

# Transactive Energy Challenge

## Common Transactive Services

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### 1. Purpose

As Transactive Energy system deployments proliferate, they need to work together at boundaries between systems. The Software Engineering *Bridge Pattern* (see Section 5) describes how to connect independently evolved and independently evolving technologies without re-implementing the systems at the ends of the bridge. Per the IEC Smart Grid User Interface [1] and the NIST Framework and Roadmap for Smart Grid Interoperability Standards [2] this protects investment and decouples to simplify evolution.

Our goal was to identify common services that may meet the needs of transactive energy and describe how those services could be used as a basis for interoperability among existing TE systems; that is, whether they may be taken as a set of Common Transactive Services that are both minimal and complete with respect to a specific set of existing transactive systems.

We describe a simple standard and complete set of transactive services (the Common Transactive Services, because they semantically interoperate with all of our systems of interest) to address this need and to

(1) Simplify interoperation and integration between transactive systems

(2) Allow *mix and match* combining of systems—for example, deploying PowerMatcher and other microgrids inside a TEMIX system inside a CIM Markets system

(3) Simplify design of simulations by using the Common Transactive Services

(4) Allow straightforward generalization of simulation results to other transactive systems

This work builds on the work of the GridWise Architecture Council (GWAC) and the SGIP/OASIS-produced Energy Interoperation and Energy Market Information Exchange.

The team plans to release this report under the Apache 2 license allowing broad application and reuse of this work. This document has been provided to other teams

in the Transactive Energy Challenge, including the Co-Simulation, Transactive Microgrid, Transactive ADR, and Business & Regulatory Model Teams.

## 2. Common Transactive Services Requirements

We analyzed five transactive systems of interest and two proposed transactive systems to better understand their nature and requirements for bridging to, from, and between them.

By *Common Transactive Services* we mean a minimal set of standardized services that can interoperate with each of the existing transactive systems, possibly with extensions, and at an architectural level appropriate to the semantics of all transactive systems. Message payloads need to be standardized as well to allow decoupled evolution.

The Common Transactive Services (CTS) should be

- (1) Extensible
- (2) Standard
- (3) Open (including free to read and use)
- (4) Amenable to open source implementations
- (5) As simple and minimal as possible

And capable of implementing broadly used definitions of transactive energy and

- (1) Supporting GWAC's Transactive Energy Principle 1 [3] in order to allow "highly automated coordinated self-optimization".
- (2) Bridging to and from each transactive system of interest
- (3) Having a clean and clear mapping to each transactive system of interest

The ability to integrate and interoperate is key to obtaining widespread benefit from transactive energy.

## 3. Transactive Service Names

Operations and interactions have many and varied names. For this report we use the names and definitions drawn from economics and markets, as codified in OASIS Energy Interoperation [4], to describe Transactive Services.

OASIS Energy Interoperation is an OASIS standard undergoing international standardization as IEC 62939-3, and used for bridging both event-based demand response and general transactive services, and the profile base for both TEMIX and OpenADR2 [4].

The services are described in greater detail below and in Annex 2. They are:

- Quote—Request and receive a quote on a product
- Tender—Make an offer to buy or sell a product (offer, bid in some environments)

- Transaction—Accept a Tender, creating a Transaction binding on the parties (acceptance, contract, clearing in some environments)
- Delivery—Verify, certify or otherwise determine that delivery has occurred

Some TE systems do not use these names for their various services and may not have one or more of these concepts. We describe some aspects of bridging including terminology differences in Section 8.

## 4. Transactive Systems of Interest

The transactive systems examined below and in Section 8 are:

- (1) OASIS Energy Interoperation [EI] – designed as a bridge between diverse systems [4]; profiles include TEMIX and OpenADR2
- (2) PowerMatcher [PM] – used in power balancing among devices and subsystems [5] [6]
- (3) Pacific Northwest Demonstration Project [PNW] – a Department of Energy Project using incentive signals for balancing power across a region [7]
- (4) IEC 62325 Family [IEC Markets] – as used in national and regional markets [8]
- (5) TEMIX or Transactive EMIX [TEMIX] – A profile of OASIS Energy Interoperation [4] and OASIS Energy Market Information Exchange (EMIX) [9].

In addition we briefly discuss two systems in development:

- 1) Transactive ADR [TADR]—a project underway in the NIST TEC to extend OpenADR2 with transactive services and supported by participants including the OpenADR Alliance [10]
- 2) The MIT Transactive Control System [MIT-TC]—a system under development to address transactive algorithms [11] [12],

## 5. Semantic and System Interoperability

*Semantic interoperability* implies that core transactive functions can be mapped between transactive systems. However, *semantic interoperability* is necessary but not sufficient for *system interoperability*; there is a broader set of *system interoperability* requirements. The GridWise Architecture Council stack (Figure 1, the GWAC Stack) [13] illustrates this clearly.

