The "Transactive" Electricity Grid: An Appraisal of Alternative Market Structures

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Introduction

A number of individuals and institutions throughout the U.S. are currently exploring methods of implementing a transactive electricity system. At the national level, these include the Department of Energy's GridWise® Architecture Council, the National Institute of Standards and Technology, and the Smart Grid Interoperability Panel, and at the state level these include the New York Market Design and Platform Technology Working Group and California's More Than Smart Working Group. All of these models, while differing in approaches, share certain common design objectives. These include:

- A method for providers of distributed energy resources, such as electricity from solar panels or storage or demand response, to sell these resources into the electrical grid.
- A mechanism or set of mechanisms for pricing services provided on the grid.
- A system for communicating pricing information and relevant operational data to all stakeholders.
- An efficient means, with the aid of pricing signals, of allocating electricity and other resources across the grid.
- A suitable set of incentives and/or delegation of responsibility to ensure that basic electricity service is maintained, and that necessary investments to support the continued operation of the electricity grid will occur

In each of the models, some of these features are more explicitly addressed than others, but they are nevertheless common to all.

While the four approaches share common objectives, each has some unique features that set it apart. For example, the first ("Two-Way Subscription Retail Tariff") and the fourth ("Prices, Programs & Procurements") can be characterized as "market-driven" systems, in that the prices which emerge in them are mainly a function of the market interactions among participants buying and selling services on the grid. The second ("DMP") and third ("LMP+D"), on the other hand, are best characterized as "model-driven" systems, in that many if not most of the prices that are playing a critical role in allocating resources are calculated by computer models. Even this principal difference, however, is really one of degree, because in all of the approaches, market negotiations play a role in pricing at least some of the services and, in all of the approaches, a component of pricing is achieved through the imposition of costs derived from computer models, rather than through the market processes of auctions or bilateral contracts. Another distinction is that the first and second approaches tend to focus strictly on pricing electricity and its delivery, while the third and fourth approaches broaden the discussion to other services that might be offered on the grid in addition to these, such as steady-state voltage management. Again, however, this may merely be a difference in emphasis, as there is no inherent reason why the first two approaches couldn't also provide methods for pricing products and services other than just electricity and delivery.

Two-Way Subscription Retail Tariff

Ed Cazalet of TeMix has developed a model for transactive energy which is based upon the concept of establishing a set of retail transactive energy platforms for energy and delivery. These platforms would essentially serve as an interface between distribution operators (including utilities) and load-serving entities on the one side, and customers and providers of distributed energy services on the other. (The platforms would function by using a set of open, and free, standard protocols.) Load-serving entities, such as wholesale electricity providers, would provide forward market offers, via the platforms, for energy and delivery services. On the other side of the interface, customers enter into long-term contracts for these services, which entails locking into prices and delivery quantities for every hour of the contract period. (This is done through a set of subscription tariffs.) During the ensuing period, for each hour that any customer exceeds the usage that had been contracted for, additional electricity will be provided at the current calculated spot price applicable to the customer’s location, and for each hour that the customer uses less electricity than contracted for, the difference will be sold into the system at that same spot price. Implicit in this arrangement is that if any customer is intentionally providing electricity into the system (through the use of distributed energy resources such as solar panels or storage) or is intentionally lowering usage to engage in demand response, then these resources will be provided at the spot price. The spot price will be a function of both the wholesale electricity price and the cost of delivering electricity to the customer’s location in that hour. (The latter will rise and fall due to system congestion in that particular location.)

Customers can manually adjust their energy use in response to hourly prices, or alternatively the process could be automated with smart appliances and other energy management systems. Retail customers also have the ability, with this system, to engage in direct energy transactions with other customers, and when these other customers are in a proximate location on the distribution system, net distribution costs will be negligible, meaning that they will be able to buy and sell electricity services to one another at essentially wholesale rates.

One of the advantages of this method is that a simple formula is used to calculate distribution prices, and there is no need for sophisticated optimization software and an elaborate system of sensors to do the calculations. The tariffs, too, while representing a significant departure from conventional methods of billing residential and small customers for electricity, are still relatively simple to understand and use. Together, these advantages might make the two-way subscription approach relatively attractive for utilities and regulators who do not want to contend with the adoption of complex, data-intensive methodologies to make a transactive energy system possible.

DMP

Integral Analytics has proposed an extension of the LMP pricing methodology to the distribution level which it has named Distribution Marginal Pricing (DMP). As with nodal LMP prices at the transmission level, the methodology entails calculating locational marginal costs, but at a greater level of granularity. This is accomplished in the short-run with bid-based inputs and in the long-run through the use of a “Distribution Integrated Resource Plan”, which is similar to the traditional Integrated Resource Plan (IRP) that a utility uses to calculate the optimal portfolio of generation supply sources and demand side management programs over a long-term planning horizon. Similar mathematical optimization methods are used in the Distribution IRP, but with the inclusion of distribution-level avoided costs beyond simply those related to energy supply, such as KVAR, power factor, and voltage, and across a much larger number of nodes. These computations produce a set of marginal prices at the nodes, which can then be used to signal the value of both delivering electricity to and receiving electricity from each node. Because the values are derived from a long-term integrated resource planning methodology, long-term DMPs can be calculated which actually cover periods of time spanning years, but real-time cost calculations which are incorporated in the model allow for the calculation of more dynamic prices which can correspond to time intervals as short as 5 minutes.

