

Compliance & Conformance: Enabling Grid-Responsive Heat Pump Water Heaters.

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ELECTRICAL & COMPUTER
ENGINEERING



PSU Power Engineering Group



PSU PEG WH Testing Bays

Power Engineering Group Capabilities:

- Dedicated 100 kVA feeder
- 120/240V, 120/208V & 277/480V services
- Water Heater 2045 Testing Bays (4)
- Inverter Testing Bays (3)
- Load & Grid simulators 12kV/33kVAr

PSU Power Engineering Group



PSU PEG Invert Testing Bays (L)
Grid & Load Simulators (R)

Power Engineering Group Capabilities:

- PSU DERMS & UCM
(IEEE 2030.5, CTA-2045-B)
- Grid & load simulation s/w
(GridLab-D, OCHRE)
- ADMS s/w (GridApps-D)
- PMU Data Archiving
- Frequency monitoring & event detection

Flex Load Research

- Utilities and aggregators use flex loads to provide grid services.
 - Communication with flex loads is based on a *protocol*, e.g. ANSI/CTA-2045-B.
- ⇒ Our research:
- Examine how residential flex loads respond to 2045-B messaging
 - Quantify the value of flex loads within the context of demand response programs and utility balancing areas.
 - Propose how messaging responses could be improved to provide greater value to DR programs.

Grid Service Categories

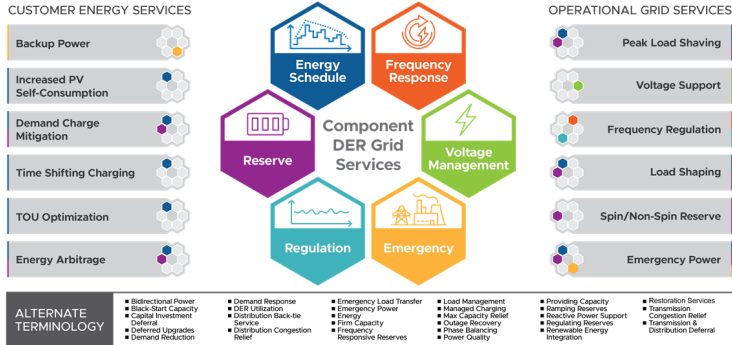


Figure: Common utility grid services can be provided by distributed energy resources, including flex loads, here categorized into six general services.

Grid Service Definitions

Service	Purpose	Actions
Energy	Ensure adequate energy resource supply.	Consume or produce a specified amount of energy over a scheduled period of operation.
Reserve	Reserve source or load capacity.	Adjust real power of sources or loads within a 5 to 30 minute time frame for dispatch in a contingency.
Blackstart Support	Support recovery of a collapsed electrical power system.	Sources supply power and support voltage. Loads defer post-recovery consumption.

Table: Grid service definitions for Energy, Reserve & Blackstart Support. Grid services can be provided by coordinated dispatch of flex loads aggregations.

Grid Service Objectives

- Reduce peak-time operation costs.
- Ensure resource adequacy.
- Extend T&D asset life.
- Facilitate renewable energy integration.
- Defer capital investment.
- Perform economic arbitrage.
- Reduce CO₂ emissions.
- Support system recovery after loss of service.

Flex Load Compliance

Compliance:

- Flex loads must understand and respond to protocol messages.
- Pertains solely to messaging. *Does the flex load meet the messaging requirements of the communications protocol?*
- Compliance testing validates protocol messaging requirements.
- Compliant HPWH flex loads receive an endorsement within NEEA's Qualified Products List.
- Compliance alone does not guarantee that a flex load is a useful grid service asset.

Flex Load Conformance

Conformance:

- Flex loads must also *behave* in accordance with protocol intentions.
- Pertains to how the flex load behaves in response to messaging. *Does it conform to expectations for a useful program asset?*
- Conformance testing focuses on aligning flexible load behavior with utility and customer expectations.
- Conformant flex loads provide utilities with capacities and capabilities that contribute to successful delivery of grid services.
- Conformant flex loads minimize disruption to utility customers while providing opportunities to participate in grid service programs.
- Conformance is not a consideration for the Qualified Products List.

