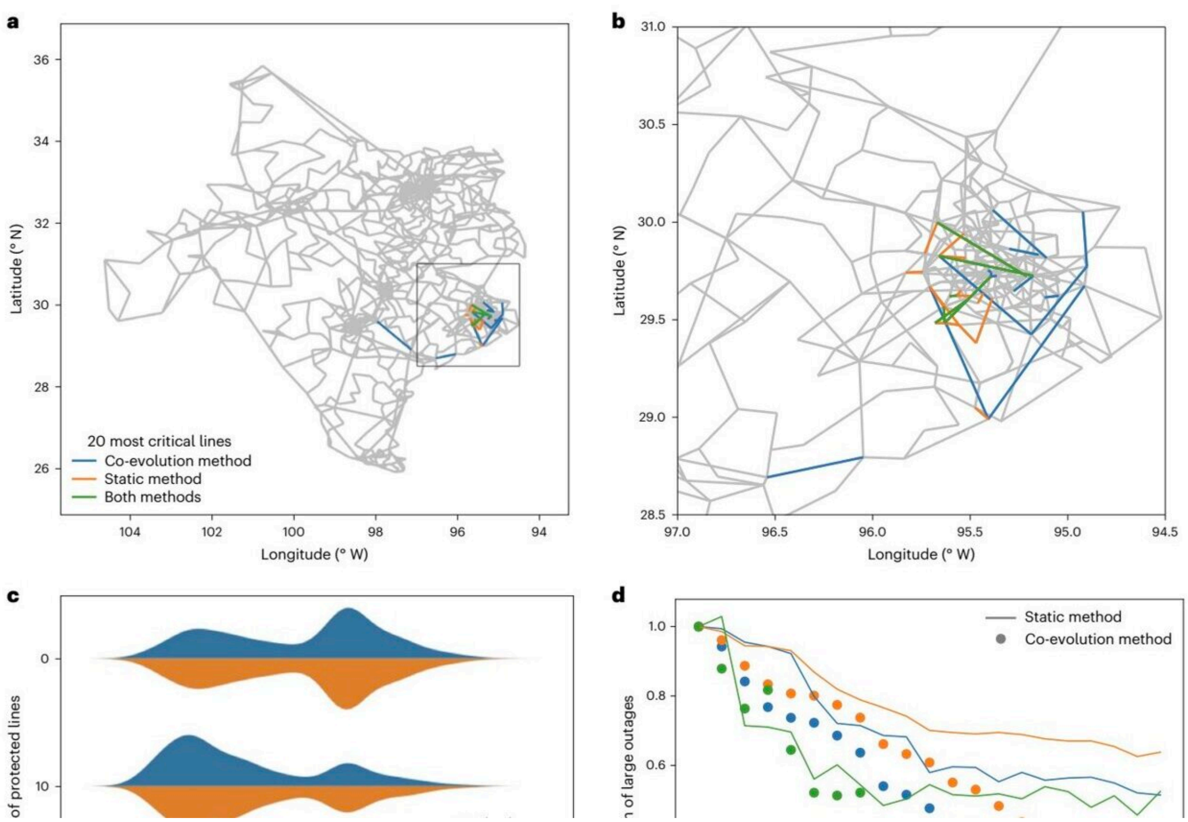
Exploring the resilience of the Texas power grid against extreme weather conditions

April 4 2024, by Ingrid Fadelli



Reduction of large outage probability that can be reached by hardening power lines according to the priority index: comparison of co-evolution and static model. a, The 20 lines of the Texas power grid with the highest priority index obtained from the static model (orange lines), the co-evolution model (blue lines) and both models (green lines). b, Detail enlargement (black rectangle in a) of Houston and Harris County, which contain most of the critical lines. c, Power outage distributions of Hurricane Harvey as a function of the number of protected critical lines, as obtained by the coevolution model (blue) and the static (orange) model. d, Relative reduction of the probability of large power outages as a function of protected lines as obtained from the static model (lines) and the co-evolution model (dots) for the three hurricanes Harvey (blue), Ike (orange) and Claudette (green). Credit: *Nature Energy* (2024). DOI: 10.1038/s41560-023-01434-1

The Gulf Coast of the United States is often hit by tropical cyclones (TCs), hurricanes and other extreme weather phenomena, which can cause widespread electricity outages. Climate change and global warming are expected to increase the risk of these events occurring, which could significantly disrupt activities in the area.

