Low-Power, Load-Balancing Whole Home Electrification Solution

Cooperative Research and Development Final Report

CRADA Number: CRD-23-24262

NREL Technical Contacts: Bethany Sparn, Prateek Shrestha, and Noah Sandoval

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Technical Report
NREL/TP-5500-95492
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Cooperative Research and Development Final Report

Report Date: June 10, 2025

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the CRADA final report, including a list of subject inventions, to be forwarded to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: Redwood Energy and NeoCharge

CRADA Number: CRD-23-24262

CRADA Title: Low-Power, Load-Balancing Whole Home Electrification Solution

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Sponsoring DOE Program Office(s):

Office of Energy Efficiency and Renewable Energy (EERE), Building Technologies Office

Joint Work Statement Funding Table showing DOE commitment:

Estimated Costs	NREL Shared Resources Government In-Kind
Year 1	$75,000.00
Year 2, Modification #1	$.00
Year 3, Modification #2	$.00
Year 4, Modification #3	$.00
TOTALS	$75,000.00

Executive Summary of CRADA Work:

Testing was conducted at the Systems Performance Laboratory in NREL's Energy Systems Integration Facility to test the performance of 120V wall-mounted heat pumps, 120V heat pump water heaters (HPWH), Electric Vehicle Supply Equipment (EVSE), and other plug-in loads, using NeoCharge Smart Splitters and whole home energy software as appropriate. Four different simulated occupancy scenarios were used to evaluate the package of technology and controls.

CRADA benefit to DOE, Participant, and US Taxpayer:

- Assisted laboratory in achieving programmatic scope, and
- Used the laboratory's core competencies, and
- Enhanced U.S. competitiveness by utilizing DOE developed capabilities.

Summary of Research Results:

NeoCharge and Redwood Energy have developed a home electrification solution that integrates NeoCharge's energy management technology with Redwood Energy's Watt Diet approach. This solution empowers homeowners and renters to adopt electric vehicles (EVs) and electric appliances without the need for expensive and time-consuming electrical panel upgrades, making the transition to clean energy more accessible, affordable, and equitable.

NeoCharge software platform, which includes the NeoCharge Mobile App, the intelligent current transformer (CT) clamp Monitor, and the plug-and-play Smart Splitter, forms the core of this solution. The NeoCharge Energy Management System (EMS) continuously monitors the home's total electrical load in real-time via noninvasive CT Clamps, dynamically adjusting EV chargers, and other home energy-consuming devices to ensure the electric panel remains within safe operating limits. NeoCharge's Smart Splitter enables two 240V devices to share a single circuit, further reducing the need for significant home infrastructure upgrades including Level-2 EV charging. The NeoCharge App provides users with valuable energy insights, EV charging optimization, and seamless integration with utility rates and solar generation, empowering them to make informed decisions and maximize their energy savings. The NeoCharge App and Smart Charging algorithms provide time-of-use rate optimization and savings for consumers.

Redwood Energy's Watt Diet methodology complements NeoCharge's technology by prioritizing the use of efficient 120V appliances, strategically reducing the home's overall electrical load. This synergistic approach was tested and validated through extensive laboratory simulations at NREL and real-world demonstrations, consistently proving its ability to electrify homes with limited 60 to 100 A panels, while maintaining optimal safety, performance, and comfort. The results of the testing are outlined below, proving the viability of the NeoCharge EMS and Watt Diet approach in all building types and climates.

Task 1: Develop Test Plan

The Participants and the Contractor held meetings to define the timeline and coordination of the tests being conducted. The Test Plan (Table 1) shows each scenario that was planned to run as a 24-hour test using the same house model across all of the following scenarios. That model was based on the SF Detached Home described in the EAS-E Prize Rulebook. The baseline scenarios included all electric appliances to measure the electrical power draw from the most typical electrification package. The test scenarios were intended to show that low power appliances and smart switching can reduce the electrical load significantly.

Table 1. Test Plan for Laboratory Experiments

Scenario		Weather	HVAC Equip.	Water Heater Equip.	EV Charging Equip.	Oven	Dryer	Controls
1.0	Mild Summer Baseline	San Fran summer day	240V Central HP	240V HPWH	240V EVSE	Standard Electric	Standard Electric	None
1.1	Mild Summe r Test	Same as 1.0	120V Room HP	120V HPWH	Shared circuit with Dryer	Induction Electric	Shared with EVSE	NeoCharge controls
2.0	Hot Summe r Baselin e	Cleveland summer day	240V Central HP	240V HPWH	240V EVSE	Standard Electric	Standard Electric	None
2.1	Hot Summe r Test	Same as 2.0	120V Room HP	120V HPWH	Shared circuit with Dryer	Induction Electric	Shared with EVSE	NeoCharge Controls
3.0	Mild Winter Baselin e	San Fran winter day	240V Central HP w/ ER Aux heater	240V HPWH	240V EVSE	Standard Electric	Standard Electric	None
3.1	Mild Winter Test	Same as 3.0	120V Room HP	120V HPWH	Shared circuit with Dryer	Induction Electric	Shared with EVSE	NeoCharge Controls
4.0	Cold Winter Baselin e	Cleveland winter day	240V Central HP w/ ER Aux heater	240V HPWH	240V EVSE	Standard Electric	Standard Electric	None
4.1	Cold Winter Test	Same as 4.0	120V Room HP	120V HPWH	Shared circuit with Dryer	Induction Electric	Shared with EVSE	NeoCharge Controls
4.2	Cold Winter Test V2	Same as 4.0	120V Room HP	240V – share with Dryer	Standalone	Induction Electric	Shared with WH	NeoCharge controls

