# Considerations for Designing and Operating Transactive Grids and Microgrids

Edward G. Cazalet, William T. Cox, Toby Considine, Jennifer Worrall

***Abstract*—We describe some considerations for applying transactive energy to microgrids and grids. A broader view of business and policy approaches, in addition to practical application considerations, will help design and build more robust grids. For example, decoupling and avoiding assumptions of uniform objectives is important for all grids.**

**We start with a brief survey of microgrid application and transactive operation, considering buildings, neighborhoods, devices, and grids as microgrids, which may be viewed as recursively assembled and disassembled.**

**The Virtual Top Node and Virtual End Node concepts from demand response standards do not always work well in transactive systems. Avoiding restrictions as to potential buyers and sellers drives greater value to the grid edge nodes and customers. We suggest a bilateral transaction approach.**

**In a transactive system unbundling transport products from electrical energy products can improve market liquidity, while making both simpler.**

**The concept of "the next level" is more fluid than commonly thought. Designing for fluidity allows us to build more robust and more scalable systems using transactive energy.**

*Index Terms*—transactive energy, transactive operation, energy storage, microgrid, architecture, design, interoperation

## I. Introduction

MICROGRID implementations have increased significantly in recent years in parallel with increased interest in Transactive Energy. [1] [2] In this paper we examine design and implementation considerations for transactive grids, applying transactive operation [3] and flexible recursive composition and decomposition of grids and microgrids. [4]

As interest in transactive energy has increased, the authors have encountered misconceptions about applying transactive energy to grids and microgrids. We have grouped these into four classes:

- Definitions of grids and microgrids
- Architecture and structure of transactive grids
- Market and control considerations
- Business considerations

Under our definition there is little functional difference between *grids* and *microgrids,* so we use the terms interchangeably.

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## II. Business Background—Microgrids and Transactive Energy

Everett Rogers identified five types of customer segments: the innovators, the early adopters, the early majority, and the late majority. [5]

Microgrids are moving out of innovation into early adoption. While Everett's divisions are usually used for discussions of consumer technology and IT, Rogers based his segments on 12 years studying the adoption of hybrid corn seeds. Grain seed is critical infrastructure for the grain farmer.

Rogers asserted that early adopters are critical to overall success of a new technology because early adopters are "opinion leaders" with a greater social status, a higher level of education and, frequently, a higher income. Rogers concluded that early adopters were more socially active and play a crucial role in influencing the next group's adoption of the product. Apple, for one, has built its explosive growth in part by careful cultivation of early adopters. The early majority members follow the early adopters, and together these groups can account for half of the sales of a new technology.

For these reasons, we concentrate on the early adopters, their motivations, and the barriers that prevent them from acting.

Each of these segments adopts new technology for their own reasons. Rogers characterized the motivations of early adopters as follows:

- Risk Taking. A desire for novelty that exceeds caution and reflects a "universal openness to new experiences, including new products.... They are willing to take a chance on a product with little to no market history." There is also a desire to be first."
- Information Gathering. "There is an informational burden that needs to be overcome for new products, and early adopters are more likely to seek out the information needed to inform their adoption decisions." But they also "seek to mitigate risk through information."
- Status Seeking. Early adopters take pride in showing off their purchases. Early adopters choose products that represent them to the world—their preferences as well as their social status." The study notes that this motivation dates back to 1899 and Thorstein Veblen's "conspicuous consumption" [6]

These are generic motivations, and we will try to explore the specifics of microgrids and how transactive energy meets these specific needs of the early adopter. What must be noted, however, is that how little these motivations apply to the centralized decision-making of a price regulated cost-recovery entity. Innovations in smart energy in general, and microgrids specifically, will achieve wide market adoption to the extent they can satisfy the early adopter.

Risk taking is the balancing of benefits and costs, as well as the balancing of the benefits of potential success and risks of potential failure. The risks and benefits may be personal, that is, the entity may value the success more than others, or risk more with failure more or less than others.

