REAL-TIME OPTIMIZATION AND CONTROL of Next-Generation Distribution Infrastructure

A project funded by ARPA-E under the Network Optimized Distributed Energy Systems (NODES) Program

The National Renewable Energy Laboratory (NREL), California Institute of Technology, University of Minnesota, Harvard University, and Southern California Edison (SCE) developed an innovative control architecture for distributed energy resource (DER) systems that addresses the unique needs of utility companies, DER aggregators, and end customers who own grid assets.

The new architecture is applicable to distribution systems, microgrids, and soft-microgrids. It unifies real-time voltage and frequency control at the level of the home, building, or energy resource, with network-wide power management at the level of the utility or aggregator. This real-time distributed control architecture allows unprecedented flexibility, reliability, and efficiency of DER operations.

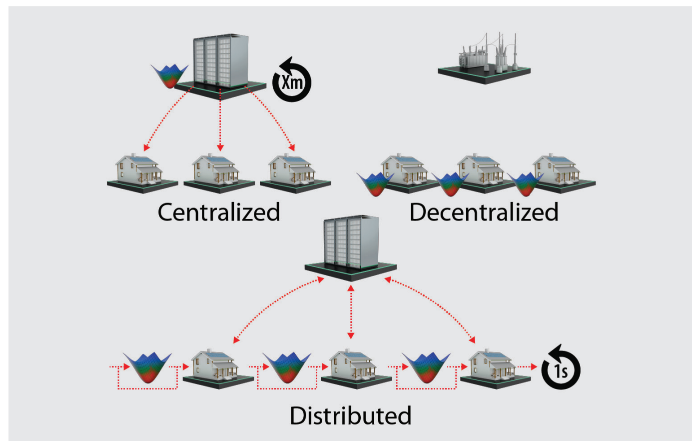
The real-time optimization architecture enables:

- Optimization of an entire distribution grid in real time to increase system efficiency and reliability
- The ability for feeders, neighborhoods, and communities to emulate virtual power plants providing services to the grid (such as frequency support, regulating services, or capacity reserves), while concurrently addressing unique operational objectives
- Reliable integration and seamless, large-scale coordination of DERs
- 100% integration of renewable energy resources
- Interoperability with legacy grid components and advanced distribution management systems.

Targeted applications and customer segments

The real-time optimization architecture offers:

- A solution for **investor-owned utility (IOU) companies, cooperatives,** and **municipalities**, providing control **modules** located at the utility and at the DER level, synergistically coordinating in real time through the developed technology.
- A solution for urban and rural **microgrids** for real-time distributed optimization of DERs



The real-time optimization architecture offers distributed decision-making capabilities while systematically coordinating the operations of DERs to increase reliability. This is in contrast with centralized and decentralized control systems. Illustration by Josh Bauer, NREL.

- A solution for urban **soft microgrids** (community-, campus-, and neighborhood-level systems connected to the rest of the grid through one point of interconnection) and **Community Choice Aggregations**

Hardware-in-the-Loop Validation and Field Deployment

The project team built a hardware-in-the-loop (HIL) research platform where the proposed technology is being validated using realistic distribution feeder models with hundreds of controllable assets. The team is currently performing the first-of-its-kind power HIL experiment with at least 100 DERs at power, controlled in real time and operated as if connected to the feeder. The experiments are being performed at NREL's Energy Systems Integration Facility *(see www.nrel.gov/esif).*

The technology is currently being tested at the Stone Edge Farm Microgrid in Sonoma Valley, California, and will be deployed in the territory of the electric cooperative Holy Cross Energy in Colorado.

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ENABLING REAL-TIME COORDINATION
to address Customer and Utility Needs

Addressing Customer and Utility Needs

The real-time architecture provides unique coordination and feedback-based optimization capabilities to enable large-scale integrations of DERs by:

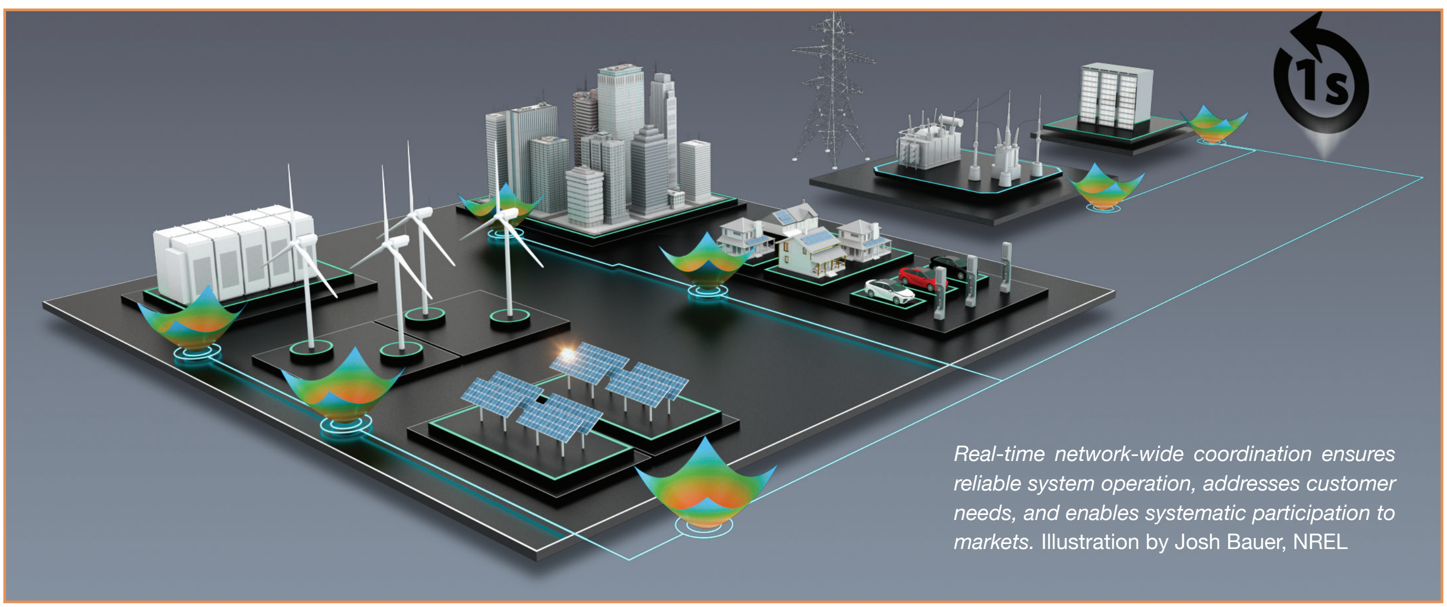
1. Leveraging real-time network-wide coordination to ensure reliable system operation in the midst of fast-changing ambient conditions and loads and to enable fast response to disturbances precipitating from the main grid, sudden loss of load, and network failures
2. Ensuring voltage regulation and ampacity limits for any integration level of DERs
3. Automatically managing a large number of DERs without requiring the utility to run extensive feasibility studies and keep track of their usage patterns
4. Enabling behind-the-meter DER management based on local objectives that are flexibly defined by end-users, while partaking in grid operations to enhance reliability.

Enabling Virtual Power Plants

Traditional approaches to regulating frequency and maintaining reliable operation of transmission systems use primary frequency response, automatic generation control, and regulation services provided by large-scale synchronous generators. In the future, dispatchable DERs could supplement generation-side capabilities by providing additional flexibility in regulating frequency and maintaining reliable system operation. Toward realizing this vision, the project team leveraged real-time coordination and feedback-based optimization to develop an algorithmic framework for DER aggregations in distribution feeders, to emulate a virtual power plant that can effectively provide regulation services to the bulk system and guarantee power quality across the distribution network.

To provide primary frequency support, the team synthesized controllers for DERs located throughout a feeder so that the active power injected at the feeder head could collectively adjust in response to frequency deviations. This framework enables analysis at the transmission level, where distribution-level DER aggregations can effectively be modeled as virtual power plants that provide primary frequency response needs at the feeder head.

To provide secondary frequency support and regulating services at multiple temporal scales, the team developed a distributed control architecture that manages active power at the feeder head in real time to track given setpoints. For example, a setpoint could be an automatic generation control signal, a ramping signal, or a 5-minute dispatch commanded by the transmission system operator. Controllers are designed to track the setpoint at the feeder head, concurrently maximize customer and utility performance objectives, and ensure that electrical limits are enforced throughout the feeder.



Real-time network-wide coordination ensures reliable system operation, addresses customer needs, and enables systematic participation to markets. Illustration by Josh Bauer, NREL

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