Transactive Energy Application Landscape Scenarios

- Distributed Energy Resources
- Interoperability
- Grid Architecture
- Cybersecurity

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WHITE PAPER

A technical white paper, developed by SGIP's Transactive Energy Coordination Group

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About SGIP

SGIP is an industry consortium representing a cross section of the energy ecosystem focusing on accelerating grid modernization and the energy Internet of Things through policy, education, and promotion of interoperability and standards to empower customers and enable a sustainable energy future. Our members are utilities, vendors, investment institutions, industry associations, regulators, government entities, national labs, services providers and universities. A nonprofit organization, we drive change through a consensus process. Visit www.sgip.org.

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Executive Summary

This paper presents an analysis of the transactive energy (TE) application landscape, specifically examining the transactive process, business functions, actors in different smart grid (SG) application domains, and time scales. These process steps, business functions, actors and time scales comprise the dimensions of the landscape. Six high-level, operational scenarios are presented which, together, cover the identified TE dimensions, and which can collectively be used to explore TE interactions. This paper also reviews the process that was used to analyze the TE landscape, including use case analyses, TE mind map, and a transactive agent interaction model. The final exercise described was validation of the set of six scenarios against a set of TE dimensions.

These scenarios may be useful for different purposes, for example: input to TE stakeholders (e.g., utilities, regulators, and policymakers) seeking to understand the scope of TE and TE applications; development of TE reference architectures that include the TE dimensions; and development of more detailed use cases to serve specific business functions.

Transactive Energy . . .

A system of economic and control mechanisms allowing balance of supply and demand across an electrical infrastructure

Objectives

The goal of SGIP's Transactive Energy Coordination Group (TECG) was to identify a core set of scenarios to act as a common foundation for identifying areas where standard interfaces between interacting parties can be defined, interoperability gaps in existing standards and practices can be described, and opportunities for new standards and practices can be explored. Such a foundation can assist SGIP members and other electric-system stakeholders with identifying priorities for advancing interoperability that focus on resolving near-term application issues in the context of future work that will be required.

A manageable number of core TE scenarios can more generally be helpful to provide focus to the many diverse TE-related activities and efforts by utilities, utility vendors, third party service providers, regulators, policymakers, and researchers who contribute to addressing emerging issues in the electric system including simulations, demonstrations, and tests. In addition, the exercise of developing a core set of TE scenarios will aid in refining our understanding of the characteristics of TE systems.

The scenarios developed in this report outline a landscape in which a TE system operates. A specific TE system provides for transactive operations between different parties (e.g., transactive agents in building controllers, aggregators, and markets) to accomplish objectives that are captured in the scenarios. While this paper does not specify TE methods within the high-level scenarios, it does provide boundaries, which can help the users of this document to develop more detailed use cases.

Defining Transactive Energy

Transactive energy is a term that has received recent attention in the electric utility industry and has been used to describe a range of next-generation approaches to managing the grid. The GridWise Architecture Council (GWAC) has led the effort to develop a common understanding and communicate the meaning of TE. The GWAC TE Framework [1] defines TE broadly 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*." The Pacific Northwest National Laboratory report on Transactive Valuation Methodology [2] states that a *"transactive system is itself a method for monetizing values and incentivizing assets to respond."*

Objectives, Principles, and Attributes

The problems TE systems address and their *objectives, attributes,* and *principles* from the GWAC TE Framework [1] Sections 2.1, 3.2 and 3.3 are valuable to help understand what a TE system is and does.

The key TE system *objectives* are to: integrate distributed energy resources (DER) with an emphasis on distribution-level operations and integration of behind-the-meter customer DER (including demand flexibility); coordination of resources to improve system efficiency; provide grid ancillary services including ramping and balancing; and management of congestion. A set of landscape scenarios should include situations that would exercise a TE system to address these objectives. Ultimately, TE systems must facilitate the efficient and reliable integration of large numbers of DER (including the diverse resources behind the customer meter which cannot be directly controlled by an external entity), beyond what is possible today.

The TE Framework *principles* specify that a TE system implements some form of coordinated self-optimization, integrates DER while maintaining reliability with observable and auditable transactions, and does this in a manner that is scalable, adaptable, and extensible across a number of devices, participants, and geographic extent. A TE system specifies specific products or services that are transacted, as well as the rules and protocols for transacting.

The TE system *attributes* can be summarized as follows:

- A TE system exists in some architecture, centralized or distributed.
- A TE system exists within some geographic, organizational, political, or other measure of extent.
- A TE system involves transacting parties, typically automated agents exchanging information (thus requiring interoperability with common infrastructure and messages).
- A TE system assigns value via some discovery mechanism to energy products or services (such as energy, transport, or ancillary services). Between independent parties, value is set by financial transactions between parties (in markets, bilateral agreements, or by other means). The focus of TE systems is standardized inter-party valuation.
- A TE system may interact across multiple-time scales. This extends from transactions for forward planning, to near-term transactions and, finally, real-time control actions.
- A TE system negotiates objectives across the multiple parties to balance the whole system while maintaining the stability of the grid.

The above principles and attributes describe the characteristics of a TE method or design, providing boundaries for expectations of TE system implementations. The high-level scenarios presented in this paper avoid specifying a method. They do not describe system architecture, or how a TE design manages scalability, or how regulations constrain it. However, a given scenario provides some constraints and requirements that a specific TE design must meet.

