How a butterfly's wing can bring down Goliath
Chaos theories calculate the vulnerability of megasystems

Keay Davidson, Chronicle Science Writer
Friday, August 15, 2003

URL: http://www.sfgate.com/cgi-bin/article.cgi?file=/c/a/2003/08/15/MN191082.DTL

The massive power failure on the East Coast illustrates the risk of building ever-larger power networks to transmit electricity, experts said Thursday.

When a system becomes extremely complex, a normally survivable event -- say,

a lightning strike like the one Canadians initially suspected in Thursday's blackout -- can trigger what scientists call a devastating domino effect. The effect is well-known to physics experts in the fields of complexity theory, chaos theory and the theory of self-organized criticality.

"As you try to make the system perfect, there is always more danger," said physicist Ben Carreras of Oak Ridge National Laboratory in Tennessee, who uses supercomputers in an effort to model and predict super-power failures. "The whole grid is very strongly coupled, and when you do something in one point, it can affect (the system) very far away," he said.

At the Oak Ridge nuclear weapons lab, Carreras and computer expert Vickie Lynch have been computer-modeling the vulnerability of electrical grids for several years. Ironically considering Thursday's electrical debacle, Carreras and Lynch in 2002 had concluded that the probability of such a catastrophic failure was "lower than you might expect."

However, Carreras is concerned that terrorists might learn to exploit the vulnerability of complex power systems. And when they do, "it's going to be very difficult to protect against things like (power blackouts)," Carreras said. "This (terrorist issue) is one of the biggest worries I have."

Even before complexity theory became trendy in the 1980s, many researchers realized that innumerable natural and social phenomena defy easy scientific explanation because they're so complex. The mysteries of particle physics are child's play compared with the forecasting of weather, riots, stock market wobbles, fluctuations in animal populations and other so-called nonlinear events.

In such complex or chaotic phenomena, an infinitesimal change can make all the difference between system stability and system collapse.

In the 1960s MIT meteorologist Edward Lorenz popularized the notion of the butterfly effect: An infinitesimal shift in the weather -- say, the turbulence caused by a butterfly flapping its wing -- can set in motion atmospheric events that climax in a hurricane. Such events are for all practical purposes unpredictable, Lorenz said.

Carreras and Lynch's computer equations are based partly on those used to model a sandpile on a beach that a child steadily builds, higher and higher, until it suddenly goes ker-flop.

"The shifting sand pile is a paradigm for self-organized criticality, in which complex systems tend to rearrange themselves to be close to their limits,

living at the edge of chaos," they wrote last year in an update of their work for the journal ORNL Review. That is, complex systems can remain stable for a long time -- then suddenly, the bottom falls out.

The sandpile models have also been used to understand the behavior of plasmas -- clouds of electrically charged ions and free electrons -- within prototypes of nuclear fusion reactors.

Engineers have dreamed of developing nuclear fusion energy for commercial electricity generation for a half-century. But a major obstacle has been the plasma's "chaotic" behavior, in which the slightest perturbation causes the particle cloud to collapse like a souffle.

Carreras and Lynch have had trouble developing more sophisticated models for blackouts partly because the power companies have been reluctant to share, for proprietary reasons, specific details about how their systems fail.

Generically speaking, a common cause of blackouts is too much energy squirting through too few transmission lines, said Luther Dow, director of power delivery and markets for the Palo Alto-based Electric Power Research Institute, a think tank for power utilities.

"Think about the freeway system: If you had more roads and more lanes, you'd have an easier time getting from point A to point B," Dow said. Using the roads as a parallel, he says California's version of the Thursday blackout -- a multistate blackout in 1996 -- was caused at least partly by an insufficient number of transmission lines.

As if they don't already have enough problems, could a 1996-style blackout clobber Californians again? "I'm sure it could," Dow said. "For me to say it couldn't happen in California would be neglect on my part."

E-mail Keay Davidson at *kdavidson@sfchronicle.com* .