Transactive Control and OpenADR Roles and Relationships

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Introduction

The purpose of this document is to provide a framework that simplifies understanding the interrelationships between Transactive Control (TC), Transactive Energy and Transactional EMIX (TeMIX), and OpenADR source standards – Energy Interoperation (EI) and Energy Market Information Exchange (EMIX). The goal is to clarify for the smart grid community the various roles, complements and overlaps of the emerging standards. Rightly or wrongly, the market has begun to view TC and OpenADR as competitors.

We start with a high level overview of each of the relevant technologies and standards, followed by an analysis of where they complement each other and where they overlap.

The complexity of smart grid technologies can make it difficult to differentiate the roles that many of the standards and profiles discussed in this paper play in smart grid operations. By profile, we are referring to a well-defined subset of a standard, typically with a set of conformance rules that bound the profile's implementation. For instance, OpenADR is a well-defined subset of Energy Interoperation.

Please note that many concepts related to these standards have been over-simplified in the following narrative in order to aid the reader in grasping big picture roles and differences between the standards.

The conclusions to this paper are framed from the perspective of Transactive Control and provide a framework for assessing the relevant standards in this context. Companion papers could easily use the source material in this paper to assess relationships from different perspectives.

Transactive Energy

Transactive Energy is not a standard, but rather a technique whereby the consumption or flow of electric power is managed using economic or market-based constructs. Energy transactions and/or operational decisions are based upon a value that represents the relative or actual economic value associated with the energy and its delivery.

The drivers behind the adoption of Transactive Energy include an increasing proportion of intermittent resources on the supply side, such as solar and wind, the addition of distributed energy resources that may not flow in a top-down manner, and the addition of electric vehicles as a potentially significant load factor. Traditional top-down control systems may be inadequate to economically and efficiently maintain system reliability as these drivers evolve over time. Transactive energy represents a more dynamic long-term solution where market forces are utilized to implement a decentralized closed-loop control system to deal with these new drivers.

There are several somewhat divergent definitions of Transactive Energy. The GridWise Architecture Council (GWAC) has described a formal framework for Transactive Energy, based on a definition in which Transactive Energy includes both economic mechanisms and control mechanisms. The objectives of the transactions within this framework include stabilizing the grid and dynamically balancing energy flow through the entire electrical infrastructure. The "value" considered in these transactions includes not only economic value but also operational concerns, such as grid stability and human preferences, that are not necessarily economically based – e.g., comfort at any cost. This broad interpretation of "value," along with the notion that a primary motivation for the transactions is the direct operational control of the grid and its distributed assets, is a key element of the Transactive Energy, in the Council's view. The Council's definition is purposely broad with the intent of being applicable to a number of different specific implementations of Transactive Energy systems.

A narrower definition of Transactive Energy comes out of the work done on TeMIX that is described further on in this paper. The concept is that Transactive Energy consists of frequent, easily-understood, peer-to-peer automated transactions between buyers and sellers. Buyers and sellers may be generators, loads, storage, or traders with no actual delivery and metering. Parties to a transaction take a position, which is a contract for delivery of a quantity of an energy product over a duration delivered to a location. Positions may be modified by additional buy and sell transactions as the forecasted market value of energy and consumption needs change. It is this continuous adjustment of positions based upon frequent transactions driven by changes to the market value of energy that characterizes Transactive Energy. Note that with this model, the "value" is purely economic and the assumption is that market forces (many transactions) will cause operational concerns to take care of themselves.

However, we are in the early stages of the adoption of an end-to-end Transactive Energy ecosystem, as shown in figure 1. In the broadest context, any current technology where the decision to participate in an energy transaction or make operational decisions based upon a value representative of economic or operational value could be considered Transactive Energy. Examples might include trading in the wholesale electricity market or decisions to participate in Demand Response events based upon electricity pricing information.