Under these definitions, direct control demand response (DR) and time of use (TOU) tariffs are not transactive concepts. Direct control DR is effective for load reductions, but does not provide a continuous interaction between transactive parties that can be used by the actors (customer system operators, grid operators, aggregators, etc.) to jointly seek multi-objective operation of the grid and customer DER systems, nor is it based on an economic interchange between the customer and the electricity system in which the customer is an active decision maker. TOU is a useful approach to incentivize customers to manage loads and DER on a regular, time-of-day basis, but itself is not tied to a real-time grid condition and thus cannot provide dynamic response. For example, it cannot serve the grid to alert a customer of a temporary loss or excess of generation, nor of local transmission and distribution (T&D) constraints.

Describing TE Systems

Figure 1 presents the conceptual relationships of grid scenarios to TE system design, operation and performance verification. The grid scenario chosen informs the objectives of a transactive system. Those objectives identify the impacts that are expected from operating the transactive system, and they drive the transactive exchange design, which defines the transactive agent interactions (see Figure 2). The transactive agents then control their local equipment subject to the physical laws and state of the operational system. The resulting state, which changes over time, is then used to ascertain the impact measures. The resulting operational state (e.g., voltage, frequency, load demand) provides input to the monitoring and measurement system identified by the transactive exchange design and is used to reconcile the actions of the agents with agreed upon expectations.

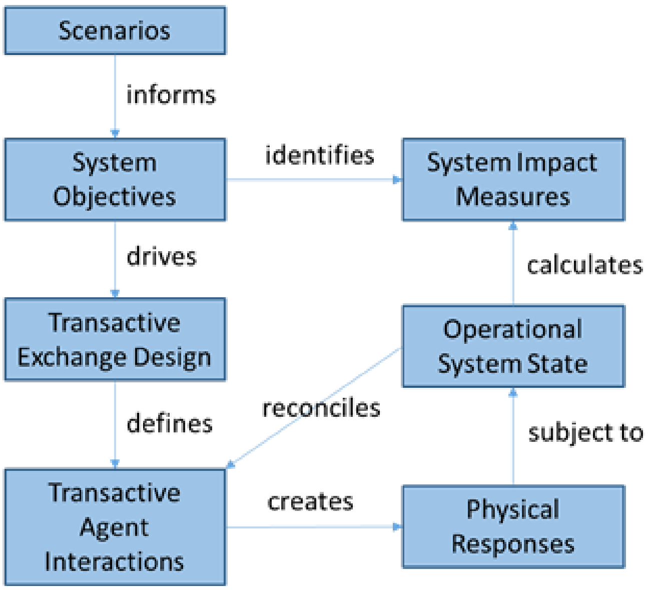

Figure 1: Grid scenarios inform TE system design. Transactive agents impact DER operation with resulting performance measured and verified against stated TE system objectives.

Transactive interactions described in a transactive design need to cover a set of coordination steps from initiation to resolution as shown in Figure 2 (double-headed arrows from top to bottom). A transactive agent acts to represent some local device or system (such as a building, a piece of equipment, a microgrid, a market operator, or a resource aggregator) with interactions to another transactive agent. To engage in transactive interactions requires registration and qualification of all participating transactive agents. Registered transactive agents may then engage in transactive interactions that will use some negotiation process that involves forward or real-time market prices or other signals used to agree on the value of some exchanged energy product or service. After completing an agreement, local action is taken in real-time or planned for an agreed-to future time (or both) to manage energy resources. The energy consumption, service provision, or other result of the transaction must be observable and measurable so it can be verified and used in settlements.