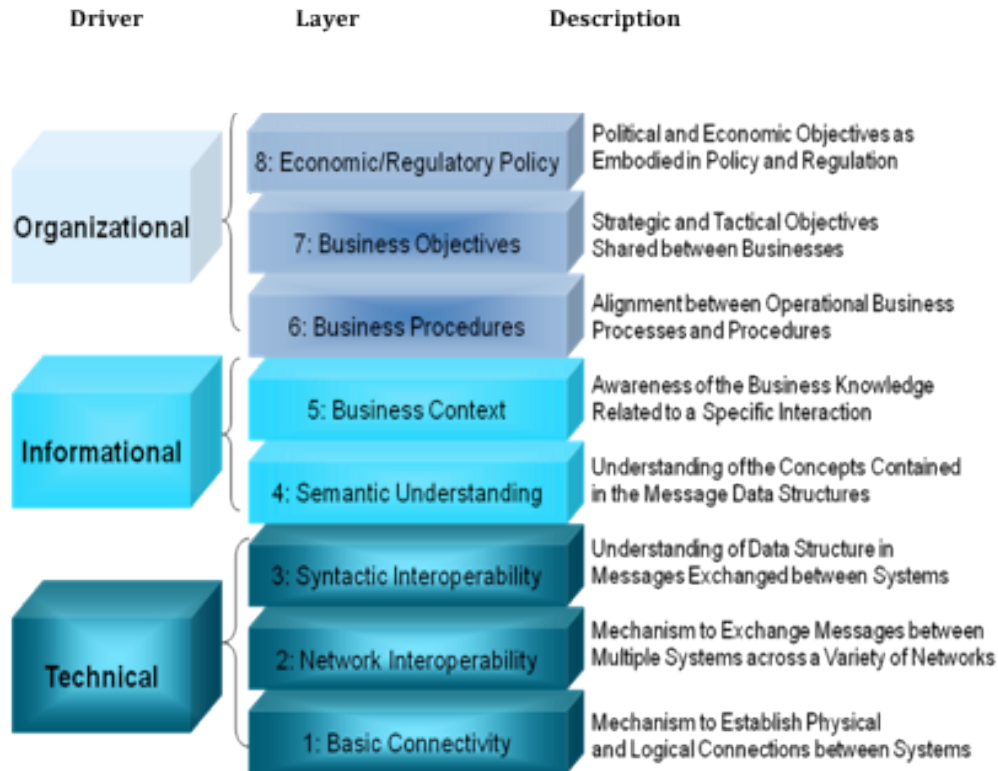


Figure 1 Gridwise Architecture Council's Interoperability Context Setting Framework Diagram.

This report focuses on the Semantic Understanding layer. If one were to connect a PowerMatcher system to a TEMIX system, there is a need to bridge at the Semantic Understanding layer. The Syntactic Interoperability and lower layers are different; we must bridge those lower levels for communication to take place by applying the aptly named Bridge software engineering pattern [14].

A set of Common Transactive Services that semantically support the services in any transactive system can also satisfy the requirements for semantic interoperability between systems—going from the first system to the common services to the second system.

This satisfies our goal that at boundaries—system or grid or microgrid—we can connect diverse transactive systems. So a PowerMatcher implementation could interoperate with an IEC Markets system or a TransactiveADR or TEMIX system.<sup>1</sup> We describe the system semantic relationships in Section 8.

The Common Transactive Services define what needs to be mutually understood<sup>2</sup> by the parties to a transaction:

<sup>1</sup> A similar result applies with respect to schedules (WS-Calendar Platform Independent Model [25]) and Demand Response (Energy Interoperation and its profiles). In fact, Energy Interoperation was designed as a bridge between diverse system models.

<sup>2</sup> This is called a Joint Action Model [33] between participants.

- Transactions are energy-economic exchanges between parties. The exchanges between parties necessarily include information exchange to support the services including product description, delivery locations, and time interval
- Transactions reference products and services (such as energy, transport, reserves, frequency support)
- Participants determine value of energy they may produce or consume. Value is reflected in willingness to buy or sell. Automatable systems typically mediate transactions with price
- Participants typically have different objectives<sup>3</sup>

## 6. Transactive Energy Background

### 6.1. Transactive Energy Overview

We want to develop transactive systems to meet these Transactive Energy objectives:

- Renewable resource integration
- Economic optimization of resource mix
- Wholesale prices/production costs minimization
- Provision of ancillary services, ramping, and balancing (especially in light of renewables)
- Managing transmission congestion costs
- Managing peak load
- Managing resource ramps
- Reduction of the need for new transmission capacity, relief from existing dynamically constrained capacity limits
- Minimizing the requirement for new distribution capacity
- Management of distribution voltages in light of rapid fluctuations in rooftop solar PV
- Accommodation of new loads and integration of responsive loads
- Maintenance or improvement of the services electricity provides in homes and buildings.

The GridWise Architecture Council Transactive Energy Framework defines Transactive Energy as follows:

A system 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. [15]

The Transactive Energy Association describes Transactive Energy as follows:

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<sup>3</sup> For example, a grid operator must maintain grid stability; a building owner must meet requirements of their buildings' business functions; cost of energy is one input to both management objectives.

Transactive Energy engages customers and suppliers as participants in decentralized markets for energy transactions that strive towards the three goals of economic efficiency, reliability, and environmental enhancement [16]

Our transactive systems of interest fit within these definitions and descriptions.

We consider the following common elements, interconnection features, and functions of TE systems.

- TE systems use transactions to help manage grid reliability and improve system efficiency
- TE systems primarily use transactions that are economic and energy-related to coordinate customer resource operations and investment; and grid resource operations and investments<sup>4</sup>
- TE systems engage multiple parties (system operators, generators, markets, customers, aggregators, etc.)

Common system aspects of transactions include information, financial and control communications. These different kinds of communication exist in the context of a TE process. There is a progression from forward planning to real-time markets/interactions followed by control actions taken based on dynamic negotiations and finally reconciliation based on actual usage. TE recognizes the value of forward planning information as well as the need for control decisions made based on a continuous flow of real-time information.

The authors recognize that Energy Interoperation services do not cover the entire TE process. The EI services provide for pre-transaction (Quote), transaction (Tender and Transaction), and post-transaction (Delivery) services, but do not cover all information exchanges, nor address communications. Nonetheless, EI services are shown to provide a minimal set of common transactional services semantically consistent with and capable of mapping to and from other transactive systems. See Section 8.

To summarize, Transactive Energy enables the use of economic constructs for grid and energy management. This report demonstrates that these constructs can work with a variety of TE approaches using the Common Transactive Services.

## 6.2. A Market Perspective

There are significant similarities and significant differences across Transactive Energy Systems. Addressing only the GWAC definition, the North American wholesale markets are transactive in nature, as are systems proposed for more local use such as forward delivery contracts, transactive balancing of microgrids, and more.

In fact, markets and algorithmic resolution of competing tenders take many forms.

