Vulnerability of US power grid identified

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Vulnerabilities inadvertently built into the U.S. power grid, which is one of the most complex systems ever constructed, have been identified by a research team lead by Reka Albert, assistant professor of physics at Penn State. The team's topological analysis of the grid structure reveals that, although the system has been designed to withstand the random loss of generators or substations, its integrity may depend on protecting a few key elements.

"Our analysis indicates that major disruption can result from loss of as few as two percent of the grid's substations," says Albert, whose research team includes Istvan Albert, research associate in the Bioinformatics Consulting Center at Penn State, and Gary L Nakarado at the National Renewable Energy Laboratory. One implication of the research is that identification of strategic points in the grid system can enhance defense against interruptions, whether by equipment failure, natural disasters, or human activity. Major blackouts caused by failures in the grid, such as the one that affected the northeastern part of the country during the summer of 2003, incur tremendous economic, public-health, and security risks.

The study, titled "Structural Vulnerability of the North American Power Grid," was published in a recent issue of the journal Physical Review E. The researchers constructed a model of the entire transmission grid with over 14,000 "nodes," including generators, transmission substations, and distribution substations, and over 19,000 "edges," corresponding to the high-voltage transmission lines that carry power between the nodes. They measured the importance of each substation node based on its "load," or the number of shortest paths between other nodes that pass through it. "While 40 percent of the nodes had a load below one thousand, the analysis identified 1 percent of the nodes--approximately 140--that have a load higher than one million," Albert says.

This high degree of connectiveness in the grid system allows power to be transmitted over long distances, but it also allows local disturbances to propagate across the grid. "There are systems to protect the nodes from overload, such as a controlled shutdown to take a substation out if it overloads or to shut off a generator. In general, these systems do a good job of protecting the nodes," says Reka Albert. "What this model really looks at is the effect of losing a number of nodes in a short period." If the nodes are removed randomly, the effect on the system is roughly proportional to the number of generators or substations removed. However, the grid quickly becomes disconnected when the high-load transmission substations are selectively removed from the system--if the nodes that have the highest load are removed first, followed progressively by the nodes with successively lower loads. According to the model, a loss of only 4 percent of the 10,287 transmission substations results in a 60 percent loss of connectivity. During a cascading failure, in which the high-load substations fail in sequence, the model shows that the loss of only 2 percent of the nodes causes a catastrophic failure of the entire system.

The authors point out that this vulnerability is an inherent part of the existing system. If the power grid were highly redundant, however, the loss of a small number of nodes should not cause power loss because the system reroutes through alternative paths. Possible remediation schemes include increased redundancy focused on key substations and transmission lines, or more distributed generation, which would decrease the load on these key points. "Future additions to the system should consider the effect of the new nodes on relieving strain on key nodes," Albert says. "From this model, we know how defects can propagate through the system, we have identified parts of the system that need to be improved because they are not redundant, and we can show which substations need to be protected from failure in order to avoid widespread system failure. These are considerations that could help guide energy policy decisions."

Source: Penn State