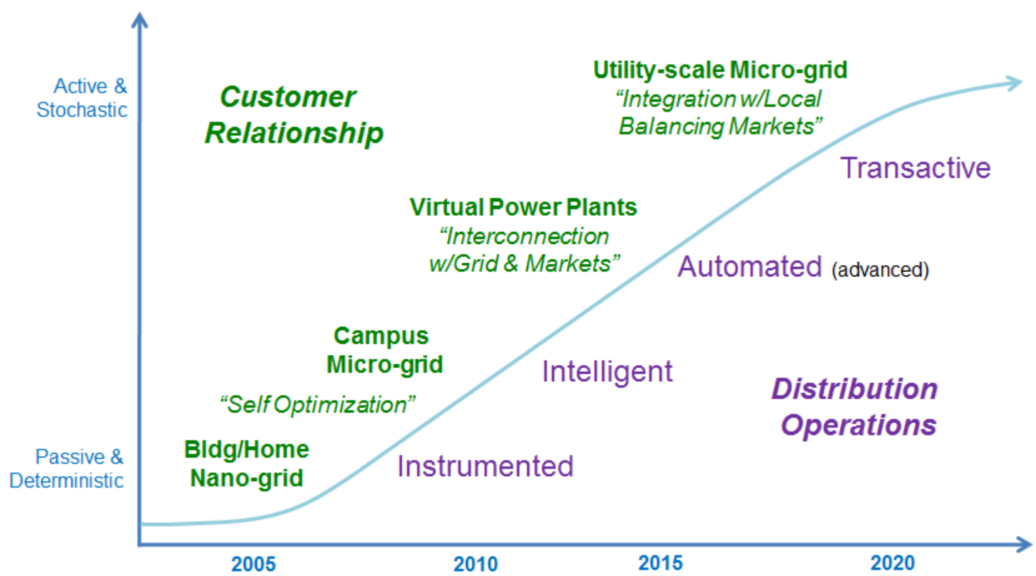

Figure 1: Stages of adoption of transactive operations for industry

Source: Paul De Martini, 1st International Conference and Workshop on Transactive Energy[9]

Transactive Control

Transactive Control is a specific case of the general class of techniques referred to as Transactive Energy. The focus of Transactive Control, as the name implies, is on making operational "control" decisions based upon a "value," which may represent purely economic or some more abstract notion of value that could encompass factoring in operational concerns.[1] The PNW-SGDP is an example of a Transactive Control implementation. The Project demonstrates a distributed hierarchical system that includes a set of transactive signals that are distributed to coordinate future supply and load. This system of transactive nodes is designed to distribute the decision making throughout the transmission and distribution system, and has been architected to scale from large transmission sites down to customer premises. The transactive signals exchanged between nodes include a Transactive Incentive Signal (TIS) representative of forecasted energy costs and a Transactive Feedback Signal (TFS) representing forecasted energy flow through a node. By distributing these incentive and feedback signals, each transactive node can make informed local decisions to optimize costs across its energy supply and load consuming assets.

Figure 2 on the following page illustrates a simplified use case to aid the reader in understanding the core functionality of Transactive Control. Assume a Transactive Control network with two nodes, one that supplies energy (a supply node) and one that consumes electricity (a load node). The load node is associated with one or more responsive assets capable of modifying their load profiles. Similarly, the supply node is associated with one or more responsive assets capable of modifying their energy supply profile.

The following is a typical Transactive Control exchange from the perspective of the load node:

The supply node and load node exchange incentive and feedback signals every five minutes or when there is a change in conditions resulting in a significant change in the value of the TIS or TFS.

The load node's decision logic looks at both the future incentives (costs) and local conditions, including load requirements, and makes a decision whether to modify the planned behavior of responsive load assets at each future time interval in response to changes in the incentive signal or due to modified plans for use of the asset.

The load node will then update its energy flow forecast, based on the updated plan for load behavior, and a revised set of incentive and feedback signals will be exchanged between the supply and load nodes. This exchange results in another cycle of these steps until there is no significant change in TIS or TFS values. At that point the system has settled and agreement has been reached on the future action on both sides.

