Pacific Northwest
NATIONAL LABORATORY

PATENTED TECHNOLOGIES FOR TRANSACTIVE ENERGY CONTROL

OUR POWER SYSTEM IS CHANGING

OVERVIEW

With significant growth in renewable energy resources, power generation is becoming more intermittent and distributed. Further, millions of smart sensors and meters are transforming the traditional, one-way electricity delivery system into a two-way, information-packed power grid. Transactive energy and control combines economics with power engineering. In essence, how much is an individual or entity that consumes power willing to pay for energy when there is too much demand and not enough supply based on that consumer's preferences and lifestyle choices? These factors work together via smart devices that communicate with the energy market to make decisions on behalf of the consumer—whether to pay higher energy costs during times when power use peaks or delay energy use to pay less and alleviate strain on the power grid.

Through this ground-breaking research and these demonstration projects, PNNL has developed a portfolio of intellectual property, primarily patents, that cover a broad range of transactive energy and control concepts, systems, and functionality. These patents are generally available for licensing to help your organization take a lead role in transforming the U.S. power grid.

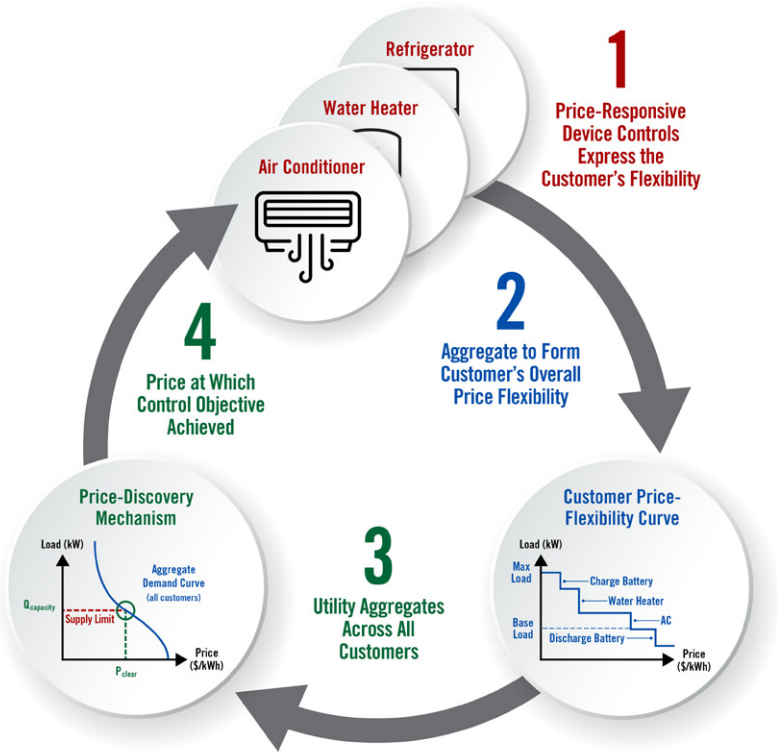
Pacific Northwest National Laboratory (PNNL) pioneered the concept and philosophy of transactive energy and control back in 1996. We laid the groundwork for and demonstrated a choice-oriented model that incentivizes consumers, suppliers, and distributors. We also conducted two large, successful transactive demonstration projects: the Olympic Peninsula demonstration in 2006 and the Pacific Northwest Smart Grid Demo in 2013.

The benefits of transactive energy and control include the following:

- Greater optimization of energy and the coordination of consumption, alleviating strain on the power grid, and improving reliability and predictability.
- Increased consumer flexibility around energy pricing, including the ability to buy or sell energy according to consumer preferences and lifestyle choices, predetermining actions, timing, and cost of energy use.
- A beneficial supply and demand model for energy distributors and consumers. For example, when the amount of power from renewable sources is higher on the grid, energy costs may be lower than usual to avoid excess power generation and encourage greater use of electricity to balance the supply. This approach allows distributors to offload extra electricity while allowing more choice for consumers such as precooling their homes at reduced cost during periods of excess generation.