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<sup>4</sup> While the purposes of the actors vary, one purpose from the grid side is to engage participants that might not otherwise participate in grid-related actions.

One purpose in defining the Common Transactive Services is to allow transactive participants to interact with any market that supports the broadest interpretation of Tender, Transaction, and Delivery. This enables the use of TE in hardware/firmware devices such as appliances using the Common Transactive Services.<sup>5</sup>

- Use of the same code regardless of market design
- Use of the same code regardless of the nature of the product exchanged, allowing energy, power, thermal energy, and more<sup>6</sup>
- Common terminology for describing and discussing transactive systems
- Alignment with Transactive Systems of Interest
- Use of the same code regardless of currency, product definition, or units of measure

And also enables

- Use of Common Transactive Services for simulation of transactive systems
- Simulation results can be generalized to any transactive system
- Common understanding, terminology, and training for software architects and engineers

We want to develop transactive systems and markets outside those wholesale markets<sup>7</sup> in order to meet the objectives of Transactive Energy as given in 6.1.

These common transactive services are based on Energy Interoperation and provide a standard set of services<sup>8</sup> and provide a foundation for retail, wholesale, and in fact all market transactions and associated information exchanges. [17]

Any Transactive System of Interest (and indeed any transactive system) can enable grid-edge devices, prosumers, smart buildings, and microgrids.<sup>9</sup>

### 6.3. Products Transacted

Value is with respect to the parties engaged in a Transaction—a Transaction increases value to both parties. More precisely, a selling party's total value is increased when the revenue (price times quantity) for the transaction is greater than the party's reduction in total value from the quantity sold. Similarly, a buying party's total value is increased when the payment (price times quantity) for the transaction is less than the party's increase in total value from the quantity purchased.

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<sup>5</sup> A project in the AllSeen Alliance (Linux Foundation Internet of Things) uses the Common Transactive Services for managing resources; appliance manufacturers are involved.

<sup>6</sup> Power and energy are two sides of the same coin; the choice of products in the various transactive systems depends on what is being balanced. See Section 8.5.

<sup>7</sup> Including but not limited to between and within participants at the retail level

<sup>8</sup> In the Service-Oriented Architecture context [30]

<sup>9</sup> Some authors [17] frame these Common Transactive Services with respect to systems already in use in the wholesale markets; other paradigms are in use (e.g., NIST Transactive Energy Challenge Microgrid Team [24])



214 Financial instruments (F), Goods and Services (GS) or Information (I) used in existing  
215 and anticipated transactive systems include but are not limited to:

- 216 1. Contracts (F)
- 217 2. Options (F)
- 218 3. Energy (GS)
- 219 4. Transport (GS)
- 220 5. Demand (GS)
- 221 6. Regulation Services (GS)
- 222 7. Resource Status (I)
- 223 8. Historical Price Information (I)

224 EI Quotes, Tenders and Transactions include definition of the product transacted. In  
225 the UML models and XML Schemas defining Energy Interoperation [4],  
226 ProductDefinitionType is an abstract class, and addresses items 1-6 above. In EI, item 7  
227 is reflected in Delivery. Item 8 is addressed by the non-transactive Report service.

#### 228 6.4. A Financial/Information View of the Common Transactive Services

229 As context we describe the Common Transactive Services in Section 3 and below in  
230 Section 7 using the financial and information perspective in this section.

#### 231 *Information Related Activities*

232 **Information Exchange:** the exchange of information to enable parties to produce  
233 value.

234 **Quote:** Declaration of price of a Product (Service or Good) without a contractual  
235 commitment expectation:

- 236 • Specification of a Product Definition—a Good or Service (Energy, capacity, call  
237 /put option,<sup>10</sup> a grid service such as spinning reserve, etc.)
- 238 • Locational attribute: Where product or service is needed. For example, a  
239 descriptor for a Transactive device or system, a point of common connection  
240 (PCC) of a microgrid, a consumer or prosumer, or a building, (part of) a  
241 distribution system, a phase (A, B, C) on a feeder or transformer, a substation,  
242 a transmission substation, a market pricing node, a hub, a service area, a zone,  
243 Balancing Area, etc.), point of delivery or supply
- 244 • Temporal attribute: Start date/time and duration or start/stop date/time, etc.)  
245 (Schedule)
- 246 • Unit of Measure and Quantity of Product (MW, MWh, ramp rates, etc.)<sup>11</sup>
- 247 • Price<sup>12</sup> for the product or service, e.g. a single value or a quantity-price curve)  
248 (In the Common Transactive Services a Tender)

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<sup>10</sup> An option is technically not a product, rather an agreement for delivery or acceptance of a product.

<sup>11</sup> A non-binding Tender provides equivalent function.

<sup>12</sup> Value is to the respective participants, not shared across participants.



## *Financial Value Activities*

**Tender:** Declaration of willingness to buy or sell a product or service. A Tender may have the following attributes in addition to those in Quote:

- Price Tendered for the product or service, e.g. a single value or a quantity-price curve) (In the Common Transactive Services a Tender)
- Identification of the Tendering party

A non-binding Tender is informational.

**Transaction:** Agreement between a buyer and a seller to exchange a product. A transaction may have the following attributes. Some are essential:<sup>13</sup>

- Nature of Transaction (metadata on the financial or concrete aspect—most Common Transactive Services exchange products, but Options are defined and used for, e.g., regulation services)
- Product definition
- Transaction ID
- Identification of the Buying and Selling parties
- Points of Delivery and Receipt (may be the same)
- Quantity of the defined Product
- Schedule for delivery

**Delivery:** Informational indication that the transaction was realized (product or service delivered/received). Often referred to as “meter data” for the actual delivery quantity. Transaction tracking and verification service may use attributes such as the following for physical transactions:

- Quantity of product or service delivered
- Quantity of product or service received
- Time of delivery
- Time of notification of delivery

While e.g., Business and Regulatory Models may affect how a market operates, the products available, and other issues, the Common Transactive Services allow consistent and straightforward treatment of a broad variety of markets and/or systems interactions.

