

The smart-grid evolution

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When the vision of a smart grid first appeared over a decade ago, it was revolutionary and broadly recognized as being so. Yet even an informal assessment of the facility and technology development necessary to realize that vision made it clear that smart grids would require a lengthy *evolution*.

Of course the smart grid concept didn't just pop up like toast, a notion fully formed between a pair of ears. Many of the intellectual and technological underpinnings date back at least to the 90s. Operational challenges to large-scale electric-power generation, transmission, and distribution date back much further.

One of the early underpinning developments was the electronic energy meter, which predated submicron semiconductor processes. These first electronic meters merely had to measure, totalize, and report energy use—a direct replacement for their electro-mechanical predecessors, which they were almost immediately poised to replace.

Originally, the most obvious rationale for switching to electronic metering was that it would reduce utilities' reading costs. Since the deployment of smart meters began, however, they have allowed utilities to make fine-grained, geographically and temporally distributed measurements of grid utilization and grid performance throughout their networks. That data stream supports both infrastructure management efforts and grid-modernization investments. These activities make use of smart-grid devices that are less visible to individual customers but more critical to the realization of smart-grid benefits: Robustness in the face of growing load, environmental, and equipment-aging stresses; capacity management; and flexibility to exploit distributed — often *renewables*-based — generating facilities.

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Over 37 years, the CAGR (compound annual growth rate) in electric-energy use worldwide has outpaced increases in both population and overall energy use by more than two to one, according to the World Bank. Electric grids have not enjoyed proportional growth in their power-delivery capability so, in many regions, electric-power infrastructure is under increasing capacity stress. This growing strain manifests, for example, in transformers operating at or beyond their nameplate current ratings, which can lead to overheating and a reduction in the equipment's useful operating life. In severe cases of load outpacing capacity, utilities have had to resort to rolling blackouts at great inconvenience to their residential customers and great cost to their commercial and industrial ones.

The development of smart grids has provided a smooth path for integrating distributed generating facilities into transmission and distribution networks designed for traditional generating plants. Distributed generation can help reduce capacity stresses in two ways: Large-scale generating facilities — both traditional plants and those operating from renewable sources — help reduce transmission distances and provide greater sourcing flexibility. Small-scale generation, like diesel-electric, solar-array, or wind turbine, sites power sources adjacent to their loads, effectively taking load current off transmission and distribution networks.

One of the surprising consequences of smart grid technologies is the enormous scalability of coexisting energy resources. On the large end of the spectrum are the mammoth generating facilities, the largest of which is currently the 18.2 GW *China Yangtze Three Gorges Project* hydroelectric plant in Xilingxia gorge, China, according to China Three Gorges Corporation. On the other end of the generating spectrum are small solar arrays and wind generators with capacities in the range of 10 kW or so, appropriate for individual residences and small businesses (**Figure 1**). That's a seven order of magnitude range — the ratio of, say, the weight of a car (1000 kg or so) to that of a flea (0.1 g).



I mention that range, not because it's instructive by itself, but because of what's behind it. Once you get past the transduction method — the means of converting energy from its available form to electric — there are few architectures in use that make that energy available through the smart grid. Monitoring and control architectures also tend to be quite similar, in gross, over most if not all of the scale. As you descend the design hierarchy through topology and underlying technology, the enormous creativity designers and technologists have applied to this field bloom. The contribution of software and communications to the formation of robust and flexible infrastructure also become apparent.

This range of scale has also created strange bedfellows among companies best known for operating in power applications several orders of magnitude apart from each other. For example, in 2011, Eastern Wind Power commissioned their 50-kW prototype vertical-shaft turbine at the Martha's Vinyard airport with power-conversion gear that Siemens Energy supplied. For the small windpower firm, the conversion system was critical apparatus. For the giant Siemens Energy, the project was a proof of concept demonstration, scaling a conversion system for an emerging market.

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Smart-grid technologies are taking on a broader range of critical functions that are improving grid performance and robustness in the face of stressing events. Smart relays reduce actuation time compared to traditional relays, minimizing the disturbance to customers during events that force feed switchovers. For example, equipment suppliers such as ABB have measured total times for system fault detection, isolation, restoration, and feed transfer as fast as 59 ms — less than four line cycles.

The evolution continues with a wide range of developments. These include, at the supply end, HVDC transmission technologies that reduce line losses. At the customer end, lower cost transformer-monitoring devices help extend the working life of aging components. As individual buildings — particularly large commercial sites — install small-scale generation capabilities, smart-grid technologies and concepts inform designs within the site as well.

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