For distributed energy based on intermittent generation, there are substantial risks that the adopter may not be able to make full use of their capacity for generation; they may not be able to fully consume what they produce.

Adopters also face the risk that they may not be able to sell what they produce, or sell at the price which they would like. On-site storage mitigates these risks to the adopter because surplus can be stored for later use. By the same token, storage enables an adopter to decide when to come to market, and what price he will accept. Without storage, the adopter can only sell while generating, only sell at the command price, and may not be able to sell at all. In economic terms, the adopter does not own these energy assets because he cannot control them. That the adopter has raised capital and born risks of ownership is immaterial without economic control.

For these reasons, we consider site-based storage to be critical early-adopter microgrids.

This does not answer the question of why take on any risks at all? Early adopters value some service provided by microgrids more than do later adopters. Some examples are:

- Greater desires for independence and security. The military microgrids at Camp Pendleton are an example of an innovator that values potential grid independence and security of supply more than does the average adopter.
- Desire to be perceived of as supporting "green" values or in demonstrating leadership in the use of renewals. Museums and some educational institutions may opt for microgrids for this reason.
- Greater costs of outages than most users. Wastewater pumping stations, for example, are energy intensive and even a brief outage may result in an ecologically damaging spill creating poor public perceptions.

These are examples of early adopters who see higher benefits to weigh against the risks of early adoption.

Early adopters face higher costs than later adopters. Storage technology, while still immature, costs perhaps 40% less this year than last year. Next year, storage is anticipated to cost 15% less than now. Early adopters must put more capital at risk than later adopters, for higher technology risk.

Early adopters do not have ready access to a work force skilled in operating and maintaining their microgrid. These adopters may seek to mitigate this risk by outsourcing the microgrid operation.

The early adopter, even when they can control when to come to market, may find no takers. Today's market is shallow and they may be only a single legal buyer.

## III. Transactive Energy to mitigate risk

Transactive energy can mitigate the risks of the early adopter, enabling the values the adopter finds to compensate for the higher early price.

If an asset has predictable income streams, then a buyer can be found to own and operate site-based microgrids. This can eliminate the capital risk to the adopter, especially important to the institutional early adopter who may be required to work within budgets that change little over time. Contracted sales between the microgrid and the adopter can be the basis for such contracts.

In today's markets, the capital provider will want to augment the on-premises income with market-based transactions. If the adopter requires real energy surety, the expensive storage required will be greater than the day-to-day needs. The capital provider will want to be able to hedge those transactions to provide a competitive price to the adopter.

Occasional Demand Response is not predictable enough, and does not occur regularly enough support a large capital requirement. The larger the market that the microgrid is able to intermittently participate in, the more reliable the income stream that can be earned. With a sufficient density of transactions, this income stream itself becomes securitizable, reducing the cost of capital and thus the energy costs to the early adopter.

Using transactive energy as a means to self-organize can have the benefit of increased cybersecurity when communications are between trusted parties and the messages are encrypted. The transactive character becomes an additional layer in a comprehensive defense in depth cybersecurity architecture, which helps to mitigate risks in both energy security and privacy.

## IV. Detailed Considerations—Overview

The following sections address the four (overlapping) classes of considerations for and advice to transactive grid architects, implementers, and operators.

## V. Physical Grids / Microgrids

What we call *Physical Grids* are composed from contained grids; a subset of a grid may typically be treated as a microgrid. For example, a building may be characterized as a microgrid, which in turn is a sub-grid of a containing grid. This recursive view is the essential architecture of smart energy. [7]

Microgrids can be supply-only, consumption-only, or a mixture of supply and consumption, including storage. [3] [7], Behavior changes dynamically; in transactive grids these changes are driven by forward contracts, markets, and anticipation of a component's own surplus or shortfall.

The IEEE definition of a microgrid[1] is a sub-grid that can be islanded and continue to operate. However, the terms microgrids, sub-grids, and grids are used interchangeably in many cases, even where islanding is not possible.

[1] The revision in process of IEEE 1547 addresses more dynamic behavior.

