Science & Technology

Protecting the Grid from the Bomb

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Gil Zussman and Daniel Bienstock are investigating how the US electric grid could be protected against a nuclear attack. Photo: Jorg Meyer

The US electric grid is designed to keep power flowing to customers by almost any means necessary. But its flexibility may prove to be its downfall.

Because the grid allows power plants to send electricity over multiple routes to any destination within a few hundred miles, it has obvious advantages: if one power line fails, a computer will reroute its load to parallel lines so that the lights stay on. The danger is that if those lines become overburdened, a vicious cycle of “load shifting”

and line failures can quickly spiral out of control, causing a widespread blackout.

Daniel Bienstock, a Columbia professor of industrial engineering and operations research, has spent years studying this problem, which is known to power-industry insiders as a cascading failure. By designing computer models that simulate how electricity will flow through the grid in different circumstances, he can identify which sections of the grid are most vulnerable to cascades. Power companies rely on this information to take preventive measures: they may increase the carrying capacity of certain lines or install elaborate monitoring systems in the most vulnerable locations.

This past fall, Bienstock, along with Gil Zussman, a Columbia associate professor of electrical engineering, and MIT's Eytan Modiano, received a $1 million grant from the Pentagon's Defense Threat Reduction Agency to study how a cascading failure might be avoided in the worst circumstance imaginable: a nuclear strike intended specifically to start one. The engineers aim to help the government protect the grid against a so-called electromagnetic pulse (EMP) attack, an oft-hypothesized yet never before attempted military maneuver that involves detonating a nuclear warhead in outer space above an enemy country in order to generate a wave of electromagnetic energy that overloads and destroys its grid.

"Our job is to see if you might contain that surge," says Bienstock, "before it causes the largest cascade we've ever seen."

It starts with a spark

The largest blackout in US history occurred in August 2003, when a power line sagged too close to a tree limb in Walton Hills, Ohio, and shorted out. Workers at the local utility failed to redistribute power appropriately, and within a few hours this minor incident had grown into a massive outage, with fifty million people losing electricity in eight Northeastern states and southern Canada.

"That was a classic cascade," says Bienstock. "People lost power not because of any shortage of electricity in the system but because the utilities allowed the lines to become overloaded."

A blackout caused by a nuclear explosion high above the American heartland would likely be worse in every way, he says. For starters, it could affect a much larger area: perhaps one-third of the United States.

“The US grid is actually divided into three sections: the eastern, western, and Texas interconnections,” Bienstock says. “A well-executed EMP attack could easily wipe out one of them.”

But the most important difference, he says, is that an EMP attack could inflict severe and long-lasting physical damage to the electric grid.

In the case of the 2003 blackout, he says, many people lost electricity not because any power lines or transformers malfunctioned in their area but because a utility company preemptively shut off power to protect its infrastructure. As a result, power was restored in many areas within a few hours, after Northeastern power plants temporarily reduced their output and brought the system back into equilibrium.

An EMP attack, Bienstock says, could send a burst of electricity coursing through the grid too quickly for utility companies to contain. This is the idea behind an EMP attack: electrons would be knocked loose from air molecules and hurtle downward to the Earth at nearly the speed of light, causing a brief but ferocious electrical storm. This wave of energy would penetrate a huge swath of the grid, in a circle tens of miles in diameter or more, and then emanate outward in all directions, burning up every power line and blowing up every transformer, generator, and substation in its path.

“This means it could take forever to fix,” says Bienstock. “Some of that equipment, especially the transformers, would need to be custom-built. You could be looking at a full year or more before it all got replaced.”

Old idea, new threat?

Scientists first realized that an explosion in the sky would generate a burst of electricity in 1962, when the US conducted a nuclear test above the Pacific Ocean. In Hawaii, lights went out.

For many decades, the idea that any nation might attack the US by raining down electrons upon us was dismissed by national-security experts as too far-fetched to warrant serious concern. Why would any country do that, the thinking went, when it might instead lob a warhead at a city?

As our society has become increasingly reliant on information technology and digital communications, however, the prospect of a foreign power taking direct aim at the US grid has come to seem less outlandish. In fact, a recent report by the National Academy of Sciences concludes that the grid's ricketiness is a national-security risk. The report, which is the most thorough ever on the topic, offers a frightful vision of life following any shutdown of the grid that lasts a few weeks or more: food distribution, water supplies, health care, emergency services, energy systems, and transportation would stop.

To prevent this from ever happening, Bienstock and his colleagues are now designing computer models that can simulate how a cascade resulting from an EMP attack would travel through the grid. The analytic tools they are creating will help government engineers answer questions such as these: what would be the best way for utility companies to contain the surge? Could this be done by shutting down all power stations in the vicinity, or would it require more drastic action, like preemptively tripping lots of power lines around the periphery of the attack? What types of new monitoring and communications systems would be necessary to coordinate a rapid response? And how might cell-phone networks and the Internet be kept functioning during a widespread blackout?

"It will take years to address these questions because they are so complicated," says Zussman, who is the project's principal investigator. "Part of the challenge is that nobody has ever looked into them before, since the prospect of an EMP attack was considered too slim to worry about."

He says the group's work is applicable to other threats, too, including powerful releases of energy from the sun, called solar flares. A solar flare caused six million people to lose power in Quebec in 1989.

"Strictly from a science and engineering perspective, this project is exciting because it gives our research teams a fresh set of problems to look at," says Zussman, whose role is to investigate the impact of an EMP attack on the Internet. "If you punch a big hole in the middle of a complex system, what happens? Is there a way to fix it? Our work could have theoretical implications for making lots of systems more robust."

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