Conformance Guidance

Some guidance has been provided for how residential HPWHs should behave in response to *some* 2045 messages.

- In response to a *Shed* request:
 - AHRI 1430-2022: “[*Shed*] directs the water heater to prevent using energy that the device otherwise uses ... unless user needs cannot be met.”
 - CA Title 24 JA13: “The System will defer complete recovery for the duration of the shed event unless user needs cannot be met.”
- Load shifting:
 - AHRI 1430-2022: “[flex load WHs] shall be able to load shift at or above ... 0.50 kWh ...”
 - CA Title 24 JA 13: “... shall be able to shift: A minimum of 0.5 kWh of user electrical energy per (Basic Load Up + Light Shed) event.”

Compliance vs Conformance

- **Compliance** Example:

- An aggregator requests *power* data from a flex load.
- The flex load responds with a properly formatted number.

- **Conformance** Example:

- An aggregator requests *power* data from a flex load.
- The flex load responds with a number that represents its power consumption.

Compliance vs Conformance - Example

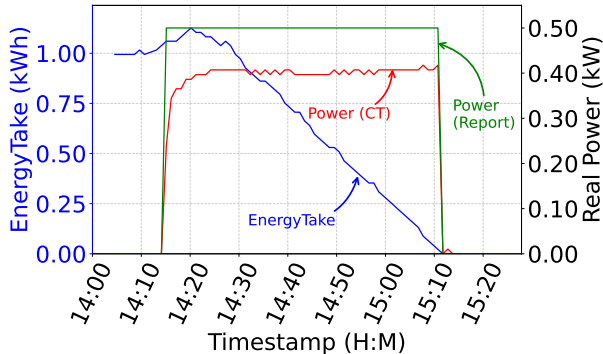


Figure: Example of a compliant, but non-conformant, response to a request for *power* data. Measured power shown in (red). Reported power shown in (green).

Utilities, Manufacturers, and Customers

- **Utilities** want to aggregate flexible loads to provide grid services.
- **OEMs** want to maintain customer satisfaction and performance standards.
- **Customers** want their device to work as intended, without disruption.

Each actor needs to work together for the larger goal of grid stability and reliability.

Key CTA-2045 Functions

- Commodity Read (*Energy Take, Reported Power*)
- Shed-type (*Shed, Critical Peak Event, Grid Emergency*)
- Load-type (*Load Up, Adv. Load Up*)

Load Shifting Differences between OEMs

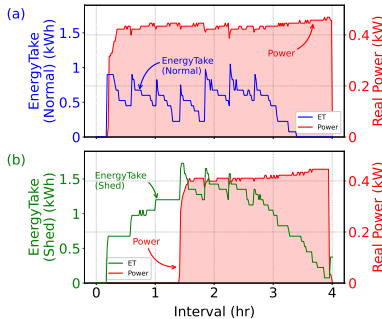


Figure: OEM A: (a) The HPWH operates in *Normal* mode, and (b) in *Shed* mode. *Shed* mode reduces consumption and delays energy consumption by 1.5 hrs.

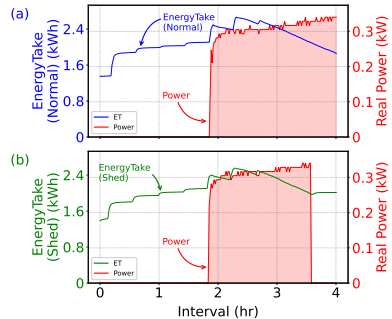


Figure: OEM B. (a) The HPWH operates in *Normal* mode, and (b) in *Shed* mode. *Shed* reduces consumptions but does not delay consumption.