Each five minutes during the current time interval, the plan for load behavior is implemented by communicating to the responsive asset(s) via an advisory control signal

[1] It should be noted that the term "transactive control" was chosen for the Project's technology before the techniques had been fully developed. A more correct term is "transactive control and coordination."

(ACS). The ACS signal is functionally equivalent in this example to a Demand Response event in the OpenADR standard.

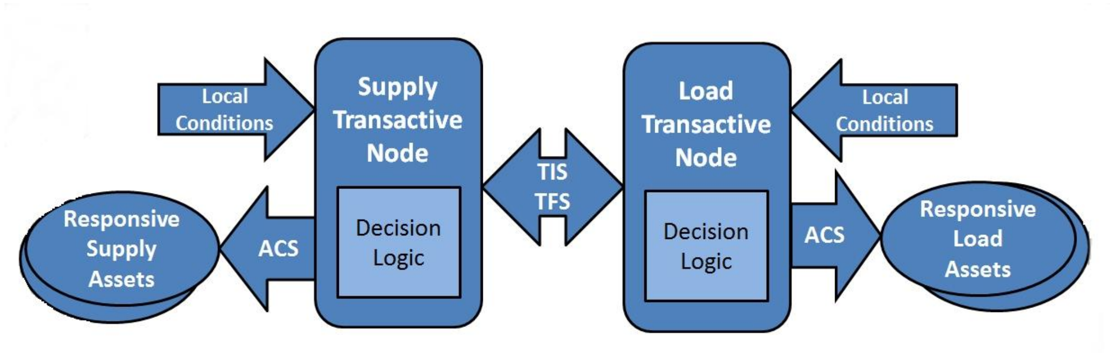

Figure 2 - Transactive Control

The core framework for the PNW-SGDP reference implementation of transactive control is IBM's Internet-scale Control System (iCS) an implementation of ISO/IEC 18012. This standard outlines a methodology for abstracting control system primitives such that the triggering and reporting on the control behavior can occur across disparate implementations from different vendors. In transactive control this provides a framework for the control of responsive assets that may uses a wide variety of control standards and transports.

Energy Market Information Exchange (EMIX)

The OASIS Energy Market Information Exchange (EMIX) standard defines an information model to exchange price and product information for power and energy markets. Prices and products are actionable information. Automated systems can use the EMIX standardized information model to make decisions which optimize energy and economic results.

In energy markets, the price is strongly influenced by the time of delivery. EMIX utilizes the OASIS WS-Calendar standard to efficiently convey a delivery schedule context around the EMIX price and product information. Price may also be influenced by how the energy is produced or generated and EMIX allows energy products to be differentiated along these lines.

EMIX is intended for commercial transactions in all types of energy markets. Transactions start with a tender, which is an offer to buy or sell between two parties. Once agreement is reached, parties agree to a transaction, which is a contract or award. The parties to the transaction then perform by arranging for supply, transport, consumption, settlement, and payment. The EMIX standard provides a generalized information model for the tenders and transactions. EMIX also supports energy options, which is an instrument that gives the buyer the right, but not the obligation, to buy or sell a product at a set price during a given time window.

It is best to think of EMIX as a tool box that can be utilized to construct energy products for a given market and need. The tools include inheritance methods to efficiently communicate the same product being delivered in different time frames (gluons, sequences), methods to describe standard terms and market expectations (market context), and methods to express the source of energy or its environmental characteristics (warrants).

The EMIX standard defines a set of extensions specific to representing power products with support for characteristics such as real, apparent, or reactive power, as well as ways to describe levels and tiers. These extensions are used in the standard to define the following detailed EMIX product descriptions:

- Power products that are bought under terms that specify the energy and its rate of delivery over a duration, or made available for up to the maximum deliverable by the in-place infrastructure
- Resource offers that include characteristics of generators, storage resources, and loads that produce power through curtailment, as well as the prices and quantities of products/services offered
- Transport products provide for the transport of a product using transmission and distribution facilities from one location to another. Transport pricing includes factors such as energy loses and congestion prices.

