Transactive Energy and Operation–Research Issues and Challenges

William Cox (The Energy Mashup Lab, Cox Software Architects)

Toby Considine (The Energy Mashup Lab, TC9)

David Cohen (The Energy Mashup Lab, Evolution7)

Abstract

We introduce Transactive Energy and Transactive Operation for an economically sophisticated audience, without assuming detailed knowledge of electrical switching, engineering, and physics.

Transactive techniques including transactive energy and transactive operation allow dynamic balance of supply and demand where energy is in surplus or shortage, in contrast to traditional techniques, which typically address shortage well but surplus less effectively.

We describe several areas for research supporting transactive energy, with explanations and research questions. We discuss structuring of software for transactive operation, and software agents to facilitate participation in transactive operation and transactive energy.

We show how to apply an open source implementation of the standards-based NIST Transactive Energy Challenge Common Transactive Services (CTS) to simplify experimental design and implementation, allowing any product definition, price, market, and clearing method to be used without change of the basic interoperation.

Keywords: Transactive Energy, Market Design, Product Definition, Transactive Operation, Transactive Grid

Introduction

Transactive Energy is the term for an energy balancing approach using economic techniques for dynamic balance of supply and demand within energy and power grids.[1]

We address a number of technical challenges in building, deploying, and managing transactive systems, with the goal of engaging economic research projects to enhance and support transactive environment.

First we introduce Transactive Systems, Transactive Energy, Transactive Operation, and Transactive Services. We then describe the Common Transactive Services (CTS), which permit a single, simple set of transactive services to be used.

We describe six major areas for research in Transactive Systems, with research questions and examples as a starting point for further elaboration and discussion.

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[1] Transactive energy is also used across grids. For example, one can recursively consider microgrids as components in a larger grid. [4,15]

Energy agents allow for packaging of knowledge gained from transactive operation experiments. We discuss an open source agent framework and opportunities to share technologies developed and extended through open source.

We close with guidance on how to build software for transactive energy experiments, again applying the Common Transactive Services.

Transactive Energy and Systems

A primary goal for transactive energy is "highly automated coordinated self-optimization." [1]

As one might expect there are a variety of definitions for transactive energy. [1] [2] Transactive energy is considered by most to involve transactions for buying and selling products, though some more general frameworks try to address broader but potentially less concrete concepts such as value exchange not involving price.

Background on transactive energy can be found in recent papers including [3] [4]

The following is adapted from [4]:

It is a truism, all too frequently ignored by grid architects and modelers that not all participants have the same objectives, not to mention the same value for energy—and these objectives and values change over time.

The willingness to pay, driven by the *internal-to-the-actor* value function may be much higher when a time-critical and *important-to-the-actor* function must be done.

Analyses and experiments where all actors have the same value functions ignore important considerations: the internal determination of value is guaranteed to be different.

The Common Transactive Services

Brief overview and why it's important to have a universal/common set for experiments and simulations. Shown that all research and commercial transactive systems are equivalent in expression, so we use the CTS as the simplest and most universal.

A team in the NIST Transactive Energy Challenge [5] specified a set of Common Transactive Services (CTS) that are standard, extensible, free to read and use, available for open source implementation, and as simple and minimal as possible. [3] These CTS are a profile of the open standard OASIS Energy Interoperation [6] similar to the standard's TEMIX profile.

The purpose was to be able to perform experiments and simulations and modeling and know that the results done in one transactive model can be readily translated to another.

Various projects including the NIST Transactive Energy Co-Simulation effort [5] and continuation, The Energy Mashup Lab [7], and the TEMIX commercial products [8] use the CTS today.

Research Issues and Questions

We describe five major areas for research in areas that are open questions in Transactive Systems, with research questions and examples as a starting point for further discussion.