Example of Transactive Energy and Control

A water heater is connected to a smart device that includes a software "agent" acting on the consumer's behalf for lifestyle preferences previously programmed by the consumer. The device communicates with the energy distributor on the amount it will pay to operate the water heater in a coming period (for example, five minutes). Once all smart device requests are balanced against available energy, a market price for energy is obtained—typically higher during peak use and lower during non-peak use. Finally, depending on that market price and the consumer's programmed preferences, the water heater will decide when to operate so that the consumer gets the lowest price while the grid balances load with supply on a continuing basis.



PATENTED TECHNOLOGIES

FUNDAMENTAL TRANSACTIVE STRUCTURES

PNNL tracks all its intellectual property with a five-digit code, used below with short titles. Specific U.S. patent numbers are available on request.

Market-Based Pricing System

13202, one patent

This 2001 invention and the resulting patent claims are a resource allocation system controlled by a market-based pricing system. Specifically, the patent claims multiple requests for demand, offers to supply, provides price setting, and then alters the electrical loads in response to the price. This approach was referred to as hierarchical, because the demand and price information is gathered and disseminated at multiple levels. This patent is the result of the application of transactive control for demand response as designed for the Olympic Peninsula demonstration project.

Distributed Hierarchical Control

16046, six patents

These patents are also based on the Olympic Peninsula demonstration project and bring the concept of distributed control to the hierarchical nodal price structure of 13202. Specifically, among many other features, these patents cover the concepts of providing and receiving price and demand information at the nodes; the user comfort setting, which is the slider function given to users to select degree of participation and willingness to respond to price signals; and details on the bidding and dispatch value calculation process.

Futures Market

16920, four patents

These patents add the concept of using a futures market, specifically a day-ahead market, for the source of price information and using the electricity futures market and the availability of supply at the time. The overall system is like the 16046 series, and the various claims sets embody those features from the 16046 patents (e.g., user comfort and tolerance settings).

VOLTTRON™

17008, three patents

VOLTTRON™ is an execution platform for an agent-based, transactive control system. This independent, language-agnostic agent platform has built-in security for resource management and supports distributed control of various devices for better energy efficiency and reliability. The patents cover the data verification, validation, and security aspects of VOLTTRON™, specifically for power system applications. An open-source version is available specifically for buildings control. Users of this open version have access to these patents via the Eclipse Foundation.

Transactive 2.0

30210, two patents (one issued, one pending)

This pending patent covers the fundamental and novel features of the transactive system used in the Pacific Northwest Smart Grid Demo, which PNNL refers to as Transactive 2.0. The primary claimed attributes are 1) a feedback signal to each node that adds a temporal dimension to the market clearing function (the bids and asks can fluctuate over time but will converge as the closing time nears) and 2) the toolkit architecture in which each device has specifically defined inputs and outputs (incentive and feedback signals) with a common data structure. The specific intelligence for each device is in the node, not the general system, so additional types of devices can be easily added. This application will likely result in multiple divisional patents.


EV

SPECIFIC SUPPORT TOOLS

Market Managing Energy Storage Systems

31487, patent pending

Energy storage systems are rapidly being deployed throughout the grid to firm intermittent renewable generation and to provide load control. This pending patent describes a method for creating day-ahead bidding strategies for energy storage systems (e.g., batteries) to participate in the transactive retail day-ahead electricity market. The bidding strategy is developed based on look-ahead electricity prices obtained from the forecasts of the day-ahead electricity prices and optimum operational schedules prepared by maximizing the profits over the given electricity prices. This invention builds a novel idea to adapt the battery bid by incorporating flexibility of the battery and battery characteristics, while bidding battery into the transactive day-ahead market.

