National Institute of Standards and Technology
U.S. Department of Commerce

Transactive Energy Challenge Kickoff Workshop

September 10-11, 2015

Summary Report

November 2015

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TRANSACTIVE ENERGY CHALLENGE KICKOFF WORKSHOP

September 10-11, 2015

SUMMARY REPORT

November 2015

Hosted by the
National Institute of Standards and Technology

Acknowledgments

The Transactive Energy (TE) Modeling and Simulation Challenge for the Smart Grid (TE) Kick-Off Meeting held September 10-11, 2015 in Gaithersburg, Maryland, is summarized in this report. The kick-off meeting is part of a series of planned meetings in the TE Challenge sponsored by the National Institute of Standards and Technology (NIST).

Thanks are extended to the NIST Steering Committee for their considerable effort in guiding this workshop toward a successful outcome. The excellent contributions of the expert participants are acknowledged and greatly appreciated. Thanks are also extended to the Energetics Incorporated team for their assistance in facilitating the workshop and preparing this report.

Organizers

David Holmberg, NIST

Steering Committee

Chris Greer, David Wollman, Steven Bushby, Martin Burns, Sokwoo Rhee (NIST)

Ron Melton, Pacific Northwest National Laboratory (PNNL)

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1 Introduction

1 INTRODUCTION

Transactive energy (TE) is an emerging concept encompassing technologies and mechanisms that enable dynamic exchange of electricity over the electrical infrastructure. The GridWise Architecture Council defines TE as follows:

"A set 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." [1]

TE is associated with electrical grid issues such as the internet of things (IoT), integration of renewables, microgeneration, smart grid, and both existing and emerging governing policies. As the electric grid transforms to integrate more wind and solar energy and to give customers more choice and control in their use of energy, the TE concept may become more prominent. TE is a concept that includes an intelligent, device-enabled grid that optimizes resource allocation following the constraints of the grid. Benefits to the TE concept include increased reliability, potentially reduced cost for customers, integration of distributed energy resources (DER) and renewable technologies, and energy efficient production and delivery of energy.

As illustrated in Figure 1.1, electricity buyers and sellers are connected with one another in a network configuration.[2] The customers/ producers in the residential area can choose to produce and sell energy, shop for energy based on specified criteria, and interact with new energy services. Flexible microgrids arise from advanced control and coordination. New energy services become available to a wider audience through new and wider data exchanges. Efficiency and reliability can be increased through interoperability between regional and local markets coordinating energy resources.

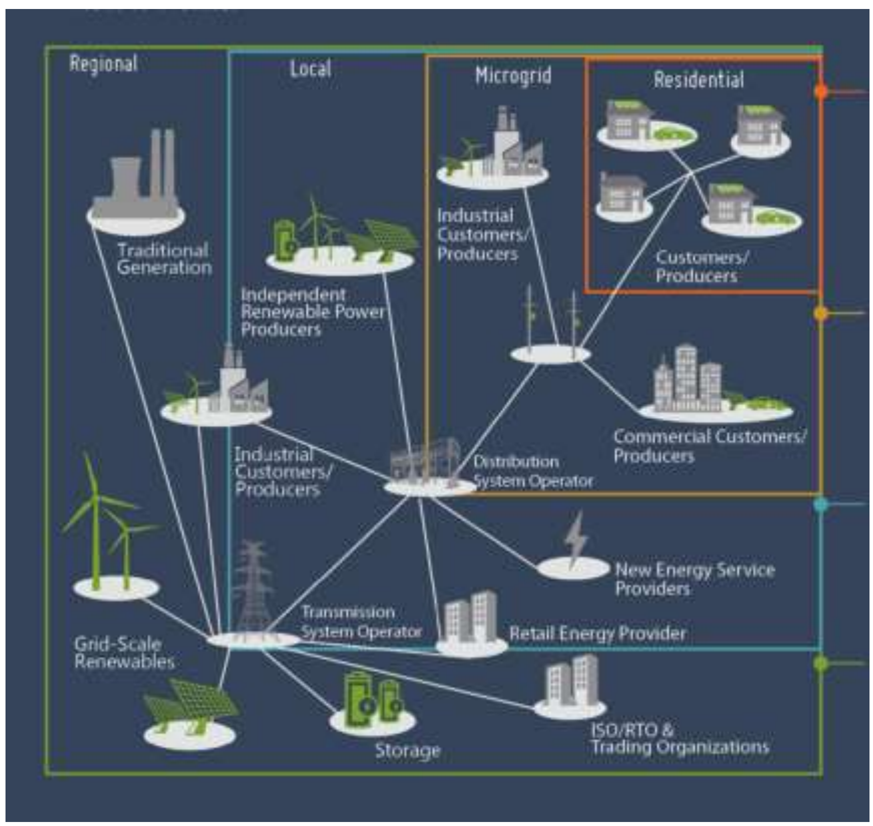


Figure1.1. Transactive Energy Concept[2]

The evolving smart grid, with increased use of renewable energy generation technologies, offers the potential for significant efficiency improvements through market-based transactive exchanges between energy producers and energy consumers.

To understand this potential and support technology developers and policy makers, the smart grid community will require simulation tools and platforms that can be used to explore the impact of alternative ways to create and operate transactive energy systems.

Challenges to the adoption of TE were identified in the Transactive Energy Challenge Preparatory Workshop, held in March 2015 at NIST (visit the workshop website for more information http://www.nist.gov/el/building_environment/mechsys/te-challenge-preparatory-workshop.cfm). The key challenges identified are summarized in Figure 1-2.

Integration of renewable energy resources is an important challenge, in particular load capacity and stability, and ramping and balancing. Another significant challenge is management of DER behind the meter, such as electric vehicles (EVs), batteries, smart thermostats, and solar panels, which come in small size packages. Utilities and grid operators typically want to pull together megawatts or hundreds of kilowatts for grid services like frequency regulation or demand response. Combining DERs to meet requirements for this scale can be a challenge. These sources ideally would respond as a unit and have appropriate market mechanisms to allow their integration in TE. Distribution system flows, voltage control, constrained transformers, and microgrids are other technical challenges that need to be resolved.

TE transactions offer game-changing capability as they allow energy customers to be both consumers and sellers of electricity. However, design of market mechanisms must consider a number of challenges. Utilities may be concerned about consumption uncertainties or system reliability. Regulators may view TE as a potential loss of ratemaking control if customers can negotiate outside of a public utility commission (PUC). Regulatory constraints and what regulations should apply to TE need to be identified and addressed. Market volatility and its impact on transactions is also a consideration.

Figure 1.2. Critical Challenges for Transactive Energy*

Development of Toolsets for TE

- Stable and more capable platforms
- Improved tools for filling gaps, extending range, and that are easier to use with reduced configuration time.