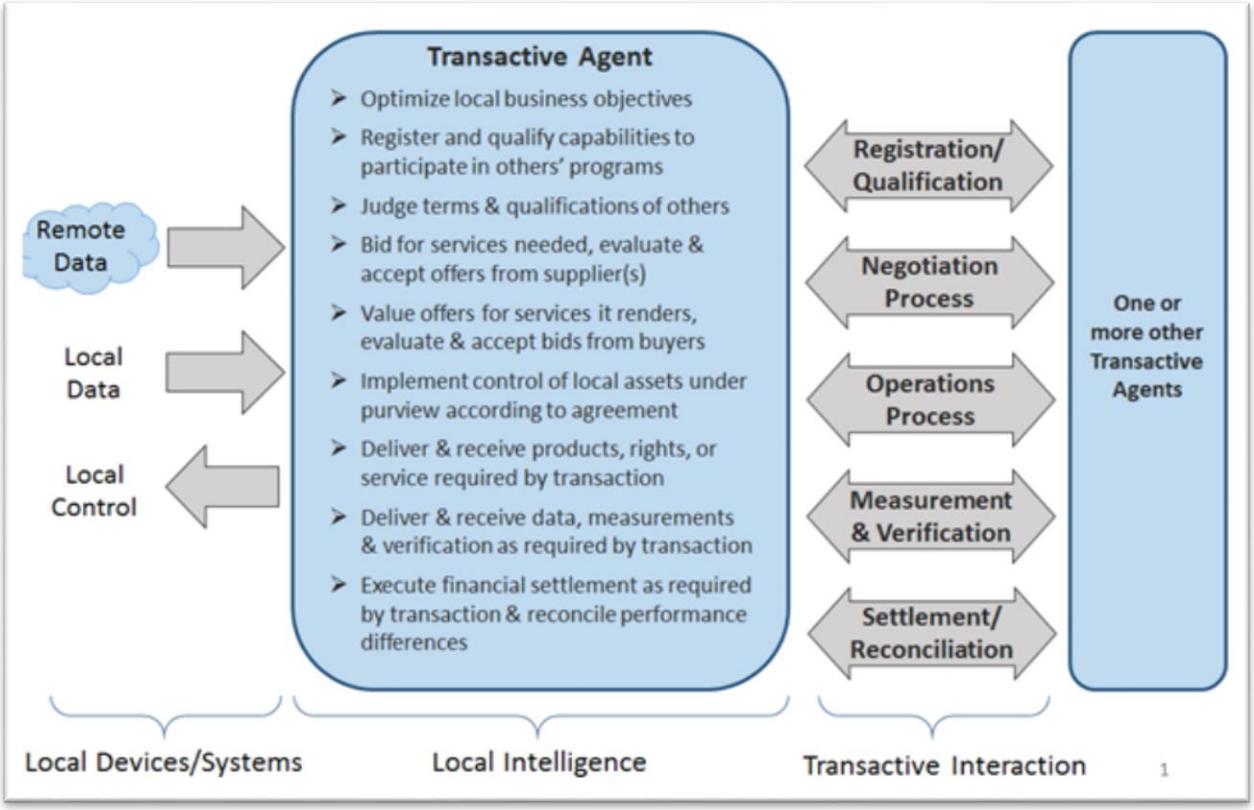

Figure 2: Transactive agent model with interactions to other agents

In the time dimension, a transactive agent considers the behavior of the system (e.g., building equipment, generator), which the agent represents in order to negotiate the changing positions of the agent's local business objectives. This representation can include designing a progression of negotiations from planning stage transactions in forward markets to operational stage transactions in real-time markets. Two other aspects of the time dimension are the frequency of agreement negotiation and the time required to complete transactions. Forward markets may operate in time periods of months, days, or hours. While real-time markets are generally considered in sub-hourly (e.g., five-minute) cycles. Finally, local device/system response times vary with transacted product.

Approach to Scenario Development

The goal of this work was to identify a set of characteristics of TE that could then be used to identify published use cases that covered the "TE Landscape." Two approaches were initially taken. The first was to perform a mind map exercise (details below) to identify TE characteristics that would define the TE Landscape. This exercise included review of the GWAC TE Framework and input from the SGIP Smart Grid Architecture Committee on use-case filtering criteria (details below). The mind map helped to clarify the scope and dimensions of TE. The second exercise was to identify and review existing collections of use cases that could be filtered and cataloged for TE characteristics. The use case collections listed below were reviewed. The use cases vary widely in level of abstraction, metadata, actors, and format.

- PNNL Reference Guide for a Transaction-Based Building Controls Framework [3]
- EPRI Smart Grid Use Cases Repository [4]
- SGIP Customer Energy Services Interface White Paper [5]
- IEC TR 62939-1:2014 Smart Grid User Interface [6]

Analysis of Existing Use Cases

The analysis of the above use case collections resulted in the following observations. First, the utility use cases (primarily contained in [4]) describe existing solution approaches that do not well-represent the developing ideas of transactive energy. In addition, the published use cases typically circumscribe a solution, such as specifying grid architecture and providing details on which standards are used and the messages exchanged between a set of actors (such as Grid Operator or Residential Load).

Second, the building transactive use cases presented in [3] provided a good collection of use cases that were further analyzed to understand the business functions, actors and domains, time scales, and methods of building-related TE use cases. (See analysis in Appendix D.) That analysis (as summarized in the pictures and graphics at the bottom of Appendix D) shows that most of these use cases address balance of supply and demand with less emphasis on operational issues from distribution power flows and power quality. In terms of time scales, the "sweet spot" of building response times seen in the use cases was on the order of minute to hour, similar to what is seen with DR response today. Some use cases had faster or slower time scales. Finally, the use cases included typical DR scenarios as well as more market-oriented or control-oriented scenarios. However, that collection of use cases did not cover the complete TE landscape as indicated by the mind-map exercise.

After performing the above use case analysis, it became clear that it would not be possible to pick from existing use cases to form a set of use cases that would "represent TE" in a complete way. The decision was then made to develop from scratch a set of high-level (no implementation details) scenarios that covers to a large extent the TE concepts within the mind-map. The goal was to capture the different key characteristics in a small set of unique scenarios. The final step was then to use a matrix approach to evaluate the scenarios against a set of TE dimensions that were condensed based on the sum total of analysis, as discussed in more detail below.

Filtering Criteria

As part of the initial effort to identify transactive use cases, the SGIP Smart Grid Architectural Committee (SGAC) provided the following filtering key words to help evaluate the degree of "transactive-ness" of existing use cases.

TE Keyword Search Criteria

A TE system will [transact | auction | negotiate for | agree to buy | agree to sell | offer to provide] something specific to:

[servicing | providing | limiting use | aggregating] of [real power | load | demand | firm capacity | voltage support | frequency control | VAR support],

between at least 2 entities,

restricted by [electrical grid constraints and system optimization].

