Assessing Power Distribution Resilience Hardening Effectiveness Using Combined Physics-Based and Data-Driven Modeling

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Background/Objectives. While modern society relies upon resilient power infrastructure for the efficient functioning of everyday life, severe storms can threaten the integrity of the power system and produce widespread and cascading power outages, with social and economic impacts to both utility companies and customers. As climate change is expected to produce more frequent and devastating storms, power system vulnerability to storm-induced damages and power outages remains a pressing issue for utility companies, engineers, and decision-makers. To improve grid resilience, various hardening strategies can be implemented, including strengthening of the physical infrastructure, vegetation management, or undergrounding of lines. However, such intervention and maintenance strategies can be expensive, particularly if applied at a large scale. Moreover, their efficacy in reducing power outages remains challenging to capture due to the technical difficulties in quantifying resilience provided the complex set of interacting factors which could lead to power outages. For instance, the state of Connecticut faces a particularly unique set of hazards, including tropical storms, tornadoes, and Nor'easters, and many powerlines lie within forested regions, increasing their risks of interaction with trees.

Approach/Activities. To quantify the effectiveness and feasibility of resilience improvement actions and inform executive decision-making, accurate models sensitive to changes in grid hardening are needed. To these ends, a novel and comprehensive framework is developed combining machine learning and physics-based simulations for power outage prediction under various hypothetical grid hardening scenarios. The model is trained on 15 years of historic storm and outage data, including characteristics describing the physical infrastructure fragilities and vegetation, land cover, and meteorological conditions. The model is demonstrated for the distribution system in the state of Connecticut, and counterfactual analysis of various grid hardening strategies is conducted.

Results/Lessons Learned. The model has similar predictive to similar established models while reducing the number of variables. Moreover, the model is sensitive to key resilience parameters, such as structural fragility or amount of vegetation management, in intuitive ways, allowing for effective evaluation of the impacts of grid hardening. The results indicate the relative effectiveness of different resilience plans. For Connecticut, undergrounding is found to be the most effective at reducing raw outage counts but with low cost-effectiveness. Meanwhile, targeted vegetation management is found to have high cost-effectiveness. Such results could inform utility companies on more optimal methods of adapting the grid to climate change.