Load Shedding: Types & Unit Differences

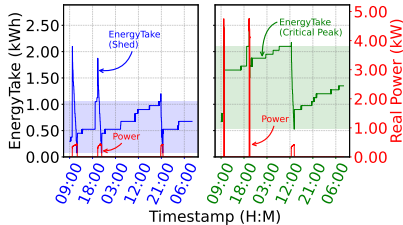


Figure: Unit A: *Critical Peak Event* is a deeper shed response than a *Shed* request. However, the units consumed ~50% more energy in *CPE* compared with *Shed*.

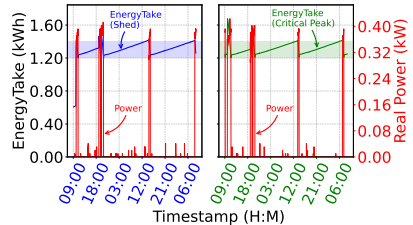
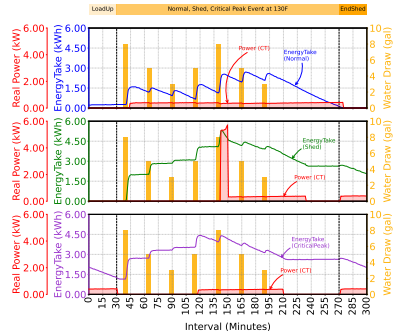
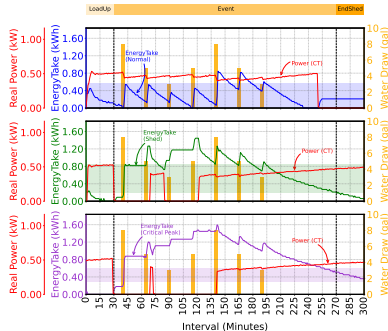


Figure: Unit B uses the same response for *Shed* and *CPE* requests, reducing load flexibility. Very little energy is consumed in either the *Shed* or *CPE* modes.

Mode Sequencing



Mode	Normal	Shed	Critical Peak
E_{event} (kWh)	1.67	1.12	0.88
ΔE	-	-33%	-47%

Mode	Normal	Shed	Critical Peak
E_{event} (kWh)	1.3	1.1	0.79
ΔE	-	-15%	-60%

Trends Among Tested Units

- All units exhibit grid-friendly conformance behaviors.
 - All units have room for improvement.
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- Insufficient differentiation between shed-type functions
 - Approximating power
 - Misreporting of Present Energy Take
 - Inefficient energy consumption during shed-type events
 - Rare implementation of Advanced Load Up and other 2045-B capabilities

Challenges

- *Does the unit conform to expectations for a useful program asset?*
- *Does the unit behavior align with both utility and customer expectations?*

- ⇒ OEMs need an understanding of flex load conformant behaviors.
 - Differentiated, efficient, effective implementation of shed & loadup modes
 - Representative reporting of attributes, particularly *Power* and *Energy Take*
 - Implementation of the full suite of 2045 attributes & modes.
- ⇒ How can the OEMs' products provide additional value to their customers as flexible loads?

Recommendations

1 HPWH CTA-2045 Implementation Guide:

- OEMs:** Guide the development of 2045 functions that contribute to grid service programs.
Describe how 2045 functions contribute to program operation.
- Utilities:** Increase the number of conformant HPWHs that can participate in programs.
Describe the impact 2045 functions will have on program operation.
- Customers:** Improve program participation since routine 2045 function calls do not affect hot water service.
Participation provides economic benefits.

2 Qualified Products List Endorsement:

- OEMs:** Incentivize OEMs to develop HPWH products that contribute to grid service programs.
Improve the appeal of their HPWH products to both customers and Utilities.
- Utilities:** Provide means for utilities to identify HPWHs that will contribute to grid services.
Lower the recruitment and integration costs of units into programs.
- Customers:** Help HPWH owners identify products that qualify for rebate or incentive programs.
Know their HPWH will help aid renewable energy integration, lower energy CO₂ emissions, etc.