Evaluation of TE approaches

- Costs and benefits of various TE approaches, including impacts on required system investments
- Performance of TE systems during weather events, power transients, power outages, communication networks failure, and other grid challenges
- Performance of approaches with changes in scale and other metrics and validation
- Robustness and stability of approaches
- Set of scenarios covering TE landscape

Standards

- Common input/output formats, common reporting, data formats, and protocols

Stakeholder Awareness and Buy-in

- Building the TE community and collaborative models
- Utility pilots and roadmap for achieving implementations
- Communicate to utilities, regulators and policy makers about TE

**Identified at the TE Preparatory Workshop, March 2015.*

Overview of TE Challenge and NIST Role

The Transactive Energy Modeling and Simulation Challenge for the Smart Grid ("TE Challenge") brings researchers and companies with simulation tools together with utilities, product developers, and other grid stakeholders to create and demonstrate modeling and simulation platforms while applying TE approaches to real grid problems. The products of the TE Challenge will provide insights into the potential for TE and create a path for real-world trial implementations.

The TE Challenge has been initiated by the National Institute of Standards and Technology (NIST), and developed in collaboration with federal partners and industry. The following meetings and milestones have been developed to further the progress of the TE Challenge:

- TE Challenge Preparatory Workshop (March 2015): held to vet the concept with industry stakeholders and design the TE Challenge
- Collaboration Website online (July 2015): includes resources, team information, and links to join the TE Challenge
- Kick-off Meeting (September 10-11, 2015): successfully launched the TE Challenge; five initial teams were formed
- Midpoint Coordination and Team Building Meeting (December 3-4, 2015)
- Summit at the Transactive Energy Systems Conference and Workshop (May 17-19, 2016). Goal is to present the good work that has been done and consider next steps.
- Phase II Kick-off Meeting (September 2016) – this will launch the second phase of the TE Challenge.

The objectives of the TE Challenge are the following:

1. Development and enhancement of modeling and simulation tools, and integration into modeling and simulation platforms for TE evaluation.
2. Demonstration of how different TE approaches may be used to improve reliability and efficiency of the electric grid for different grid challenges and scenarios.
3. Development of a set of scenarios that can serve as ongoing reference points for modeling and simulation.
4. Development of TE community—increasing the number of organizations and individuals working together and sharing data and knowledge to cooperatively advance TE.
5. Development of the foundation for utility pilots and successful TE implementations. This includes modeling and simulation advancements as well as communications with utilities, regulators and policymakers about TE.
6. Provision of a stage (the Challenge Summit meetings and media) where teams can present the exciting work they have accomplished.

Members of NIST's Smart Grid Team have been working closely with the Department of Energy to understand TE's potential and to support utilities, technology developers and policy makers. The TE Challenge will bring researchers and companies with simulation tools together with utilities, product developers, and other grid stakeholders to create and demonstrate modeling and simulation platforms while applying transactive energy approaches to real grid problems.

During the Challenge, it is hoped that the teams will share information that help the TE community understand the following:

- Modeling and simulation tools used and the purpose for use
- Tool extensions created or new co-simulations performed
- TE approaches investigated and results of the investigations

- Data resources used, tools developed, results discovered, collaborations formed, lessons learned, and other information and resources useful to the TE community

Some TE stakeholders and their interests are as follows.

- Utilities are concerned about the impact of dynamic pricing and markets on grid stability
- Researchers are interested in the development of economic and grid models for the new complex grid
- Vendors are looking for how to use developing modeling tools to guide technology design and implementations

Objectives of Kickoff Workshop

NIST, in collaboration with federal partners and industry, hosted the NIST Transactive Energy Modeling and Simulation Challenge for the Smart Grid Kick-Off on September 10-11, 2015. The purpose of the Kick-off Meeting was to provide background information, frame the Challenge, bring together interested partners, form teams, and formulate each team's goals and path forward. The Kick-off Meeting included plenary talks, partner/project participant 'briefs' to introduce capabilities and interest for project collaboration, group discussions around a series of questions, and a networking and team formation session.

Additional information on the TE Challenge Kick-off meeting can be found on the following website: http://www.nist.gov/smartgrid/te_challenge_wkshop.cfm.

Organization of the Report

This report is organized around the major discussions that occurred during the workshop, including a section outlining the potential projects and teams that were formed. The information presented here reflects the perspectives of the experts that participated, and is not necessarily all-inclusive of the views of the transactive energy community.

A complete list of the participants in attendance is provided in Appendix A. Appendix B provides a synopsis of introductory information provided by potential partners. Appendix C lists the acronyms used in this report; Appendix D summarizes references.

2 Plenary Highlights

A number of speakers provided insights on the Transactive Energy Challenge, current and proposed projects, and future perspectives. Highlights of presentations are outlined below; full presentations, where available, can be found at http://www.nist.gov/smartgrid/te_challenge_wkshop.cfm.

Welcome and Context for the Transactive Energy Challenge

- NIST TE Challenge Kick-off: Welcome—***Howard Harary**, NIST, Director of the Engineering Laboratory*
- TE Challenge Vision—***Chris Greer**, NIST, Director of the Smart Grid and Cyber-Physical Systems Program Office and National Coordinator for Smart Grid Interoperability*

  The NIST TE Challenge aims to lay the foundation for moving TE forward with modeling and simulation tools and platforms, standards for tools and communications, TE simulations, and collaboration. The motivation for initiating the TE Challenge includes maintaining grid reliability and stability while integrating DER and demand resources, state legislation as a driver, and unknown factors such as market potential and effective integration with controls. The TE Challenge consists of several milestones—preparatory workshop (March 2015), website launch (June 2015), Kick-off meeting (September 2015), midpoint coordination meeting (December 2015), and summit expo (April 2016).
- Global City Teams Challenge—***Sokwoo Rhee**, NIST, Associate Director of Cyber-Physical Systems Program*

  The motivations, goal, approach, and progress of the Global Cities Team Challenge (GCTC) were discussed. The goal of the GCTC is to establish and demonstrate replicable, scalable and sustainable models for incubation and deployment of interoperable, adaptable and configurable IoT/CPS technologies and solutions in Smart Communities/Cities.
- TE Challenge Context: Where we are, What we Have, Where we're Going—***David Holmberg**, NIST*

  The TE Challenge held a preparatory workshop in March 2015 and launched the website in June 2015. This event is the kick-off meeting. Future events include midpoint coordination meeting in December 2015, summit expo in April 2016, and a second expo in September 2016. The output from the March 2015 preparatory meeting included grid challenges, gaps in tools, critical challenge results, and goals for reporting. The collaboration site is located at https://pages.nist.gov/TEChallenge/. An initial set of six baseline scenarios is under development on the collaboration site.
- TE Background: What is it, why does it matter, and where is it headed?—***Ron Melton**, PNNL, Director, Smart Grid Demonstration Project*

  The GridWise® Architecture Council defines TE 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"[3]. TE system attributes, system principles, and workings of control and coordination were discussed.

