Common Transactive Services

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***Abstract*—** The NIST Transactive Energy Challenge Common Transactive Services (CTS) Team identified common services for transactive energy based on the NIST and SGIP-driven OASIS Energy Interoperation Standard (IEC 62939-3 in progress) that are minimal and complete for bridging between a set of deployed Transactive Energy Systems:

- Pacific Northwest Smart Grid Demonstration Project
- Power Matcher
- IEC 62325 national and regional markets
- TeMIX

The results show that the CTS allow integration and interoperation, e.g. deploying a PowerMatcher node within a containing transactive system, or a TeMIX node in a PNWSG system that in turn interoperates with an IEC regional market.

This summary paper is based on the full report[6]

I. Purpose

As Transactive Energy system deployments proliferate, they need to work together at boundaries between systems. The Software Engineering Bridge Pattern [1] 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 [2] and the NIST Framework and Roadmap for Smart Grid Interoperability Standards [3] this protects investment and decouples to simplify evolution.

We identified common services for transactive energy that are both minimal and complete with respect to a set of deployed transactive energy systems. These Common Transactive Services can be used as a basis for interoperability among existing and future TE systems.

These services semantically interoperate with all of our systems examined 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), the Transactive Energy Association, and the SGIP-supported and OASIS-produced Energy Interoperation and Energy Market Information Exchange.

We were fortunate to have team members and additional contributors that were experts in, architects of, interoperation with, and/or implementers of the transactive systems examined. The team plans to release the full report under the Apache 2 license allowing broad application and reuse of this work.

II. Common Transactive Services Requirements

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) Standard, providing service requests and responses that are clearly defined and standardized
(2) Extensible and adaptable, with standard models for price (in any currency) and product definition
(3) Open (free to read and use)
(4) Amenable to open source implementations
(5) As simple and minimal as possible

CTS should be capable of implementing transactive energy and

(1) Supporting GWAC's Transactive Energy Principle 1 [4] to allow "highly automated coordinated self-optimization".
(2) Bridging to and from each transactive system studied, and preferably to most transactive system

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

III. Common Transactive Service Definitions

The services are listed in Table 1. There are active open source projects implementing the Common Transactive Services.

Not all TE systems use these names for their various services and may omit one or more of these concepts. We use names and definitions drawn from economics and markets to describe Transactive Services, as standardized in OASIS Energy Interoperation. [5] [6] Each service has several Service Operations; we omit the *Ei* prefix for the standard service descriptions.

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[6] Available in https://github.com/EnergyMashupLab/TransactiveEnergyChallenge/tree/master/CommonTransactiveServices

Table 1 -- Common Transactive Services

Common Transactive Service	Description	Other Names Used
Quote	Provide or request a price quotation on a product	Price quote, quote
Tender	Make a tender to buy or sell a product. Tenders may be binding or non-binding.	Offer, bid
Transaction	Accept a Tender, agreeing to and creating a Transaction binding on the parties.	Acceptance, contract, clearing[7]
Delivery	Meter the actual delivery quantity[8]	Verify, certify, meter, read meter

IV. SEMANTIC AND SYSTEM INTEROPERABILITY

S*emantic interoperability* suggests that core transactive functions can be mapped between transactive systems. *Semantic interoperability* is necessary but not sufficient for *system interoperability*; there is a broader set of *system interoperability* requirements described in the GridWise Architecture Council stack. [7]

We focus on the *Semantic Understanding* layer; this layer and lower layers must be bridged for communication to take place by applying the aptly named Bridge software engineering pattern [8].

The Common Transactive Services define what needs to be mutually understood [9] by the parties to a transaction:

- Transactions are energy-economic exchanges between parties. The exchanges between parties necessarily include information exchange including product definition, delivery location, and time interval
- Transactions reference products and services (such as energy, transport, reserves, frequency support)
- Participants determine value to them 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[9]

The Common Transactive Services semantically support the services in any transactive system also support semantic and syntactic interoperability between systems—by going from the first system to the common services to the second system. So at the boundaries—system or grid or microgrid—we can connect diverse transactive systems using the CTS. For example, a PowerMatcher node can interoperate with an IEC Markets system or a TransactiveADR or TEMIX system.

