Transactive Energy Systems

By Ron Ambrosio

SINCE THE TIME OF EDISON'S first central generation station on Pearl Street in lower Manhattan, New York, electrification has evolved to continuously improve on several key characteristics: efficiency, reliability, and resiliency. Over the last century, the individual components of electrified systems have improved exponentially, and, as a result, more attention shifted to improvements at a system level rather than the component level to make the overall system more efficient, reliable, and resilient.

Today, the infusion of advanced information technology and the growth of distributed energy resources (DERs), including flexible loads, storage, and microgeneration, present both opportunities and challenges for the continued improvement of electrification. For example, while DERs can improve resiliency by eliminating single points of failure in the electrification system of a building or a microgrid, they also introduce complexity of coordination and interoperability that, handled poorly, can lead to reduced reliability as a result of poor power quality or reduced efficiency in the form of higher cost of implementation and/or operation.

Digital Object Identifier 10.1109/MELE.2016.2614234
Date of publication: 5 December 2016

Definition of Transactive Energy Systems

A transactive energy system (TES) is an approach to designing and operating an electrification system that helps address these issues. The TES establishes a distributed information system architecture that can be used to coordinate the various components of the system. It also provides a means of addressing interoperability through a uniform signaling mechanism between those components. The U.S. Department of Energy's GridWise Architecture Council defines transactive energy as "a set of economic and control mechanisms that allows the dynamic balance of supply and demand across the entire electrical infrastructure using value as a key operational parameter." What this means is that all business and operational objectives and constraints of the system can be described in terms of their value or cost; there is value associated with achieving an objective, and conversely, there is cost associated with addressing a constraint.

The infusion of advanced information technology and the growth of distributed energy resources present both opportunities and challenges for the continued improvement of electrification.

Think of a TES as a collection of intelligent software agents, some responsible for managing a DER asset such as a battery or a flexible load, others responsible for aggregating and coordinating collections of DER assets (perhaps within a building or defining a microgrid on a campus), and still others that may be responsible for points along electrification paths that are constrained. There can also be hierarchies of aggregation agents representing collections of collections (e.g., multiple nanogrids might be part of a larger microgrid).

All these TES agents communicate with each other through transactive signals representing the dynamically changing needs of the system in the form of economic values that combine the objective values and constraint costs. By adjusting these signals, a transactive agent can influence the behavior of other transactive agents in the system. For example, a transactive agent managing a battery might decide that the battery should switch from charging to supplying energy based on the signals it is receiving and the current state of the battery. In doing so, it would also adjust the transactive signals it is sending to its neighboring transactive agents, perhaps increasing the economic value in the signal to indicate that a more expensive, limited resource is now part of the energy supply, allowing other transactive agents to decide how to adjust the DER assets they are managing.

By using economic value representation as the basis for the transactive signals exchanged between transactive agents, a TES can address the challenge of interoperability in an elegant fashion: as long as appropriate value representations can be determined, virtually any DER asset, system component, constraint, or integration management point can be connected to any other, regardless of the underlying technology implementation. The transactive agents become the interoperability bridges, and the exchange of transactive signals between the agents becomes the interoperable communication paths within the system.

The Challenge of Assigning Value

While the concept of using economic value representations is simple, the determination of those value representations in transactive signals can be complex. What is the best way to quantify the value of achieving a business or operational objective? Is there one methodology that can work for all value assignments? Very likely not.

Value assignment is one of the most active discussions currently under way in the TES community, and defining an analysis recipe and a manageable set of methods for quantifying value is critical to making TESs practical and repeatable design and implementation approaches for improving electrification systems.

The Distinction Among Economic Value Signals, Pricing, and Incentive Mechanisms

Throughout this column I've referred to economic value signals, not price signals. There's an important distinction that needs to be explained. The economic value signals in a TES are constantly changing to reflect the changing conditions in the system. It's very tempting to think of this as a price signal, but that is very limiting. The reason is that dynamic price is an incentive mechanism: it's a way of influencing the owner of a flexible energy asset such as a DER component to make some or all of that flexibility available to the system so it can be used to improve efficiency, reliability, or resiliency of the system. The act of making that flexibility available might be a manual action, or (preferably) it might take the form of the owner setting business and operational objectives as parameters to a transactive agent that is managing the flexible asset on his or her behalf.