Each of these products supports a wide variety of transaction types such as Full Requirements Power, Transport Services, and Demand Charges. Finally, the EMIX standard defines a profile for representing power products used in a Transactive Energy exchange, referred to as TeMIX. This profile is described in more detail in the following section.

Transactional EMIX (TeMIX)

Transactive Energy requires clear signals that can be easily understood within the context of frequent automated exchanges. The OASIS EMIX standard provides a tool box to construct energy products that encompass all the complexity and diversity of the energy marketplace. The TeMiX profile defines a subset of the EMIX power product descriptions by defining conformance rules that constrain the complexity of the power product offerings used in Transactive Energy. Note that the term "profile" refers to a formally-defined subset of a standard targeted at a well-defined usage model.

TeMix products are transactions to deliver power at a constant rate over a single time interval. The price of a TeMIX product does not vary during the single time interval that represents a product. The notion of a constant delivery rate and unchanging price for the limited time durations represented by a TeMIX product greatly simplifies transactions. Each transaction imposes an obligation on the buyer to purchase and on the seller to deliver one of the four TeMIX Power Products listed below:

- TeMIX Power Product
- TeMIX Transport Product
- TeMIX Option Power Product
- TeMIX Option Transport Product

The TeMIX option products describe a transaction type where one party to the transaction has a put option (right to sell) or call option (right to buy). Once the option is exercised, it becomes a TeMIX power or transport product. Option transactions can provide "price insurance" or be used to transact capacity, ancillary services and Demand Response.

The TeMIX profile defines a small subset of EMIX schema elements that are used to define the four TeMIX products, accomplishing the goal of having clear and easily understood transactions.

Note that TeMIX is also a profile in the Energy Interoperation standard, which defines services for exchanging TeMIX products. Energy Interoperation is described later in this document. Furthermore, a broader description of TeMIX from both a technical and business context has been defined in an EMIX white paper (see references in Appendix A).

While TeMIX is an intriguing profile of EMIX, there is not a formal industry alliance attempting to implement the technology and TeMIX does not explicitly account for incorporating consideration of system balancing and control. It is also important to note that TeMIX reflects a specific approach to implementing transactive energy systems and the TeMIX product profiles reflect that particular approach.

Energy Interoperation (EI)

The OASIS Energy Interoperation (EI or Energy Interop) standard describes an information and communication model to coordinate the supply, distribution, and use of energy between two parties. The parties could include energy suppliers and customers, markets and service providers, and many other domains. Messages communicated between parties can communicate price, reliability, and emergency conditions in the context of real time interactions, forward projections, or historical reporting.

EI is intended to support market-based balancing of energy supply and demand while increasing the fluidity of transactions. To balance supply and demand, EI facilitates the scheduling of resources, management of aggregation, communication of scarcity and energy surplus, emergency and reliability events, trading of curtailment and supply of energy, and much more.

EI relies on a standard format for communicating time and intervals (WS-Calendar) and for energy price and product definitions (EMIX). EI further expands the information model for representing energy transactions in the following areas:

- The actors and context around which a transaction takes place - parties, resources, market context, targets, Virtual End Nodes (VENs), and Virtual Top Nodes or (VTNs)
- A framework for describing event-based interactions, typically used in Demand Response transactions (Event Descriptions, Active Periods, Event Signals, Baselines).
- A framework for describing resource availability (opt schedules)
- A framework for monitoring, reporting, and projection (report specifier, report scheduler, reports)

EI defines a number of services that use a request-response interaction pattern between parties in a transaction. The payloads contain subsets of the energy information models described in EMIX and the expansion of this model as defined in EI. The services are divided into five broad categories as follows:

- Transaction Services - for implementing energy transactions, registration, and tenders (EiRegisterParty, EiTender, EiQuote, EiTransaction, EiDelivery)
- Event Services - for implementing events and linked reports (EiEvent)
- Report Services - for exchanging remote sensing and feedback (EiReport)
- Enrollment Services - for identifying and qualifying service providers, resources, and more (EiEnroll)
- Support Services - for additional capabilities (EiAvail, EiOpt, EiMarketContext)

As with EMIX, it is best to think of EI as a tool box that can be utilized to construct automated energy transactions. The EI standard defines profiles which recommend specific EI services for implementing OpenADR, TeMIX, and Pricing Distribution transactions. However, to apply EI to real-world use cases requires substantial sub-setting of the existing information models, adoption of the relevant service interaction patterns, and the development of conformance rules specific to the business and behavior patterns for the use cases. The following section describes OpenADR 2.0, which is an example of using EI for a specific set of use cases.

OpenADR 2.0

OpenADR is an application layer message exchange protocol used for two-way communication of Demand Response (DR), price, and Distributed Energy Resource (DER) signals between the electricity service provider and its customers. OpenADR 2.0 is a subset of the OASIS Energy Interoperability standard. There are two defined subsets for OpenADR 2.0, referred to as the A and B profiles, with the B profile providing much more robust functionality. This discussion will focus on the B profile.

Open ADR has two primary entities: A Virtual Top Node (VTN) that can initiate Demand Response events and a Virtual End Node (VEN) that can participate in an event (i.e., shed load). VTNs and VENs can be implemented in a hierarchical relationship, such as a utility playing the role of a VTN sending events to an aggregator that receives the event as a VEN then propagates the event downstream playing the role of a VTN, as shown in figure 3.

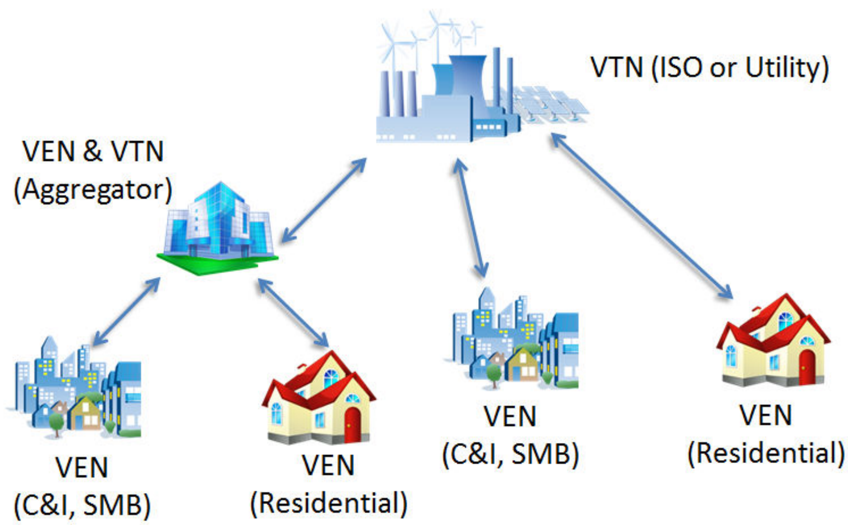

Figure 3 - OpenADR

VENs are associated with one or more resources that have a load profile that can be modified. Each VEN has some application logic associated with it, such as an Energy Management System, that has been pre-programmed to initiate a specific set of actions in response to signals contained in the Demand Response event payload sent by the VTN. Note, however, that the application logic is NOT part of OpenADR. The actionable information contained in a Demand Response event can include values such as energy pricing, load dispatches, simple levels, and a wide variety of other signal types, all associated with specific future time intervals.