Researchers at Potsdam Institute for Climate Impact Research (PIK) and Fraunhofer SCAI in Germany recently carried out a study aimed at investigating the impact of extreme weather events on the Texas power grid, to identify lines that should be strengthened to prevent serious outages in the future.

Their paper, published in *Nature Energy*, could guide efforts by the local government and engineers in the area aimed at increasing the resilience of the electricity grid in the state of Texas.

"Our paper is an interdisciplinary collaboration between the impact modeling and the infrastructure research carried out at PIK," Mehrnaz Anvari, the author who coordinated the research, told Tech Xplore. "Recent studies and statistics have shown a significant increase in power outages caused by extreme weather events. Our study focuses on extreme wind events, which have a significant impact on transmission lines and towers."

The damage caused by extremely windy weather events to transmission lines often leads to further system and infrastructure failures, resulting in widespread blackouts and power outages. As some weather events, such as hurricanes and severe TCs, can last for several hours and even days, the damage they cause can also reduce their resilience to future adverse weather,

"During these events, tens or even hundreds of transmission lines and towers can be damaged," Anvari explained. "This contrasts with the N-1 or N-2 security rules that are applied to the power grid. According to these rules, the power grid should remain resilient even after one or maximum two components fail."

Notably, every time that a transmission line fails, the topology and dynamics of a power grid change. This means that the grid's response to future adverse weather events and associated damage will depend on the history of previous damages and how they functioned after these damages.

"The primary objective of our study was to understand the interplay between evolving storm conditions and the partially destroyed state of the grid," Frank Hellmann, co-author of the paper, said. "This required us to study the temporal-spatial structure of damages and outages, a topic with little preexisting research."

The recent paper by Anvari, Hellmann and their colleagues is based on a key intuition rooted in complex systems research. This intuition is that if a complex but robust system fails due to external stresses, it typically does so following fairly well-defined patterns or failure modes.

"If we can identify these failure modes, we can hope to prevent such catastrophic failures," Hellmann explained. "Concretely, this means identifying lines that are critical for keeping the system operational; or, to put this the other way around, we identify the lines whose failure during the hurricane is most likely to trigger large-scale blackouts."

Contrary to other previous efforts in this field, the researchers' approach does not only fail lines that are most likely to trigger outages in the unperturbed fully functional systems, but also examines their impact in instances where a power grid has already suffered extensive damages. This ultimately allowed them to better determine the "backbone" of the grid, which supports its resilience.

"Once the critical lines are identified, we should focus on enhancing their resilience against extreme wind events, for example by replacing overhead lines with underground cables," Anvari said. "In our study we assume that this ensures 100% safety against wind damage. However, it is important to consider that underground cables are significantly more expensive than transmission lines, and may not be cost-effective for long distances, reinforcing transmission towers might be a viable alternative."

A further consideration outlined by the team is that hurricanes can also be accompanied by flooding, which can damage underground cables. This should also be taken into account when trying to increase the resilience of power grids.

"Our most notable finding is that there really is a small set of critical lines, and that protecting these can dramatically reduce major blackouts, which was not a given," Anvari said. "In principle our modeling approach could relatively directly be applied by transmission grid operators to identify targets for reinforcement in their systems.

"In practice, one would want to expand the model to cover other aspects of storms, such as flooding, into the damages. Many tweaks to the underlying model are feasible and could allow to incorporate operators' expertise and knowledge of their system."

The recent work by this team of researchers introduces a new model that could be used to identify all critical lines in a power grid, so that they can be enhanced to prevent large-scale outages during extreme weather. To demonstrate their approach, they used it to identify the critical lines in the Texas power grid.

In the future, the modeling approach could be used to plan the construction and enhancement of transmission grids, allowing engineers to identify specific failure scenarios and devise strategies to prevent these scenarios. These scenarios and strategies could then be tested in simulations and studied in depth, before implementing expensive interventions and infrastructure maintenance processes.

"We now intend to expand our research to include the analysis of other extreme weather events, including floods, and explore their potential correlations," Hellmann added. "Additionally, we are actively considering the propagation of failures from the power grid to other interconnected sectors, such as the gas supply sector, and vice versa. As such studies are complex and time intensive, we also are exploring AI methods that could directly predict where vulnerabilities for further study might lie."

More information: Julian Stürmer et al, Increasing the resilience of the Texas power grid against extreme storms by hardening critical lines, *Nature Energy* (2024). DOI: 10.1038/s41560-023-01434-1 resilience-texas-power-grid.html