GRID 2030 INITIATIVE

Goal: Reinventing the grid for 50% distributed renewable energy

VISION

The legacy power grid has served the United States' electricity needs reliably and efficiently for more than a century. Large, centralized plants generate electricity, which is transmitted through high-voltage networks and supplied to end customers over low-voltage distribution networks. Power and information flow only one way.

Now we are seeing transformational changes. Renewable costs are approaching grid parity, their penetration is increasing rapidly, new generations of instrumentation can sense and actuate grid components, and advances in data analytics offer disruptive opportunities. Driven in large part by climate change concerns, many States are mandating ambitious targets for renewable energy penetration from wind and solar. To meet these targets, the future grid must be reimagined. It should be capable of supporting significant fractions of electricity generation from renewable resources from a mix of assets – utility scale wind farms and solar plants, as well as small-scale distributed rooftop photo-voltaics. Information and power flow will be bi-directional, organized by a scalable and robust grid management system. This vision of Grid 2030 is at the core of our research agenda.

BERKELEY LIVING LAB

The test bed for grid revolution

Reinventing the grid requires a real-world, commercial test bed that can demonstrate the integration of smart, energy efficient and net-zero-energy buildings and renewable generation. The Living Lab is a public-private partnership designed to unleash the full potential of renewables and efficiency on the grid, advance development of microgrids, and enable utility evolution. Learn more on page 65.

The legacy grid architecture is not designed to cope with the intermittency, uncertainty, and complexity that accompany very deep renewable penetration. A new paradigm for the grid management system is necessary. The advent of ubiquitous and inexpensive sensing, the development of modern data-analytics methods, and the emergence of controllable loads, strategic electrochemical storage, and new power electronics technologies combine to offer spectacular opportunities to re-engineer the electricity grid architecture.

Under the Grid 2030 Initiative, Berkeley Lab's Energy Technologies Area (ETA) ambitiously targets 50% or more of power demand served from distributed renewables. The EAEI Division at the Berkeley Lab studies integration of transmission scale renewable assets intimately related to this Initiative. The distribution system is organized into a collection of interacting resource clusters. Clusters are geographically defined – a campus, community, or industrial parks, or micro-grids. Each cluster boasts renewables, battery storage, flexible demand, ubiquitous sensing, and actuation capabilities supported by power electronics assets. Clusters are

managed through an aggregator, which is respo
reliability, and power quality. The aggregator cou
regulated utility. Distribution assets could be leas
interact through the legacy high-voltage transmis
power to be generated and consumed locally, re
transmission infrastructure.

The grid management system (GridMS) organizes these distribution-side resources. Clusters communicate, exchanging power and information. The scalable peer-to-peer GridMS supports these transactions, assuring resilience. The Grid 2030 Initiative visualizes our distributed energy resource (DER) future as a collection of interconnected behind-the-meter, grid-connected resources, combining storage, photovoltaics, electric vehicles, and flexible demand, to reduce reliance on legacy centralized generation and transmission. In this vision, customers are transformed from passive recipients of electricity to active participants in our sustainable energy future.

The Grid 2030 Initiative is driven by and supports the objectives of diverse stakeholders, including end use customers concerned about climate change and electricity costs, entrepreneurs seeking innovation opportunities, utilities looking for new business opportunities in managing DERs, military facilities requiring security of supply and resilient operation, and regulatory agencies mandated to decrease systemic greenhouse gas emissions.

RESEARCH OBJECTIVES

EAEI DIVISION

Institutional and Policy Support for Grid 2030 Initiative

The Energy Analysis and Environmental Impacts (EAEI) Division develops and interprets information to inform governments, regulators and industry groups about energy-related issues. In the grid space, our research informs these stakeholders on policy and business choices that guide the adoption of technologies and architectures that support the Grid 2030 vision. Well-informed choices can greatly accelerate realization of a future electric grid that maximizes public and private benefits.

How can the interests of utilities, solar providers, and consumers be aligned to actively support our collective sustainable energy future? What impacts do various policy choices have on the regulated utility business model? What consumer protections must be put in place to foster growth of a vibrant industry of distributed renewable energy vendors, aggregators, and technology providers? What are the factors that will lead consumers and firms to purchase distributed renewable, energy storage/electric vehicle, and load control technologies? What is the value of emerging energy technologies at progressively higher market penetrations, and how can the variable nature of renewable energy output be best integrated into existing and new energy markets? These questions are at the heart of the EAEI Division research agenda.

We provide thought leadership to state regulatory utility commissioners and staff on the future of electric utility regulation. We quantify the economic value streams offered by renewable and distributed technologies, including those for which formal markets have yet to be established. We review the state of the market for demand response aggregation firms. We assess the technology, market, and business factors that explain differences in both utility and consumer adoption of solar PV. We analyze consumer responses to innovative electricity tariffs. We develop tools that enable utility planners to factor in the value consumers place on electricity reliability into their reliability investment decisions.

At LBNL we recognize that the technological and architectural revolution envisioned by Grid 2030 must be underpinned by a sound understanding of the regulatory, business, and consumer policies necessary to embrace these transformations.

Our initiative aims to address fundamental barriers and challenges for Grid 2030 in the context of reliable and cost-effective power balance with 50% or greater distributed renewable generation. Our focus is on systematically coordinating and managing millions of distribution-side resources to reduce reliance on the legacy high-voltage transmission grid. Some assets will submit to centralized control. Others will insist on autonomy, controlled through price proxy signals. The GridMS must flexibly support both control paradigms.