TE systems are responding to the need to coordinate variability and flexibility. Good TE system designs address key barriers to deploying and utilizing DER. Initial TE system types have included double auction, transactive control and coordination, and TeMix. Future TE systems should establish value, assure performance, and demonstrate persistent deployments at scale.

Transactive Energy Team Projects and Platforms

- PowerMatcherSuite in the European Union—***Alexander Krstulovic***, *Alliander*

  The open source PowerMatcherSuite aims to leverage flexibility to address the electrification of everything, IoT, and integration of renewables without causing grid congestion. The suite comprises two technologies—Flexible Power application infrastructure (FPAI) and agent based optimization—through a network of auctioneer agents, concentrator agents, and device agents.

- Reference Grid Model for TE Simulation—***Steven Ray***, *Carnegie Mellon University (CMU), Silicon Valley*

  The project goal is to develop a common system design and interoperability requirements to test different TE approaches in different grid simulation environments while producing comparable results between prearranged scenarios. Developing and/or agreeing on several testing guidelines will allow individual teams to perform independent simulations and compare results. Challenges include the lack of a common corpus of data and scenarios to allow comparisons and the need to develop a co-simulation environment that allows diverse simulations to work together.

- C2WT-TE: Command & Control Wind Tunnel for Transactive Energy —***Himanshu Neema,*** *Vanderbilt University*

  Transactive Energy presents a highly complex "cyber-physical-human-economical problem" and huge challenges for correct modeling and simulation. An open co-simulation platform is needed that will provide modeling, experimentation, and analysis facilities to enable "weaving" of a customized TE simulation by selecting from already supported or custom tools. Transactive energy issues to be studies include understanding and tracking consumer behavior, dynamic utility functions, seamless integration of automated controllers and market forces, and system level impact analysis.

- TEMIX for multi-Microgrid communications—***Jennifer Worrall***, *Cleanspark*

  CleanSpark's TE goals include using a well-defined TE standard to share power within a system of microgrids and determining cost distributions among microgrids in a system. Potential contributions to reach these goals include an open source software implementation of TEMIX-style TE framework, open ADR 2.0c profile definition/reference implementation, and a live reference demonstration/implementation using an existing FractalGrid or other system of microgrids.

- Smart Grid in a Room (SGRS) Platform for Distributed Simulations —***Marija Ilic***, *Carnegie Mellon University (CMU), Electrical and Computer Engineering Department*

  This CMU project is supported by a grant from NIST and is comprised of a SGRS emulator platform that incorporates cyber algorithms, physical power system processes, and inter-dependencies of cyber and physical processes. The project plans to begin simulating a real-world, sanitized microgrid, share with the industry via webcast, develop testing for feasibility and potential of the smart grid, and prepare input for standards and protocols.

Partner Briefs

Interested partners provided introductory briefs during the TE Challenge to communicate their area of interest, capabilities, proposed scenario, motivation for participating, and the type of partners sought for their proposal. The TE Challenge kick-off meeting was designed to provide a networking opportunity for interested partners so collaboration opportunities could be identified and teams could be formed. The partners listed below (in alphabetical order) provided introductory briefs during the TE Challenge kick-off; summaries of this information are included in Appendix B for each potential partner.

- ABB Inc.
- Alliander
- Bluewave Resources, LLC
- Businnovation – Vehicle-Solar-Grid
- Carnegie Mellon University
- CleanSpark
- Edison Electric Institute
- Energy Mashup Lab
- General Microgrids
- IBM Research
- MACT USA
- Massachusetts Institute of Technology (MIT) – ACC Lab
- National Electrical Manufacturers Association (NEMA)
- Navigant
- Pacific Northwest National Laboratory (PNNL)
- PEPCO Holdings
- Resilient Energy (Microgrid)
- Robert L. Hershey, P.E.
- Schneider Electric
- Tata Consultancy Services
- TeMix, Inc.
- The MITRE Corporation
- U.S. Department of Energy, Office of Electricity
- University of Oklahoma, Building Energy Efficiency Lab
- Vanderbilt University (with MIT, University of Michigan)

3

Knowledge and Research Gaps in Modeling and Data

Several gaps in TE knowledge and research relevant to TE have been identified, based on discussions at the March TE Preparatory Workshop and the TE Challenge Kickoff. These have been combined and presented here. Gaps center on models, simulation and data requirements.

Models and simulation are important to development of TE systems and market mechanisms, as well as assessing and predicting their performance and viability at demonstration scale and after implementation. Predictive models can provide an evaluation of success factors and provide the foundation for new business models that provide a rationale for TE adoption.

Data is a central foundation of TE at many levels. A number of data-related gaps were identified relating to taxonomy and common data paradigms. Some of the important gaps identified for modeling and simulation and data are shown in Figure 3-1.

Figure 3-1. Knowledge and Research Gaps for Transactive Energy

MODELS AND SIMULATION

- Common platform and standards for co-simulation of markets, grid, and consumer actions.
- Ability to address security and reliability concerns when connecting grid control and financial markets—and doing this at the feeder level, then at city and regional levels
- Modeling societal change and public policy; simulations on the behavioral aspects of the different stakeholders.
- Models for consumer behavior and intelligent agents (autonomous agents acting on behalf of owners to control grid edge devices)
- Scalable physical modeling
- Gaining a deeper understanding of business and regulatory models in order to develop more realistic simulations; Evaluating and predicting the impacts of changing business and/or regulatory models
- Sound models incorporating stakeholders and targets for TE
- Introducing gamification as part of TE, including virtual reality and game theory
- Integrating TE into existing models (non-equilibrium models like TE have greater uncertainty)

DATA

- Common data models (not a rigid data model)
- Identification of the data elements needed to drive scenarios
- Investigating deeper levels to define data flows and definitions
- Determining the basic external data elements
- Agreement on broader terms, language, and other issues

4 Strategic Questions

A set of questions related to strategic approaches for TE and implementation of the TE Challenge were posed during a moderated discussion. A lively exchange between Dr. Chris Greer and experts in the TE community resulted in some insightful perspectives. A synopsis of discussions is provided below, organized by the major topic questions.

Question: What important work is not being done that should be a target for team formation and action? What foundational elements are needed to strengthen the teams and support TE project goals?

