Transforming Buildings Through Integrated Energy Systems

A Novel Approach to Integration

As modern society becomes increasingly dependent on electricity, the implications are more apparent during grid disruptions—such as extreme weather events or cascading power failures that can leave homes and businesses without power for weeks at a time. Moreover, at least 1.3 billion people worldwide have no access to electricity at all; for a billion more, access is unreliable.

Distributed energy generation from solar arrays holds promise to help address these challenges, especially given the falling cost of photovoltaic (PV) technologies. However, rapid deployment of distributed power is beginning to create new challenges for centralized grid systems that must now be addressed.

A cross-disciplinary research team at Oak Ridge National Laboratory (ORNL) is tackling the challenge of providing reliable, resilient, and responsible energy use in buildings through an integrated approach to electricity generation, distribution, and consumption.

When successful, this research will enable

- cost effective, sustainable integration of distributed and renewable energy sources into building systems and
- cost-optimal development, design, and management of integrated energy systems (load, generation, and storage) in buildings.

This research will foster a built environment of integrated energy systems that (1) efficiently transacts with existing centralized grids while also providing increased resiliency and reliability and/or (2) effectively provides reliable energy services to buildings where no centralized grid is available, that is, “off-grid.”

Meeting the Challenge

To meet this challenge, ORNL is using a fully integrated approach that will

- develop advanced generation and storage systems that cross cut vehicles and buildings;

Integrated energy systems enable buildings to use and store energy from available resources (such as solar energy) efficiently.

- implement an integrated energy system control to optimally manage the building load, distributed generation, and required energy storage; and
- enable use-inspired research to understand the science needed to make transformative breakthroughs in energy storage.

The expertise of members of this research effort spans various areas including materials science, building technologies, vehicle research, advanced manufacturing, power systems, optimization, sensors and controls, and microgrid research. ORNL facilities such as the flexible research platforms (FRPs), 50-kilowatt solar array, and the Distributed Energy Communications and Controls facility will provide an empirical environment where research can be evaluated and proven.

Primary Tasks

Outputs from four individual tasks, run in parallel, will be integrated to achieve the proof-of-concept integrated energy system for off-grid and grid-connected buildings.

- Advanced heat engine generators
- Ground-level integrated diverse energy storage
- Flexible and scalable integrated energy system control
- Demonstration of use-inspired basic research

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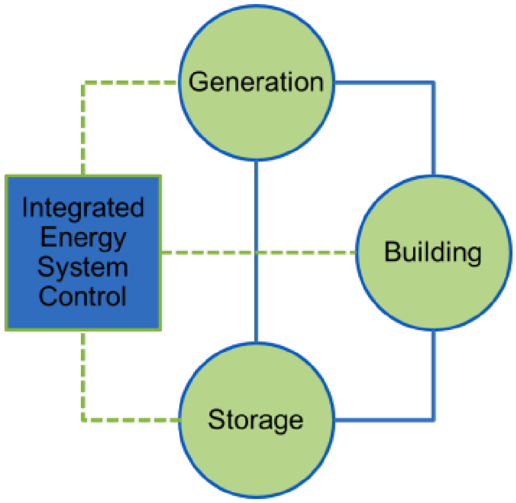

Strategy for off-grid integrated energy systems.

Advanced Heat Engine Generators

An advanced heat engine generator (HEG), such as a Stirling engine, will be used to demonstrate power generation potential for both vehicles and buildings. Unlike internal combustion engines, HEGs are adaptable to different sources of fuels or external heat sources, including waste heat, PV arrays, and vehicle engines. The research team will draw upon its expertise in HEG systems, heat transfer, natural gas as a fuel, vehicle technologies, and additive manufacturing to improve key operational metrics (efficiency, weight, cost, etc.). The HEG will be integrated into the controls and energy storage systems of both the vehicle and buildings.

Ground-Level Integrated Diverse Energy Storage

In this task, ORNL will explore energy storage methods for localized power generation that will supplement or substitute batteries, including a novel technology under development called Ground-Level Integrated Diverse Energy Storage (GLIDES). This unique, potentially low-cost system stores energy by compressing gas in high-pressure tanks. However, to maximize efficiency, a high-efficiency hydraulic pump with minimal frictional losses is used to pump liquid into the tanks and thereby raise the gas pressure. This novel approach is scalable and dispatchable, and early analyses indicate round-trip efficiency that outperforms lead-acid batteries at dramatically lower cost.

Flexible and Scalable Integrated Energy System Control

In this task, ORNL will develop an integrated energy management and control system to optimally manage the building load, distributed generation, and required energy storage. While the system will be developed for generic building loads, energy generation, and energy storage, ORNL will demonstrate integrated energy system control of the 1-story FRP, HEG, and GLIDES. The flexible system will be scalable to multiple buildings for residential and commercial applications. By considering operational tradeoffs, the generic integrated control framework will also enable better research and development of new building load management, energy generation, and energy storage systems needed to meet both the real-time and long-term demand requirements for off-grid buildings and/or cost-effective and reliable microgrids.

Demonstration of Use-Inspired Basic Research

As a final transformational phase of this research, atomically thin capacitors based on assemblies of graphene (electrodes) and boron nitride (dielectric) monolayers will be fabricated and evaluated. Atomically thin electrostatic capacitors have tremendous potential for breakthrough advances that will position them close to the best performing electrochemical capacitors in terms of energy density, while still maintaining superior power density values greater than 1 MW/kg. Capacitors developed in this research from two-dimensional materials can result in next-generation electrostatic capacitors that operate at high electric fields, exhibit low dissipation factors, and can be charged and discharged at high rates.

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