Performance Modeling - Data Sources

OCHRE: Object-Oriented Controllable High-Resolution Residential Energy Model

- Models residential energy use from the envelope to the end-use load.
 - Thermodynamic interactions between thermal sources, domiciles, and loads
 - Produce high-resolution energy consumption data
- Can model grid-enabled flex loads and DER like HVAC, water heaters, EVs, residential PV and BESS
- Integrates with grid modeling tools: OpenDSS and GridLab-D

Performance Modeling

- **ResStock** end-use load profiles to model ~400 residential homes and HPWHs
- **Regional Building Stock Assessment Metering study (RBSAM)**: Used as a baseline to develop generic, flex load specific, load profiles.
- **NREL End-Use Load Profiles for the US Building Stock (EULP)**: Combines RBSAM, HEMS, Pecan Street, FSEC residential end-use load profile data.
- **Form EIA-930**: For developing balancing authority load shapes.

Flex Load Modeling

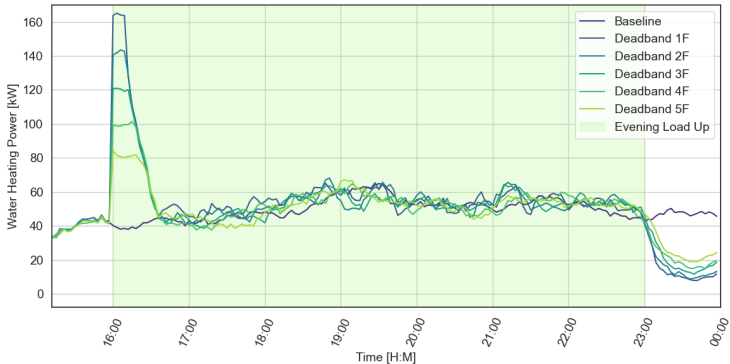


Figure: HPWH flex load responses to *Load Up* requests can be tuned to model behaviors from different OEMs. Shown here, different *Load Up* operating dead bands result in different amounts of thermal energy storage.

Flex Load DR Modeling

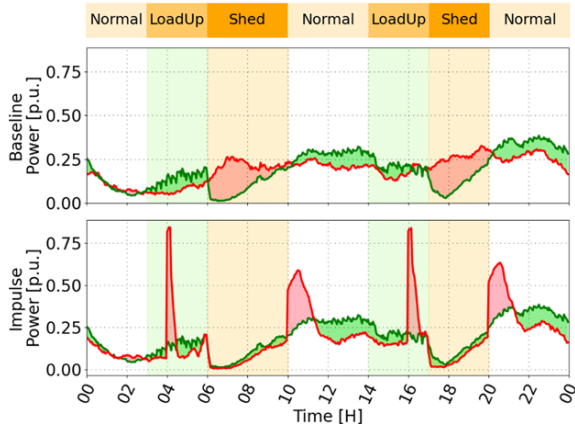


Figure: Upper plot: compares the uncontrolled baseline vs the ramp-controlled demand response (DR) curve. Lower plot: compares the impulse-response DR curve and the ramp-controlled DR curve.

Simulation Scalability

- Can scale the number of flex load samples
- Beneficial for quantifying per-home energy-shifting capacity

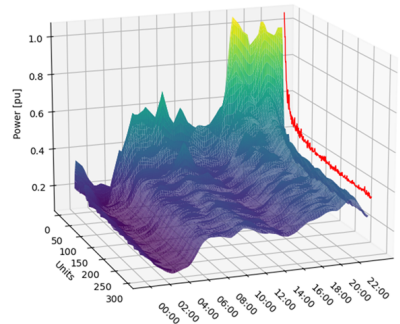


Figure: Energy consumption of flex load aggregations vs time of day. As aggregation size increases, the average max demand converges.