Transactive Electric Vehicle Charger

32100, patent pending

This patent claims a transactive electric vehicle (EV) agent capable of controlling charging and discharging through coordination with real-time and look-ahead markets. This transactive EV agent incorporates a coordination mechanism between the real-time and look-ahead markets such that the agent can use the real-time market as a correction to the look-ahead markets. Moreover, the look-ahead market factors real-time market uncertainties into its optimization to compensate for uncertainties stemming from the real-time market. The methodology also characterizes desired state of charge so that EVs can participate in the market, either to minimize their costs or to maximize their comfort.

Blockchain Smart Contracts for Energy Markets

32107, patent pending

Applying blockchain smart contracts to a transactive control system presents an opportunity to increase the scale and security of a modern grid, where distributed energy resources and real-time energy market applications require an increase in security and control of data. Blockchain provides a unique path for a more decentralized and resilient integration of "Energy Internet of Things" and grid-edge devices. Energy delivery systems operating at the grid's edge require unprecedented levels of security and trustworthiness to verify integrity of data and manage complex transactions. Blockchain-based smart energy contracts can help fill these optimization and security gaps and improve the state of the art in grid resilience by providing an atomically verifiable cryptographic signed distributed ledger to increase the trustworthiness, integrity, and resilience of energy delivery systems at the edge.

Load Manipulation

16919, one patent

The first patent covers the double-curve method for thermostatically controlled loads, one for heating and one for cooling. The second adds a random number feature to the probability calculation to determine when a device operates. This randomizer feature addresses the situation when too much load can respond to a price signal, so the participating loads are randomly selected.

Thermocline Measurement

17054, one patent

This technology measures the position of the thermocline in a water heater, thus providing information on the state of charge of the water heater, which the transactive control system needs for bid generation.

Transactive System Coordination

30156, two patents

Generally, this patent claims the coordination of a transactive system and smart grid assets, including PNNL's autonomous, frequency-based demand-response system. In addition to peak shaving and load control, this approach to demand response allows the use of transactive control to provide various ancillary services such as frequency regulation, load following, and spinning reserve.

Submission of Response Curves

30589, one patent

One of a set of intellectual property that is optimizing and perfecting the transactive system. This patent application claims the submission of response curves for devices to the system, as opposed to just sending bids, which moves the model of the device from the system to the device.

External Temperature Controlled Loads

30658, one patent

Expanding on 30589, this patent application claims controlling a population or group of thermostatically controlled loads, even without direct information on each one, by considering them generally based on temperatures measured in the area.

CONTROLLING DERs AND DISTRIBUTION SYSTEMS

Controller DERs for Grid Resiliency

31489, patent pending; 31489, patent pending

This pending patent describes a novel method and system for a transactive framework to engage behind-the-meter distributed energy resources (DERs) during abnormal grid conditions to support service restoration. Consumer-owned DERs usually are neither accessible from central distribution management systems, nor is their control economically justified without proper design of transactive framework. This innovative transactive framework provides a foundation to transact reactive power from behind-the-meter DERs for improving service restoration and system recovery.

Providing Ancillary Services with DERs

31624, patent pending

This pending patent describes a novel method and system for a transactive framework to engage behind-the-meter DERs during abnormal grid conditions to support service restoration. Consumer-owned DERs usually are neither accessible from central distribution management systems, nor is their control economically justified without proper design of transactive framework. This innovative transactive framework provides a foundation to transact reactive power from behind-the-meter DERs for improving service restoration and system recovery.

Providing Ancillary Services with DERs

31624, patent pending

This transactive-based software tool addresses the co-optimization problems faced by independent system operators in day-ahead energy and ancillary service markets when there are DER assets to consider. The tool simultaneously allocates power generation, demand, and reserves in a power network, such that supply and demand are balanced, service requirements are met, and network constraints are satisfied. It also addresses the key issue of privacy preservation when designing the market bidding structure so that dynamic cooperation among DERs is facilitated. The independent system operator communicates its energy price and ancillary service price, and the DERs respond only with their corresponding power generation or consumption levels, as well as energy reserve levels.

