Engineer says 'smart grid' needed for shift to alternative energy

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Development of a smart grid that matches load with demand and increases use of sustainable energy is a goal for Stanford Assistant Professor of Civil and Environmental Engineering Ram Rajagopal.

(Phys.org) —Electrical grids are balky beasts, and nobody knows that better than Stanford Assistant Professor of Civil and Environmental Engineering Ram Rajagopal. He grew up in Brazil, where no one took electricity for granted. Brownouts were an unavoidable – and sweltering – fact of life.

No surprise, then, that Rajagopal's research is focused on the development of a more resilient, responsive electrical grid, one that can adroitly adjust electrical loads to energy demands, preventing the shutdowns that leave people bereft of air conditioning just when they need it most – a smart grid, in other words.

"A smart grid is a flexible grid," Rajagopal said. "It's the infrastructure that allows you to shift load and demand around effectively, ultimately balancing the electrical power and delivery system at lower costs."

Two developments respectively help and hinder the emergence of smart electrical grids. On the plus side are sophisticated monitoring devices that quickly identify any glitch in transmission systems. These intelligent technologies allow two-way communication between energy consumers and utilities, and scalable storage devices such as batteries and fuel cells.

On the negative side – paradoxically – is renewable energy. Such sources, of course, have much going for them. Hydroelectric turbines, wind turbines and photovoltaic panels produce power from sources that are sustainable and clean. And because they don't emit atmospheric carbon, they are essential in any plan to mitigate global warming.

The problem is that photovoltaic panels and wind turbines only produce power when the sun shines or the wind blows (or, in the case of hydroelectric power, when the reservoirs are full) so production doesn't necessarily dovetail with demand.

Indeed, Rajagopal said, a massive infusion of sustainable energy into the current U.S. electrical grid could be – well, unsustainable. If we went mostly to renewable sources, we could be bedeviled by brownouts.

Utilities would ultimately be forced to build new ecologically unfriendly power plants as a back-up. The grid would be burdened by excess generation capacity that would be needed only rarely, gathering dust and burning dollars the rest of the time.

"It's a universal problem," said Rajagopal, an affiliate of Stanford's Precourt Institute of Energy.

As an example, he cited a study in Brazil that concluded the country faces a 56 percent gap in electricity needed to keep its economy running at peak until 2021.

"Hydropower is pretty well tapped out – it faces environmental and legislative challenges there – and solar and wind implicitly entail variability challenges, so a big chunk of the new production would come from thermal plants," Rajagopal said. "Brazil is a champion of sustainability, so that's a major political and social issue. How do you maintain grid reliability while increasing your sustainable energy sources ?"

The best solution is to boost the intelligence of the electrical grid. Smart sensors can greatly improve the flexibility of the electrical generation and delivery system, making it possible to both match load with demand and increase the use of sustainable energy. The grid's IQ will further be enhanced, Rajagopal said, by the expanding "Internet of things" – the increasing connectivity between the Internet and infrastructure.

Utilities and regulators can't do it alone, however. Consumers have to be part of the solution. Specifically, large numbers of customers must be willing to adjust their energy consumption to the fluxes of demand.

"Which raises three questions," Rajagopal said. "How do we measure flexibility potential in any given system? How do you identify customers who might be willing to participate? And how do we devise programs that elicit flexibility?"

Until recently, answering those questions would have been exceedingly difficult, if not impossible. But smart grid technology is yielding a treasure trove of information on consumption patterns. Such datasets, in turn, can be employed to tailor incentives for big blocks of customers.

Utilities are in the early stages of implementing such programs. Pacific Gas and Electric, which supplies energy to northern and central California, had enrolled 120,000 residential customers in its SmartRate program as of September 2013. The program provides customers incentives for reducing energy consumption during peak times.

SmartRate resulted in energy savings of 203 megawatt hours (MWh) in 2011 and 563 MWh in 2012. (A megawatt hour is roughly equivalent to the amount of electricity used by 330 homes for one hour.) It also resulted in about 8 million fewer pounds of carbon dioxide being discharged into the atmosphere.

Rajagopal wanted to know if incentive programs like these could be quantified on larger and more significant scales, so he contacted PG&E. The utility supplied anonymized consumption information taken over a full year from 218,000 households and 100,000 businesses. The hourly data included outside temperatures and ZIP codes.

"This really allowed us to do a comprehensive study," Rajagopal said. "All prior research was based on only 100 to 1,000 households."

He ultimately derived some startling – and heartening –conclusions from the data.

"We found that 60 percent of daily load is variable, meaning there were some major opportunities for peak shifting – moving consumption around so it was more even," Rajagopal said.

Further, 11 percent of daily load occurs during the "peak hour" – but the peak hour varies according to customer. For many people it occurs late in the afternoon, when they return home from work, crank up the air conditioning or the heat, turn on the television, cook dinner and so forth. But people who work at home or are retired may have different peak hours.

Ultimately, Rajagopal was able to describe 272 unique "load shapes" that encompassed 90 percent of the customer base. In other words, most customer patterns conformed to one of the 272 shapes, each of which had different rates of consumption and different peak hours.

"Everyone has some randomness in behavior, but certain patterns can be identified and ultimately estimated," Rajagopal said. "That allows a utility to offer demand/response (incentive) programs that are tailored to each customer's patterns, moving them away from power consumption during peak loads."

Such incentives work best for customers with high variability in their consumption patterns. "People who are variable in their behavior are open to energy efficiency and pricing messaging," said Rajagopal. "They tend to respond positively when presented with different options for changing their behaviors."

The programs could be accompanied by smart technologies such as thermostats that automatically turn down the air conditioners of participating customers. Even a few degrees difference could benefit grid operations enormously.

"We've determined that for 1 million homes, you can reliably provide (i.e., save) 250 megawatts of capacity for every degree Fahrenheit of air conditioning controlled by a demand/response program," Rajagopal said.

These strategies, of course, can also result in significant reductions in carbon dioxide – and that doesn't even account for the additional carbon cuts that can be achieved by increasing the ratio of sustainable sources in the energy supply. By leveling out demand, notoriously fickle wind and solar power can be integrated smoothly into the grid.

Further, said Rajagopal, additional load flexibility can be achieved by judiciously expanding the grid's storage capabilities. Batteries and fuel cells can be charged during hours when usage and rates are low – often, late at night – and exploited during peak demand.

That's all well and good for the utilities and the planet, of course. But what's this Brave New Grid's bottom line for the consumer?

"It's dramatic," Rajagopal said. "If you buy your personal peak power off the general peak, you could save 20 to 70 percent on your electricity bill."

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