## 7. The Common Transactive Services

In this section we define the Common Transactive Services.

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<sup>13</sup> The notion that chained or related transactions can be a single product limits automation. Standard techniques for addressing these problems have been in wide use for decades, including Transaction Processing (in the consistency aspect) [29] and Distributed Agreement Protocols such as WS-Transaction BusinessActivity [28]. Path-based transmission rights present the same problem.

## 7.1. Requirements for Common Transactive Services

We need a complete and simple set of common transactive services, which should

- Be adaptable to at least the existing Transactive Systems of Interest and preferably to any transactive system,
- Provide service request and response payloads that are clearly defined and standardized,
- With subjects of the services including price and product definition, which are defined separately, or factored out,
- And where adaption might include extending the service definition(s), adding or deleting products, and defining market rules and constraints.

Price may be expressed in a particular currency, or nominal, or a non-standard currency (e.g. BitCoin). The price and product definition standard EMIX [9] allows any of these, and in fact anything that can be processed and compared mathematically as price is.<sup>14</sup>

As discussed in 6.5 only IEC Markets and Energy Interoperation address all of the products among the Transactive Systems of Interest. Energy Interoperation is far simpler (as shown in IEC 62939-1 [1]).



Figure 2 Transactive Energy Stack and Participant Capabilities<sup>15</sup>

*Fully Transactive Participants* participate in all levels of the stack in Figure 2. *Price-Responsive Participants* accept Tenders (and prices) as presented and may select among tendered prices but do not make Tenders.

## 7.2. Common Transactive Service Definitions

The four common transactive services as defined in Energy Interoperation are Quote, Tender, Transaction, and Delivery.

Each service has several Service Operations; see Annex 2 for detail:

<sup>14</sup> One could construct barter systems; the reason for non-currency prices in EMIX is that exchanging energy for currency may incur onerous regulation.

<sup>15</sup> Adapted from *A Taxonomy of Transactive Energy* [34], slide 6, presented at [32]

Common Transactive Service Name	Energy Interoperation Service Name	Description
Quote	EiQuote	Provide or request a price quotation
Tender	EiTender	Make a tender (offer) to buy or sell a product
Transaction	EiTransaction	Agree to a transaction to buy or sell, accepting a Tender
Delivery	EiDelivery	Meter the actual delivery quantity <sup>16</sup>

Table 1 Common Transactive Services

In this report we use the common name, which is the standard name without the *Ei* prefix.

There are active open source projects implementing the Common Transactive Services.

### 7.3. Considerations for Product Definition

Many transactive systems of interest are bus/node oriented and others are path-based. In the US, transport products for systems outside of ISOs are typically path based. US ISOs use node-to-node congestion charges and congestion revenue rights products.

In all cases it is up to the transmission provider to not sell more transport service to all takers than the underlying physical network can accommodate.<sup>17</sup>

The potential conflict arises when the transport product definition presumes full connectivity, with no conflict between independent transactions of the product. Since this doesn't match the physical network constraints, apparently independent transport transactions may interfere by using transport capabilities that are not actually independent in the real power network.

In a system presenting this anomaly, various solutions have been developed. For example, a utility function (say *Deliverability*) might be defined, which looks below the transport products transacted in order to test for whether an energy product can be delivered at a particular future time.<sup>18</sup>

This example highlights that product definitions must be carefully considered.

<sup>16</sup> If the measured delivery does not match the contracted (transacted) total quantity then a balancing transaction will be necessary.

<sup>17</sup> Including consideration of offsetting and parallel flows

<sup>18</sup> Note that this function could violate architectural layering.

## 8. Common Transactive Services and Transactive Systems

We include a brief description of each of the Transactive Systems of Interest. The products for each system have been discussed in Section 6.3.

The Transactive Systems differ in the range of products supported; while there are similarities and overlaps, the common transactive services themselves can be adapted to each system as discussed below.

The products of interest may include power, energy, or both—power and energy are related physically; we distinguish because the focus of some cited systems is on demand management. See Products in the Transactive Systems of Interest.

Energy Interoperation products include Energy, Power (Demand), and Ancillary Services. The abstract framework has been extended to thermal energy and other non-energy resources.

### 8.1. IEC 62325 Family [IEC Markets]

Also called CIM Markets. These are the set of standards in IEC that define the large-scale wholesale markets around the world. [8]

Products include Energy, Capacity, Demand, and Ancillary Services.

The nature of adapting the Common Transactive Services relies on the abstract nature of bids (tenders) and market results (transactions). Concepts including Offer Curves were directly incorporated in EMIX, and used in product and resource definitions in Energy Interoperation.

Adaptation is necessary; the semantics of interaction with CIM Markets are aligned.

### 8.2. Pacific Northwest Smart Grid Demonstration Project [PNW]

PNW [7] addresses balancing demand through the near-real time exchange of forward value information (delivered unit cost) of energy and the calculated forward load (demand) curves using an incentive signal to improve demand elasticity, and a feedback signal to improve operations planning for generation, transmission, and distribution operations.

The location-dependent incentive signal at each system location (node) is a blended cost of energy that is either imported into, or generated at, that system location. [18] The principle has been demonstrated in the field using nodes that represent large transmission regions and utilities [7] but the conceptual model describes extending nodes consistent with visions for the Internet-of-Things.

Demonstrated products include Power, incentivized consumption of renewable energy, outage contingency response, and the incorporation of existing time-of-use and demand charges. Incentivized objectives are further extensible for each node owner to represent the impacts of not only marginal resource costs, but also the impacts of utility programs (e.g., demand charges, time-based and tiered charges), transport constraints, infrastructure costs (that represent about 2/3 the delivered

costs of energy), regulations, and other things that affect the delivered cost of energy. The PNW approach designed “toolkit functions” for the functional relationships between the signals, resource costs, other incentives, and elastic load behaviors. [19]

Some adaptation of Energy Interoperation services is necessary to communicate PNW service information. The coordination signals of a field demonstration are described in [20]. An extension to a supply or demand curve-based tender may be needed to carry the additional signal information.