V. TRANSACTIVE ENERGY BACKGROUND

V.1. Transactive Energy General Considerations

The GridWise Architecture Council Transactive Energy Framework defines Transactive Energy as

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. [10]

The Transactive Energy Association describes Transactive Energy as follows:

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 [11]

The transactive systems studied fit within these definitions and descriptions.

We note 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
- TE systems engage multiple parties (system operators, generators, markets, customers, aggregators, etc.)

The authors recognize that the CTS are universal in only a limited way, and do not cover the entire TE process, providing pre-transaction (Quote), transaction (Tender and Transaction), and post-transaction (Delivery) services, but do not cover all information exchanges, nor address communications. Nonetheless, the CTS provide a minimal set of common transactional services semantically consistent with and capable of mapping to and from other transactive systems.

To summarize, Transactive Energy enables the use of economic constructs for grid and energy management. We indicate how the CTS work with a variety of TE systems.

V.2. A Market Interoperation Perspective

There are significant similarities and significant differences across Transactive Energy Systems. 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.

Using the Common Transactive Services allows 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[10] and also enables

[7]7 This is different from *market clearing* which is a function internal to a market.

[8] If the measured delivery does not match the contracted (transacted) total quantity then a balancing transaction will be necessary.

[9] For example, a grid operator must maintain grid stability; a building owner must meet requirements of their buildings' business functions while minimizing expense; cost of energy is one input to both parties' objectives.

[10] A project in the AllSeen Alliance (Linux Foundation Internet of Things) led by The Energy Mashup Lab uses the Common Transactive Services for managing resources; appliance manufacturers are involved.

- Use of Common Transactive Services for more broadly applicable simulations of transactive systems
- Common understanding, terminology, and training for software architects and engineers

VI. Transactive Systems

More information and detailed references are in the CTS Team Report. [12] The Team was fortunate to have members that were experts in, architects of, and/or implementers of the transactive systems examined.

VI.1. Overview

The transactive systems examined were:

(1) OASIS Energy Interoperation— designed as a bridge between diverse systems; profiles include TEMIX and OpenADR2. [5] The basis for the Common Transactive Services
(2) Pacific Northwest Demonstration Project—a Department of Energy Project using incentive signals for balancing power across a region [13]
(3) PowerMatcher—used in power balancing among devices and subsystems [14]
(4) IEC 62325 Family [IEC Markets]—as used in national and regional markets [15]
(5) TEMIX or Transactive EMIX—a profile of OASIS Energy Interoperation and OASIS Energy Market Information Exchange (EMIX) [16].

In the full report we apply the CTS to bridging to and from two additional systems in development:

1) Transactive ADR—a project underway in the NIST TEC to extend OpenADR2 with transactive services and supported by participants including the OpenADR Alliance [17]
2) The MIT Transactive Control System—a system under development to address transactive algorithms [18]

VI.2. Products in Transactive Systems

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

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 whether the subject of transactive balancing is demand, energy, or both.

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

Table 2 -- Products in Transactive Systems

Products	CIM	PNW	Power Matcher	TeMIX	CTS
Power	Yes	Yes	Yes		Yes
Energy	Yes			Yes	Yes
Forward	Yes	Near term		Yes	Yes
Transport	Yes			Yes	Yes
Ancillary	Yes			Yes	Yes

Only IEC Markets and Energy Interoperation address all of the products among the Transactive Systems of Interest. Energy Interoperation is far simpler [2].

VI.3. 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. [15]

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.

VI.4. Pacific Northwest Smart Grid Demonstration Project [PNW]

PNW [13] 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. For an extended discussion of this system see the Common Transactive Services report. [12]

Some adaptation of Energy Interoperation services is necessary to communicate PNW service information. An extension to a supply or demand curve-based tender may be needed to carry the additional signal information.

Transactions are 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.

PNW incentive signals can likely be implemented as tenders with transactive state = indication-of-interest tenders. 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.

VI.5. PowerMatcher [PM]

PowerMatcher [14] balances power across sets of devices; PowerMatcher nodes may in turn participate in higher-level sets of "devices."

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[11]) 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.

VI.6. TeMIX

TEMIX [19] 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.

No adaptation of Energy Interoperation services is necessary.

TEMIX restrictions on product definition and implications for market liquidity are relevant to market design.

