Oak) are generated by finite element analysis.

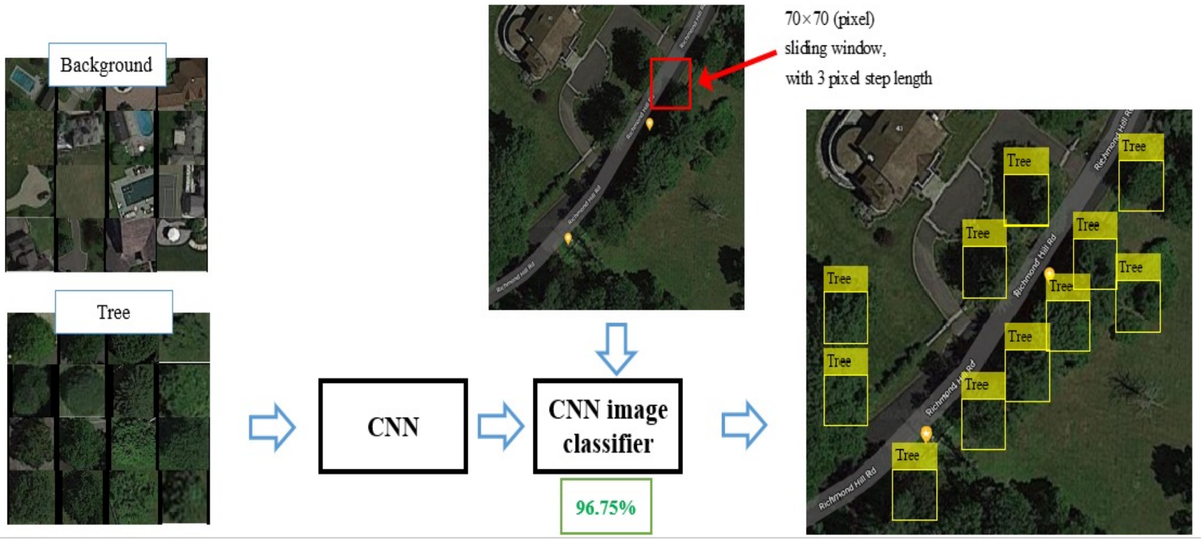


Fig. 2: Tree identification from satellite images

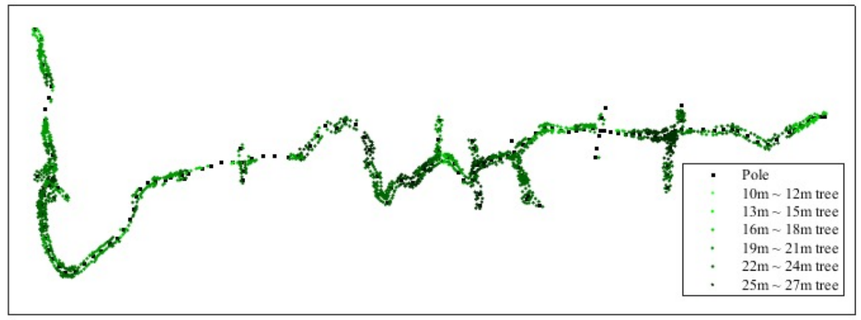
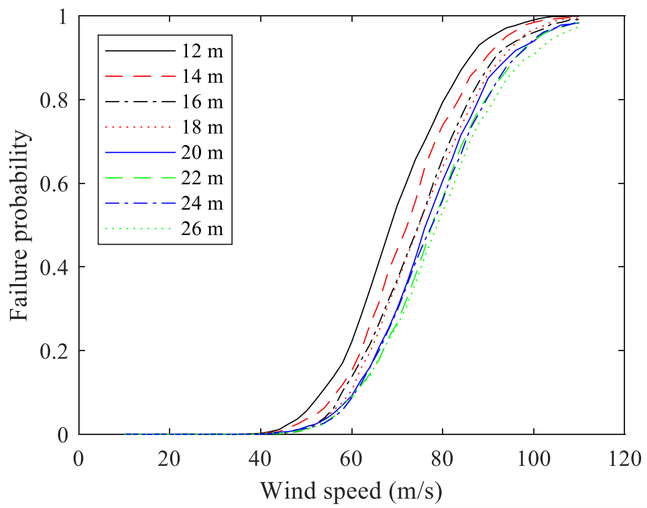