Actor Keyword Search Criteria

Retailer/Wholesaler, Aggregator, Home/Building Manager, Building Space Customer, Utility Provider, Energy Market Clearinghouse, Generator, ISO/RTO, DSO, DG, DER

TE Mind Map

The mind map in its most compact form is as shown in Figure 3. The detailed mind map with all branches expanded is presented in Appendix B. The exercise of capturing TE in a mind map (via authors' analysis of use cases and ongoing discussions) led to grouping TE materials according to business functions (the WHAT) as objectives of the TE system (the WHY), notes on time scales (the WHEN), grid management methods (the HOW), and notes on actors and domains (the WHO and WHERE).

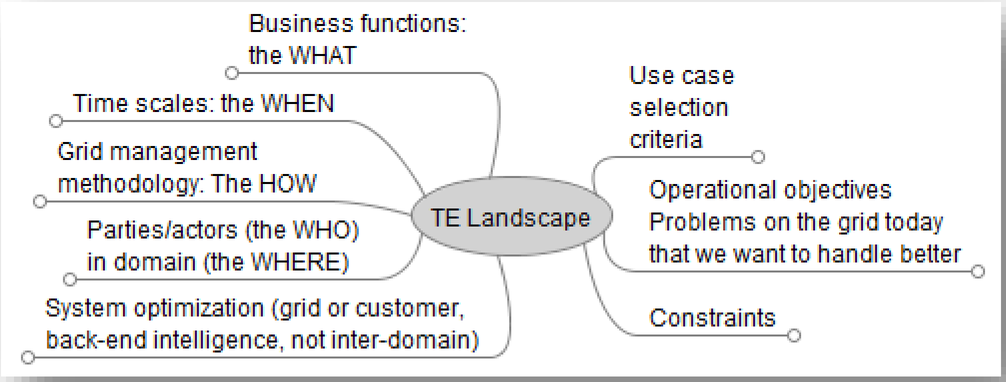

Figure 3: Top-level categories of transactive energy landscape mind map. See full mind map in Appendix B.

High-Level Use Case Scenarios

A set of six scenarios was developed which the authors believe cover a substantial majority of the TE landscape. These scenarios are presented in Appendix A.

1. Peak Heat Day and Energy Supply: The grid is severely strained in capacity and requires additional load shedding/shifting or storage resources.
2. Wind Energy Balancing Reserves: DER are engaged based on economics and location to balance wind resources.
3. High-Penetration of Photovoltaics (PV) and Voltage Control: High-penetration of rooftop solar PV causes swings in voltage on the distribution grid.
4. Electric Vehicles (EV) on the Neighborhood Transformer: TE is used to manage overloading at a specific transformer which serves several homes that each have fast-charging EVs.
5. Islanded Microgrid Energy Balancing: A microgrid controller manages local resources and loads to maintain power quality in islanded mode.
6. System Constraint Resulting in Sudden Loss of Supply: A sudden transmission system constraint results in emergency load reductions.

The scenario descriptions include a narrative as well as TE landscape analysis. In general, the TE landscape can be described in terms of a set of dimensions: process from qualification to transaction to reconciliation, type of service (business function), actors in different SG domains, and time scales in planning, negotiation, and operation. Each of these dimensions is highlighted in the TE landscape analysis. The scenarios have been developed with a goal that the set of scenarios covers the range of TE business cases, along with appropriate time scales (from planning through negotiation to sub-second operational time scales), for a set of actors that covers all the SG domains. The scenarios do not specify a TE design. One might build on this set of scenarios to produce a set of detailed use cases which focus on different business functions with their specific time scales, actors, and process steps. In addition, one might

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The scenarios are described at a high level for several reasons: (1) The high-level view is the appropriate level (at least initially) to judge coverage of the TE landscape; (2) specifying detailed actors, technologies, and event messages (using some specific protocols), for some subsets of the time scales will necessarily reduce the coverage for a specific use case; and (3) the current set of scenarios could be broken out into several more detailed use cases, covering some common sub-classes, such that together, the set of more detailed use cases still covers the TE landscape. Developing more detailed use cases will be done as needed for a specific application, and the scenarios themselves will be drawn from, but not be identical to, existing scenarios.

Those that use this work may determine how much further work and details are required. For example, the National Institute of Standards and Technology (NIST) TE Challenge[1] effort intends to use these scenarios in a detailed format to describe specific events that impact specific devices and actors as input to simulation efforts. However, the scenarios will still not include any information about *how* a TE design incentivizes grid actors to respond to some event, since the goal of the TE Challenge is to test different TE designs with a common scenario.

Another use of these scenarios might be to develop a set of use cases that could potentially be deployed operationally within 3 to 5 years in regions that do not require changes to state regulatory frameworks.

Scenario Validation

Each of the six scenarios was compared to a set of TE dimensions in a matrix format as presented in Appendix C. The goal of this exercise was to confirm that the set of scenarios covers the TE landscape as captured by the dimensionality in the left-hand column. Each use case was weighed against each TE dimension with a rating given or other note as to coverage. The TE dimensions themselves are a summary based on the work items presented in this paper and TECG discussion. The TE dimensions include: Process, Time (Performance Period, Type of

[1] https://pages.nist.gov/TEChallenge/

Service), Business Function, Type of Resource, and Actors. The Process items are taken from Figure 2. The Time items are taken from the discussions summarized in the last paragraph of the "Describing TE Systems" section above and captured in the mind map (Appendix B). The Business Functions were based on a summary and reformulation of the "Business functions" in the mind map. The Type of Resources and Actors were added for completeness to allow consideration of the impact of the different scenarios at a more granular level.

