

A formula for preventing power outages

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Could a blackout start here? Could the failure of this line for any reason cause a major regional outage? By way of a formula, scientists from the Max Planck Institute for Dynamics and Self-Organization are able to make predictions.
Credit: M. Duffek / CC-BY-SA 3.0

The power supply of a city or an entire region often hinges on just a few lines. The loss of an important section may lead to a blackout with potentially severe economic consequences. Power grid operators therefore use complex simulations to detect weak points in the grid. Thanks to a new formula, developed by a team headed by physicist Marc Timme from the Max Planck Institute for Dynamics and Self-Organization (MPIDS) and Dirk Witthaut from Forschungszentrum Jülich, this analysis could become a lot simpler in the near future. The formula provides reliable data on whether a particular line is critical or not in next to no time.

Blackouts – not a major issue for most people in Europe, where major power outages have rarely occurred. The blackout of November 2006 was an exception. To allow a cruise ship to travel from a shipyard on the Ems River to the North Sea, an electricity supplier shut off an important high-voltage line across the river for safety reasons. The shut-off, however, caused unplanned disturbances in the grid which, in just a few minutes, escalated to an extent that triggered a power outage on a European scale. Gradually, the lights went out in parts of Germany, France, Belgium, Italy, Austria and Spain; in some places, for as much as two hours.

No power cut on the same scale has occurred since, but the experts assume that the expansion of green energy will increase the load on the grid, and therefore the likelihood of outages. Power generation using solar energy and wind turbines means greater fluctuations in the electricity supply. Moreover, the future will see large amounts of current needing to be transported from giant offshore wind farms or sunny regions to urban areas and industrial zones. This increases the need for utility companies to find weak points in the power grid.

A simple formula instead of complex simulations

Normally, the search for these weak points concentrates on specific sections of the grid – individual lines that connect two points, e.g. two cities. For a long time, the rule of thumb was that a section will primarily be critical if it carries a lot of current in relation to its modest size. Experts work on the following assumption: the larger the current flow and the greater the load on the line, the higher the probability of an outage occurring if the line fails. Utility companies and grid operators employ complex simulations to detect weak points and to test possible scenarios for how the grid will react if a single line fails. This type of check of the grid requires many thousands of simulations.

However, simple rules of thumb can be deceptive if they conceal apparently insignificant effects. We automatically assume that the higher a current a cable carries, the more important and indispensable it is. This may often be the case, but in crucial situations this simple rule could be misleading. This issue is highlighted in an article written by physicist Marc Timme from the Max Planck Institute for Dynamics and Self-Organization in Göttingen and Dirk Witthaut from Forschungszentrum Jülich together with other colleagues in Göttingen, and published in the *Physical Review Letters* journal. What's more, the scientists have succeeded in establishing a formula which can be used to swiftly assess whether a line is indeed irreplaceable or not – without complex and time-consuming simulations.

"Using the topology and the load distribution of the network, we are able to calculate which lines constitute the critical links ahead of an outage," Timme says. Whether the failure of a line becomes a problem is not merely a question of the current capacity of this line; it is also determined by the topology and the capacity of the surrounding grid.

The likelihood of a power outage depends on the structure of the entire network

As a rule, the failure of any line becomes a problem if the current cannot find an alternative route to get to the consumer. The principle is similar to that of a drainage system which overflows because one pipe is blocked. A line with a high load does not have to be indispensable if the grid is connected in a way which offers the current one or several alternative routes in the event of a failure.

The challenge in this area of research is that, once a particular line fails, the load of all the other lines in the grid changes because the current finds new routes on a self-organized basis. The local situation is therefore interlinked with the overall structure of the network. The scientists have explicitly taken into account the network structure in their mathematical calculations. Firstly, the knowledge of the original grid prior to the line failure is used in the formula. Then, a disturbance is introduced in a specific section of the grid; the "AB" line. The result is a number which indicates how well the remaining grid can compensate for the line failure. If the number is too small, a blackout is likely. General mathematical results and the analysis of the British grid demonstrated that the intuitive assumption that "high load" equals "critical" offers a rough indication. "However, it is not consistently true, because network effects play a central role," Timme says.

A ranking list of problematic grid sections

Simulations usually use a local failure as the point of departure and then calculate the reaction of the grid in detail. In the formula, the team of scientists has found a much simpler alternative to the conventional "What happens next" simulation. With lightning speed, the criticalities of any number of power line sections can be calculated without having to run through thousands of failures in the simulation. According to Martin Rohden, co-author and former employee at the Max Planck Institute, "predicting whether a grid section is indispensable or not has become much more straightforward". However, the formula does not render the

simulations superfluous. These simulations include a lot of data based on experience. They can be used to replay a failure in the grid in minute detail. The benefit of the new method is that it unequivocally points to the causes of the problems and how they can be eliminated. Potential risks can be detected at a glance. The formula therefore also offers an approach for optimizing the power grids of the future. This can contribute to making the entire grid more robust, to compensate for discrete failures. Timme states an additional advantage: "using our formula, we can compile a ranking list which serves as a guide for the detailed simulations." This will most likely reduce the workload considerably for [grid](#) operators and utility companies.

More information: Dirk Witthaut et al. Critical Links and Nonlocal Rerouting in Complex Supply Networks, *Physical Review Letters* (2016). [DOI: 10.1103/PhysRevLett.116.138701](https://doi.org/10.1103/PhysRevLett.116.138701)

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