Photo from iStock 1042067682

Autonomous Energy Systems: A Distributed Approach to Control Millions of Energy Devices

Energy systems of all sizes are becoming increasingly complex. The National Renewable Energy Laboratory has developed new controls that will support real-time operations and management of renewables, storage, electric vehicles and loads for grid efficiency and resilience.

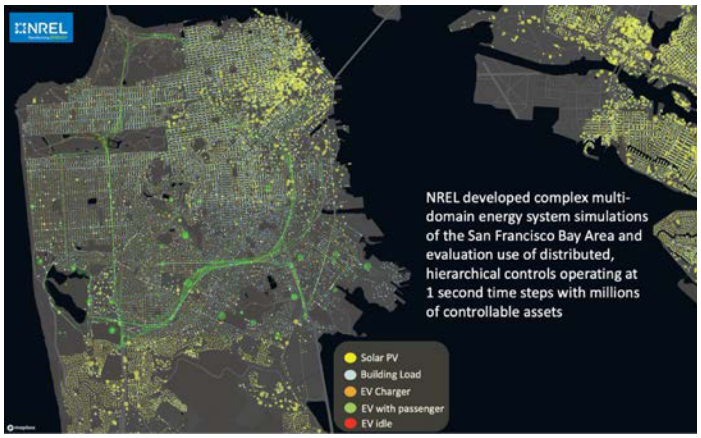
One clear trend will shape tomorrow's energy systems: The proliferation of distributed energy technologies such as solar, storage, electric vehicles (EVs), home automation, and smart appliances. Projected onto the San Francisco Bay Area's approximate 4.5 million customers, this could result in 20 million controllable devices that produce, store, and use electricity. No modern control system can effectively manage so many distributed devices, not to mention the deluge of data and extensive metering that will follow.

The National Renewable Energy Laboratory's (NREL's) solution to this paradigm shift is a concept called autonomous energy systems. **Autonomous energy systems will enable electric grids to respond with the speed and flexibility necessary for the robust control of many millions of unique devices**. This solution has been demonstrated on real power systems and with applications that include wind and photovoltaic (PV) plants, buildings, and EV fleets, and it is ready to be used for energy transitions everywhere.

The Keys to Distributed Energy

The idea behind autonomous energy systems is to decompose large-scale grid control into smaller sized decisions so that central operators are not overwhelmed by data and communications. To make this a reality, NREL developed control algorithms with particular objectives:

- **Real-time operation**—fast enough for grids that balance load and generation every second
- **Asynchronous data and control**—for variance in energy resources and delays in communications
- **Robustness**—including recovery from a failed state and tolerance to faults, outages, and communication failures
- **Scalability**—with a design that can conveniently scale to control hundreds of millions of devices.



Simulation of a future grid scenario in the San Francisco Bay Area with millions of distributed energy technologies deployed and operating.

Inside the Algorithms

Autonomous energy systems are possible because of breakthroughs in control and optimization methods, with NREL making fundamental advances in areas such as:

- **Multi-area state estimation for distributed communications**
- **Online distributed optimization for real-time control**
- **Reinforcement learning for model-free and data-driven optimization**
- **Consensus-based optimization for distributed decision making.**

From left to right: A neighborhood of all-electric homes in Basalt, Colorado, that is currently managed by Holy Cross Energy as an autonomous energy system; researchers examine the use of autonomous energy systems on a simulated grid at NREL; a fleet of EVs to research autonomous control at NREL; and wind, solar, and storage capabilities for system-scale evaluations

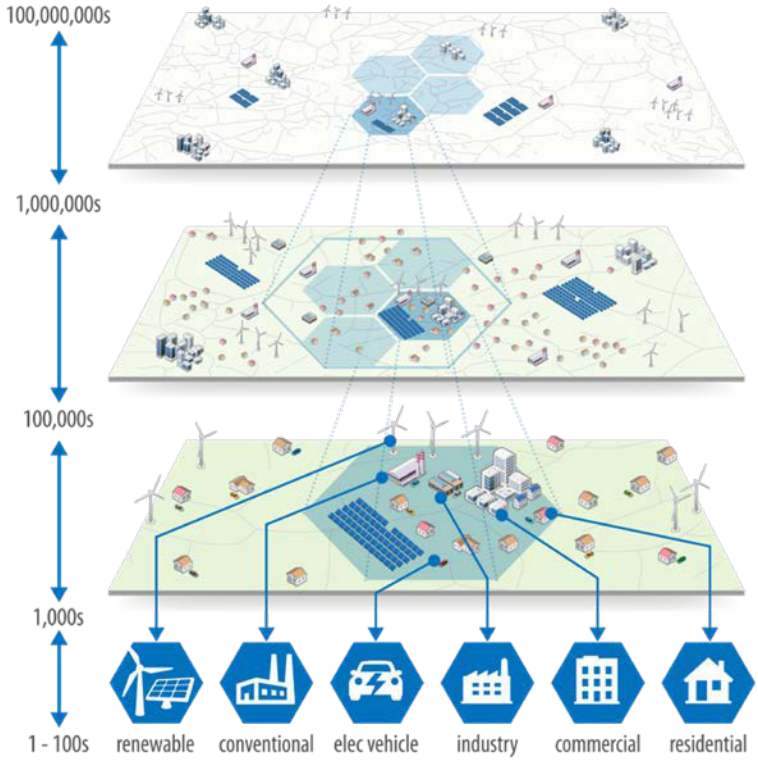
Advantages of Autonomous Control

With autonomous and distributed control, every load or resource of an energy system can contribute to stability and savings. NREL's algorithms enable automated islanding and protection for system resilience, and real-time optimization makes efficient use of variable renewable energy such as wind and solar. Autonomous control reduces the costs of operation and supports the streamlined integration of renewables and innovative technologies, potentially also facilitating future transactive energy markets.

No Limits to Large-Scale Control

NREL has demonstrated autonomous energy systems in a variety of applications and environments, consistently showing that distributed control can address the challenge of widespread distributed energy resources. Demonstrations have been performed on:

- Simulated urban areas with more than 10 million diverse energy devices
- NREL's utility-scale wind and PV experimental platforms
- A commercial microgrid that includes hydrogen generators, microturbines, and aqueous hybrid ion batteries
- A net zero energy residential neighborhood
- More than 100 controllable devices, including inverters, EVs, batteries, microcontrollers, and others.



Working With Us

We are looking to take autonomous energy systems even further—to apply the concept to a wider variety and larger scale of power systems and to continually develop new principles for reliable and efficient grid control. Partners that are interested in working with NREL to advance their energy systems are encouraged to connect and learn more.

Contact Benjamin.Kroposki@nrel.gov | 303-275-2979

NREL Transforming ENERGY

National Renewable Energy Laboratory
15013 Denver West Parkway, Golden, CO 80401
303-275-3000 · www.nrel.gov

NREL prints on paper that contains recycled content.

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

NREL/FS-6A42-79194 • February 2021