Conclusion

A set of high-level scenarios has been developed that includes a range of grid locations, events, actors, and time scales that together cover a significant range of TE applications. The scenarios provide a collection of high-level grid situations for which TE designs may offer effective approaches for engaging distributed resources to help maintain grid power quality and reliability. The paper summarizes TE objectives, principles and attributes, as well as a conceptual model of transactive agent interactions (registration, negotiation, operations, measurement and settlement). The scenarios' development process has also been presented, specifically the analysis of published TE-related use cases and preparation of a TE mind map. Finally, a validation analysis was used to see how well these scenarios fulfill the various attributes and demonstrate coverage of the identified TE landscape.

Document References

[1] GridWise Architecture Council "GridWise Transactive Energy Framework Version 1.0," 2015, available at: http://www.gridwiseac.org/pdfs/te_framework_report_pnnl-22946.pdf

[2] "Transactive Valuation Methodology Insights," PNNL-SA-113294, 2015, available at: http://www.gridwiseac.org/pdfs/workshop_20150929/pnnl_sa_113294.pdf

[3] Somasundaram et. al., "Transaction-Based Building Controls Framework, Volume 1: Reference Guide," PNNL-23302, 2014, available at: http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23302.pdf

[4] EPRI Smart Grid Use Case Repository, available at: http://smartgrid.epri.com/Repository/Repository.aspx

[5] SGIP Customer Energy Services Interface White Paper, available at: https://cdn2.hubspot.net/hub/147290/file-17893656-pdf/docs/energyservicesinterfacewhitepaper_v1_0.pdf

[6] IEC TR 62939-1:2014 Smart Grid User Interface, Part 1: Interface overview and country perspectives, 2014, available at: https://webstore.iec.ch/publication/7478.

Appendices

A. High-level TE Application Landscape Scenarios
B. Mind Map of TE Landscape
C. Validation of Scenarios versus TE Dimensions
D. Spreadsheet Analysis of PNNL Building TE Use Cases

Appendix A: High-level TE Application Landscape Scenarios

Scenario 1: **Peak Heat Day and Energy Supply**

Scenario 2: **Wind Energy Balancing Reserves**

Scenario 3: **High-Penetration Photovoltaics and Voltage Control**

Scenario 4: **Electric Vehicles on the Neighborhood Transformer**

Scenario 5: **Islanded Microgrid Energy Balancing**

Scenario 6: **System Constraint Resulting in Sudden Loss of Supply**

Scenario 1: Peak Heat Day and Energy Supply

Summary: The grid is severely strained in capacity and requires additional load shedding/shifting or storage resources.

Narrative: The weather has been hot for an extended period, and it has now reached an afternoon extreme temperature peak. Electricity, bulk-generation resources have all been tapped and first-tier DER resources have already been called. The grid operator still has back-up DER resources, including curtailing large customers on interruptible contracts. The goal is to use TE designs to incentivize more DER to participate in lowering the demand on the grid.

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TE Landscape analysis:

Type of Service (business function): this scenario covers most of the range of the "manage energy" branch of the TE landscape mind map. The sweet spot for this scenario is balance of supply and demand in the minutes to hours range via customer demand response (whatever the method). A typical detailed use case would look at using different approaches to engage customer load/DER to meet peak demand. However, some other use cases in this class might look at business cases outside the sweet spot, e.g., call out ramp rates as an issue, or address power quality at faster time scales. Some other use case might look at the roles of forward markets.

Smart Grid Domains and Actors: every domain of the smart grid is likely involved, and potential actors include:

- Regional Transmission Operators and Distribution Grid Operators
- Customer Facilities with customer-owned devices and systems
- Markets
- Generators
- Aggregators

Type of Resources Engaged: The focus of this scenario is on engaging any and all customer DER resources to reduce demand levels and increase supply.

Time Scales: The focus of this scenario is on energy capacity supply. Needed capacity would be supplied by behind-the-meter DER with minutes to hours for negotiation times and seconds-to-minutes for response times.

Process: Customers must be qualified and enrolled. A particular TE design may use different forms of negotiation and transaction, control actions, measurement/verification and finally settlement/reconciliation. A specific use case may only address a subset of these process steps.

Scenario 2: Wind Energy Balancing Reserves

Summary: DER are engaged based on economics and location to balance wind resources.
Narrative: A regional, bulk-power system operator must balance wind resources with power ratings making up 40 percent of the bulk resource in the region. Balancing is needed for both wind ramps and for fast regulation of wind variability. The objective is to match wind variability closely enough that base load generation can provide fine levels of balancing through automatic generator controls.

[i]Traditionally the system operator has used bulk-power resources such as hydropower or spinning reserves to provide wind balancing. The system operator desires to have alternatives, including responsive distributed energy resources. For wind ramps, the requirement is to be able to provide net supply, load increases, or load reductions of up to 1000 MW for up to 15 minutes with a minimum advance notice of 15 minutes. For fast regulation, increases or reductions of up to 200 MW are required with a possible need for geographic localization (response near the wind interconnection point).

Total available DER response is up to 2000 MW distributed among 20 distribution network operators' service areas. The bulk power system operator engages the DER via distribution level aggregators.[2] A mechanism is needed for aggregators to: (1) recognize the location and number of DER units available to be engaged, (2) provide incentives (value) to the grid and to the owners to engage the resources, and (3) select from among DERs that can be engaged. The decision on which balancing reserve to engage (base load, spinning reserves, or DER) is to be made based on lowest cost.

