Redesigning the Grid

Challenge

Our present electrical grid was originally designed to accommodate more-or-less continuous energy input from fossil-fuel-burning (or nuclear fuel-burning) power plants—and as a "one-way" system (electrical energy flowing from power company's power-generation sources to consumer, sometimes over long distances). This design naturally leads engineers to question the extant grid's adequacy to accommodate the more-intermittent—and potentially two-way electrical current flows that have become a reality with renewable energy sources such as solar photovoltaic (PV) and wind. Add to this concerns about its vulnerability to both natural disasters and acts of terrorism, and it is easy to understand why Sandia's energy security mission has been focused on several lines of research aimed at redesigning the grid to accommodate renewables and become more resistant and more rapidly responsive to damage mitigation.

Research

<u>Microgrids</u>

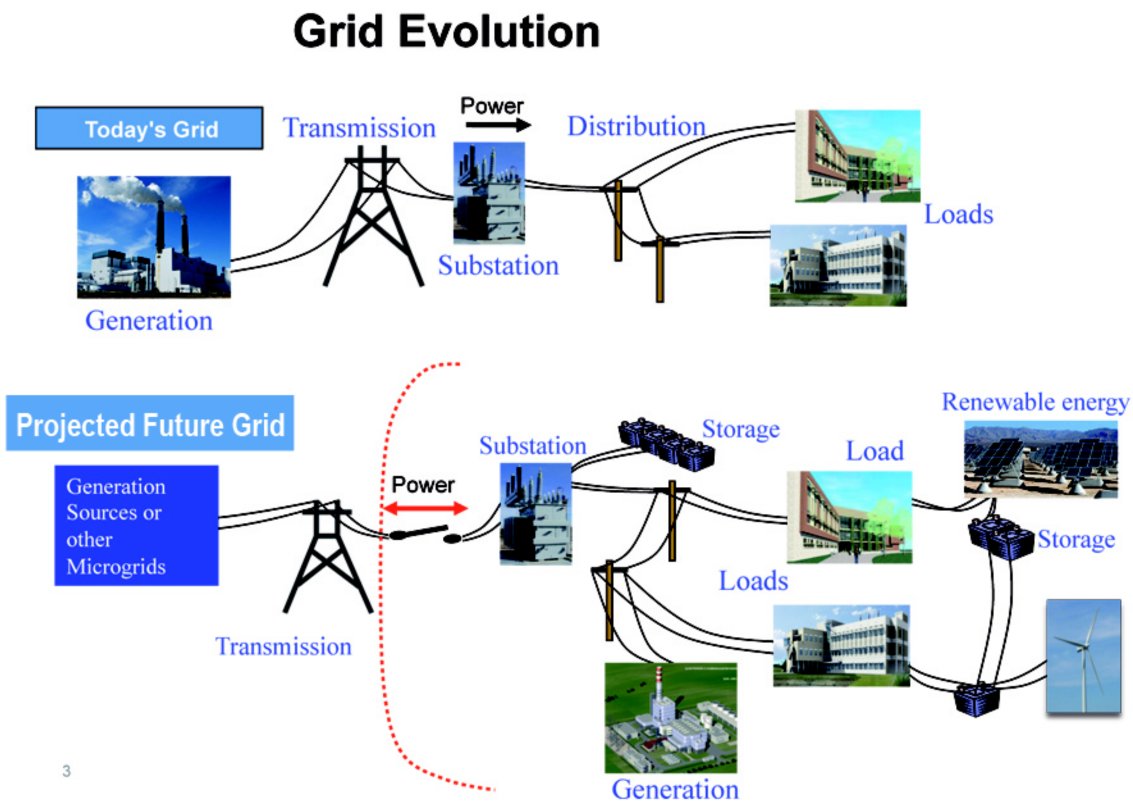
A key reconceptualization of grid design is based around the concept of a microgrid, a delimited group of homes and businesses each capable of both receiving power from the grid and generating power, for example from solar photovoltaic arrays, in amounts potentially exceeding their immediate needs, the excess of which is either stored in batteries or fed back into the grid, essentially sold to power companies. Such an organization requires grids richly endowed with sensors to monitor power generation, control loads (a "load" is any device that consumes electricity), and that quickly respond to changes. The most desirable solution may be that of interconnected microgrids, each microgrid encompassing power generation and usage in a small geographic area, with redundancy in information processing to avoid central failure points and to enable pooling of local resources in the event of a failure. Power generation in a more-local context also ameliorates the problem of the inevitable losses when current must travel long distances from a centralized power-generation point to user homes and businesses.

