PUBLISHED: 29 APRIL 2016 | ARTICLE NUMBER: 16059 | DOI: 10.1038/NENERGY.2016.59



ELECTRICITY GRID

# When the lights go out

The resilience of distribution power grids is put to the test by daily operations as well as by extreme weather events such as hurricanes. An analysis of blackout data in upstate New York now reveals that larger blackouts have a disproportionate effect on grid reliability.

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Suppose one is at home in the evening and suddenly all the lights go out. The first step is to gauge the local extent of the blackout by observing the neighbours. If they have no power, the problem is outside on the electrical grid. It is likely that the blackout has arisen in the distribution grid that takes electrical power from large substations and distributes it to customers. But what are the chances that the blackout is more widespread than the immediate neighbours? Blackouts get rarer as they get larger, and one might think that only a small fraction of blackouts are widespread in terms of the number of customers disconnected. However, as they report in *Nature Energy*, Chuanyi Ji and colleagues at the Georgia Institute of Technology and several US utility companies have analysed detailed distribution outage data, and found that the top 20% of the distribution grid blackouts typically accounts for 84% of the total number of customers disconnected in all blackouts[1]. That is, despite the larger blackouts being rarer, they still dominate the overall impact of outages on customers.

Ji and colleagues analysed blackout data from a large area of upstate New York from four distribution system operators. The data related to outages occurring both during daily operations and during Hurricane Sandy (Fig. 1). To evaluate the resilience of the grid, the researchers developed a model to study failures, recovery and impact on customers, using metrics such as disruption rates and failure/recovery probability distributions over time. By fitting the distribution of the number of customers disconnected with a power law[2], the researchers concluded that the relatively large impact of rarer, larger blackouts can be traced to the presence of heavy tails in the distribution of the number of customers disconnected. Heavy tails have also been observed in blackouts of Swedish distribution grids[3].

Heavy tails are also observed in blackouts of the transmission grid, which is the high-voltage backbone network that supplies the distribution grid. Although blackouts in the transmission grid are less common, they are more consequential, ranging up to continental scale. The power laws in the size of transmission grid blackouts are related to the cascading phenomena of successive weakening of the grid by successive outages, and can be explained by an evolutionary complex systems process by which investments to maintain reliability balance against societal demands for minimum spending on infrastructure[4]. Although tempting, one cannot transfer the mechanisms and insights from transmission grids to distribution grids, because they are designed and operated quite differently. Transmission grids are meshed networks; when a transmission line fails, power diverts to parallel paths to maintain the supply of electricity. Occasionally this can lead to overloads of the parallel paths and successive outages and cascading blackouts, but usually the meshed design is reliable. The distribution grid is typically operated like a tree network, with the trunk at the power substation and leaves at the customers. Outage of a distribution line usually leads to blackout of all components downstream (nearer the customers) and this explains the range of blackout sizes observed by Ji and colleagues. However, the physics, engineering and societal factors driving the particular power law form in the blackout sizes remain to be explained.

Going further in explaining the design and operational trade-offs underlying the pattern of reliability could lead to insights into what can be changed and what effective investments in the grid could be made to limit and mitigate blackouts. For example, Ji and colleagues discuss how the pattern of blackout sizes affects strategies to restore the power. How much society chooses to invest in the resilience of essential, lifeline

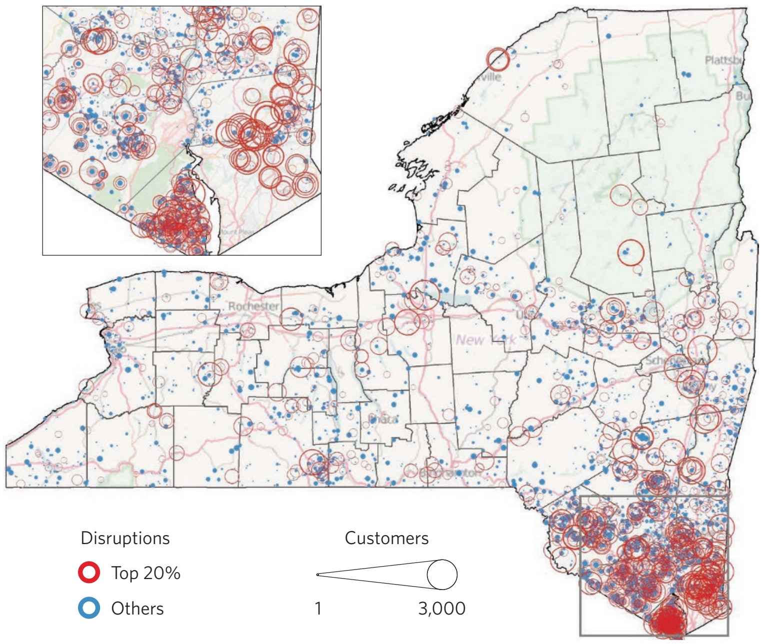


**Figure 1 |** Disrupted customers in upstate New York during Hurricane Sandy. Each marker represents a system disruption; the marker size represents the number of interrupted customers. Figure reproduced from ref. 1, NPG.

infrastructures is largely a political question, but when the question is asked also matters: how much extra would we pay in our electricity bill for improved resilience when the lights are out?

Interestingly, by studying the resilience of the distribution grid under normal operations and during Hurricane Sandy, the researchers noticed that, although there were far more outages during the hurricane, some patterns of the outages remained the same. That is, the storm damage only exacerbated an underlying structural pattern of performance of the grid.

Overall, the analysis of detailed distribution grid outage data by Ji and colleagues is most welcome, as data-driven insights are much needed in the study of engineered network infrastructures. Indeed, models consistent with observed data are essential for the science of these engineered networks to progress. ❐

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