Control for Smart Grids

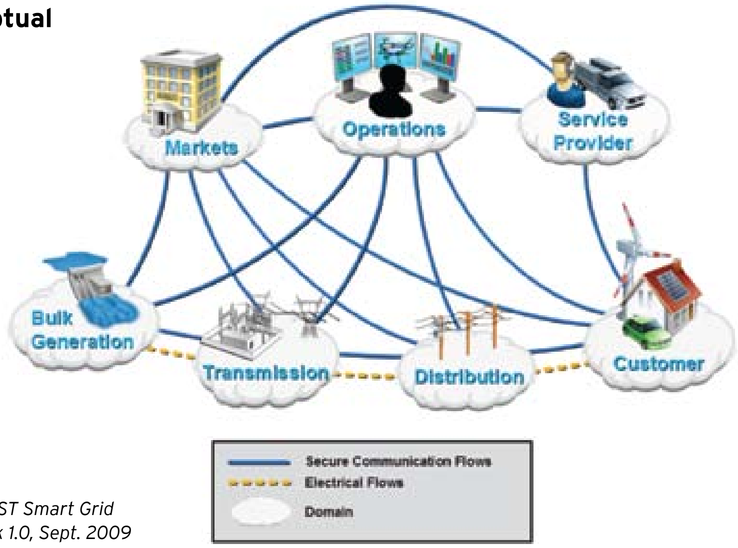
Today's electric power infrastructure is ill suited for dealing with global energy and environmental concerns. The "smart grid" promises a solution to this predicament. By incorporating a communication, computing and control overlay on the power grid, we can integrate large-scale renewable generation and emerging storage technologies, provide (direct and indirect) control signals to loads to match supply, dramatically improve energy efficiency and reduce consumption in homes, buildings, and industries, and increase the performance and reliability of transmission and distribution networks.

Dynamics, feedback, stability, optimization—these and other concepts that are core to control science and engineering are at the heart of the smart grid. It is perhaps only a slight exaggeration to say that the smart grid is, in essence, a controls problem!

Demand Response

Electricity demand varies significantly over the course of a day (and over longer-term cycles), and the cost of servicing the demand varies even more dramatically. For example, the marginal cost of generating the electricity needed to satisfy demand on a hot summer afternoon can be more than an order of magnitude greater than the baseload generation cost.

Conceptual Model

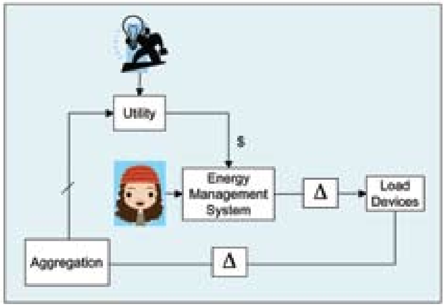


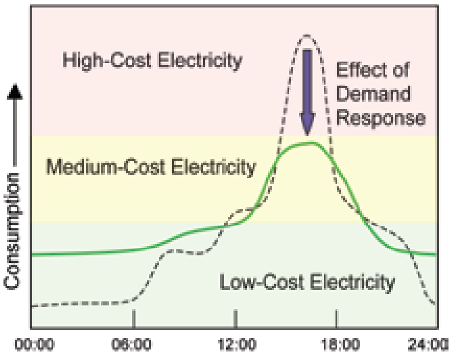
Source: NIST Smart Grid Framework 1.0, Sept. 2009

Demand response refers to mechanisms that can enable electricity consumption to be better aligned with generation cost structure—and with other imperatives such as the use of renewable sources. Demand response comes in different forms, such as direct load control in which the utility directly switches loads in consumer premises, remote adjustment of set points of equipment, and, perhaps most interestingly, dynamic pricing signals to consumers (see figure below).

Demand response is practiced today in very limited fashion—for example, hourly day-ahead prices may be communicated to energy management systems in commercial buildings. Real-time pricing and more dynamic demand response schemes have garnered much interest, but this tighter closing of the control loop must be carefully thought out.

- Models are needed that capture the dynamics of customer behavior in response to price signals.
- The effect of delays (the Δs in the diagram below) in adjusting loads must be understood—this is critical from a stability perspective too.
- Control strategies will need to tolerate the high level of noise and uncertainty in this application.





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From: *The Impact of Control Technology*, T. Samad and A.M. Annaswamy (eds.), 2011. Available at www.ieeecss.org.

Renewables, Distributed Generation, Storage

For all the potential of renewable generation, it complicates the overall balance of supply and demand. Traditionally, power companies have been able to control generation with reasonably complete authority, thereby addressing variation in demand. With renewables, variability is extended to the supply side as well, compromising control of generation. Distributed generation—for example, small-scale renewable sources owned and operated by power customers—further complicates the picture.