Berkeley Lab's research activities have led to a fundamental understanding of the problems faced in energy distribution systems given high renewable penetration, and have also shown how advances in sensor hardware, modeling methods, control algorithms, and optimization tools can mitigate these problems. Existing industry efforts in these domains do not adequately capture system behavior at the diverse timescales necessary.

The central thrusts of our research are:

- Engineering scalable, **flexible architectures** for interconnected resource clusters that coordinate the flow of data, power, and money
- Developing modern **data analytics** and machine learning methods that exploit ubiquitous **sensing** in the distributed system for planning and operations, and
- Designing distributed **real-time control algorithms** that economically accommodate high renewable penetration while assuring reliability and power quality.

GRID MODERNIZATION @DOE

DOE Grid Modernization Initiative and Grid Modernization Laboratory Consortium

The Grid 2030 initiative will coordinate and align with the DOE's Grid Modernization Initiative launched in November 2014. LBNL is one of 14 national labs participating actively in the Grid Modernization Laboratory Consortium (GMLC), which is developing and implementing an integrated approach for planning and delivering innovations and thought leadership on grid modernization. For example, GMLC members played a leading role in developing a multi-year (2016-2020) program plan that defines the vision, identifies key challenges and targeted outcomes, and describes integrated demonstration projects across six technical areas: (1) Devices and Integrated Systems Testing, (2) Sensing and Measurement, (3) System Operations, Power Flow and Control, (4) Design and Planning Tools, (5) Security and Resilience, and (6) Institutional Support. Key technical goals outlined in the demonstration projects and technical teams are: transmission and distribution system operating reliably on lean reserve margins; resilient distribution feeders with high percentages of low-carbon distributed energy resources (50%); advanced modern grid planning and analytics platform. While the 2030 Grid Initiative is most closely focused on the second objective, LBNL researchers also participate actively in multi-lab teams on DOE funded grid modernization projects centered on the other two goals.

Working with EAEI, the initiative will study economic, institutional, and customer behavioral factors that are central to the adoption of GridMS into the future U.S. electric power system. This will involve quantifying the economic value of distributed resources to utilities and customers in existing and new markets. These studies will be stratified geographically, driven by supply and demand cost models, and by forecasts of DER capabilities.

FLEXIBLE GRID ARCHITECTURES

The development of grid architectures that support reliable, economic service provision by coordinating transmission side assets with millions of controllable distributed resources is challenged by a lack of functional definition at the hardware level, sensing infrastructure, data associated analytics, and appropriate control algorithms. Microgrids can be viewed as existing examples of clusters. Power balance, power quality, reliability under normal and contingency operations, and ancillary service provision for microgrids is not sufficiently understood, in large part due to inadequate testing and the limited number of deployments. Our research aims to understand how different hierarchical microgrid configurations affect intra- and inter-network stability, and also how these might affect the ability of microgrids to provide ancillary services to the bulk electric system. We also explore the study of novel markets for a networked community of microgrids, and the analysis of dynamic ownership boundaries based on control objective such as resiliency or reliability.

SENSING AND DATA ANALYTICS

Our research at Berkeley Lab has resulted in a fundamental understanding of the behavior of distribution systems at fine spatial and temporal granularity through advanced sensors and data analytics. Visibility into the distribution grid is limited. Existing industry sensor sets cannot measure and characterize short time-scale distribution system behavior accurately. Our approach combines appliance-level consumption data in homes with real-time substation and line measurements from our novel micro-PMU sensors. Using this wealth of information, we devise data analytics algorithms to isolate faults and anomalies in distribution circuits. These are designed to process enormous data sets in run-time and isolate anomalies with low latency and high reliability. We will build on these sensing and analytics activities to develop predictive models for control and synchronization of microgrids, which would scale to the interconnected resource cluster architecture envisioned in GridMS. Berkeley Lab teams are also developing algorithms to determine the risk of events impacting high penetration of distributed energy resources, and using new control strategies to mitigate these risks. These will be tested at the **FLEXLAB™ HIL** (Hardware in the Loop) and the inverter test lab.

DISTRIBUTED REAL-TIME CONTROL ALGORITHMS

Modern inverters that accompany distributed renewable generation have advanced power electronics capabilities that are not exploited. Controlling millions of inverters to manage power quality while serving power balance is an extraordinary challenge. Our approach has two components - power flow simulations of distribution feeders populated with advanced inverters, and using these simulations to model relationships between inverter settings and feeder performance metrics. The modeling effort relies on applied machine learning methods ranging from simple clustering to nuanced Bayesian inference.

METRICS

- Hardware-in-the-loop demonstrations of cluster capability with integrated PV, storage
- Quantitative assessment of reliability, reserve requirements under GridMS
- Reduction in cluster control loop latency to near real-time
- Distributed algorithms for coordinated resource clusters,
- Demonstration of the interconnected cluster architecture in several pilot projects.

THE PATH TO DISTRIBUTED CLEAN ENERGY

Working with DOE's Grid Modernization framework and VTO Initiative, the ETA's Grid 2030 Initiative will help enable the nation's power grid to accommodate deep penetrations of distributed renewable generation. This vision for Grid 2030 leverages new developments – from the broad distribution of electric vehicles to emerging power storage options to ubiquitous sensing – and drives the development of new technologies and systems that will power America's sustainable future.