Commitment (as a Transaction) is undefined in the PNW system, but the implementers suggest that the framework could be extended to tag and track portions of suppliers’ and consumers’ future schedules as “committed,” in which case their flexibility would be lost for subsequent balancing iterations. [21]

Indicative Tenders could continue in order to negotiate the remaining, uncommitted loads and resources. PNW incentive signals can likely be implemented as tenders with transactive state = indication-of-interest tenders.<sup>19</sup> Once agreement is reached (or the algorithm converges to near stability) the transactive state could be set to “transaction” and committed.

The feedback signals can be viewed as second-order balancing transactions as in the treatment of reconciliation of Delivery.

### 8.3. PowerMatcher [PM]

PowerMatcher [5] [6] balances power across sets of devices; PowerMatcher nodes may in turn participate in higher-level sets of “devices.”

Products include Power.

Participants provide their demand and/or supply curves; these are used to match (or clear) the market for each time interval. Time intervals are sporadic so a clearing persists until one or more of the input curves change.

There are two ways that Energy Interoperation can be used to integrate with PowerMatcher services. The PowerMatcher demand/supply curves are expressed in the Common Transactive Services model either directly (using offer curves<sup>20</sup>) or as a set of simultaneous tenders, where the clearing process would accept tenders up to the cleared quantity.

PowerMatcher uses time intervals differently from the other systems (which typically use nesting intervals). A PowerMatcher settlement is valid until the inputs change. See Section 5.

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<sup>19</sup> A full analysis is beyond the scope of this report.

<sup>20</sup> EMIX [9], page 57

#### 8.4. TEMIX

TEMIX [22] is a profile of OASIS Energy Interoperation: the service definitions are those of the Energy Interoperation TEMIX profile; the product definitions used are simplified to enhance liquidity and market performance.

Products include Energy and Transport.

No adaptation of Energy Interoperation services is necessary.

TEMIX restrictions on product definition and implications for market liquidity are relevant to market design and the factored out concepts. (See Products above)

#### 8.5. Products in the Transactive Systems of Interest

The Transactive Systems of Interest reviewed in this work use overlapping products. Specifically,

- PowerMatcher negotiates power. It balances power demand through the real-time exchange of power price curves and responsive or automated control of grid attached systems and devices
- TEMIX addresses both physical and financial transactions for energy and energy transport and physical options on those products that are ancillary service and capacity products. TEMIX makes no assumptions as to the market or negotiation process.<sup>21</sup>
- CIM Markets address energy and financial products including options and transport. They concern power, energy, and regulation services in an extensible framework.
- PNW uses selected energy products and information exchange, balancing demand and supply through the near-real time exchange of price (forward value information) of energy and the calculated load curves. Information provides an incentive signal to improve demand elasticity, and information feedback serves to improve operations planning for transmission and distribution operations.

Detailed notes on the transactive environments and relationship to the Common Transactive Services are in Annex 1.

Power and Energy are two sides of the same coin: energy is the time integral of power over a time interval, and power is the rate of delivery of energy. The Common Transactive Services product definition classes support both, and applications may focus on energy and/or power depending on the subject of transactive balancing. Only CTS and CIM Markets support both. See Section 8 introduction and Section 6.3.

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<sup>21</sup> The TEMIX implementation and design is most useful for highly automated retail transactions.

## 9. Two Example Applications for the Common Transactive Services

We close with two examples.

### 9.1. A Sample Application—Transactive ADR

Consider OpenADR 2b [23] with the addition of the four Common Transactive Services. The profile implementation would be able to interact transactively, and could use the same security and technologies as the OpenADR 2b profile. International Standard IEC IS 62746-10-1 OpenADR is in progress.

The service definitions do not need to be adapted at the semantic level. For interactions and security, the transformations have already been done for the Demand Response service definitions.

Transactive ADR is a team in the Transactive Energy Challenge. [10]

### 9.2. A Sample Application—MIT Transactive Control Algorithm

This MIT project sends the demand and supply curve value at a single point along with the slope at that point. [11] [12] The algorithm converges over a fairly short time period, requesting additional demand/supply as well as slopes during the process.

An extension to a supply or demand curve-based tender could be defined to carry the additional information. There are plans to experiment with these algorithms in a transactive microgrid. [24]

## 10. Discussion and Conclusions

We have defined and used a small set of standard-defined Common Transactive Services. The transactive services from the Energy Interoperation [4] standard (in progress as IEC 62939-3) were designed as a bridge and proved to be suited to our purpose.

We have sketched how these Common Transactive Services simplify integration and interoperation between the Transactive Systems we examined. This means that a project in any of these environments may benefit by using the Common Transactive Services—for integration in a surrounding transactive system, to mix and match diverse transactive systems, and as a simple complete set of transactive services for new implementations.

For example, the PNW system goes to a system operator such as a utility. Could the PNW techniques be extended to microgrids contained in that utility's domain? Must those microgrids use PNW services? Certainly not—what's needed is to play nicely at the boundaries. That is achieved by the Common Services approach.



468 The Common Transactive Services address the [abstracted] stages of a transaction's  
469 life cycle<sup>22</sup>, and are expressed as four services. They are easily automatable and place  
470 responsibility for standards of performance with the transacting parties, consistent  
471 with the GWAC TE Principles and further support the TEA Transactive Energy  
472 description.

473 We recommend that implementers and integrators of Transactive Energy Systems and  
474 other teams in the NIST Transactive Energy Challenge use these Common Services to  
475 simulate simulations, generalize results, and to accelerate their work.

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<sup>22</sup> Since the EI services were defined as a bridge, in fact they abstracted from a broad range of markets; the Technical Committee has received no market system examples that cannot be implemented using these services.