I say that equating a transactive signal with a price signal is limiting because dynamic prices are just one of many incentive mechanisms that might be employed, and it might not be the most effective one for a given asset owner or customer segment. It's important to build the TES in a way that can support any incentive mechanism that might be employed (and, in fact, support multiple incentive mechanisms concurrently, depending on the owners and customers that are part of the TES).

By designing a TES on a more generalized economic value signal concept, that signal can then be used to drive any incentive mechanism selected as part of the implementation. Examples include lower fixed energy costs in exchange for a certain amount of flexibility, monthly or quarterly refunds based on the amount of flexibility provided during the period, or even noneconomic incentives such as carbon reduction or renewable supply preference. One practical approach, which has been implemented on a large TES project, is the use of cost (of energy delivery to a point in the system) as the basis for the economic value signal. This approach works well because there is a concrete basis for the value, and most electrification system owners/operators understand the various costs of operation and can also quantify the costs of achieving or missing business objectives.

> ***One practical approach is the use of cost (of energy delivery to a point in the system) as the basis for the economic value signal.***

Prototype Implementations

The first implementation of a TES was the GridWise Olympic Peninsula project in Washington state 2005–2007. This project involved just over 100 single-family homes, a marine science laboratory, and a pumped drinking water reservoir. Each home had programmable communicating thermostats, electric water heaters, and some had electric clothes dryers, all of which were managed by transactive agents. The coordination across the assets was done by a double-auction market integrated into the TES by an additional transactive agent that served as the market interface.

In the Olympic Peninsula design, the transactive agents for each flexible resource (e.g., a thermostat) would send a signal to the market agent indicating the market clearing value that the resource would respond to. If the market cleared above or below the value bid (depending on whether it was a supply or consumption resource), the transactive agent managing the

Digital Object Identifier 10.1109/MELE.2016.2628260

resource would cause it to react (e.g., the thermostat set point would be adjusted up or down).

Another implementation, one that closely models the previous description of a TES, was the basis for the Pacific Northwest Smart Grid Demonstration project (PNWSGD) 2010–2015. This was a very large project involving system operator Bonneville Power Administration and 11 distribution utilities across five states and 60,000 customers in the Northwest. Some of the resources involved included residential and commercial demand response, electric vehicle charging, large-scale substation battery installations, and renewable generation.

> ***Transactive energy systems should enable a broad range of operational, business, regulatory, and incentive models to be supported by future systems.***

The PNWSGD project successfully demonstrated a TES made up of a large-scale distributed transactive agent network exchanging cost-based economic value signals to address multiple concurrent objectives, including intermittent wind integration, peak smoothing/shifting, unplanned event response (resilience), and constrained resources. Today, there are many TES projects in progress using a variety of designs and addressing many different objectives. Utilities have also started to release requests for information and requests for proposals for TES-based solutions to specific problems.

Conclusion

TESs are a scalable, flexible approach to designing and implementing efficient, reliable, and resilient electrification systems, both large and small scale. They can be implemented within a single building or home, across a campus, or across an entire region, as shown by previous demonstrations and current projects. Because of their ability to address both interoperability issues and optimization and management issues, they're an important technique for future electrification designs and will become even more practical as the process of understanding and assigning value to flexible DER and system objectives (both business and operational) matures. Ultimately, they should enable a broad range of operational, business, regulatory, and incentive models to be supported by future systems.

Biography

Ron Ambrosio (rfa@us.ibm.com) is an IBM Distinguished Engineer and chief technology officer of smarter energy research at the IBM T.J. Watson Research Center in New York. He is a founding member and chair emeritus of the GridWise Architecture Council, and he also served as chair of the Smart Grid Interoperability Panel Architecture Committee for its first five years.