Fig. 3: Identified risk trees along the powerline



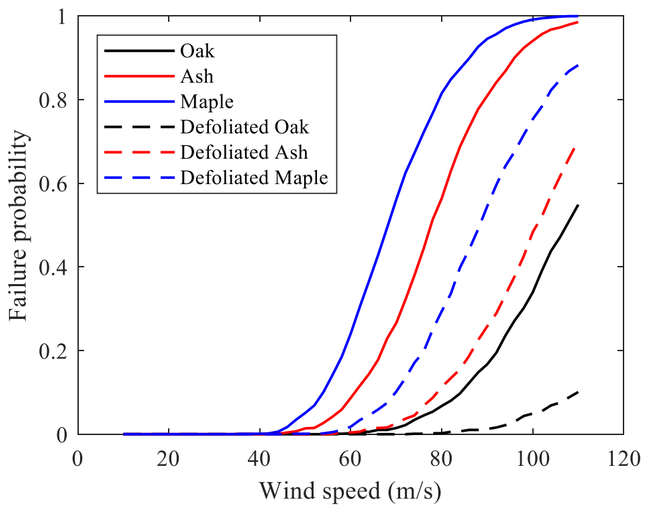


Fig. 4: Fragility curves of trees

Power distribution system-level fragility

- Demonstration of combined tree and wind load fragility is carried out for demonstration on line in Connecticut
- Assuming a fallen tree on a line can bring down the poles, the failure probability of the pole given the tree loads only can be obtained using series system approach.
- The failure probability of the pole given wind load only can be obtained by finite element analysis, and the system reliability is generated based on the connectivity-based theory.