The specific areas are

1. Market Behavior and Analytics
2. Market Design
3. Market Initial Conditions
4. Financial Support of Transactive Markets
5. Architecture of Transactive Systems
6. Beyond Transactive Energy

Market Behavior and Analytics

How is a specific market behaving? In fact, how do we characterize behavior in a manner that is useful for determining market health? What indeed is market health, and what metrics are useful for describing and comparing health across markets?

One goal for application of these results is to determine when a grid managed by both OpenADR2 and Transactive Operation selects mode(s) of operation—more on the request/response end of the scale.

A frequently voiced concern is that the markets in a transactive energy deployment may (informally) fail, break down, or otherwise be less useful. Engineering for deployments would be simpler with reasonably efficient and effective

Figures of Merit for Market Behavior

How does one characterize market behavior? What dimensions, measurements, and qualities are required or desired? Adapting evaluation techniques from markets with different scope, scale, and design is a challenge.

It is common to consider Demand Response systems as similar to transactive systems; but the former may have only a dozen transactions a year, while the latter may have many transactions per second. For investment in transactive systems, it appears that a higher transaction flow than those common in Demand Responses systems is needed for adequate market stability and to recover investment.

Many investors want to arbitrage themselves from market risk. To understand risk, investors want to see a cloud of transactions—enough to predict what there may be tomorrow. Preliminary research [9] suggests that even purely financial participation in markets offers benefits beyond those offered by most technologies. But regulators are loath to permit more transactions without understanding how to create stable markets.

In particular, in a pure transactive environment, how do bad actors affect the total market? What market rules are necessary and sufficient to ensure orderly clearing? What social effects will result from moving to markets that allow forward committed transactions?

If you don't know there's a problem, it's difficult to correct or compensate. Figures of merit should be useful for determining health.

Market Health and Stability

How does one detect the health of a market? What exactly is "health" in this context—ranges of values for figures of merit? What signs anticipate possible unsuitable behavior in transactive systems? This will leverage the Figures of Merit research project.

Figures of merit are an abstracted input to address broader issues of market health and correction (below).

Correction of Market Issues once Detected

When actual, potential, or indicative market health and/or stability issues are detected, what remedial actions can be taken?

Larger scale markets, for example, might as appropriate inject liquidity, change trading rules, or other activities on a timescale inappropriate for day-to-day and second-by-second management of energy balance.

Research guidance would improve the response to market instability, market failure, lack of liquidity, and other potential issues. In effect the feedback loop for an executing transactive energy environment involves detection of issues and responses that ameliorate detected issues; long-term control system stability is a second order problem.

Market Design and Clearing

Market Design

What are the tradeoffs for market design?

How does market design interrelate with

- Size of market (participants, value in currency…)
- Product definition(s)
- Scope of market (nodes, similarity of interests)
- Similarity between the market participants or parties

The goal is to apply research results to build engineering guides for deployment of transactive energy. Existing deployments have largely ignored or skirted these issues[2].

There is some guidance in the literature; see e.g. [4]

[2] In the literature, the primary comments on market design is what choice is

Product Definition for Transactive Energy

Typical transactive markets use single time periods with forward transactions for improved liquidity and acceptable market behavior. [8] [4] See *Product Definition* below.

Are specific market designs (e.g. double auction) effective for transactive energy? Are other designs more effective? What characteristics could drive a deployment decision?

As one approaches limit cases such as small, illiquid markets, complex load and supply profiles, and large distributed neighborhood markets, how do we characterize the tradeoffs in market design? Are these tradeoffs significant, relevant, or irrelevant?

There are many guidelines in the literature on design for transactive energy markets. See, e.g., [10] [4] [1] [11] [1] p17.

Clearing and Transactive Energy

Transactive energy deployments have used continuous clearing, periodic clearing (e.g. the ISO *Real Time Markets*) and variations.

Are specific clearing approaches more or less useful for transactive energy? How would the advice differ for differing market characteristics?

Are there negative results attached to specific clearing algorithms?