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480 12. Annex 1

481 Summary of analysis of Transactive Systems of Interest and integration with Common Transactive Services.

482

Abbreviation	EI	IEC Markets	PNW	PM	TEMIX
<i>Common Transactive Service</i>	<i>Energy Interoperation</i>	<i>IEC 62325 Family</i>	<i>Pacific Northwest Smart Grid Demonstration Project</i>	<i>PowerMatcher</i>	<i>TEMIX</i>
Quote	For the OpenADR profile, EiEvent with timed series of prices. Quotes are logically and formally equivalent.	Various Open Access Same-time Information System (OASIS) functions for previous market cycle clearing. Information on current and future cycles is within the market facilitation function and not disclosed.	A forward curve for a blended energy price, based on energy that is intended to be imported into and/or generated at a node in an upcoming time period is exchanged between nodes This incentive signal represents a forward "delivered cost of energy" at the location, on which demand planning decisions may be made.		<i>Typically not used.</i> Use the Tender Service with indication of interest set.
Indication of Interest	A "soft tender" that cannot be accepted; transactive state in the tender service must be set to "Tender" to allow transition to Transaction. If interested, a party responds with a Tender.		Node locations respond to the price signals with forward demand intentions for the aggregate loads at this location, including for the energy that is planned to become exported from this location.		A "soft tender" in the Tender Service that cannot be accepted; If I'm interested, I respond with a Tender.

Abbreviation	EI	IEC Markets	PNW	PM	TEMIX
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Tender	Binding price, quantity and product buy/sell offer to counterparty at an Energy Services Interface(ESI) for an interval with an expiration date/time. CIM demand and supply curves may also be used.	The equivalent term is <i>Bid</i> as defined in 62325-301 (classes Bid, ResourceBid) which in turn is associated with a MarketProduct.  Subclasses are GeneratingBid, LoadBid, InterTieBid, each with a specific start and stop time (equivalent to a WS-Calendar Interval)	An offer for a sale or purchase is implicit in the Incentive and Feedback signals. An Incentive signal is similar to an offer to sell energy at that price from the transmission system, while an offer to purchase is an expression per node in terms of the load expected at that price by time period.  The framework does not presently support commitment, but it may be extended to support commitment, which would recognize resources and loads as no longer offering their potential for flexibility to the system.	Send demand and supply curves to a 'matcher agent', which clears the market. Equivalent to sending set of tenders.	Binding price, quantity and product on an interval for a buy/sell offer to a counterparty at an Energy Services Interface(ESI) with an expiration date/time.
Transaction	Binding acceptance of all or a portion of an active tender quantity at tendered price	Cleared by Market Operator based on Bids (Tenders) received for a market cycle.	Discovery of the price and demand curves results in an expected interconnect schedule, however, schedules would need to be tagged by a balancing authority for transmission transparency and scheduling. Transactions that occur in the market would be settled after-the-fact, based on the expected power flow (schedules vs actuals). Thus, the transaction is based on the last clearing price, but no affirmation of the transaction is passed between the nodes. See the possible extension discussed in the "Tender" row.	Receive notification from matcher as to market clearing prices	Binding acceptance of all or a portion of an active tender quantity at tendered price.
Delivery	Verified asynchronously by meter data.	Verified asynchronously by meter data.	It is perhaps implicit that the final negotiated schedules are delivered. The framework allows for delivery through constrained conduction pathways to become disincentivized.	Implicit	For each metered delivery interval for the ESI the meter reading is compared to the net position from all forward transactions for the interval and any difference resolved ex-post by a transaction formed by acceptance of a tender from a balancing party.

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Product Definitions	Real, Reactive, Apparent Power and/or Energy; transport for those products.  Work under way in The Energy Mashup Lab and published expressing products including thermal energy/power and non-energy products such as bandwidth	MarketProduct and related classes. Broad classes of products with many market-based variations (part of market description or common understandings) including power, energy, cross-tie, transport, congestion	Demonstrated products include power, incentivized consumption of renewable energy, outage contingency response, and the incorporation of existing time-of-use and demand charges.  Products are further extensible for each node owner to represent the impacts of not only marginal resource costs, but also the impacts of utility programs (e.g., demand charges, time-based and tiered charges), transport constraints, infrastructure costs (that represent about 2/3 the delivered costs of energy), regulations, and other things that affect the delivered cost of energy.	In practice power only, product and currency can be configured on cluster level	Real energy only or real and reactive Energy and energy Transport. Energy and Transport products are typically intended for physical delivery Financial Energy and Transport products settled against a market index price are also supported.
Setup for Transactive Environment	Parties register an ESI and an enabling agreement with potential transaction counter parties. Initial budgeting is a pre-requisite; currency and product definitions are part of the enabling agreements and should be reflected in market rules.	MarketParticipant must register, show financial solvency and stability. Once registered as a participant submits demand or supply tenders (bids)	Services require nodal participation in a regional network. Nodes are standardized for communication with other nodes.	Services implemented in prospective participants; participant discovers and binds to a Power Matcher or Aggregator node	Parties register an ESI and an enabling agreement with potential transaction counter parties.



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Timing	Asynchronous tender creation and acceptance	Various. The majority of instances fall under forward (usually next day), real time with 5 minute to 1 hour periods	As demonstrated, signal exchange occurs every interval (e.g., 5 minutes), but the designers intend to eventually make systems event-driven, and rapid signal exchange for arriving at an equilibrium may require iteration.	Event-driven: When something changes at the device level, the PowerMatcher market re-clears. PowerMatcher can be connected to external markets with different timings.	Asynchronous tender creation and acceptance on forward intervals of years, months, days and hours, 5 minutes and 4 seconds, for example. After the fact tenders might be used to correct for overdelivery and underdelivery.
Market	Each party decides how much of each tender to accept as a transaction. Continuous creation and acceptance of typically small forward tenders	Many diverse markets, products, and rules.	A specific market design. System may accommodate price impacts from existing markets if such pricing is transparent and available.	A specific market design. Straightforward curve/clearing.	Each party decides how much of each tender to accept as a transaction. Continuous creation and acceptance of typically small forward tenders. TEMIX markets can be interfaced with existing markets.
Other	Can use CIM curves and select specific tenders. Tenders may be partially accepted.	Typically market participants must know their supply/demand curves	The system framework is potentially very distributed. The framework allows for an extensible set of functional behaviors through the formulation of "toolkit functions" that model system responses as functions of the transaction signals.	Knowing your own supply and demand curves may be difficult a priori.	No communication of supply/demand curves. All parties can self-dispatch based on forward tender prices.