- An **inventory of existing models**, especially in key states for TE adoption, such as New Jersey. The state university in New Jersey has an environmental and energy policy model that regulators rely on. Outreach to others doing modeling and simulation will identify available resources and make them aware of future model efforts, providing opportunities to make sure existing models are compatible. Outside the regulated environment is the only place to experiment, modify, and retry new models.
- **Outreach, awareness, and education** are needed. The building owners and non-regulated microgrid buyers are an opportune place to start with education about TE. PUCs, thought leaders, and some in state governments care about resilience, but the ‘buzz’ is missing. The value proposition and characteristics of TE need to be communicated.
- **Co-simulation** would help to enable systems and domains to communicate with each other. Co-simulation should be viewed broadly as a system of systems. This is an important concept for the future success of TE and could require significant work activities.
- **Common data models** are needed. While many assume a common data model will be available, there are different ideas of what constitutes a common data model. A common data model will be based on what market players need. With co-simulation, where multiple units are talking to each other, common data models will be critical to allow information exchange. A data model approach is needed to go from reference models to the data that feeds into models. For utilities, most models are integrated and input data is needed.
- **Appropriate market models and functions** are essential to TE. Today’s model is central optimization with a general equilibrium approach, but in reality today’s markets are not in equilibrium. TE will create a different set of interacting markets, with emerging behaviors that can’t be predicted very well. TE will not totally replace central station generation, but will evolve in unanticipated ways. The markets and business models need to evolve. Stakeholders need to be comfortable with a reduction in central control management. Efforts to support this would include:
  - Market optimization
  - Early-on involvement with brokers of the transaction on the financial side (e.g., to develop common terminology)
  - Realistic business and regulatory models (not just tariffs)
  - Understanding existing markets
    - Market signals, options, and methods for handling the money from TE

- Market clearing and liquidity
- Market impacts (shifts due to TE, possible negative or positive impacts to existing financial systems)

Question: What can be learned from existing systems to help set up new systems that do not exist yet?

- **Existing systems** in the market place must be examined (e.g., market intermediaries) (e.g., what systems are in place, can these systems evolve, what systems must remain). This requires an understanding of customer and end-user needs as well as existing business models. A major challenge is that a transition will have to take place because an infrastructure already exists.
- **Profit maximizing functions** are needed for utilities and TE—current economics are very under-developed.
- **Data exchange requirements** need to be determined (e.g., what data needs to be exchanged to demonstrate to stakeholders that TE works). In current markets data is part of the transfer. To show that TE works in terms of money and cash flow, information must be exchanged to make sure the transactions are possible and reliable.

Question: What other spheres have influence on/might be influenced by TE and what actions could be taken?

Utilities

Utilities need to be engaged to move TE forward. This includes identifying utility needs, and pulling in larger utilities first. Utilities can be engaged and brought on board during events. The value proposition for TE must be demonstrated to utilities. Some approaches include:

- Create sound models for utility stakeholders; create a compelling simulation that demonstrates the value. Utilities might be threatened by TE as they perceive it is taking customers away. They need to be educated to show the value proposition. Simulations can help demonstrate the opportunities that TE presents (via examples). How will utilities benefit or save costs? While money is involved, utilities won't be receiving it.
- Speak to the utility perspective, which is all about providing safe and reliable electricity. The value proposition to utilities should focus on showing how they can use TE to advantage to manage multiple activities; utilities will buy-in to a system if it works for them. They are using legacy systems that work now, and will wait to see if TE works before becoming invested. Value includes:
  - Real time optimization, which has eluded utilities for some time (pinnacle of the smart grid).
  - Tool for integrating distributed energy sources into the grid.
  - Coordinating the operations of many different storage vendors, i.e., managing storage as a benefit of TE; who owns storage, who pays for it, where should it be, and how should it be coordinated. Customers may believe they are independent of the grid if they have solar and a storage element. TE can provide a way of putting these small pieces of generation together and managing them effectively.
  - Before and after scenarios to help understand the transactive world. Utilities know they need to get involved in a transactive animated market, but have no idea what the business implications are and are worried about impacts.
  - Using TE to provide at-work charging stations to offset other grid uses; rates won't rise for customers, but will utilities benefit?

  - Demonstrating capabilities that utilities can take advantage of and that they are interested in; TE can also show what doesn't work.
- Explain and demystify the implications; many understand that transactions are going to be a huge part of their future, but need assistance with understanding the implications, and don't have the necessary tools to do so.

Government Agencies

- The **Federal Energy Regulatory Commission** (FERC) is an independent agency that regulates the interstate transmission of natural gas, oil, and electricity, including natural gas and hydropower projects. FERC is an interface between the wholesale market, utilities, and users.
- The **Department of Defense** is a large consumer of electricity and a growing user of microgrids. Their perspectives and presence in TE would be helpful.
- **Regulators** need to understand how TE works, its value, and how it will be integrated. For example, should storage be regulated as a load, or something else? Helping regulators understand some of these questions will be helpful. Better understanding of policy and other drivers for TE is needed. Utilities may be interested in TE to meet goals set by regulators; we need to understand U.S. drivers and equivalent drivers in Europe. Some states (California) are in a position where they need to create technology to catch up with policy; this can drive utilities towards TE.

Private Sector Spheres (Users, Industry, Suppliers, Software Developers)

There are a number of private sector spheres outside the immediate stakeholder community that could influence or impact development and adoption of TE. Examples include:

- **Edge device manufacturers** – They represent a step before microgrids (microgrids-ready).
- **Gaming** – Game theory / gamification could be used to make TE more attractive to new generation users and make it more accessible to the virtual community. Gamification could allow you to compete with your neighbors or compete with yourself
- **Cybersecurity** – Security of systems is key to TE and needs to be addressed (engage that community).
- **Advanced device users** – The do-it-yourself people like to push the technology edge. As avid users of technology, they can provide impetus for applications of TE (e.g., do it yourself device connections).
- **Customers** – The voice of the customer should be brought in. TE benefits can be packaged and presented to customers with a focus on their needs. Customer needs should be identified and analyzed.

Question: How do we take these projects and communicate their value to customers?

- **High-value projects** would speak to needs of utilities and regulators, while showing the technical aspects. There should be clear drivers for utilities to use TE. Utilities could have an adverse view of those outside of the utilities sector making technical decisions about the sector, so early stage involvement is important.
- A **design competition** is one way to demonstrate and socialize the TE concept. It could focus on development of building blocks that can be used and improved upon. A group of regulators

and utilities could be engaged to identify which teams did the best, with awards given out to those teams.

- **Simulation projects** are important but the value can be difficult to communicate. Projects should demonstrate that they provide more than just simulation (i.e., could be perceived as too fundamental or academic). Simulation projects can demonstrate value by answering the 'what if' questions that may arise in the future; this requires an understanding of business models and economics, not just simulation.

5

Potential Projects

Preliminary TE Challenge Projects

Based on working group agreement, several of the identified technical challenges were deemed priority impediments to TE and suitable for a TE Challenge Project. These topic areas are summarized below and developed in more detail in Figures 5-1 through 5-5. For more information on current partners and project teams as they evolve, please visit the TE Challenge community website at https://pages.nist.gov/TEChallenge/community/ .

- ***Transactive Energy Interoperations and Abstract Interaction***
  Simulated and real TE message exchanges will be aligned by finding common meanings across environments. This alignment will allow simulations to more closely approximate future TE deployments.
- ***Business/Regulatory Models***
  By defining fundamental business/regulatory model types, characterizing participant interfaces, and identifying applicable legislative features, positive impacts could be stimulated in TE development and integration.
- ***Reference Grids TE Scenarios—"Well Posed Problems"***
  By identifying topologies and element identities and capacities at a high level, this project aims to improve inputs to models.
- ***Demonstration of Transactive Control for Energy Management in Microgrid Systems***
  The demonstration of transactive control will include accounting for devices inside of buildings to full external market, exploring theoretical grounding, and investigating graceful degradation. Impacts include reduction in overall carbon footprint, decreasing initial capital expenditure, and changing perceptions of transactive business model.
- ***Co-Simulation Platforms***
  A system of systems will be created, using a central platform with attached nodes or a multiple simulation platform design.