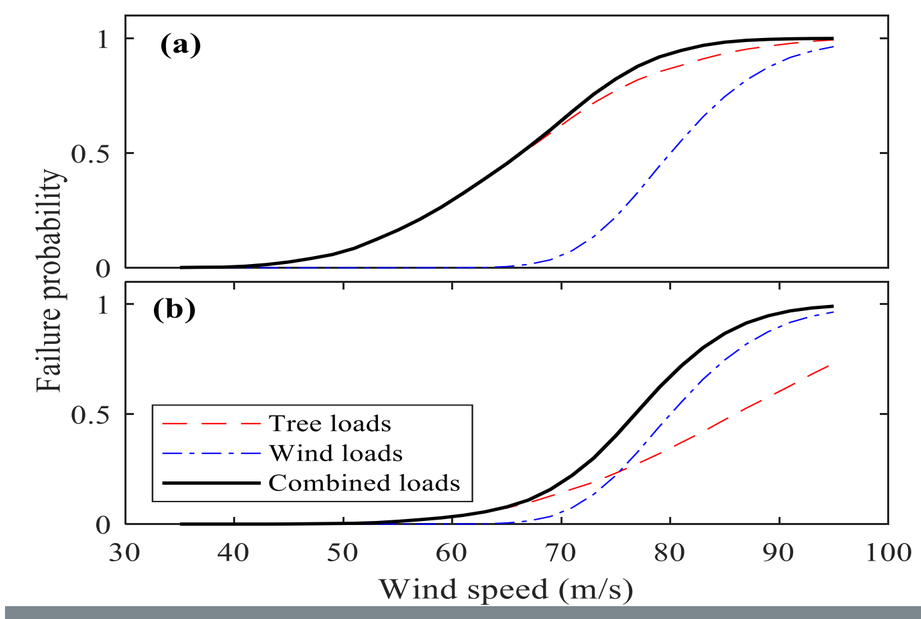


Fig. 5: Fragility curves of poles

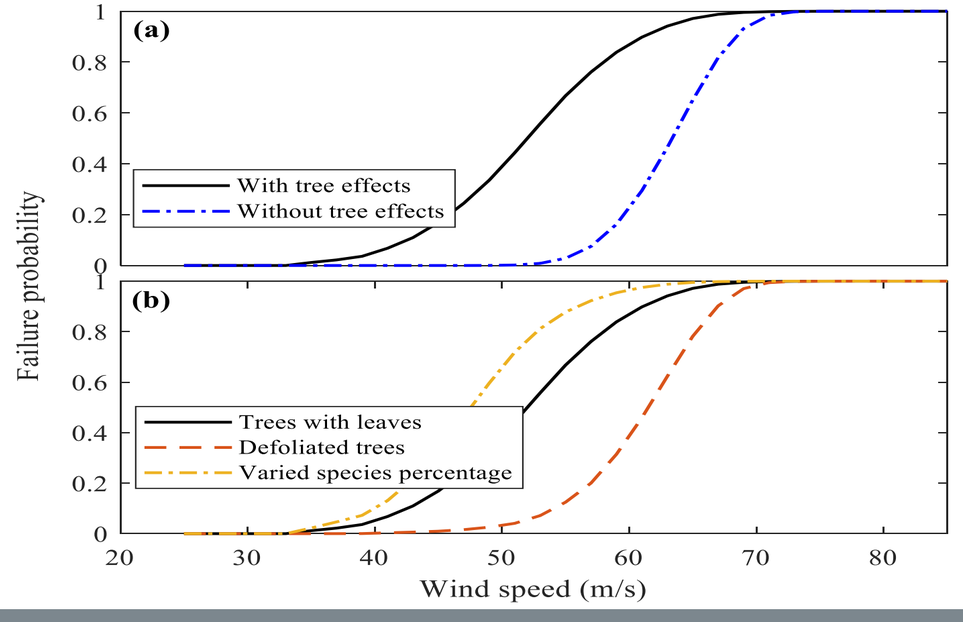
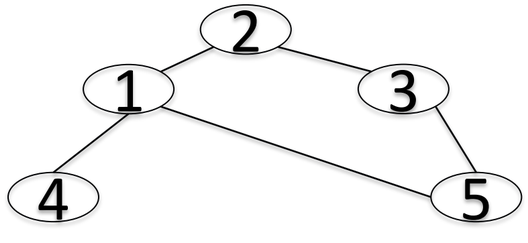


Fig. 6: Fragility curves of the system

Power Distribution System Based on Complex Network Theory

- A **hybrid method** combining the complex network theory and the physics-based method is applied to perform the resilience analysis based on graph theory using **fragility-based adjacency matrix**



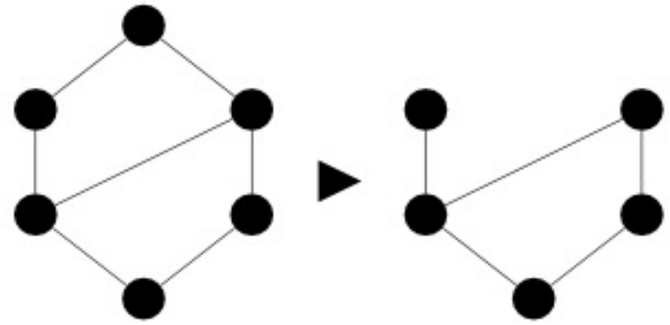
	1	2	3	4	5
1	0	1	1	1	0
2	1	0	1	0	0
3	1	1	0	1	1
4	1	0	1	0	1
5	0	0	1	1	0

Traditional adjacency matrix

	1	2	3	4	5
1	0	w_{12}	0	w_{14}	w_{15}
2	w_{12}	0	w_{23}	0	0
3	0	w_{23}	0	0	w_{35}
4	w_{14}	0	0	0	0
5	w_{15}	0	w_{35}	0	0

Fragility-based adjacency matrix

Fig. 7: Fragility-based adjacency matrix



Original network A node removed

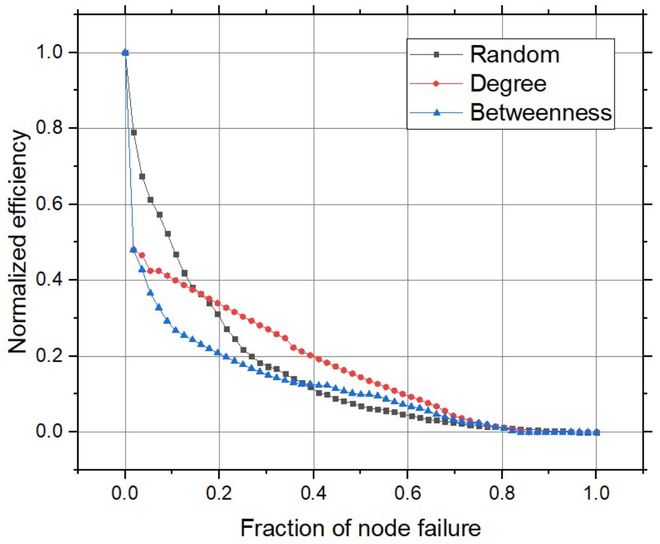
Fig. 8: System change after failure occurrence

Power Distribution System Resilience Analysis

- Network efficiency E_g is used to assess the network's behavior.

$$E_g = \frac{1}{N(N-1)} \sum_{j \neq k \in G} \frac{1}{l_{jk}}$$

- Three failure scenarios: **random**, **degree-based**, and **betweenness-based failure** Three hurricane categories are applied in the dynamic resilience analysis considering the power flow characteristics metaphorically.