Better predictive models of renewable generation are needed at all levels; the management of generation and load is now a multi-variable, non-convex optimization problem with numerous constraints, and decision and control schemes are needed that factor in this complexity.

One solution to the problem of intermittent generation is storage, and approaches are being pursued at different scales and with different technologies—from compressed air underground to flywheels to novel battery materials. Electric vehicles, including plug-in hybrids, may also be useful for storage. The inclusion of storage devices brings that many more assets to be coordinated and optimized.

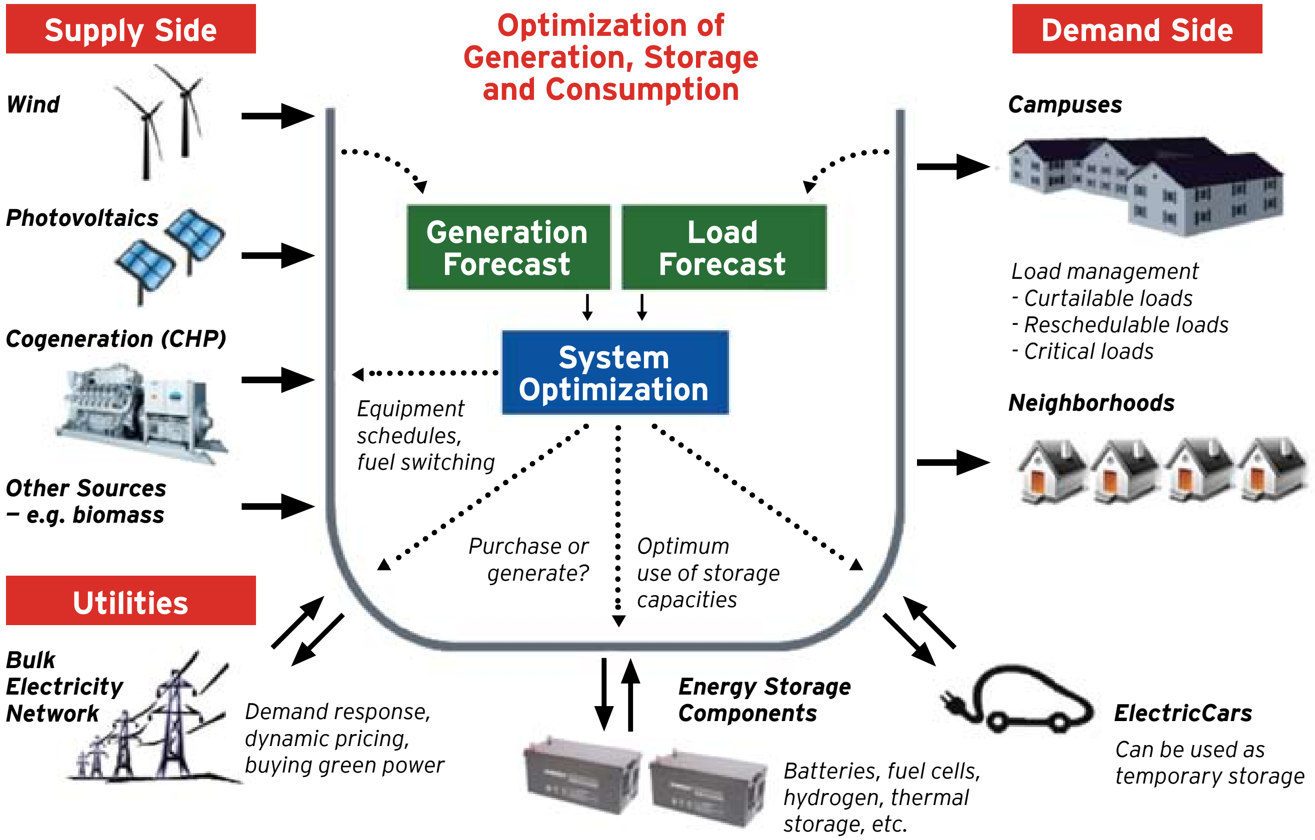

Figure courtesy of Petr Stluka, Honeywell

And there's much more!

The smart grid is an emerging technology domain with numerous sub-problems that require sophisticated treatment of dynamics, modeling, and control. Opportunities also exist in the transmission and distribution area that are not presented here. The time scales range from the milliseconds in which power electronic devices and converters must react to the days or weeks over which some loads must be scheduled (and policy-making with its even longer cycle could benefit from advanced control concepts too).

The bottom line: Control is critical for the smart grid, and there's no shortage of outstanding problems for control scientists and engineers to address.