Figure 5-1: Transactive Energy Interoperations and Abstract Interaction

DESCRIPTION: This project will

- Align simulated and real TE message exchanges by finding common meanings across environments (e.g., double auction markets, load price iterative exchange, including a product definition for volt/var specifics, CIM, TeMIX, PowerMaker, and maybe ICCP)

CHALLENGES: Major challenges include

- Mapping core semantics (most are fairly similar)
- Finding and engaging experts on the various technologies
- Engaging simulation experts

PROJECT APPROACH

- Survey IE methods, standards, and technologies
- Define core semantics (maximum of 1-2 clusters) and map to identified technologies
- Publish transforms
- Build a simulation that can engage the various technologies

MAJOR MILESTONES

Complete

- Approach -6 weeks
- Design – 6 weeks
- Build – 6 weeks
- Evaluation – 6 weeks

PERFORMANCE TARGETS

Consolidation of items, to be determined

IMPACTS

- Alignment of simulation work to make it more applicable to future TE deployments

PROJECT PARTNERS & POTENTIAL ROLES

Team Lead

- To be identified

Potential Participants and Roles

- Computational modeling / software developers
- Transactive players (aggregator/broker/intermediary, billing/settlement, market operators, etc.)
- Other TE stakeholders

DEMONSTRATION PLAN

- Not identified yet.

Figure 5-2: Business/Regulatory Models

DESCRIPTION: This project will

- Define fundamental business and regulatory model types; characterize and define interfaces among the participants and players (physical/financial); and identify legislative regulatory features that are applicable to each model.

CHALLENGES: Major challenges include

- Untested/untried models
- Integrating with existing power generation/distribution business models
- Regulatory/legislative resistance
- Balkanized markets
- Resistance by potential market 'losers'
- Consumer resistance to new paradigms
- Business models for disruptive technological change

PROJECT APPROACH

- Survey/summarize existing initiatives
- Examine current / past experience
- Explore additional models
- Identify legislation/ regulatory features for each model
- Characterize/ define interfaces
- Describe/formulate application of transactive energy system to models

MAJOR MILESTONES

Complete

- A draft of models (December 3)
- A draft of TE approach interfaces, business models (March)
- Recommendations for demonstration projects

PERFORMANCE TARGETS

- Economic feasibility and positive payback for participants
- Achievement of vital clean energy and reliability goals at lower cost than alternatives

IMPACTS

- Positive economic impact
- Reduced GHG emissions
- Increased innovation
- Improved reliability/ resilience
- Increased national energy security, diversification
- Increased cybersecurity challenges
- Increased system complexity problems
- Emergence of new markets
- Safety

PROJECT PARTNERS & POTENTIAL ROLES

Team Lead

- To be identified

Potential Participants and Roles

- Micrograids
- Distribution
- Storage (Professional, consumer[pro-consumer])
- Energy producer (control station, distributed)
- Aggregator/broker/intermediary
- Billing/settlement
- Market operator, balancing operator
- Passive Consumer, active consumer
- Telecom/metering/sensor (RD, DR)
- Regulators/ legislators
- Distributed energy supply chain
- Transmission operator

DEMONSTRATION PLAN

- One model through entire process

Figure 5-3: Reference Grids TE Scenarios—"Well Posed Problems"

DESCRIPTION: This project will

- Develop topologies and classify identities and capacities of elements for TE. The approach is to keep the scenarios relatively simple and address one complexity at a time.

CHALLENGES: Major challenges include

- Utility distribution engineering input
- Avoiding duplication of PNNL work

PROJECT APPROACH	MAJOR MILESTONES	PERFORMANCE TARGETS	IMPACTS
• Conduct interconversion of data from standard library to a form usable by the model • Use IEEE test cases (e.g., transmission/ distribution) • Polish the grid • Define actors (plus TE Actors) • Address challenges on top of a baseline (early in work) • Define minimum description for credible analysis/simulation	Complete • Identification of initial set of base cases • Topologies development • Population of base cases • Population and structure of base cases	• Well-defined set of scenarios for TE	• Improved sequence of problems • Enhanced inputs for validation tests • Development of a credible tool for models

PROJECT PARTNERS & POTENTIAL ROLES

Team Lead

- Neutral standards based party who could validate the output

Potential Participants and Roles

- IT architects, software developers
- Trade groups, associations
- Universities
- TE stakeholders

DEMONSTRATION PLAN

- Successful execution on multiple platforms

Figure 5-4: Demonstration of Transactive Control for Energy Management in Microgrid Systems

DESCRIPTION: This project will

- Address issues of scalability, accounting for devices inside of the building to the full external market. The approach will produce a theoretical grounding for transactive processes, and achieve graceful degradation of the grid.

CHALLENGES: Major challenges include

- Lack of formal simulation experience in TE
- Establishing a larger test bed - Alstom - Gridstar

PROJECT APPROACH

- Conduct requirements gathering scenarios
  - Performance targets
- Develop theory/ design/ simulation
- Develop software/ test
- Refine the above
- Conduct analysis of regulatory aspects

MAJOR MILESTONES

Complete

- Requirements
- Design
- Development
- Testing
- Analysis

PERFORMANCE TARGETS

- Graceful degradation of the grid
- Development of microgrid as participant
- Automated DR
- Measurement of load following signal
- Improvement in achieved value of microgrid

IMPACTS

- Reduced overall carbon footprint
- Lower initial capital expenditure
- Positive perception of transactive business model
- Improvements to the regulatory process

PROJECT PARTNERS & POTENTIAL ROLES

Team Lead

- To be identified

Potential Participants and Roles

- Microgrids
- Regulators
- Software developers

DEMONSTRATION PLAN

- Simulation
- Physical Grid Demonstration

Figure 5-5: Co-Simulation Platforms

DESCRIPTION: This project will

- Create a system of systems for co-simulation, with an approach of different nodes/planets revolving around a central 'sun' (Figure 5-6). The system could use multiple simulation platforms, not just a single central one. Communication between nodes and also with the central 'sun' would be possible. The approach includes 'wrappers' behind each node (e.g., clock control, data exchange, mapping, etc.).

