# Modeling Tomorrow's Power Grid to Enable Decarbonization and Resilience

How PNNL power grid modeling unlocks critical insights to achieve a clean, resilient, and equitable energy future.

Utilities and grid operators are at the intersection of climate change, potential power system disruptions, changing consumer expectations, and a rapid technological evolution. As the energy industry changes rapidly, these utilities and grid operators must move nimbly to integrate renewable and variable generation resources onto the grid while keeping the lights on and costs reasonable.

For utilities and grid operators to keep pace with this global energy transition, they need to know what's happening across their systems as it happens—and often before it happens—at both the bulk power and distribution system levels. They want to see and understand the future—whether that's the next hour or the next decade—and predict the potential impacts of extreme events, changes in demand and load shapes, and new grid dynamics brought on by increasing penetration of inverter-based resources. Today's utilities and grid operators need tomorrow's tools. High fidelity modeling and highly detailed simulations of the power system's increasingly complex interdependencies and dynamism of the changing power grid inform important planning, investment, and operational decisions.

Pacific Northwest National Laboratory (PNNL) helps utilities and grid operators achieve clean, resilient energy outcomes in a rapidly changing energy landscape increasingly impacted by climate change. We combine the application of high-performance computing with new artificial intelligence and machine learning techniques and deep power grid domain expertise to model energy system dynamics across different spatial and temporal scales.

## POSITIONING UTILITIES FOR LARGE-SCALE RENEWABLE ENERGY INTEGRATION

To answer challenges posed by climate change, the Biden Administration has established goals for America's decarbonized future. They include a 50–52 percent reduction in economy-wide net greenhouse gas emissions by 2030, emission-free electricity generation by 2035, and a net-zero emissions economy by no later than 2050. As a result, utilities and grid operators must choose their optimal pathway toward decarbonization. This necessitates a clear understanding of how system interdependencies and new operational complexities will impact grid reliability and resilience. Accurate power grid modeling and simulation, combined with expert analysis of the data, is critical for utilities to understand the impacts of decarbonization and maintain system cost, efficiency, reliability, and resiliency.

PNNL offers new approaches to grid analytics and control technologies that deliver unprecedented situational awareness and the ability to manage rapidly changing grid conditions and dynamics. Our modeling approaches are customizable and can accommodate a wide range of system operating conditions with different renewable forecasts, enabling better long-term decarbonization planning. Partnering with PNNL, utilities and grid operators can look ahead to the future energy markets and apply hybrid resources to their models, while also simplifying parallel power grid application development.

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## MODERNIZING ENERGY FORECASTING AND SYSTEM PLANNING

Modern and future-focused forecasting models help decision makers link decarbonized energy systems with distributed energy resources. PNNL's modeling experts can account for behind-the-meter generation associated with electric vehicles, wind and solar power, demand response applications, and transactive energy control, as well as quantifying load impacts associated with curtailment or weather events.

New analytical approaches at PNNL also enable accurate forecasting, allowing utilities and grid operators to better serve customers' dynamic energy consumption and increasing load volatility. Miscalculations can be costly and lead to increased costs or instabilities in the power system. If grid modeling incorporates more analytical processes and advanced grid data sets, utilities can more effectively forecast for multiple unknowns.

## IMPROVING GRID RELIABILITY AND RESILIENCE

Utilities and grid operators must deliver a safe and reliable supply of electricity to businesses and consumers. Yet, this is becoming more and more challenging in the face of extreme weather events, natural disasters, continuously evolving cyber threats, and the operational challenges of managing an energy resource portfolio with increasing amounts of intermittent generation.

PNNL-developed technologies help prevent small problems from becoming big outages. Our ability to model detailed interactions among interdependent energy infrastructure, apply cascading failure analysis, and even recommend corrective action to minimize risk helps utilities understand and respond to power instability during extreme events. These early, valuable insights into changing grid conditions can reduce compounding power losses or blackouts. PNNL's modeling capabilities are also used to solve stochastic, security-constrained, and multiperiod grid optimization problems.

To maintain reliability and resiliency, utilities and grid operators can also benefit from modeling and simulating different subsystems in a coordinated manner, or co-simulation. PNNL's robust co-simulation tools can integrate simulators from separate domains to mimic regional and interconnection-scale system behaviors at unprecedented levels of detail and speed. This co-simulation framework powers another PNNL offering: our comprehensive resilience modeling system for North American energy-sector infrastructure, which analyzes and evaluates complex power system threats and hazards at national scale.