Transactive Mechanisms for Rationing Power to Loads

31766, patent pending

This transactive-based mechanism is used to ration electrical power to loads (residential, commercial, and industrial) when faced with or after entering a period when the supply of electrical energy is not sufficient to meet the total system demand. This mechanism allows system operators to dynamically adjust the allocation of power to each customer based on the available, distributable supply through a transactive operation. Any customers not using their full ration, or those able to supply some of their own energy through local energy sources (such as solar photovoltaic, CHP, electrical energy storage, etc.), would be able to sell some or all of their ration to those interested in paying. Thus, a market would be established for trading of these rations.

Enhancing Distribution System Resiliency

32018, patent pending

Researchers invented a new transactive method that improves the distribution system resiliency by enabling additional switching operations for electric utilities. The proposed transactive mechanism incentivizes and engages customer-owned DERs to provide voltage supports to the distribution systems under both normal and abnormal conditions. The key novelty of this technology is the integration of the network voltage sensitivity into the transactive bidding mechanism to capture the locational value of the DERs. This methodology provides a transactive mechanism that engages DERs to reduce the voltage difference across those switching devices and enables the utilities to achieve more switching operations and, hence, restores additional network segments.

Day-Ahead Retail Transactive Market for Distribution System Operations

32096, patent pending

This patent describes a retail transactive market for distribution system operators to support the day-ahead and real-time market participation of spatially DERs. While the other transactive patents are primarily focused on the real-time energy market participation of DERs, this invention provides a new future (e.g., day-ahead) retail transactive market and its coordination with other markets (e.g., real-time). Distribution system operators can use this market to engage DERs, not only for solving distribution system congestion, but also for enabling participation in day-ahead and real-time wholesale electricity markets on behalf of the DERs. The hourly, periodic, day-ahead market provides a unique opportunity for DERs to adjust their bids every hour, unlike the case in the wholesale day-ahead market where the opportunity for the bid adjustment does not exist.

Navigating Between DERs and Larger Markets

31133, patent pending

This pending patent will claim the system and method for aggregating the modeling of a distribution system with DERs into a larger transmission or market pricing model. Traditionally, distribution circuits are modeled in larger systems as static equivalents, which do not reflect the variability of DER output or smart loads. This system will step between the hierarchical models to continually adjust the equivalents, and it works in both directions—it can inform the larger models with information from the DERs and it can inform distribution circuits with changes in market prices.

WORKING WITH US

These innovative software tools are generally available through open-source platforms, no-fee licenses, or fee-based commercial licenses. We also offer a low-cost, six-month exploratory research and option agreement to "test- drive" the technologies.

At PNNL, we can collaborate with you to customize these tools for your systems and needs. We can test, demonstrate, and integrate technologies at either your site or at ours. A specialized facility—the Electricity Infrastructure Operations Center—is available on the PNNL campus in Richland, Washington. The facility integrates industry hardware and software, real-time grid data, and advanced computation in three functional control rooms with a dedicated server farm. This facility is available via physical and remote access to utilities, vendors, government agencies, and universities for development, integration, verification/validation, testing, and training.

ABOUT PNNL

Interdisciplinary teams at PNNL address many of America's most pressing issues in energy, the environment, and national security through advances in basic and applied science. Founded in 1965, PNNL employs more than 5,000 staff and has an annual budget of nearly $1.1 billion. PNNL is managed by Battelle for the U.S. Department of Energy's Office of Science.

PNNL is a recognized leader in electricity infrastructure, transactive energy control, cybersecurity, and buildings research. We collaborate with industry, utilities, universities, and government to improve the resilience, reliability, and security of the nation's electricity delivery system. You can view all our innovations available for commercialization at *pnnl.gov/available-technologies*.

CONTACT

If you would like more information about any technologies featured in our brochure, send inquiries to:

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U.S. DEPARTMENT OF
ENERGY

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