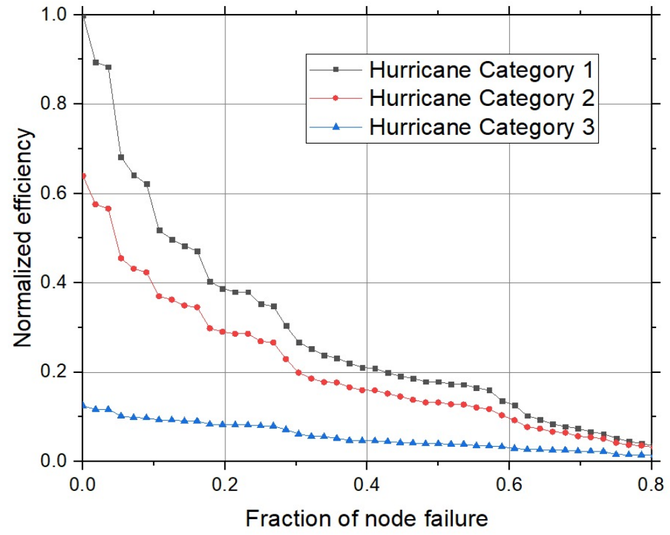
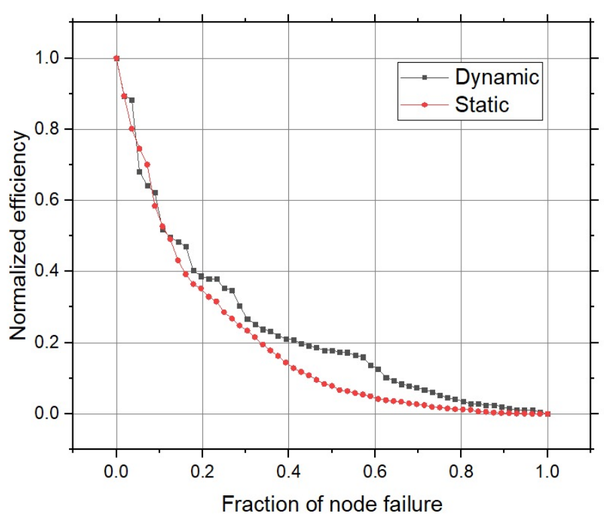


Fig. 9. Resilience Analysis of the power distribution system: Static resilience Analysis (left); Dynamic resilience Analysis (right);



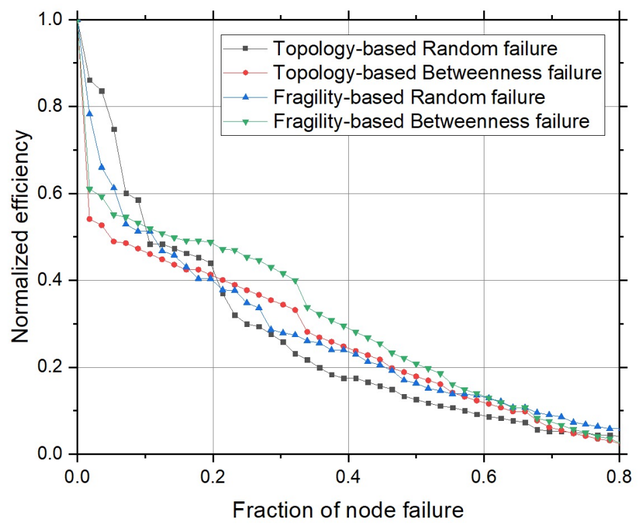


Fig. 10. Comparison between static analysis and dynamic analysis(left); Comparison between the traditional method and current study (right)

Summary and Conclusions

- **CNN-based image classifier** combined with sliding window technique can successfully **identify trees along the powerlines from satellite images**.
- The fragility curve of the tree varies with tree species.
- **Defoliated trees are less vulnerable** than trees because of the reduction of the projected crown area.
- **Without consideration of fallen trees**, the **failure probability** of the poles and the power distribution system can be **underestimated**.
- A comparison between topology-based and fragility-based resilience indicates the PDS network is more vulnerable to betweenness-based attacks
- Among the static and dynamic analysis of the cascading failure, it could be concluded that the **static analysis overestimates the failure consequence**.