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<i>Notes</i>	Components of a tender should be based on market agreements. Distributed Agreement Protocol (Transaction Processing) ramifications must be considered--the simplicity of single period tenders must be offset against the complexity of not acquiring a time series of required energy/power.	An economic demand curve are a typical attribute of a bid in many markets.	An offer to sell is very short lived, as the next computational iteration of the price/incentive signal is executed (nearly immediately) as nodes exchange signals. In theory, the signal is relaxing into an equilibrium where each node in the system is served the lowest potential price for the load they have indicated for every period. The price input for the price signal is based on the number of deliverable resources available in the grid to supply load, at their market cost of service for each period. The prices bid need not be static in time.  Each distributed generation resource impacts the price since, if the price for transmission-supplied power is "higher" than the marginal cost of a DER, then it could be scheduled, decreasing the load exposed in the balancing control area, and theoretically decreasing the price (supply is known, demand decreases, thus supply price drops).	Participants provide their complete economic supply and demand curves.  Consider relating to TEMIX/Energy Interoperation asynchrony and continuous clearing	A TEMIX tender is for a single time period and typically expires after a short time (depending on market design).  To facilitate transaction liquidity, compound forward transactions among multiple parties and across multiple intervals are automatically built up from smaller single period transactions for energy and for transport.  This results in a dynamic equilibrium across the market. Forward transactions by each party serve as a contracted baseline for subsequent transactions without loss in transaction flexibility.
<i>References</i>	OASIS Energy Interoperation, 11 June 2014, <a href="http://docs.oasis-open.org/energyinterop/ei/v1.0/os/energyinterop-v1.0-os.html">http://docs.oasis-open.org/energyinterop/ei/v1.0/os/energyinterop-v1.0-os.html</a>	IEC 62325 series including 62325-301 and information/message exchange profiles.  <a href="https://webstore.iec.ch/archform&amp;q=62325">https://webstore.iec.ch/archform&amp;q=62325</a>	Demonstration Report: Pacific Northwest Smart Grid Demonstration Project Technology Performance Report Volume 1: Technology Performance, June 2015, Battelle Memorial Institute <a href="https://www.smartgrid.gov/document/Pacific_Northwest_Smart_Grid_Technology_Performance.html">https://www.smartgrid.gov/document/Pacific_Northwest_Smart_Grid_Technology_Performance.html</a>  Additional References in Report.	Documentation at <a href="http://fpai-ci.sensorlab.tno.nl/builds/powermatcher-documentation/master/html/">http://fpai-ci.sensorlab.tno.nl/builds/powermatcher-documentation/master/html/</a>	OASIS Energy Interoperation, 11 June 2014, <a href="http://docs.oasis-open.org/energyinterop/ei/v1.0/os/energyinterop-v1.0-os.html">http://docs.oasis-open.org/energyinterop/ei/v1.0/os/energyinterop-v1.0-os.html</a>  Transactive Device Architecture and Opportunities, Grid-Interop 2012, <a href="http://www.temix.net/images/G112-Paper-12032012-Final_Cazalet_Sastry.pdf">http://www.temix.net/images/G112-Paper-12032012-Final_Cazalet_Sastry.pdf</a>

483 13. Annex 2

484 Three pages extracted from OASIS Energy Interoperation Standard, [http://docs.oasis-](http://docs.oasis-open.org/energyinterop/ei/v1.0/os/energyinterop-v1.0-os.html)  
485 [open.org/energyinterop/ei/v1.0/os/energyinterop-v1.0-os.html](http://docs.oasis-open.org/energyinterop/ei/v1.0/os/energyinterop-v1.0-os.html). The PDF is authoritative along  
486 with the associated schemas and WSDL files.

## 7.2 Pre-Transaction Services

Pre-transaction services are those between parties that may or may not prepare for a transaction. The services are EiTender and EiQuote. A quotation is not a tender, but rather a market price or possible price, which needs a tender and acceptance to reach a transaction.

Price distribution, which is sometimes referred to as *price signals*, is accomplished using the EiQuote and EiTender services. Quotes are indications of a possible tender price; they are not actionable. A Tender offers prices at which Transactions may be made; they are actionable.

As with other services, a Party MAY inquire from a counterparty what offers the counterparty acknowledges as open by invoking the EiSendTender service to receive the outstanding tenders.

There is no operation to “delete” a quote; when a quote has been canceled the counterparty MAY delete it at any time. To protect against recycled or dangling references, the counterparty SHOULD invalidate any identifier it maintains for the cancelled quote.

Tenders, quotes, and transactions are **[EMIX]** artifacts, which contain terms such as schedules and prices in varying degrees of specificity or concreteness.