## DELIVERING NEW SERVICES TO CUSTOMERS

Transition in the energy industry also offers opportunities for utilities and energy companies to enhance their focus on customers and draw from demand-driven value pools at the grid edge. To compete in this increasingly dynamic sector, utilities and grid operators must provide access to emerging technologies and deliver new value-added services to customers. These programs also help meet growing pressure from regulators and consumer groups, especially since customer satisfaction ratings can impact key regulatory decisions, rate increases, and bond ratings. Utilities can also utilize emerging grid technologies and their associated data streams to help balance consumption across the energy system. Grid modeling offers actionable insights for utilities and grid operators to scale and achieve value and growth given new customer expectations and adoption of DERs.

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Delivering new services also means harnessing the benefits of transactive energy and its intelligent, multilevel communications approach to coordinate actions with customers and delivery resources. The ability to model the impacts of transactive control technologies, especially with machine learning algorithms, can help utilities simulate delivery of new services and make sure there is capacity to execute automatic, rapid, and informed transactions between the power grid and homes. These analysis and modeling capabilities can also help utilities understand the impacts of transactive energy on energy costs, peak load management, and infrastructure buildouts. PNNL offers tools for modeling and simulation of transactive concepts as they relate to DERs and customers, while also incorporating smart loads and coordination between the distribution system operator and transactive network.

### OPEN-SOURCE DISTRIBUTION MODELING TOOLS

- Enable data integration, used to test advanced distribution controls on realistic models, including agent controls, aggregator controls, and standards-based communications layers
- Answer questions around implementation and realization of DER control systems and potential markets

### HPC FOR DYNAMIC CONTINGENCY ANALYSIS

- High-performance computing to dynamically evaluate the performance of systems with DERs to identify critical areas for increased voltage support, dynamic stability, and more

### PCM SOLUTIONS WITH TRADITIONAL AC POWER FLOW SNAPSHOTS

- Combine the values of chronological production cost model solutions with traditional alternating current power flow snapshots, offering cost-savings and reliability simultaneously

### ENHANCED FORECASTING AND RESILIENCE MODELING

- Prebuilt analysis workflows extensible to new workflows, as well as techniques to solve large-scale AC-based problems

## WORKING TOWARD ENERY EQUITY

Achieving energy equity in the power system requires building an advanced national power grid, transitioning to clean reliable energy, and designing smart buildings in ways that are just and equitable. It’s about an energy system that is not only clean and resilient, but also affordable and accessible to all. Advancing energy equity means recognizing a historically disproportionate distribution of benefits and costs of energy infrastructure, as well as unjust operation and investment. It’s about finding new approaches to distribution that rebalance outcomes and responding to customer energy burdens, vulnerabilities to disruption, and resilience needs. Technology solutions, including DERs and energy storage, should be accessible, sited, and sized to win better outcomes for underserved communities, such as wealth building opportunities, more reliable systems, and more affordable clean energy.

These concepts motivate PNNL’s modeling and analysis experts to update and apply existing tools and modeling capabilities to improve equity. Some of these tools are used to optimally size DERs in the context of microgrids to achieve both resiliency and cost-savings. These technologies can also be used to design microgrids for community centers, hospitals, or other critical facilities in regions that are increasingly impacted by the effects of extreme weather, with a specific focus on traditionally under-resourced communities. Microgrids can also

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be deployed in remote regions of the United States, where communities have less reliable access to electricity. Other PNNL tools can analyze how policies and programs can impact electric vehicle adoption and costs in communities that have historically had less access to the technology, such as residents of multi-family housing and underserved neighborhoods. This not only allows these communities to participate in our energy future more fully, but can reduce harmful localized emissions caused by internal combustion engines, which have been linked to increased incidence of asthma and other respiratory illnesses.

## ABOUT PNNL

Pacific Northwest National Laboratory advances the frontiers of knowledge, taking on some of the world's greatest science and technology challenges. Distinctive strengths in chemistry, Earth sciences, biology, and data science are central to our scientific discovery mission. PNNL's research lays a foundation for innovations that advance sustainable energy through decarbonization and energy storage and enhance national security through nuclear materials and threat analyses. PNNL collaborates with academia in its fundamental research and with industry to transition technologies to market.

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Dec. 14, 2021
PNNL-SA-169163

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