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With DER selected as the source of balancing reserves, a key challenge for response in this scenario is the ability to provide economic efficiency with an oversupply of DER for a sustained period of time.

[2] For this scenario we will assume an aggregator without concern about the relationship between aggregation operations and distribution network operations.

TE Landscape analysis:

Type of Service (business function): the focus of this scenario is the ramp rate issue, not the capacity issue of the first scenario. In this sense, it is more about speed of response of customer resources in a five-minute time scale, but it is still not the issue of ancillary services of one minute or less response time.

Smart Grid Domains and Actors: every domain of the SG is potentially involved, but certainly Grid Operator, Customer Facility and DER. A retail, real-time Market may be required. Residential, commercial and industrial customers are potentially all part of one or another scenario. Indicated actors:

- Bulk Power System Operator
- Wind Forecasting Entity
- Hydro System Operator(s)
- Wind Generation Operators
- Merchant Generator Operators (spinning reserves)
- Distribution Aggregators
- DER Asset Owners
- Optional – Bulk Power System Market Maker[3]

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Type of Resources engaged: The focus of this scenario is on engaging DER to manage ramp rates.

Time scales: Registration/enrollment may be in months to years ahead, negotiation and response (operation) may be minutes.

Process: Customers must be qualified and enrolled. A particular TE design may use different forms of negotiation and transaction, control actions, measurement/validation, and, finally, settlement/reconciliation. A specific use case may only address a subset of these process steps.

[3] For this scenario, one can consider how it would work in both structured and unstructured markets. Really these are two different scenarios.

Scenario 3: High-Penetration Photovoltaics and Voltage Control

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Summary: High-penetration of rooftop solar PV causes swings in voltage on a distribution grid.

Narrative: A high percentage of electricity supply (up to 120 percent of load on some distribution feeders) comes from solar PV. On a sunny day with low load conditions, the generation of energy on a feeder is greater than the load and reverse power flows will result. Voltage levels will also increase. Rather than curtailing PV generation, transactive methods are used to incentivize additional load, generation or storage response, and the transactive signals should be localized to the feeder level to respond to voltage fluctuations.

TE Landscape analysis:

Type of Service (business function): the focus of this scenario is distribution grid regulation (and other ancillary services). This also captures some of the "Manage flows" business functions in the mind map.

Smart Grid Domains and Actors: This scenario includes input from the transmission grid system, but is focused on distribution grid operation and customer's system response. The location (and thus scope of transactions) may be contained within a feeder or segment of a feeder. Actors may include:

- Bulk Power System Operator
- Distribution Grid Operator (or Distribution System Operator)
- Transactive Retail Market Operator or Aggregator
- DER Asset Owner

Type of Resources engaged: The focus of this scenario is on engaging distribution grid DER resources to manage voltage fluctuations and reverse power flows. Storage resources (electrical and thermal) are potentially more valuable in this scenario, but loads can also be incentivized to increase or decrease as needed.

Time scales: seconds to minutes for negotiation as well as response.

Process: Participating devices and systems must be qualified and enrolled. A particular TE design may use different forms of negotiation and transaction, control actions, measurement/validation and finally settlement/reconciliation. A specific use case may only address a subset of these process steps.

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Scenario 4: Electric Vehicles on the Neighborhood Transformer

Summary: TE is used to manage overloading at a specific transformer which serves several homes that each have fast-charging EVs.

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Narrative: A radial distribution feeder is configured with individual feeder transformers rated at 40 kW feeding three to four residential customers. The distribution network operator receives significant wind power. When the wind power is available, the utility incentivizes electric vehicle owners to charge their vehicles. In this scenario, the wind power is available (or is forecast to be available) and the utility incentivizes electric vehicle charging. One of the feeder transformers serves houses with enough electric vehicles that if they all charge at the same time, the transformer is overloaded. The overload is small enough that it will not cause the transformer to fail outright; rather, the service life of the transformer will be shortened based on the magnitude of the overload, ambient temperature, and other measurable factors. Local mitigation is required through coordination of charging times and rates to avoid transformer overload or to generate cost recovery sufficient to offset to the reduced transformer service life, all while still meeting the charging objective of the electric vehicle owners.

TE Landscape analysis:

Type of Service (business function): The focus of this scenario is hyper-local distribution delivery constraint. It picks up a special scenario tied to the power flow management business case.

Smart Grid Domains and Actors: mainly distribution grid interaction with customer loads and DER, other community storage and DER, or substation DER. Actors include:

- Distribution Network Operator
- Distribution Feeder Transformer(s)
- Electric Vehicle Owners
- EV Charging Stations

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Type of Resources engaged: Besides EVs, other customer loads and DER may be incentivized to respond to decrease load or supply power to reduce localized overloading.

Time scales: minutes for negotiation and response

Process: Use cases may include program set-up as well as operation and reconciliation steps.

Scenario 5: Islanded Microgrid Energy Balancing

Summary: When power fails on the main grid, the microgrid controller switches to islanded mode with local generation and load control. TE designs are used to balance the interests of various microgrid participants (e.g., buildings with different owners, homes, commercial and industrial facilities) and other DER.