Product Definitions for Transactive Energy

Typical transactive markets use recurring uniform time periods with forward transactions for liquidity—but this requires combining multiple time periods for real load profiles. This introduces a level of complexity and aggregation that belies the simplicity provided by single time unit products.[3]

As one approaches limit cases such as small, illiquid markets, complex load and supply profiles, and large distributed neighborhood markets, how do we characterize the tradeoffs in product definition?

More fundamentally, does product definition affect market stability and health? What studies have addressed this issue in broader markets, and how might those be applied to transactive operation?

Market Initial Conditions

For external financial support in the next section, and for a clear and consistent economic basis, the currency to be used needs to be made early in the process. The

[3] Transaction Processing [20] has little to do with Transactive Operation. It is a specialized area dealing with distributed consistency protocols, e.g. combining energy requirements in several time intervals so they can be sold or purchased as a unit.

initial distribution of assets seems to typically be treated in an ad hoc manner. [11] [4]

For transactive operation to have a sound economic base (and to be supportable external to the containing market) the market exchanges in our opinion must be grounded in economic value, expressed in a (possibly nominal) currency.

The price and product definition standards used in the Common Transactive Services permit any world currency as well as a local or nominal currency. Support for currency exchange is outside those standards.

An additional consideration is how funds to obtain energy (for net consumers) are replenished, budgeted, and managed. Is an initial assignment of funds sufficient? How could or should funding be expressed? Are formal budgets needed? For transactive systems based on the Transactive Retail Subscription Basis [10] [12] the funding for energy purchases comes from outside the system boundaries.

Algorithms and Evaluation of Agents

How do we characterize the performance (and figures of merit) for agents?

Is a simple agent framework sufficient, with focused behavioral patterns? For example, The Energy Mashup Lab has proposed eight classes of energy agents. [13]

What are the tradeoffs in agent design including but not limited to simplicity, robustness, reliability, and application to engineering guidance?

Applying agents, which encapsulate knowledge related to a particular type of actor—consumer, supplier, etc.—is a well-established way to improve autonomy in distributed systems. The agents support the Actor—a system, appliance, building, microgrid, etc.—in deciding economic activity. Transactive services are used to implement decisions made by an agent. [14]

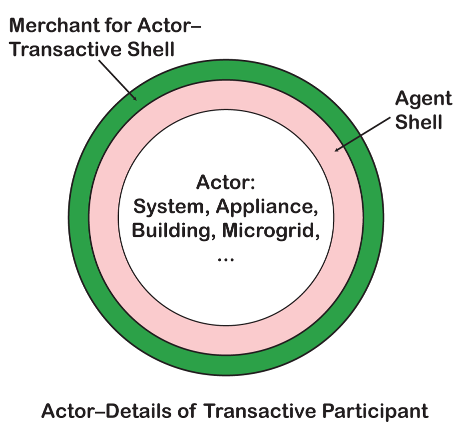

Figure 1 Transactive Actors and supporting Agents, showing the Common Transactive Services

One approach to energy agents takes as input energy characteristics of the actor/device/microgrid and produces as output supply and/or demand curves for the Actor. Of course these supply and demand curves change over time.

Financial Support for Transactive Operation

Financial markets typically have support mechanisms.

The New York Stock exchange, for example, has Designated Market Makers (*DMMs*), who have obligations to maintain fair and orderly markets for their assigned securities.

How should and could we apply these approaches to automated smaller markets?

How should and could external financial support be delivered?

How can we characterize the support, costs, and benefits of external financial support?

For example, low liquidity and other market stresses might be addressed by aggregating multiple markets, but the issue of deliverability of purchased product limits such aggregation. [15] One function of power utilities is to provide a means of delivery not relying on microgrid energy transport, but using the pool and distribution of energy provided by utilities. A similar technique is used in some local energy markets today. (See e.g. [16])

Architecture for Transactive Systems

How can we guide architects trying to design for robust transactive operation? Many of these issues respond to and effect market design and product definition.