Table 7-2: Pre-Transaction Tender Services

Service	Operation	Response	Service Consumer	Service Provider	Notes
EiTender	EiCreateTender	EiCreatedTender	Party	Party	Create and send Tender
EiTender	EiRequestTender	EiReplyTender	Party	Party	Request outstanding Tenders; request semantics with optional time Interval
EiTender	EiCancelTender	EiCanceledTender	Party	Party	Cancel one or more Tenders
EiTender	EiDistributeTender	—	Party	Party	For broadcast or distribution of Tenders

Table 7-3: Pre-Transaction Quote Services

Service	Operation	Response	Service Consumer	Service Provider	Notes
EiQuote	EiCreateQuote	EiCreatedQuote	Party	Party	Create and send a quote
EiQuote	EiRequestQuote	EiReplyQuote	Party	Party	Request outstanding Tenders; request semantics with optional time Interval
EiQuote	EiCancelQuote	EiCanceledQuote	Party	Party	Cancel one or more quotes
EiQuote	EiDistributeQuote	--	Party	EiTarget	For broadcast or distribution of quotes

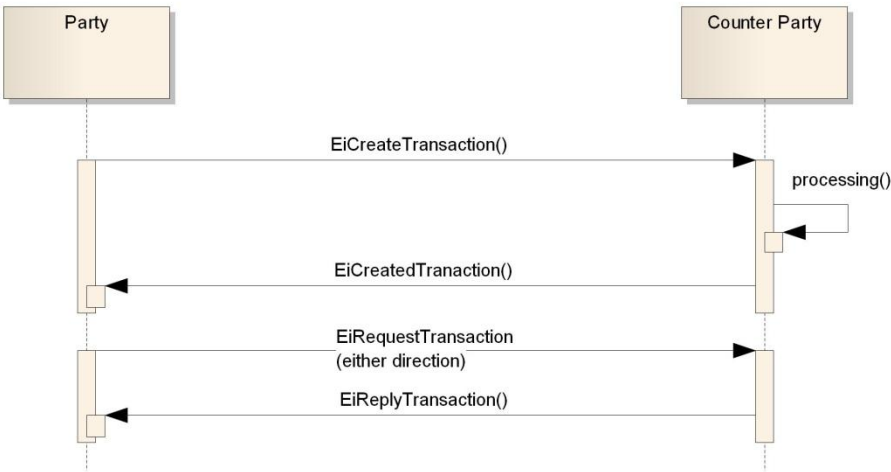
1572 There is no EiCancelTransaction or EiChangeTransaction operations. As in distributed agreement  
1573 protocols, a compensating transaction SHOULD be created as needed to compensate for any effects.<sup>7</sup>

1574 Table 7-4: Transaction Management Service

Service	Operation	Response	Service Consumer	Service Provider	Notes
EiTransaction	EiCreateTransaction	EiCreatedTransaction	Party	Party	Create and send Transaction
EiTransaction	EiRequestTransaction	EiReplyTransaction	Party	Party	Request extant Transactions

1575 **7.3.1 Interaction Patterns for the EiTransaction Service**

1576 This is the [UML] interaction diagram for the EiTransaction Service:



1577  
1578 Figure 7-8: Interaction Diagram for the EiTransaction Service

1579 **7.3.2 Information Model for the EiTransaction Service**

1580 Transactions are [EMIX] artifacts with the identification of the Parties.

<sup>7</sup> This is consistent with the way that distributed agreement protocols such as [WS-BusinessActivity] manage compensation rather than cancellation.

## 7.4 Post-Transaction Services

In a market of pure transactive energy, verification would be solely a function of meter readings. The seed standard for smart grid meter readings is the NAESB Energy Usage Information [NAESB EUI] specification.

In today's markets, with most customers on Full Requirements tariffs, the situation is necessarily more complex. Full Requirements describes the situation where purchases are not committed in advance. The seller is generally obligated to provide all that the buyer requires. Full requirements tariffs create much of the variance in today's DR markets.

These sections will apply a measurement model consistent with the [NAESB EUI] as in the EiReport Services.

### 7.4.1 Energy Delivery Information

These service operations respond with Energy Usage Information or any other single item of interest to the caller. This is very simple, requesting one thing measured for one interval, and waiting to return a value until the information is available. For anything more complex the Report Services should be used.

Table 7-5: Energy Delivery

Service	Operation	Response	Service Consumer	Service Provider	Notes
EiDelivery	EiCreateDelivery	EiCreatedDelivery	Party	Party	Party-to-Party, specifying interval, what is to be measured, and the direction for the measurement

#### 7.4.1.1 Interaction Pattern for the EiDelivery Service

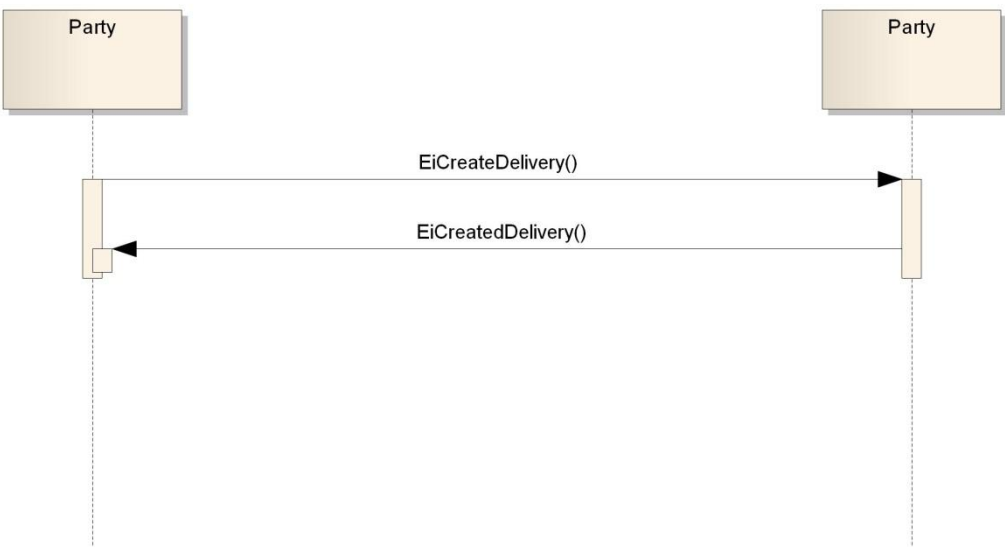


Figure 7-10: Interaction Diagram for Delivery Service

#### 7.4.1.2 Information Model for the EiDelivery Service

The EiDelivery Type is a simplified EiReport.