NREL
NATIONAL RENEWABLE ENERGY LABORATORY

ENERGY SYSTEMS INTEGRATION

ESI optimizes the design and performance of electrical, thermal, fuel, and water pathways at all scales.

SMART HOME TEST BED

Examining How Smart Homes Interact with the Power Grid

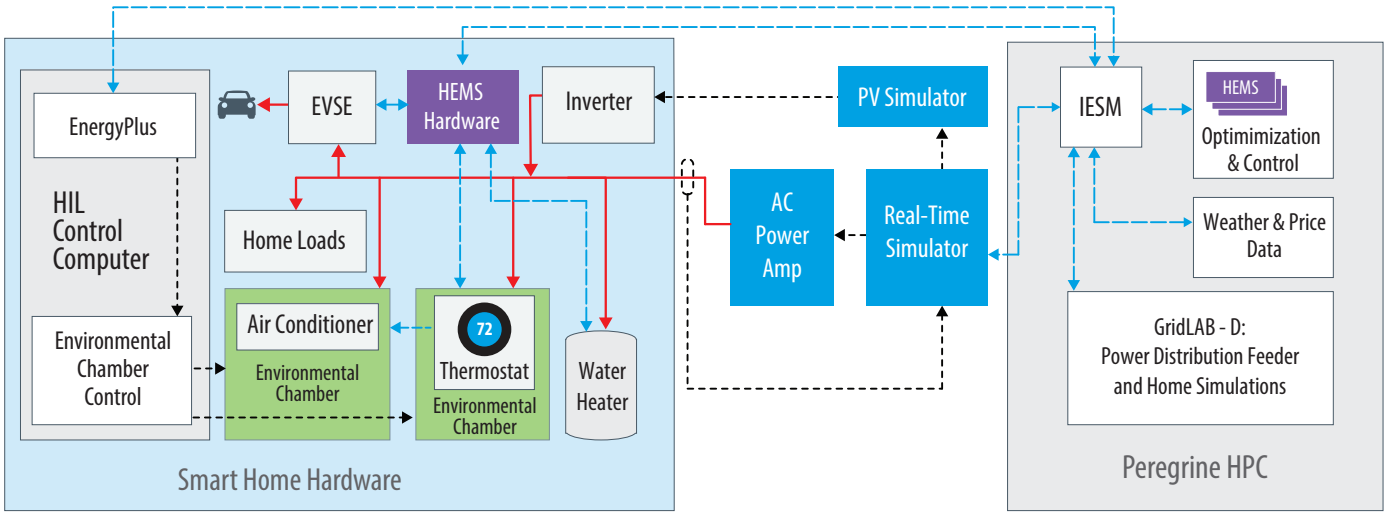
The National Renewable Energy Laboratory (NREL) is working on one of the new frontiers of smart home research: finding ways for smart home technologies and systems to enhance grid operations in the presence of distributed, clean energy technologies such as photovoltaics (PV). To help advance this research, NREL has developed a controllable, flexible, and fully integrated Smart Home Test Bed.

Hardware and Software for the Smart Home Test Bed

Located in NREL's Energy Systems Integration Facility (ESIF), the Smart Home Test Bed uses hardware-in-the-loop (HIL) technology to connect smart home technologies to software simulations. The test bed can draw on NREL's high-performance computer, Peregrine, to simulate a power distribution feeder with many homes connected to it (using GridLAB-D software). It can also run advanced home energy management system (HEMS) optimization algorithms (using GAMS or Pyomo) that use weather and price data to determine control signals, which are sent to the simulated homes and to the smart home's hardware via the HEMS hardware (a single-board computer).

A key part of the Smart Home Test Bed is the Integrated Energy System Model (IESM), a co-simulation tool developed at NREL that combines multiple simulation tools. The IESM runs on Peregrine and coordinates the power system and home simulations, the HEMS algorithms, communications with the HEMS hardware, and a simulation of the smart home (using EnergyPlus) that runs on the HIL control computer in the laboratory. The IESM also provides price signals as inputs to the HEMS, allowing users to evaluate how smart home technologies respond to different retail price structures.

The smart home hardware is powered by an AC power amplifier that is controlled, via a real-time simulator (Opal-RT), to match the simulated voltage where the smart home is connected to the distribution feeder. The total measured power of the home is fed into the power system simulation, also via the real-time simulator, thereby closing the loop.



The Smart Home Test Bed combines powered hardware with software simulations. The smart home hardware includes electric vehicle supply equipment (EVSE), home loads, a water heater, a thermostat, and an air conditioner, all powered (via red lines) by a photovoltaic inverter and an alternating current (AC) power amplifier, which emulates grid power. Grid operations, weather and price conditions, and HEMS optimization and control are all simulated in the Peregrine High-Performance Computer (HPC), and the IESM communicates digitally (via blue lines) with the Real-Time Simulator, the HEMS hardware, and the EnergyPlus simulation. The latter sends an analog signal (black line) to the Environmental Chamber Control, which sets the environments for the air conditioner and thermostat. Meanwhile, the HEMS hardware communicates digitally with the EVSE, thermostat, and water heater.

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.

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NREL's Smart Home Test Bed provides an ideal testing ground to explore the interactions of smart home devices and systems. The test bed uses hardware-in-the-loop infrastructure to connect smart home technologies to software simulations of homes and the grid. *Photo by Dennis Schroeder, NREL 38898*

In the laboratory there are currently two communicating home appliances that can be controlled by the HEMS: a thermostat that controls an air conditioner and a water heater. In Fiscal Year 2017, NREL will add the ability to control EVSE (electric vehicle supply equipment). Additional non-controlled loads include a refrigerator, stove, clothes washer and dryer, and lights to provide realistic loads for the house. There is also a PV inverter that is powered by a PV simulator, which draws on weather data to simulate changing outdoor weather and solar insolation conditions.

Two environmental chambers are used: one chamber encloses the air conditioner and the second holds the thermostat. The temperature in the air conditioner's chamber is controlled to match the outdoor temperature from the same weather data as the rest of the simulation. The thermostat's chamber recreates the indoor temperature using the EnergyPlus building simulation. EnergyPlus estimates the indoor temperature by simulating a building with properties specific to the home, weather data, and the air conditioning hardware's measured cooling load.

Test Bed Applications

The Smart Home Test Bed may prove to be a valuable tool for utilities to explore new technologies, controls, and business models. Other potential users include technology companies interested in demonstrating the impact of their technology or addressing technology integration or market risks. In addition, researchers from NREL, other national labs, and universities could use the test bed to validate their research. As an example, NREL has used an early version of the test bed to study the impact of very high penetrations of HEMS that optimize thermostat settings to minimize electricity costs and maintain occupant comfort under time-of-use rates.

Partner With Us

We believe that with the right tools and the right team, great things can happen. NREL's Energy Systems Integration Facility (ESIF) offers utilities, industry, manufacturers, universities, and other government laboratories access to an award-winning, state-of-the-art lab space and a team of specialized scientists and engineers to help move new technologies forward. Bring us your biggest energy system challenges, and let's solve them together.

Contact the ESIF User Program at 303-275-3027 or **userprogram.esif@nrel.gov** to discuss opportunities.

Learn more about the ESIF and see a list of current partners at **http://www.nrel.gov/esi/partnerships.html**.

For complete details on the ESIF's capabilities, tools, research focus areas, and user facility opportunities, please visit **www.nrel.gov/esif**.

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