CHALLENGES: Major challenges include

- Harmonization of time/ synchronization across platforms
- Load balancing
- Defining data models and what data should be exchanged

PROJECT APPROACH	MAJOR MILESTONES	PERFORMANCE TARGETS	IMPACTS
• Agree on common data model based on regions; common descriptions for experiments and domains • Define data models for different nodes (each domain can define, but basic model is agreed upon) • Explore data broker model—broker sets up simulation, remainder is proprietary; some exchanges can be private • Identify data for market exchange between nodes • Reconcile physics and data deviations • Incorporate pattern matching, analysis/ sensitivity analysis • Examine lessons learned from prior projects	Complete • Well-defined state of interfaces between layers • Direct interaction between nodes/ 'planets' • Reconciliation of physics / physical data • Substantiation of top layers interface with the bottom two layers	• Two bottom layers for modeling and simulation for TE applications (Figure 5-7) • Managing the nodes/ 'planets' effectively • Simulation tools for 'planets'/ nodes working together • Component layer that includes some generic applications or domains • Standardized communications	• Simulation of distributed systems, interfacing/talking between nodes, components, and markets • Demonstration of how to embed smart systems so market works with the grid and is complementary • Positive demonstration of value of TE

PROJECT PARTNERS & POTENTIAL ROLES

Team Lead

- To be identified

Potential Participants and Roles

- Software, platform developers
- IT infrastructure providers
- Subject Matter Experts (domain experts, economics/ finance, markets)
- Data—distributed energy side, microgrids, application data

DEMONSTRATION PLAN

- Demonstrate that TE controls work for sure; demo that grid plus controls plus communications and island layers work together better

Figure 5-6. Co-Simulation Platform Approach

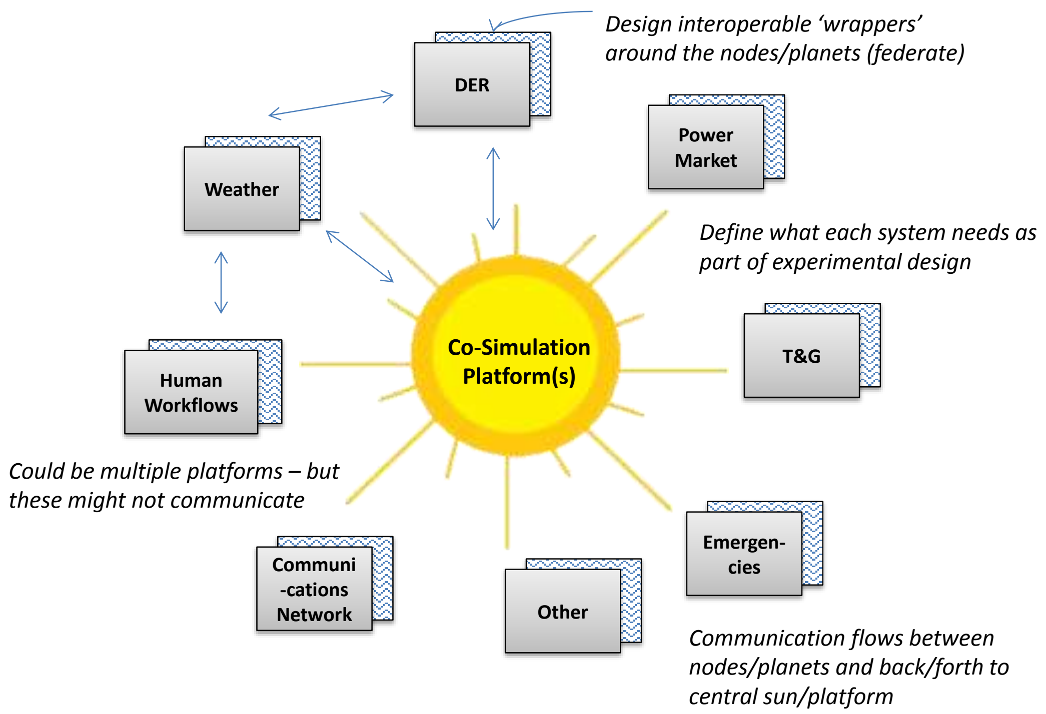
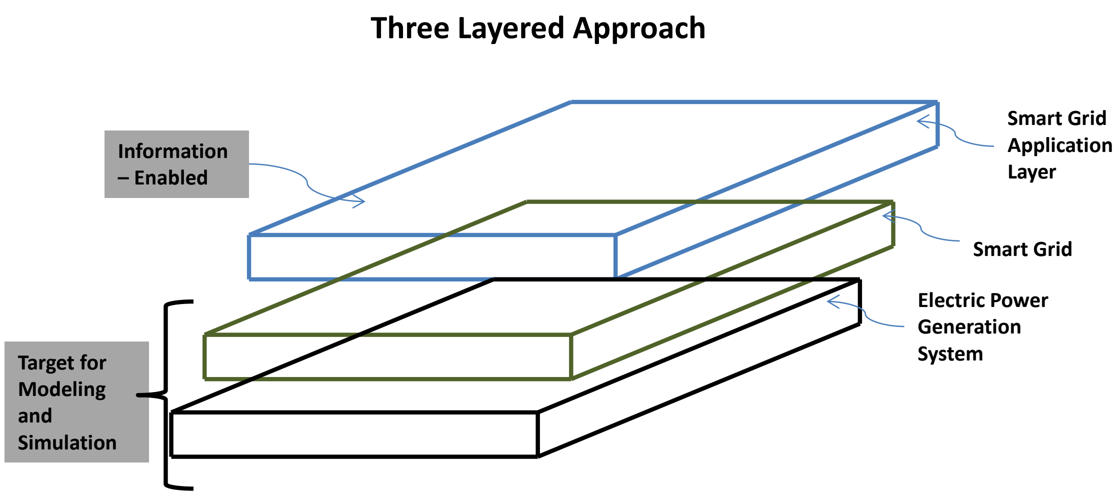


Figure 5-7. Layers for Co-Simulation Platform Approach



6 Path Forward

TE has as its goal more effective integration of customer resources with the grid via markets and controls. Understanding how this can work across the complexity of the grid domains requires simulation tools as a foundation. The TE Challenge brings researchers and companies with simulation tools together with utilities, product developers, and other grid stakeholders to create and demonstrate modeling and simulation platforms while applying TE approaches to real grid problems. The products of the challenge will help industry understand the potential for TE and create a path for real-world trial implementations.

Both the TE Challenge Preparatory Workshop and the Kick-off Meeting (reported in this document) were successful in obtaining agreement on the TE Challenge vision and forming teams to participate in the TE Challenge. The teams formed at the Kick-off Meeting will work toward achieving the goals set forth for their project. Various project-based collaborative efforts will take place as needed by the project teams. Three meetings are scheduled for the entire TE Challenge community.

- TE Challenge Interim Meeting—December 3-4, 2015
- TE Challenge Summit—May 2016
- TE Challenge Phase II Kickoff—September 2016

NIST, in collaboration with federal partners and industry, will host the TE Modeling and Simulation Challenge for the Smart Grid Interim Meeting. The purpose of the Interim meeting is to focus the TE Challenge vision, strengthen team efforts for success, bring in new participants and build new teams, and share resources, progress, and new program developments. A morning plenary session will be followed by team breakouts, discussion on cross-team issues and opportunities, strategy for success, and new collaborations.