OpenADR supports the following services in support of Demand Response interactions:

- EiEvent Service - Enables VTNs to send events and for VENs to optIn or optOut of events

- EiReport Service - Enables VTNs and VENs to declare their reporting capabilities, request reports from each other, and to deliver both one shot and periodic reports.
- EiOpt Service - Enables VEN to declare temporary availability schedules
- EiRegistration Service - Establishes a relationship between a VEN and VTN, but does not include enrollment.

The sub-setting of EI and the business rules necessary to implement OpenADR 2.0 were developed by the OpenADR Alliance. The requirements are captured in a stand-alone specification and XML schema. Part of defining OpenADR 2.0 included using the "tool box" contained in EI to construct standard event signals and report profiles that would be useful for the Demand Response use cases. Standard event signals include things such as energy pricing, load dispatches, and storage levels. Standard report profiles include telemetry usage and status reports, as well as historical reporting of power and energy. OpenADR currently supports two transports, simple http and XMPP, although there are no technical constraints to implementing OpenADR over other transports.

OpenADR 2.0 implementations have been developed by many vendors, and VENs and VTNs from these vendors are being deployed as part of utility Demand Response programs.

Summary

Table 1 below summarizes the key relationships between the each technology discussed in this paper, while Figure 3 on the following page provides a graphical view of these relationships.

	Transactive Energy (TE)	Transactive Control (TC)	EMIX	TeMIX	Energy Interoperation (EI)	OpenADR 2.0
Transactive Energy (TE)						
Transactive Control (TC)	TC is an implementation of TE					
EMIX	EMIX is a tool box that can be used to define TE products					
TeMIX	TeMIX is a well-defined TE product and a set of services		TeMIX is a power product profile of EMIX			
Energy Interoperation (EI)	EI is a tool box for constructing TE implementations		EI uses EMIX to define energy products	TeMIX is a defined power product and a profile of services for TE exchanges		
OpenADR 2.0	OpenADR could be considered an implementation of TE	OpenADR may be used to control assets in response to ACS signals	OpenADR uses EMIX for signal and report objects		OpenADR is a subset of EI as well as a defined EI profile	

Table 1 - Technology Relationships

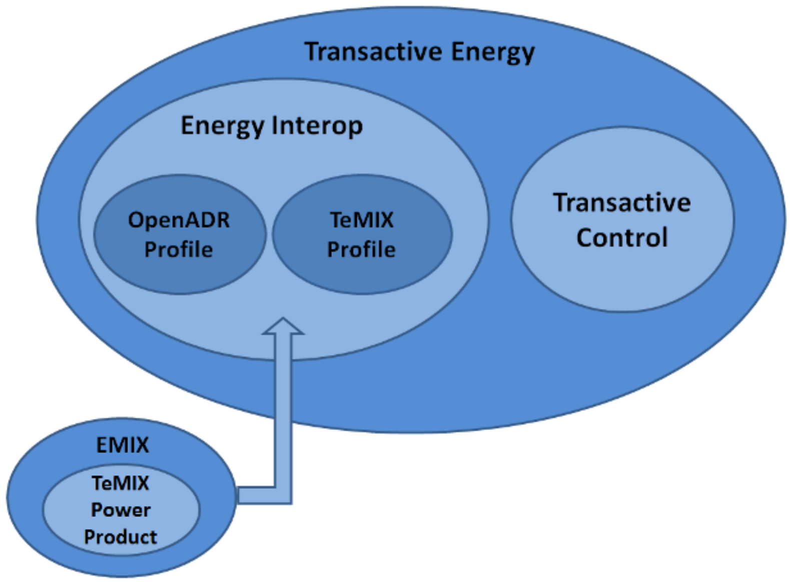

Figure 3 - Technology Relationships

The arrow in Figure 3 from the EMIX bubble to the Energy Interop bubble indicates that Energy Interop uses many of the EMIX schema elements, that the EMIX TeMIX power product profiles are related to the TeMIX profile defined in Energy Interop, and that OpenADR pulls in objects from the EMIX schema as well. EMIX serves as an "input" to the other standards/profiles in the Energy Interop bubble.