<u>Smarter Grids</u>

Sandia research has pursued a number of approaches to the issue of transforming grid architecture to enable integration of renewable, intermittent power-generation sources such as solar photovoltaic (PV), which generates power only in sunlight, and whose amount of power generation varies with the degree of solar luminance (number of photons) striking a PV array. Several of these projects are computationally modeling such systems, while others are testing actual physically assembled microgrids. These will require sophisticated control architectures, for example, sensors that are capable of a high level of internal regulation of power flows, such that changes are responded to rapidly, protecting both the grid and its users from damage. For example, one project has developed comprehensive intelligent agent control architecture for use with a 100% renewable energy system decoupled from the grid. The project is constructing a smart sensor/actuator that will be able to turn off loads based on sensed voltage and current

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND

information obtained either locally or globally in closed loop control. The research is focused on microgrid scalability at multiple levels, e.g., homes/businesses, neighborhoods, cities, and regions.



Any new power grid architecture based on interconnected microgrids must be able to use sensor information to enable real-time cooperative power generation by diverse sources, intelligent metering, load-management functions to provide decentralized coordination of potentially millions of generation sources and loads. Sandia LDRD research is testing such a sensor-control module on a small, representative microgrid at Sandia's distributed energy technology laboratory (DETL).

<u>Projecting Real-world Scenarios</u>

DETL possesses a reconfigurable infrastructure capable of simulating and testing a variety of projected real-world scenarios. Power generation sources available to the laboratory include multiple grid-connected PV arrays, microturbines, and fuel cells. Storage capabilities include several types of battery banks, and there are many types of loads that can be included in this highly reconfigurable system. In addition to serving as a test bed, DETL researchers are developing new types of power controllers and inverters (which convert DC [from, for example, PVs] to AC in the grid).

Additional LDRD research in the area of flexible and adaptive grid design is directed at the assessment of extant grid systems, for example, analysis of the grids of the smaller Hawaiian islands of Lanai and Kauai. By developing power-flow control algorithms, the research is assessing the integration of PV into the Lanai grid and wind turbines into the Kauai grid, The developed models employ dynamic programming optimization to model the most favorable way to integrate renewables in each instance.

Ultimately, Sandia's investment—ongoing through an LDRD "Grand Challenge" project—is aimed at developing technologies that enable self-healing and self-adapting microgrids to become building block structures of larger systems. Because of the sensors and intelligent adaptive software built into a microgrid, it would be responsive to numerous power-input/power-output scenarios and even be capable of adapting —to a certain extent—to events of either natural- or human-engendered disruption by shifting into a mode of operation that would be adequate to sustain operation until repairs could be initiated.

Impact

Three factors mandate a shift in national energy policy. First is decreasing supply of fossil-fuel energy and the increasing cost of extracting the fossil fuels remaining in the earth's crust; second is the dependency of the U.S. on fossil fuel sources from politically volatile sources in the Middle East and elsewhere; third is global climate change, thought to be driven to a large extent by the increasing atmospheric burden of carbon dioxide (CO_2), most of which is the result of fossil fuel combustion. In turn, this shift in energy policy requires a significant reconfiguration of the U.S. electrical grid to accommodate the characteristics of these renewable power sources. The potential payoff is no less than energy independence.