The Summit Expo/ Report Out meeting is designed to provide a platform to share results from the projects. These meetings may include plenary session with program updates, demos/ poster sessions, presentation of comparative metrics, peer evaluations, and journal publication of results. NIST will publish meeting reports that may include results for each Challenge Goal, lessons learned, next steps/ roadmap, pointers to various communication tools that have been developed (e.g., in SGIP), and a summary of data resources used/ available. The September Phase II Kickoff meeting is proposed to start the second phase of the TE Challenge, building on the work products and momentum of the first phase and also providing a platform for presenting ongoing work since the May Summit.

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APPENDIX B. PARTNER BRIEFS

The information in this appendix was provided by participants. The views and opinions expressed herein do not necessarily state or reflect those of NIST. Certain commercial entities, equipment, or materials may be identified in this appendix in order to illustrate a point or concept. Such identification is not intended to imply recommendation or endorsement by NIST, nor is it intended to imply that the entities, materials, or equipment are necessarily the best available for the purpose.

Table B.1. Potential Partner Briefs

Area of Interest	Functionality/ Capabilities	Proposed Scenario	Impacts / Why	Partners Needed
ABB Inc.				
Market-based transactive exchanges, control of distributed energy resources, local grid management, and coordination between centralized and distributed resources	Software systems for centralized markets, distributed energy resource management, and advanced distribution systems management. Distributed energy resources including solar PV, wind, demand response, energy storage EV charging infrastructure, microgrids, and distributed var control.	Evaluate viable possibilities of TE through use cases, problem definition, and high-level functional architecture	Demonstrate economic and operational viability of TE across centralized generation, transmission, distribution, and grid edge distributed resources	Potential partners for pilot projects to support the proposed scenarios
Alliander				
PowerMatcher Suite	Harnessing the power of APIs and agent optimization	TE standards; examine protocols to see gaps, overlaps	Standardization and TE implementation	Hacker and Maker space
Bluewave Resources, LLC				
Structuring of retail poser markets and their value chain integration including with wholesale markets	New tools to evaluate economic and business relationships in an even more complex and uncertain value chain	Performance and impact of alternative market structures with varying and changing regulatory and technology scenarios	Fair and effective incentives and market structures are critical	Stakeholders throughout value chain
Businnovation – Vehicle-Solar-Grid				
Allowing grid-interactive EVs to present their available battery storage capacities to market services	Bidirectional power flow controlled by optimizing economic algorithms. Evaluate logical aggregation of roaming (i.e., non-home connected) EVs and prediction of load diversity and variability	Model and predict performance of a medium sized commercial EV fleet with known drive time duty cycles and known tethered charger availability. Demo V2G, demand	Help to demonstrate viability of V2G with premise-based solar PV smart inverters and other local DER components. Identify constraints on flexibility for system wide resources	Controls company, vehicle manufacturer, wholesale market participants

Table B.1. Potential Partner Briefs				
Area of Interest	**Functionality/ Capabilities**	**Proposed Scenario**	**Impacts / Why**	**Partners Needed**
		response, peak shaving, frequency regulation and spinning reserve. Identify optimal kW power level for bidirectional inverter sizing.	aggregation	
Carnegie Mellon University				
Work together toward recommending standards/ protocols	Smart grid in a room simulator	Simulate real-world sanitized microgrid; simulate electric vehicle market	Means of testing what is doable; potential of smart grids demonstrated	TBD
Networks – simulation, communications, simulated electrical; common body of data sets	Basic scenario on which to build.	Develop / agree on one or more baseline distribution grid (topologies, scenarios, data formats)	Could support a co-simulation environment	TBD
CleanSpark				
Software to enable transactive energy exchange	Software and algorithm development, live multi-microgrid test systems	Develop a distributed, secure, open-source/ commercially-compatible software package to allow systems of microgrids to share power	Bring concepts of TE to life within system of microgrids to make use of renewable energy and lower costs, resulting in ready to use software for widespread adoption	Simulation gurus, utility partners, load control device manufacturers, balancing authority
Edison Electric Institute				
Addressing need for reliability and resiliency in the grid	Clean energy.	Business and regulatory models to implement microgrids	Identify the flow of goods and services (and relation of tariffs)	TBD
The Energy Mashup Lab				
Support for transactive interoperation and energy agents	Leaders are experts in interoperation and agent architecture including Energy Agents, EI, OpenADR2, EMIX, TEMIX	Common infrastructure for interoperation—leverage existing standards & technology to focus on your contributions	Simplify development with proven interoperation and agent framework	Any and all Transactive Energy partners. We are neutral infrastructure experts.
General Microgrids				

Table B.1. Potential Partner Briefs				
Area of Interest	**Functionality/ Capabilities**	**Proposed Scenario**	**Impacts / Why**	**Partners Needed**
Role of "Smart Microgrids" in supporting transactive energy.	Advanced Microgrid "Intelligent Energy Management;" "systems" control and communication architecture, dynamic modeling and simulation, "system of systems" methods/tools.	Model, design, and demonstrate a smart microgrid/networked microgrids prototype to assess potential for higher energy value transactions.	Evaluate contribution of Smart Energy Networks (versus individual/aggregated technologies) to TE and appropriate regulatory support.	Upstream (utility) and downstream (local government) partners, intelligent control, communications expertise.
IBM Research				
Transaction framework and transaction signals	In development	Identifying the transaction signals	Renewables integration, understanding human behavior	Partners to validate use cases
MACT USA				
TE transportation management	IoT data concentrators and adaptive software defined WAN capabilities, Advanced Wireless Services network access that is secure and scale.	Provide bridging of various protocols for data sharing and analysis for TE system	Demonstrate reliability, scalability and trust with adaptive software-defined network that is technology agnostic and protocol independent	Partners who have existing data sources to be shared using different protocols, vendor and research organizations
Massachusetts Institute of Technology (MIT) – ACC Lab				
DMM for microgrid secondary control	Software and algorithm development, existing test bed	Develop dynamic market mechanism for microgrid models; implement algorithm in hardware testbed	Huge potential to establish/ develop real world TE applications in microgrids	Microgrid testbed
National Electrical Manufacturers Association (NEMA)				
Network of manufacturers/electrical products; standards	Products / hardware that would be used in TE	Platform for standards development	Smart grid implementation	TBD
Navigant				
Coordination and control modeling to demonstrate value of TE to utilities	Simulation and model development, validation and verification; intelligent coordination and control system development.	TE-based approach to coordinate microgrids, EVs, and DER	Help to demonstrate viability of TE from generation to customers from the utility perspective	Solution providers and technical experts guide utilities in transition to TE
Pacific Northwest National Laboratory (PNNL)				
Grid modeling and	Power system modeling /	Grid modernization	Smart grid	TBD