Another way to look at these technologies is to map them to the relevant layers (2 through 5) of the GridWise Architecture Council (GWAC) Context Setting Framework (GWAC Stack) as shown in Table 2. As EMIX products are included in Energy Interop, it was not mapped separately in this table. Nor was Transactive Energy included in the table as it is a conceptual framework rather than a specific instance of an implementable technology.

GWAC Stack Layer	Transactive Control	OpenADR	Energy Interop	TeMIX
Business Context	Yes, depending on the sophistication of the toolkit functions	Not Defined	Not Defined	Yes, the TeMIX business context is described a EMIX white paper
Semantic Understanding	Yes, schema and specification describe the semantic meaning of data contained in XML data structures	Yes, schema and specification describe the semantic meaning of data contained in XML data structures	Yes, schema and specification describe the semantic meaning of data contained in XML data structures	Yes, schema and specification describe the semantic meaning of data contained in XML data structures
Syntactic Interoperability	Formal XML Schema defined for message payloads	Formal XML Schema defined for message payloads	Formal XML Schema defined, although sub-setting would be required for specific application profiles	Profiles of Energy Interop and EMIX schema are defined for TeMIX.
Network Interoperability	Not formally defined, although iCS was used to facilitate interoperability between nodes	Specific IP based transports and endpoints defined	Not defined	Not defined

Table 2 - GWAC Stack Mapping

The most notable difference shown in the table above is the inclusion of business context into the Transactive Control and TeMIX technologies. While both TC and TeMIX are forms of transactive energy, the TeMIX notion of financial transactions as part of the transactive exchange between entities is not part of TC, nor is the energy flow feedback in TC part of TeMIX.

Although most of the technologies discussed in this paper play a role in the higher levels of the GWAC stack, such as Business Procedures and Business Objectives, it was the opinion of this author that these higher level GWAC stack layers are outside the formal definition of the technologies.

Conclusions

The primary intent of this paper is to determine, from the perspective of Transactive Control, whether the other standards discussed in this paper overlap Transactive Control functionally and where they might complement Transactive Control. Based on the previous analysis, only Energy Interop and OpenADR appear to be relevant for a more detailed comparison. Both standards have support for schedules, energy products, communication between transacting parties, and do not have conflicting business contexts.

The following key technical characteristics of the PNW-SGDP Transactive Control technology will be used as the as the basis for comparing Transactive Control to other technologies discussed in this paper.

- Targeted domains span the breadth of smart grid from wholesale to residential HAN
- A topology of node relationships based on the transmission and distribution of electricity
- An interoperability framework capable of interfacing with a diversity of legacy systems
- An application logic framework (Toolkit Framework) that enables the calculation of the delivered cost of energy (TIS) and the forecasted power flow (TFS) at a given location over a series of forecasted time intervals.
- The ability to periodically communicate the delivered cost of energy (TIS) and the forecasted power flow between nodes at a given location over a series of time intervals.
- A driver framework (Toolkit Functions and Asset Models) to enable triggering changes in the load or supply profile of responsive assets in response to changes in TIS/TFS and local conditions (Advisory Control Signals)

Table 3 on the following page uses the TC characteristics to explore whether EI or OpenADR could provide equivalent functionality as that provided by TC.

TC Characteristic	Energy Interoperation (EI)			OpenADR (OADR)		
	Overlap	Complement	Obstacle	Overlap	Complement	Obstacle
Targeted Domains	EI and TC both target the full breadth of smart grid domains					OADR targets a more limited set of domains than TC, primarily the utility, and C&I entities
Nodal Network Topology	Some EI services support peer-to-peer communication and could model the communication in TC					OADR is a one-to-many with VTNs serving multiple VENs. The TC topology, however, allows for peer-to-peer relations, which would require each node to support both VEN and VTN interfaces.
Interop Framework			EI does not contain an equivalent abstracted interface to legacy systems as in TC iCS			OADR does not contain an equivalent abstracted interface to legacy systems as in TC iCS
Application Logic Framework			EI does not define an application logic framework			OADR does not define an application logic framework
TIS/TFS Communication		EI could communicate TIS/TFS using the event and reporting services, however, a subset of EI would be required		OARD could communicate TIS/TFS using the event and reporting services		
***Driver Framework Triggering Asset Changes**			EI does not provide a framework for transforming signaling into actionable behavior		OADR could be used by the local asset driver to implement changes to load profiles triggered by ACS signals	OADR does not provide a framework for transforming signaling into actionable behavior