Which of the proposed techniques for support of transactive energy are suitable? For example, there are architectures that show a great deal of promise where existing technologies such as OpenADR2 are used for management with a transactive overlay. [11]

These approaches and additional innovative approaches need careful to enable engineering guidance on architectural choices.

Broader business considerations may well drive research on interactions and co-variation between Scope of Micromarkets and liquidity, participation, and stability.

Typically one considers designs where there are micromarkets [17] with relatively small scope. What are the tradeoffs in market performance and stability as size decreases?

Some designs would assign micromarkets to the container or components of a device (e.g. the electric components of a phone handset), to floors of buildings, to neighborhoods and industrial parks.

What guidance can be provided regarding the balance between forward and current time transactions? Ranges of suitable balances would have significant benefit to system and market designers.

Beyond Transactive Energy

There are two dimensions of *beyond* that we discuss.

First, is transactive energy enough? Is there something beyond that will balance supply and demand (with constraints) even more effectively while maintaining independence of the actors?

Second, what is needed to transact Natural Gas, Water, Waste Water, and communication bandwidth? Is there more required than product definitions for those products?

The product definition framework in OASIS Energy Market Information Exchange [18], as used in the Common Transactive Services [3], allows for additional product types and definitions. For example, the product definitions and characterizations in EMIX have already expanded to (e.g.) Thermal Energy. [19]

It is clear that systems where pressure (or some analog) is affected by aggregate demand (or some analog) may benefit from transactive operation. Is this broad categorization supportable?

What product definitions are most useful and effective for transactive water, wastewater, and natural gas? Pressure is significant for water and natural gas; inflow must roughly equal outflow for waste water systems (and the pumps are very energy intensive, cross connecting to the power system and markets). Characterizing such cross-system tradeoffs would be useful.

Transactive techniques and product definition have also been undertaken for (e.g.) bandwidth over a limited connection; are there other important infrastructure areas that benefit from transactive approaches?

Building Software for Transactive Energy Experiments

NIST has created a simple agent/actor model for transactive energy with a few agents, each honest, each correct, and none gaming. This model is intended to provide the basis for large-scale market simulations. These simulations are considered critical to get regulator buy-in to transactive energy.

The model is based around the "Common Transactive Services", a profile of Energy Interoperation that incorporates the OASIS specifications Energy Market Information Exchange (EMIX) and WS-Calendar. These specifications are free to use and free to incorporate into commercial products.

Open Source implementations of the essential agents will create open markets for new technologies ready for rapid deployment with few barriers to entry. But what market rules will these agents support?

Many have focused on a recursive or fractal model of microgrids. Each microgrid can be organized internally through a micromarket among agents. Each microgrid can itself be a node participating in a containing micromarket, expressing only aggregate market position and protecting internal privacy.

Microgrids at each level may require different market rules. Within the home, a single participant supplies all funds, and simplicity of configuration may predominate. Within a commercial or military microgrid, security and resilience may predominate as concerns. Across neighborhoods, markets may be affected by maximum spans of trust.

Many issues of the current grid can be understood as problems of the commons. Across neighborhoods, market rules that extend individual rights to the commons may improve overall market performance, as per Elinor Ostrom.

Different micromarkets may require different market rules to best server their participants and society. A single software agent may be able to discover and adjust to multiple market rule sets.

To enable this, the breadth of applicable rules must be delineated, expressed in machine understandable form, and incorporated into software agent design.

Conclusions

We have shown how open source implementations built on open standards simplify experimental design and allow broad applicability of results.

Using the Common Transactive Services, and building functional components such as market implementations consistent with them can examine key research issues in transactive energy and transactive operation examined more effectively. In addition, research test beds may be more easily shared, modified, extended, and different component implementations be built and compared.

We have described a number of research questions of current interest. The authors invite collaboration in refining those questions and in open source software development and deployment to build a firmer basis for the new dynamic markets and mechanisms for transactive energy and transactive operation.

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