Shorter-term DMP cost calculations, which can be used by the Distribution System Operator to manage the system in real time, are predominantly driven by such considerations as voltage, power factor, and line losses on the grid side, and ancillary services, weather conditions, and current locational marginal prices on the supply side. Longer-term DMP cost calculations are a factor of deferred investments in circuit and bank capacity, transmission capacity, and other grid assets, as well as long-term forecasts of locational marginal price and system congestion. Forecasts take explicit account of the way that different projected events such as weather, demand, prices, and system performance interact with one another, and the probabilities of the various outcomes involving these events are adjusted accordingly. This is one of the distinguishing features between the DMP approach to calculating prices and the LMP+D approach described in the following section.

LMP+D

The New York Public Service Commission is exploring the idea of implementing a transactive energy system at the distribution level which is also an extension of the existing LMP pricing methodology used at the wholesale level. A distribution price would be derived for any particular location by calculating an adder (D) to the LMP price which exists at the transmission-distribution substation that relays power to that location. In a similar manner to which the LMP is derived, the adder will take into account such factors as system constraints, losses, power quality, and voltage, and will represent the incremental cost of delivering power from the substation to the meter. The total cost seen by the customer will be LMP+D, which will represent the total delivered value of energy at the customer's location. This will not only be the price charged for electricity received at that location, but will also be the price paid for any electricity that is supplied from the premises by distributed energy resources (although there might be additional charges for receiving standby service from the grid).

As with the DMP model described above, this model entails calculating nodal prices at a much greater level of granularity than that associated with transmission-level LMP pricing. The sheer number of pricing nodes that must be calculated within both of these models will present a daunting computational challenge. And both approaches also involve optimizing the allocation of supply and delivery of electricity across multiple time scales as well as an extremely large number of nodes. Implicit in these calculations, too, is that there will be an extensive network of grid sensors across the distribution system, supported by a corresponding communications network, to provide the informational inputs necessary to enable the calculations. The development and implementation of such networks along with the underlying computing platform could require a number of years before they are capable of supporting pricing at this level of complexity.

Pricing, Programs & Procurements (3 P's)

Paul De Martini and others have been developing a methodology for pricing and procuring distributed energy resources that includes an explicit accounting of the value of these resources to the owner and operator of the grid. (Such values might arise from the deferral of distribution capacity investments, the management of steady-state voltage, distribution line loss reduction, the maintenance of power quality, and contributions to system reliability or resiliency.) This "distribution operational market" would operate in a similar fashion as existing wholesale markets for capacity and ancillary services. Distributed energy services that are sold into the market would be priced in one of two ways: 1) based upon the locational avoided costs, as determined by comparison with a baseline of planned infrastructure investments, or 2) through a bidding process of competitive procurements, with the locational avoided cost establishing a ceiling. These services may be sourced through one or more of three alternative mechanisms: dynamic pricing ("prices"), programs implemented by the local distribution utility or third parties which establish rates for the services ("programs"), or competitive bidding processes ("procurements"). Determination of which of these mechanisms will be used, and to what relative degree, will be contingent upon how effectively they will serve to create an optimal combination of distributed energy resources with traditional grid infrastructure investments.

Alongside this "distribution operational market", a "distribution energy market" would exist which would enable the buying and selling of electricity itself among retail customers, DER providers, and traditional energy service providers across the distribution system. (Use of the transmission system might be entirely bypassed when transactions occur between parties in the same distribution area.) Transactions could occur in two ways: 1) between customers directly, in bilateral forward energy agreements, or 2) by trading through an organized spot market dealing in residual energy.

The time horizons underlying these various transactions will be a function of the products and services themselves. Generally, most grid services purchased by utilities from distributed energy resource providers would involve longer-term arrangements and/or formalized tariffs and contracts. Buyers of services that are interested in price stability, or that are making large purchases requiring financing, will probably procure these services through forward contracts. On the other hand, balancing supply and demand on the grid will require real-time mechanisms that enable a dynamic allocation of resources. Such mechanisms – to the extent that they rely upon pricing – might be modeled on the LMP+D or DMP approaches described above.

Conclusion

The four transactive energy models discussed in this paper represent four alternative means of managing a significant presence of distributed energy resources on the electricity grid. Which of these four, if any, will be adopted, will be contingent upon a number of factors. The first, and probably most important, factor will be the actual saturation level and saturation rate of these resources. At present, independently-owned resources are almost exclusively either small-scale sources of electricity, such as solar panels, or combined heat and power facilities. If these continue to be effectively managed under the traditional regulated distribution utility paradigm, with perhaps some upgrades in communications and control technologies to better facilitate this management, then the perceived need for a transactional paradigm will be minimal, and its cost difficult to justify.

Only a pronounced commitment on the part of the state regulatory and/or legislative bodies will make the adoption of a transactive energy system possible. Many such organizations that have been engaged in exploring these systems have begun to discover that the "devil is in the details" when trying to develop concrete implementation plans. However, the architects of Transactive Energy systems are continuing to improve their tenability by both developing more detailed and tangible roadmaps on how to "get from here to there", and also by incorporating new technologies that make these systems more manageable and less expensive, both in terms of capital and operating costs. Another factor that will contribute to making the adoption of these systems more feasible is the "grass roots" development of islands of transactive energy, most notably microgrids. Aggressive clean energy goals will also provide a significant boost to the attractiveness of their adoption.

And finally, a critical catalyst for widespread adoption will occur when some state (or perhaps some foreign country) actually succeeds in putting a Transactive Energy system into place, and then demonstrates its viability. The evolution of America's electricity system – particularly its legislative and market models – has always been spurred by the existence of fifty independent state "laboratories", with certain states taking the lead in exploring and implementing new designs, and when these designs have been proven to be successful, they become templates for similar innovations and even transformations in other states.

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