Table B.1. Potential Partner Briefs

Area of Interest	Functionality/ Capabilities	Proposed Scenario	Impacts / Why	Partners Needed
simulation	tools (e.g., GridPACK, GridLAB-D, Grid OPTICS)	efforts	implementation	
PEPCO Holdings				
Models in advance	Actively integrating RE in the grid/ EV pilot	How do systems get managed?	Smart grid implementation	TBD
Resilient Energy (Microgrid)				
Enabling resilient and fault tolerant distributed energy systems through transactive energy	Microgrid with intelligent critical load management and balancing. Optimization through grid (wide area) and premise (local area) resource service bidding.	Model and predict performance of a medium sized commercial microgrid in both connected and islanded state of operation	Demonstrate viability of TE architecture/ platform to offset initial infrastructure costs (by monetizing grid services); scale down to smaller islanded operation (critical load balancing).	Software simulation, energy storage system vendor, building controls company
Robert L. Hershey, P.E.				
Engineering analysis	Analyze performance and cost of generation, transmission, distribution, and storage; description that public can understand.	Analyze TE systems and compare to present situation	Compare performance and costs of TE systems	
Schneider Electric				
Modeling at facilities and interaction with grid	Facilities / user interactions	Facilities needs for TE	Smart grid implementation; standards.	TBD
Tata Consultancy Services Ltd.				
Integrated what-if analyzer for wholesale electricity market	Optimal portfolio, optimal bidding strategy, spot price under different market scenarios	Model & simulate the short term market environment to conduct "What-If" studies	Game theoretic modeling of generators in an integrated market environment; stochastic modeling of uncertainties in DER and in demand	Generation companies, market operators
Microgrid-based operations, flexible microgrids	Network, DER and storage modeling, simulation of dynamic microgrids	Optimal network configuration using Honeycombed Microgrids covering the service area; Microgrids based operations	Flexible honeycombed microgrid model covering the service area and set of scenarios and use cases based on the TE framework	Distribution companies and retailers
Impact of price on demand & on distributed energy resources	Price-Demand & Price-DER relationship models, game-theoretic model for conflict	Model impact of price on demand / DER and to model conflicts	Price-demand and price-der relationships will help	Distribution companies / retailers, DER

Table B.1. Potential Partner Briefs

Area of Interest	Functionality/ Capabilities	Proposed Scenario	Impacts / Why	Partners Needed
	of objectives	using game theory	in value-based control & DR programs	owners
Analytics for enabling demand response	Solar corrected demand forecast; optimal location of charging stations; inputs to DR programs; information on outages	Develop analytics for enabling Demand Response using smart meter data	Analytics using data intelligently to support the utility in transactive control	Distribution companies / retailers
Distribution system operator model	Model to encourage active participation of prosumers; algorithms for automatic load scheduler at Prosumer level; incentives / penalties to provide power quality) as a service based on voltage / frequency change required, duration of service, and response time	Design distribution system operator model to include direct participation of prosumers in retail market and incentives to provide PQ as a service	Optimal response of a prosumer using load scheduling algorithms & PQ as a service	Distribution companies
Mechanism design for promoting green energy	Incentive mechanism design, game theoretic modeling	Mathematical model for green energy promotion using incentive based mechanism	Promoting green energy for TE evaluation	Regulators, policy makers, academic institutions
TeMix, Inc.				
TE retail energy and distribution tariffs	Existing prototype TE platform in cloud; implement TE interfaces to end prosumers, a distribution operator, and an ISO/RTO.	Demonstrate TE for high penetration distributed PV and storage	Understanding of TE retail subscriptions, spot transactions, and business/ regulatory model	Retailer (competitive or regulated) distribution operator, ISO/RTO, and smart device providers
The MITRE Corporation				
Infrastructure interactions and the prevention of cascading failures	Modeling and simulation, complex systems analysis; bridge between government, academia, and industry	Can TE improve security / prevent cascades within and between lifeline critical infrastructures?	Early stage is crucial for determining the design features of TE that improve resilience	All stakeholders
U.S. Department of Energy, Office of Electricity				
Deployment and commercialization aspects	TE campus – PNNL and University of Washington; facility to test at.	TE implementation	TBD	TBD

Table B.1. Potential Partner Briefs				
Area of Interest	**Functionality/ Capabilities**	**Proposed Scenario**	**Impacts / Why**	**Partners Needed**
University of Oklahoma, Building Energy Efficiency Lab				
Design for control of robust, resilient, adaptable complex systems to facilitate the integration between smart grids and various types of buildings. HVAC control via responsive load of smart grids or building, development of smart grids/buildings with restoration capabilities, and its impact on grid reliability.	1) Developing hybrid models of building load and HVAC system dynamics based on physical laws and measured system behaviors; 2) developing smart virtual energy meter system that provides high-resolution energy metering capacity; 3) Designing active controller enabling smart and robust controls that meet system constraints (e.g., user's comfort and grid supplies) while minimizing operational costs; 4) planning and operation of power system restoration.	Develop model and smart TE control systems for campus and districts with multiple buildings with different requirements that are interconnected to the power grids.	1) Enhance the grid reliability; 2) extend the capability of building to support the power system restoration following blackouts; 3) dealing with computation complexity	Partners that have experience and ideas for a test-bed design and construction.
Vanderbilt University (with MIT, University of Michigan)				
Modeling and analysis of Smart Grid, TE approaches, communication network, cyber threats, and grid stability	Command and Control (C2) Wind Tunnel, an existing HLA-based generic co-simulation platform, will be extended to support tolls for power flow dynamics, transmission and distribution, and market dynamics for evaluation of TE approaches	Model and analyze stability of grid in the presence of unpredictable network behavior (potentially cyber exploits) and market-based demand-response variations	Answers critical questions about viability of TE approaches and the SmartGrid	TE tool users/suppliers interested in bringing it to the C2 Wind Tunnel co-simulation platform

APPENDIX C: ACRONYMS

API	application programming interface
ADR	Automated demand response
AWS	Amazon web services
DC	direct current
DG	distributed generation
DER	distributed energy resource
DLC	direct load control
DOE	U.S. Department of Energy
DMS	distribution management system
DR	demand response
DSO	distribution system operator
EE	energy efficiency
EPRI	Electric Power Research Institute
EV	electric vehicle
FERC	Federal Energy Regulatory Commission
GIS	geographic information system
HLA	high-level architecture
HVAC	heating, ventilation and air conditioning
Hz	hertz
IEEE	Institute of Electrical and Electronics Engineers
ISO	independent system operator
LC	load control
NEMA	National Electrical Manufacturers Association
NERC	North American Electric Reliability Corporation
NIST	National Institute of Standards and Technology
PEV	personal/plug-in electric vehicle
PMUs	phasor measurement units
PNNL	Pacific Northwest National Laboratory
PQ	power quality
PUCS	public utility commission
PV	photovoltaic
ROI	return on investment
RTO	regional transmission organization
SD	software defined
TE	transactive energy
WAN	Wide area network

APPENDIX D: REFERENCES

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