How grids, sub-grids and microgrids are managed is separate from their physical structure.

Here are some examples of physical grids in use today:

- Building microgrids
- Neighborhood microgrids
- Office and Industrial microgrids
- Military microgrids
- Devices microgrids
- Regional grids such as the Western Interconnection
- Continental grids

Microgrids may be constructed of other microgrids, such as the FractalGrid installation at Camp Pendleton [8], which is a military microgrid.

Physical grid structures can be fluid as a result of component or interconnect failures, natural or man-caused. Designing for guild physical grid structure allows one to build more robust and more scalable transactive grids, using transactions to coordinate actions.

For example, dynamic fault resilience can be achieved by pre-computed alternate configurations. [4] Transactive energy, though not required, makes the coordination of planning and operations for reconfiguration easier.

In summary, consider what sort of grid you're making or working with, and carefully define an characterize its physical structure.

## VI. Architecture and Structure of Transactive Grids

A physical grid hosts a transactive grid where the parties that invest in and operate the physical devices and systems that make up that physical grid interact using transactions to coordinate their grid related investments and operations.

Transactions are binding contracts for delivery of a grid product during an interval of time for a payment of money between parties. For reasons we will discuss in the next section it is best to keep grid product definitions simple and clear, such as by unbundling energy and transport related grid products.

Transactive grid investments in and operation of grid devices and systems are driven by forward and spot transactions for grid products. Grid devices consume, produce and store grid energy products. Transport system/networks move grid energy products.

Typically transport systems are regulated, cost-based businesses. Electric energy consuming devices are typically owned and autonomously operated by end customers. Increasingly generation and storage devices are owned by end customers and local entities, especially with the trend towards distributed resources and microgrids where generation storage may have multiple uses including resiliency in addition to electricity generation and storage.

A monoculture is not needed—different transactive systems, regimes, and business models can be bridged by transactive services. The Common Transactive Services [9] enable simpler integration at boundaries.

Virtual Top Nodes and Virtual End Nodes used in Demand Response [10] [11] [12] are well suited to the organizational boundaries typically assumed there. But transactive grids may not follow those boundaries—a transactive partner may be a neighboring business, which would be a separate VEN in typical deployments—so building in a VTN-VEN structure may not give full value from transactive grids.

The concept from the VTN-VEN decomposition suggests perhaps less flexibility; designing for greater fluidity in transactive grids benefits fault tolerance and resilience [4] in addition to expanded markets. The concept of *the next level* and *neighboring grid* is more fluid than we might think.

Note, however, that binding micromarkets [13] to the VTN-VEN hierarchy may be a useful development stage. See Market and Control Considerations below for related considerations.

## VII. Market and Control Considerations

In this section we address market scope, market design, product definition and liquidity.

Behavior changes dynamically; in transactive grids changes are driven by forward and spot transactions for products among the parties that own and operate elements of the transactive grid. Completely centralized investment and control of a transactive grid is impractical.

One approach that might appear to fit well with the existing centralized dispatch markets of Transmission System Operators (TSO) is hierarchical aggregation where sub-grids, microgrids, and end consumers are considered to be virtual power or storage resources. The most aggregated virtual resource is bid into the TSO dispatch as if it is an actual power or storage resource. The dispatch quantities are then allocated to the next level virtual or actual resources that make up the virtual resource.

An alternative market design is the automated bilateral transactions approach combined with two-way retail subscription tariffs. [14] This approach is best applied to retail markets including microgrids and can be interfaced to existing TSO wholesale markets. With this approach, end customers can subscribe to forward purchases of energy in hourly intervals at fixed monthly payments. This creates a contracted customer baselines for additional price responsive transactions (avoiding estimated baseline inaccuracies) including balancing transactions based on metered usage. Energy is priced at wholesale prices and distribution transport is priced using two-way with more of the largely fixed cost of distribution recovered with prices that are higher when the distribution feeder is more heavily loaded in either direction. Peer-to-peer transactions are easily accommodated.