VII. Discussion and Conclusions

We have defined and shown the application of a small set of standardized [5] [6] Common Transactive Services. The transactive services were designed as a bridge and were 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.

The Common Transactive Services are easily automatable and place responsibility for standards of performance with the transacting parties, consistent with the GWAC TE Principles and further support the TEA Transactive Energy description.

We recommend that implementers and integrators of Transactive Energy Systems consider the application of these Common Services to drive their architecture and design, integrate other transactive energy systems, and to accelerate their work.

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IX. Biographies

Edward Cazalet is a leader in the design of transaction services for electricity, the commercialization of electricity storage, and the analysis of energy decisions.

Ed is the founder and CEO of TeMix Inc., a transactive energy services company and a founder and VP of MegaWatt Storage Farms Inc., a grid storage advisory firm. He was previously a Governor of the California Independent System Operator (CAISO). He was also the founder and CEO of Automated Power Exchange (APX), the first on-line, wholesale power exchange.

Dr. Cazalet has extensive experience in designing, building and operating high-speed, reliable transaction systems for electric power that interface with existing transaction systems and markets. He was also co-chair of OASIS Energy Market Information Exchange Technical Committee.

Dr. Cazalet holds a Ph.D. from Stanford University focused on economics, decision analysis and power systems. He also holds BS and MS degrees in engineering from the University of Washington.

William Cox is a leader in commercial and open source software definition, specification, design, and development. He is co-chair of the OASIS Energy Interoperation and Energy Market Information Exchange Technical Committees, and a member of the WS-Calendar and OBIX Technical Committees. He leads work on UML and other models for schedule, demand response, transactive energy and interoperation. He participates in related IEC standards work.

As part of the national smart grid activities since 2008, he contributed architecture and interoperation to national reports and led key priority action plans in the SGIP.

He has developed enterprise product architectures for Bell Labs, Unix System Labs, Novell, and BEA, and has done related standards work in OASIS, the Java Community Process, Object Management Group, and IEEE.

He earned a Ph.D. and M.S. in Computer Sciences (minor in Electrical and Computer Engineering) from the University of Wisconsin-Madison.

He is Chief Technology Officer of The Energy Mashup Lab, Inc.), an open source transactive energy foundation, and Principal of Cox Software Architects LLC, a consulting software architecture firm.

William Miller is President of Maximum Control Technologies (MaCT), a MILLER W J & ASSOCIATES Company with offices in the United States and Canada.
Education: Pennsylvania State University, Electrical Engineering and Telecommunications with over 35 years of experience in systems integration and design of process control systems for power, pulp & paper, chemical, and cement industries.

Standards Associations: ISA-99 Industrial Automation & Control Systems WG, Member; ISA100.20 Common Network Management WG, Co-Chair; IEEE P2030 TF3 WG2 Interoperability of the Smart Grid Use Cases, Chairman; ISO/IEC/IEEE P21451-1-4 (Sensei-IoT*) WG, Chairman.

NIST Working groups: CPS WG – Interoperability; CPS WG - Time Synchronization; Big Data WG; Data Forensics WG; Data Analytics WG; Community Resiliency Pane; IoT-Enabled Smart City Framework WG. SGIP CyberSecurity and Uses Cases Task Forces.

Alexander Krstulovic is IT & DevOps Consultant on Energy Transitions (Medior) at Alliander, Arnhem, The Netherlands. He is a leader in the definition, deployment, and dissemination of the PowerMatcher technologies. He is currently involved in shaping the future of the PowerMatcher, a disruptive transactive smart energy technology. With a mechanical engineering masters background and hands on IT experience working as a programmer, scrum master or product owner on various IT projects combined with a wide interest ranging from fields such IT security to Logistics and Entrepreneurship he brings his wide skill base, and activation of innovation, to give pragmatic shape to the energy transition.

He was a graduate intern and then researcher at TNO, The Netherlands.

His previous work includes information security, modern software development techniques, and applying mathematical techniques to forecasting and dynamic system behavior.

Wilco Wijbrandi is a Scientist Innovator at TNO, Groningen, The Netherlands. His current projects include FlexiblePower Application Infrastructure—this OSGi-based framework provides an easy way to deploy and configure smart grid applications such as PowerMatcher, and Flexigas—working toward economic and sustainable integration of biogas into the future national and decentralised energy systems including the smart grid.