Narrative: A campus/community size microgrid with residential, commercial and industrial loads with 10 MW typical daytime peak, of which 2 MW of industrial load can be moved off peak if given some forward notice and incentives (100 percent premium to move load off with no warning, 30 percent premium to move with 24 hour notice), while a significant amount (up to 3 MW) of building and residential load are available to be shed or shifted depending on incentives (amount available to shed varies from 0 MW at no price premium up to 3 MW at 100 percent premium). The microgrid operates with a 6 MW combined heat and power generator, two 500 kW diesel backup generators, and 1.2 MW of rooftop PV. In addition, there is 1 MWh of battery capacity. The available generation resources and storage allow the microgrid to operate indefinitely in islanded mode with some potentially reduced service levels. In this scenario, the main grid power is lost and the microgrid goes to islanded mode and operates using transactive approaches to balance supply and demand at minimum cost to the microgrid operator.

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TE Landscape analysis:

Type of Service (business function): This scenario includes all the business cases since the microgrid is just a reduced scale version of the big grid.

Smart Grid Domains and Actors: picks up issues related to operation of a microgrid. Actors:

- Microgrid Controller
- Market
- Building Equipment, Residential Device, and Industrial Process Controllers
- Generator and Storage Controllers

Type of Resources engaged: Any load, generator, storage resource in the microgrid.
Time scales: all
Process: all steps

Scenario 6: System Constraint Resulting in Sudden Loss of Supply

Summary: A sudden transmission system constraint results in emergency load reductions.

Narrative: A distribution system network operator receives most of their power from interconnection to the bulk power system. On the coldest day of winter, they are notified by the system reliability coordinator, with 15 minutes notice, that they must curtail 40 MW of load for two hours due to unplanned maintenance of the transmission system. The typical winter peak load served by the distribution utility is 150 MW.

The distribution system network operator does not have local generation available to offset the bulk power system curtailment. They must drop 40 MW of load within the coming 15 minutes and maintain the curtailment for two hours. In the absence of sufficient demand response capability (in the current system) they must blackout enough customers to meet the curtailment. With a transactive system in place and sufficient load engagement, they can use transactive incentives or markets to allow customers to participate in the curtailment and self-select the duration of involvement based on the incentive or market activity. This approach will also allow for some precision in meeting the curtailment target. This scenario focuses primarily on the distribution grid and looks at ability of some TE design to get significant and sustained load reductions on a short notice. The scenario requires at least 40 MW of DER in the distribution utility service area.

TE Landscape analysis:

Type of Service (business function): This scenario focuses on energy provision, but also includes customer side demand management.

Smart Grid Domains and Actors: Possible actors:

- Reliability Coordinator
- Distribution System Network Operator
- Distribution System Network Customers

Type of Resources engaged: Any load, generator, storage resource available on distribution grid.

Time scales: all

Process: all steps

Appendix B: Mind Map of Transactive Energy Landscape

Note: Square bracket [] references in the left side branches indicate that the item called out on the left side fulfills one of the operational objectives numbered (1) – (12) on the right-side "Operational objectives" branch.

Appendix C: Validation of Scenarios versus TE Dimensions

TE Landscape Dimensions	Scenario 1 Peak Day	2 Ramping	3 Volt Ctrl	4 EV Load	5 Microgrid	6 Emergency
Process						
Registration/Qualification	x	x	x	x	x	x
Negotiation Process	xx	xx	xx	xx	xx	xx
Operation Process	xx	xx	xx	xx	xx	xx
Measurement & Verification	x	x	x	x	x	x
Settlement/Reconciliation	x	x	x	x	x	x
Time - performance period						
Planning period – longer-term for context	x	x	x	x	x	
Agreement negotiation period – 5 min, 1 hr, day, week…	min-yr	min-yr	s-hr	s-min	s-hr	s-hr
Operation response period – subsec, s, min, hr…	s-min	s-min	s-min	s-min	s-min	s-min
Type of Service - Business Function						
Energy provision	xxx	x			xx	xx
Ancillary service provision	x	xxx	xx		xx	
Managing constraints: T&D line capacity, transformer capacity	xx	xx	xx	xxx		xx
Maintain power quality (manage distribution voltages)	x	xx	xx		xx	
Consumer-side energy and demand management	xx	xx	x x	xx	xx	xx
Type of Resource						
HVAC	behind					
Battery	ESI					
PV with inverter	any	any and	any and		any and	any and
Appliance	resource	all	all		all	all
Fossil generator	may					
Pump	participate					
EV				xxx		
Actors						
DER operator	xxx	xx	xx	xx	xx	xx
Large generator operator	x	x			x	
Market operator	x	x	x	x	x	xx
Aggregator	x	x	x	x		x
Third-party Energy Service Provider	acting as Aggregato	acting as Aggregato			x	x
Retail Energy Provider	xx	xx	xx	xx	x	xx
Distribution System Operator	xx	xx	xx	xx	xx	xx

Legend: x=possible, xx=likely yes, xxx=strong yes; blank=no

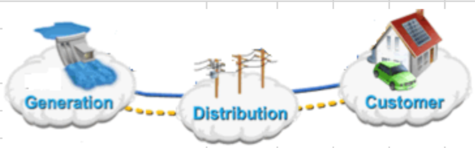
Appendix D: Spreadsheet Analysis of PNNL Building TE Use Cases

