Stabilizing the electric grid by keeping generators in sync

Better grid design should keep generators from fluctuating in phase.

by Chris Lee - Mar 13 2013, 2:35pm CDT

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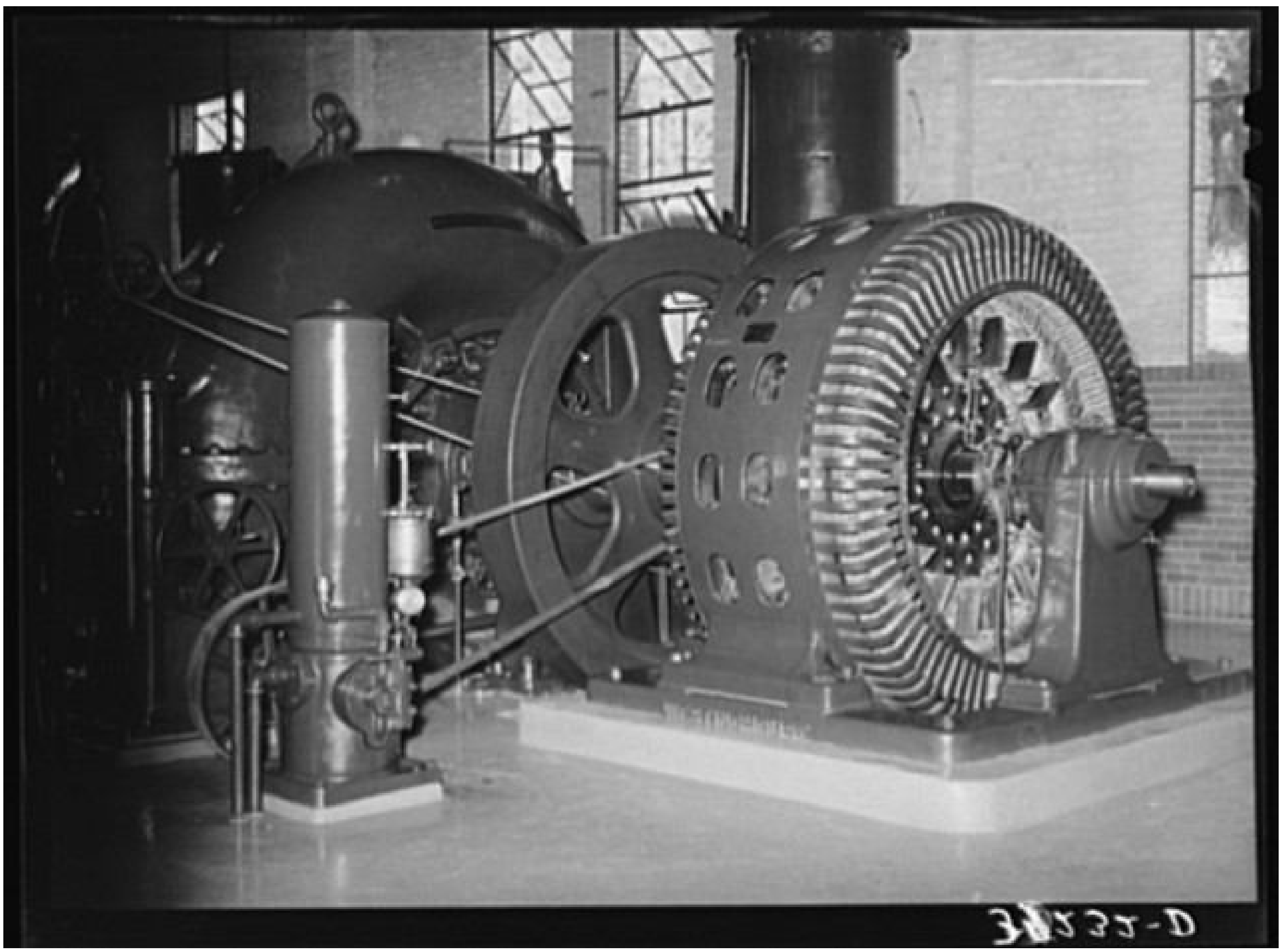

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When the lights go out, it affects everyone. It's not only the inconvenience of having the TV shut off unexpectedly—a lot of heavy equipment really dislikes having the power disappear suddenly. For the most part, the power grid is very stable. But sometimes random events and seemingly small operator errors can cascade to create massive power outages.

Underlying the stability of a power grid is the need to keep multiple generators operating in a synchronized manner. New research shows (in an annoyingly abstract way) that good network design can take advantage of the tendency for generators to self-synchronize.

