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Intelligent agents for the smart grid

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A novel approach delivers the autonomous, intelligent behaviour required of the smart grid.

Meeting the challenge of cutting greenhouse-gas emissions and ensuring energy security in the face of dwindling oil and gas reserves requires radical changes in the ways in which energy is generated, distributed and consumed. Central to delivering this is the need to improve energy efficiency through electrification of transport and heating, two key sources of carbon emissions. The resulting increased demand for electricity must then be met from low-carbon, renewable resources such as wind, tidal, solar and (possibly) nuclear energy.

This represents a challenge to existing electricity grids, which supply electricity to homes and businesses in most developed countries. They were originally designed to distribute electricity from a small number of large generators to millions of consumers and operate based on the idea that supply must always follow demand. This requires that additional generators be instantly available to respond to increases in demand and also that the total installed generation capacity is sufficient to satisfy the peak daily demand (even though this capacity may only be required for a few hours each day). In addition, consumers are typically charged for electricity on a per-unit basis, although the real cost of generating electricity varies widely throughout the day.

The inefficiencies associated with such electricity grids have long been recognized. Indeed, in the 1980s, the foresighted Massachusetts Institute of Technology engineer Fred Schweppe already proposed the need for a more dynamic grid in which supply and demand are in continual feedback.[1,2] This vision has recently received renewed interest in the form of the smart grid, an improved electricity grid in which generation from renewable resources is widely distributed, where households and businesses act as both consumers and generators of electricity, and where information and electricity flow together throughout the network.[3]

The decentralized nature and expected autonomous, intelligent behaviour of the smart grid have much in common with the Internet. Power-systems engineers are, therefore, increasingly turning to novel information- and communication-technology

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approaches to understand how to build and control this new grid. In particular, the field of multi-agent systems offers a rich set of techniques, algorithms and methodologies for building distributed systems in which desirable system-wide properties can be assured, despite the autonomous (and perhaps self-interested) actions of the component parts (here individual homes and businesses making their own decisions about energy generation and consumption).

These approaches are informed by the mathematics of game theory and enable analysis of a system's equilibrium state by considering the individual incentives of all involved. Going one step further, one can then design the interactions of the individual components such that desirable equilibria (and, hence, advantageous system-wide properties) are achieved. This approach, commonly referred to as 'computational-mechanism design', departs from standard economic approaches to game theory by explicitly considering the limited computational and communication resources (assuming that they represent real computational devices within the system and not the idealized construct of Homo Economicus).[4]

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We recently applied these multi-agent approaches to coordination of microstorage within the smart grid.[5] The ability of individual homes to store electricity in batteries (or perhaps in the batteries of their owners' electric vehicles parked outside) is a key technology envisioned within the smart grid to flatten the demand for electricity throughout the day (thus reducing the need for installed generation capacity) and to ease the integration of intermittent renewable sources (such as wind power).

In a setting in which the individual homes within a smart grid receive a continually varying real-time price for the electricity that they consume, we have shown that it is possible to calculate the system's equilibrium state as well as derive efficient local algorithms that allow individual homes to converge to this equilibrium. Based on a model of the UK's electricity grid, our results indicate that savings in electricity bills of 13% (with corresponding reductions in carbon emissions) can be realized when less than 50% of homes actually have storage devices.

These results represent just the first applications of multi-agent-systems techniques within the smart grid. Other notions from game theory, such as coalition formation, naturally find application where groups of consumers come together to form virtual power plants, selling their aggregate energy generation back to the grid. Similarly, personalized energy agents may reduce both cost and consumption by monitoring energy use to propose and encourage behaviour change and by negotiating better energy prices for their owners by autonomously comparing tariffs from different suppliers. Much work remains to be done, but we will certainly see the convergence of energy and information technologies as the smart grid becomes a reality.

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