A microgrid does not need to balance internally unless it is islanded. Consider a microgrid including multiple use generation and storage devices owned by several parties. Parties within the microgrid can transact products with each other (peer-to-peer) and with parties outside the microgrid. In the event of islanding, the transport products to outside parties will be unavailable or reduced in capability and the internal parties will self-dispatch and/or transact more with each other.

Bilateral approaches need liquidity—the availability of sufficient offers or tenders and mechanisms to purchase or sell that product. Designing a limited set of standard products typically increases liquidity because there is more of a given product available to trade. Product definition is extremely important as it affects liquidity as well as clear understanding of products by buyers and sellers. Existing trusted parties such as the TSOs and distribution operators can also act as market makers to support liquidity.

Products designed for your transactive grid should map cleanly to physical (and physics-based) aspects of your grid. In a transactive grid separating transport products from electricity products makes both simpler—and makes transactions and self-dispatch easier.

On the other hand, designing products that don't map cleanly to the underlying physics increases both complexity and risk.[2]

## VIII. Business Considerations

It is a truism, but one that is frequently ignored by designers, that not all participants have the same objectives, not to mention value for energy—and these objectives and value functions change over time.

For example, a factory may have a large order to be completed on deadline (or a building may be hosting an important meeting). The willingness to pay, driven by the *internal-to-the-actor* value function may be much higher under those circumstances.

This consideration is typically ignored in the electricity literature; these differential values drive real-world considerations of when to buy and when to sell. Analysis where all actors have the same value functions ignore important considerations.

In short, cross a boundary between actors, not to say between transactive grids, and the internal determination of value is guaranteed to be different. Even dividing into large classes and assuming that members of the class value energy at a particular time the same way is oversimplification.

Price-taking behavior [15] does not imply common value functions—the stochastic nature of price-taking is generally understood but not always considered in system design.

Improving market liquidity and the set of potential buyers and sellers (discussed above) is important from a business and economics perspective. An illiquid market does not allow full value to be taken from transactive energy. And restricting trading partners tends toward worse economic value.

In transactive grids, and across transactive grids, if transport is available, anyone can transact energy with anyone else. For example, in the case of Hurricane Sandy in New Jersey, a set of transactive grids could have flexibly supplied energy where the non-transactive control and regulatory systems prevented use of existing energy sources. [4] Instead, thousands of consumers had no energy available, even from local batteries and PV panels.

[2] See the Transactive Energy Challenge Common Transactive Services Team Report [15] [9] for a discussion on transport product alignment with grid physics.

## IX. Conclusions

Microgrids are the live test-bed of new energy management approaches, including energy storage technologies. Each microgrid site is potentially unique, with a specific mix of systems, on a specific site, and supporting a specific business, community, or individual. Attempts to make one-size-fits-all microgrids will hamper widespread microgrid adoption.

Microgrids are currently in the "Early Adopter" mode of market introduction. Diversity in microgrid technology and in microgrid implementation potentially offers unprecedented resilience in power delivery, while delivering specific value to specific sites, and taking fullest advantage of distributed energy resources and schedules.

Diversity, notably diversity in control and diversity in technologies, presents challenges to models that assume central control and isomorphic systems. The rapid innovation underway leads to inevitable and intrinsic diversity of technology, and perhaps of control.

Transactive microgrids enable site-based decision-making while coordinating aggregate behavior across entities. Transactive energy markets enable local microgrids to harvest full value from their investments and will accelerate widespread adoption.

Local markets that allow transactive energy markets to arise will encourage rapid growth of this energy sector. A patchwork of regulation often makes it difficult to establish transactive markets. Peer-to-peer markets, in particular, pose challenges to current regulatory models.

Regulatory changes that encourage widespread development of transactive local energy markets are important to our energy future. [4] These markets will encourage the rapid adoption of microgrids. Wide acceptance of the transactive microgrid model is necessary to achieve a value-based consumer driven market in energy management and storage technologies.

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## BIOGRAPHIES

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