Counting the beat

Depending on where you happen to be in the world, your power outlet supplies alternating current at either 50 or 60 Hz. The precise value doesn't really matter as long as it stays within a narrow limit. Essentially, this means that the generator supplying the power needs to rotate at a rate producing this frequency.

Maintaining the frequency is not simple. Imagine that your house is hooked up to a diesel generator. When everything is switched off, the engine only has to overcome the internal resistance of the generator, so it idles along nicely at a rotational speed that corresponds to a 50Hz alternating current. Then you turn on the stove, the microwave, the vacuum cleaner, and the washing machine at the same time. Suddenly, the generator is trying to produce about 10kW of power. That increases the internal resistance of the generator and the engine slows down. The slowing rotational speed kicks the governor on the engine into action, which revs the hell out of the diesel. The diesel speeds up, overshoots the correct rotation rate, and then settles back to the correct speed.

At the moment when the load on the generator changed, the frequency of the alternating current produced by the generator changed. It first dropped, then increased as it spun up, and finally dropped back to the correct value again. The governor actively stabilizes the rotational speed of the generator to the correct value, and it operates in what is called the critically damped regime. That is, the governor tries to minimize the number of times it overshoots and undershoots, rather than just the speed with which it makes any particular correction.

Now, imagine that the governor wasn't set correctly, so that the overshoot was larger and the oscillations above and below the correct frequency persisted for longer. Some of the electrical appliances in your house will respond to that by changing their power draw. That means the load demanded by the appliances starts oscillating in response to the oscillating frequency of the generator. Under some conditions, the two can reinforce each other, and the oscillations get larger and larger until either the load blows or the diesel engine tears itself to pieces.

That's just a single generator with a single load. Imagine a power grid that consists of multiple power stations, each with multiple generators, and a distributed load that changes all the time. If the grid finds itself in the case where the changes in frequency of each generator are *not* damped out, you get the oscillations described above on an epic scale. Then many people are in for a dark and cold night.

Doing the 50Hz dance

Network operators are well aware of the potential for disaster, so they actively stabilize their generators to keep them all synchronized with one another. But given that some relatively large power outages have been due to relatively small operator errors, researchers have been wondering if it's possible to set up a network that maintains synchronization through more passive means.

To achieve this, the researchers have looked at a well-known characteristic of power networks: under stable operating conditions, the generators will stay synchronized with each other without active stabilization. Essentially, if the load on a generator increases and it slows, the other generators "pull" it back. This occurs because, in the brief time it's slowed, the generator appears as a load to the other generators, which speed up to compensate. As long as the slowing and speeding of the various generators don't reinforce each other—that is, the changes of all generators are damped out—then the network will remain stable.

Looked at from the opposite perspective, the researchers observed that instabilities occurred when a generator appeared as a distinctive type of load on the network. That would occur when a generator got so far behind the other generators that the power supplied to it by the other generators would drive it further out of sync, while that generator would simultaneously drive others out of sync.

The probability of reaching this point is all related to the phase—the phase is the relative timing between the peaks and troughs in the alternating current from two generators. For a larger system like a power grid, the phase depends on all the different driving voltages—the other generators that respond to one going out of phase.

But the key insight of the analysis is that the phase of a single generator can also be changed by switching in and out local banks of capacitors and inductors. When a generator has fallen behind, the capacitors and inductors can change the phase of the driving current. This change brings the generator smoothly back into line with the others, without the others ever seeing it as much of a draw. This keeps the other generators from acting to compensate and limits the chances of a growing instability.

So instead of having a complicated active stabilization on the mechanical drive that is turning the generator, you measure the internal electrical properties of the generator and switch capacitors and inductors in and out of the circuit to stabilize it. This operation is very fast—the mechanical drive cannot respond quickly, while electronic components can be switched in and out every ten milliseconds or so.

On long time scales, the researchers reach a conclusion that seems to be blindingly obvious: a network should remain stable if each generator on it was strongly damped. The inertia of the generator and other factors play a role, but when all is said and done, network designers can't do a lot about most of the factors except the damping.

So what?

The first thing to note is that this will probably work. The researchers tried it out on models of real power systems from Northern Italy, Poland, and Guatemala. In simulations, they show that they could stabilize the system through simply switching capacitors and inductors in and out at generator locations. I expect that some of this will find its way into the grid.

The researchers also hit a key buzzword: "smart grids." If you ever wondered what that meant, you're not alone. However, it may be that this is what they're talking about. The current grid is too sensitive to allow a huge amount of flexibility, so we're forced to operate relatively inefficiently in order to maintain stability. Perhaps with better stabilization techniques, this will change.

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