*Referred to as a "Toolkit Framework" in the PNW-SGDP

Table 3 - TC Characteristics Comparison

It is safe to say the there is little overlap between OpenADR and Transactive Control. While OpenADR would be capable of functionally duplicating the message exchange that occurs with TIS/TFS signals in Transactive Control, most other key attributes of Transactive Control are not available as part of OpenADR's defined functionality. It should also be noted that OpenADR is focused on a very clear set of use cases, that of Demand Response, and not the more generalized Transactive Energy space.

OpenADR may serve a complementary role in that Demand Response events could be used as follows within the context of TC:

- To signal load profile changes to responsive assets based on Transactive Control ACS signals
- To signal changes to local conditions as a local input to the TC node
- To functionally duplicate the TIS/TFS message exchange to provide a vehicle for migrating Transactive Control into legacy implementations.

Energy Interoperation has a greater degree of overlap with Transactive Control, supporting the same domains and nodal topology, but it still has some notable obstacles to duplicating the functionality contained in Transactive Control. Most notably, EI lacks an application logic framework.

As previously noted, EI is really more of a "tool box" than an implementable standard, and it would require considerable effort for a group of interested stakeholders to transform a "Transactive Control" profile of EI to something approximating the current PNW-SGDP Transactive Control implementation. Nevertheless, leveraging Energy Interoperation might provide an accelerated path to national and international standardization of Transactive Control, as it has done for OpenADR 2.0.

In conclusion, neither OpenADR nor Energy Interoperation provides the equivalent functionality that Transactive Control provides. However, both may prove useful in facilitating the adoption of Transactive Control.

Appendix A: CIM and IEC 61850

Two other standards, IEC 61850 and CIM (IEC 61968/61970), do have a tangential bearing on the comparison between OpenADR and Transactive Control.

IEC 61850 defines a set of abstract data objects and services that can be mapped to data objects and protocols used in substation automation. Other features of the standard include detailed mapping of the abstract data objects and services to existing substation automation standards such as the Manufacturing Message Specification (MMS) and the definition of an XML-based substation configuration language. A substation could be a Transactive Control node and control of responsive assets may be accomplished utilizing the IEC 68150 data objects and services.

IEC 61968 and 61970 define a common information model for power systems and are used for integration of applications, such as Energy Management Systems from multiple vendors. Many emerging smart energy standards utilize CIM objects where possible in the data definitions. This is certainly true of both OpenADR and its parent specification, Energy Interop. There is an ongoing IEC effort to harmonize the data models of CIM and 61850.

Neither of these standards has a direct bearing on the comparison between Transactive Control and the OpenADR-related standards covered in this paper.

Appendix B: Reference Documents

The following documents were used as references when creating this paper:

- GridWise Transactive Control Framework
- OASIS WS-Calendar
- OASIS Energy Market Information Exchange (EMIX)
- OASIS Energy Interoperation
- OASIS Transactional Energy Market Information Exchange
- OpenADR Alliance OpenADR 2.0 B Profile
- PNW-SGDP OASIS Conceptual Design
- DR 2.0 - A Future of Customer Response by Paul De Martini
- QualityLogic Transactive Control and OpenADR Mapping Investigation
- QualityLogic What is Transactive Control
- Standardization of a Hierarchical Transitive Control System
- IEC 61850 - Power Utility Automation
- IEC 61970 - Common Information Model