		The **WHAT** (Business Functions)											The **WHERE/WHO** (Domain / subdomain, business function applied to different scopes)							The **WHEN** (time scales)				The **HOW** -- Grid Management Method			
		Manage Energy							Manage Flows		Accounting Infrastructre																
Use Case	Report Section	Ramp Rate	Supply & Demand Balance	Planning/Reserves	Selling power based on source	Maintain power quality with grid constraints	Customer energy efficiency & load shed/ shift	customer demand mgmt	Manage transmission sys power flows with constraints	Manage Distribution sys power flows with constraints	Tracking renewable energy credits	Total electricity net costs	Transmission operations	Distribution operations	Microgrids/ DER	Service Provider/ Aggregator	Customer system/ device	(Multi-owner) Customer Communities	Wholesale and retail markets	Seconds	Minute - hour	Days - weeks (planning, events (weather))	Months - years (forward investments)	Market-based	Hybrid market/ controls	DR program	Control-based
PNNL Dynamic Rates	5.1		x				x							x		x	x				x	x				x	
Optimize EV Charging for Dynamic Rate	5.2		x				x							x			x				x	x				x	
End-Use Differentiated	5.3		x				x							x			x				x	x				x	
Transactive Energy Market Exchange	5.4		x	x			x			x				x			x		x		x	x	x				
Trading Efficiency to Relieve Congestion	5.5						x			x				x		x	x						x	x			
Differentiated Reliability Service	5.6		x			x				x				x	x					x	x						x
Interruptible Service or Direct Load Control	6.1		x											x			x				x						x
Transactive Retail Energy Market	6.2		x				x			x				x			x		x		x			x			
Microgrid Coordinating DR, DG and Storage	4.7		x				x			x					x		x	x	x		x			x			
Trading Allocated Capacity Rights	6.3		x				x			x				x			x		x		x	x		x		x	
Ancillary Services via Aggregator	6.4					x							x	x		x	x			x	x						x
Transactive Acquisition of Ancillary Services	6.5					x							x	x		x	x		x	x	x			x			x
Emergency Power Rationing	7.1		x					x						x			x				x						x
Air Shed Management	7.3						x										x				x					x	
AEP Performing Real Time Price Auction	4.2		x				x			x			x	x		x	x		x		x			x			
IECSA RTP-top level scenario			x		x	x	x		x	x			x	x		x	x		x	x	x			x			

Appendix E: Spreadsheet Analysis of PNNL Building TE Use Cases

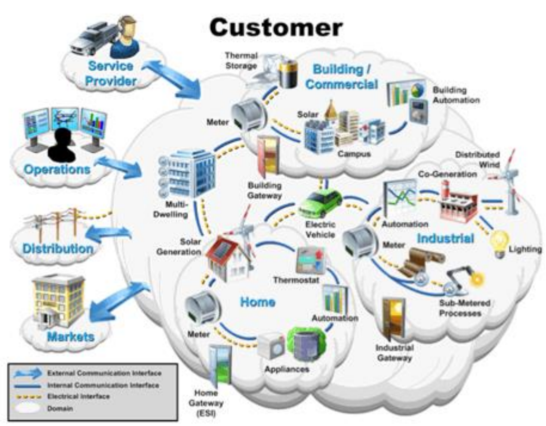
Comments/notes on use cases	
5.1	Critical Peak Price, TOU, and RTP tariffs
5.2	Special Real Time Price (RTP) rate for EVs. Could be subset of tariff below.
5.3	Both Time of Use (TOU) and RTP. RTP could be used for congestion management.
5.4	This is the TeMix approach
5.5	Where Locational Marginal Prices (congestion) are high. The customer offers energy efficiency improvements to bidders ("I could reduce monthly comsumption by 100kWh for $1000 investment"). ESCOs/utilities buy.
5.6	Customer buys rights to better reliability.
6.1	Direct Load Control
6.2	Double auction RTP plus bid curve
4.7	Same as above, but within an islanded microgrid.
6.3	Customer trades rights to capacity, either TeMix style or via some pre-negotiated utility allotment.
6.4	Four-second regulation or spinning reserve via aggregator
6.5	Customer signs up to offer some loads as regulation or spinning reserve via aggregator, bidding to respond to ancillary services signal in response to RTP.
7.1	Power is rationed based on customer class/status, with broadcast signal to meter in emergencies
7.3	This is "Smog Critical Peak Pricing", DR based on smog levels.
4.2	Utility node takes Regional Transmission Operator next-day prices together with distribution grid congestion and home energy use to calc RTP on 5 minute basis.
IECSA RTP	Utilities, aggregators and large customers bid into wholesale markets (energy, ancillary services). Energy Service Provider might aggregate bids from smaller customer. Utility takes bids together with grid conditions, weather forecast, etc. and posts RTP. Customer manages loads and DER based on prices.

Main "WHAT" business functions



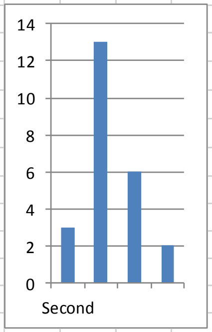
* Balance supply and demand
* manage customer demand
* less so: manage power flows in distribution system
* marginal: manage power quality

The "WHERE" -- in the Customer domain or attached domains

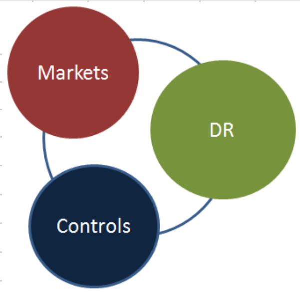


WHEN summary

Second	Min-hour	Day-week	Mont h-yr
3	13	6	2



HOW Summary



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