The thermostat set points were as follows:

- San Francisco: 72°F for cooling, 68°F for heating
- Cleveland: 70°F for heating and cooling

In the experimental cases, a single wall-mounted heat pump was installed in the lab, rated at 8,100 BTU. The central heat pump used for the baseline cases was rated 36,000 BTU. The heating and cooling delivered, and the power consumption by the wall-mounted heat pump was multiplied by four to make the comparison more reasonable.

Hot water draw profiles were chosen for each day of simulation. The hot water volumes drawn in the summer are less than in winter, partially because warmer mains water temperatures in the summer reduce the volume of hot water used in showers. Larger daily hot water draw profiles in the winter were also chosen to provide some variability and push the limits on comfort.

- San Francisco: 45.6 gallons/day in Summer, 63.7 gallons/day in Winter
- Cleveland: 36.8 gallons/day in Summer, 58.9 gallons/day in Winter

For EV charging, the following assumptions were made:

- San Francisco: 30 miles per day, charging start at 6pm – 2.5 hours of charging, do not exceed 85% SOC
- Cleveland: 40 miles per day, charging start at 5pm - 3 hours of charging, do not exceed 85% SOC

Task 2: Send loaned equipment to NREL

Redwood purchased all equipment necessary for the completion of the requested tests and shipped the equipment to the Systems Performance Laboratory in NREL's Energy Systems Integration Facility (Table 2) in late November 2023. Upon receipt of the loaned equipment, each piece of equipment underwent the usual NREL electrical safety inspection before it was installed in SPL.

Table 2. Summary of equipment loaned to NREL for laboratory testing.

Appliance	Quantity
Ephoca Innova AIO Pro – 120V Wall-mounted Heat Pump	1
NeoCharge Smart Splitter	1

Task 3: Install Equipment in SPL and set up simulated occupancy scenarios

NREL will install loaned equipment and make necessary adjustments to lab setup for testing.

Simulated Occupancy Settings:

The characteristics of each home are described in the EAS-E Rulebook

1. Mild Climate Single Family

a. Assumed Occupancy of 4
b. IECC Climate Zone 3C - San Francisco

2. Cold Climate Single Family (Will use the same characteristics as Simulated Occupancy Setting 1 aside from climate zone)

a. Assumed Occupancy of 4
b. IECC Climate Zone 5A - Cleveland

3. Single-Section U.S. Department of Housing and Urban Development (HUD) Code Manufactured Home

a. Assumed Occupancy of 2
b. IECC Climate Zone 5A – Cleveland

The NREL technical team:

- Installed loaned equipment and made necessary adjustments to the lab setup for testing.
- Modified a building energy model (EnergyPlus) file based on a typical northern California single-family detached home sampled from the ResStock1 tool (Table 3) to run in the Simulink program as a part of SPL's hardware-in-the-loop testing platform.

Table 3. Characteristics of the EnergyPlus model used with the heat pump in the laboratory experiments

Household Characteristics	Building Energy Model Characteristics
Building Type	Owner-occupied, single-family home
Vintage	1970s
Size	1 story, 1,499 ft2, 5 bedrooms
Foundation	Slab on grade foundation
Wall Construction	Wood frame, uninsulated, double-pane metal windows
Attic Construction	Vented attic, R-13 insulation
Air Tightness	15 ACH50

- Selected two actual meterological year (AMY) weather files for the year 2021, for San Francisco and Cleveland, and in each weather file we selected a typical summer and winter day to use for testing.

[1] https://resstock.nrel.gov/

Task 4: NREL Testing

NeoCharge will provide the software to NREL for the purposes of testing. The following section describes the tests that will be performed by NREL. A deliverable will be prepared summarizing the testing results.

Test 1:

This test will include a basic software integration test for the NeoCharge APIcontrolling software provided by NeoCharge. This will test the capabilities of the software to perform basic actions on the 120V equipment, such as turning each device on and off and switching between heating modes for the heat pump.

Test 2:

Test 1 will be a full day simulation and evaluation of the 120V appliance performance by measuring energy consumption and efficiency where applicable. This test will utilize the Simulated Occupancy Setting 1, the Model Home 3 in the SPL, and the equipment listed in Annex C. Weather modeling will reflect a summer day.

Test 3:

This test will use the same occupancy setting, model home and equipment as Test 2 but will model a winter day.

Test 4:

This test will be a full day simulation and evaluation of the 120V appliance performance like Test 2 but will utilize Simulated Occupancy Setting 2, the Model Home 3 in the SPL, the equipment listed in Annex C. Weather modeling will reflect a summer day.

Test 5:

This test will use the same occupancy setting, model home and equipment as Test 4 but will model a winter day.

Test 6 (Given Adequate Remaining Budget):

This test will utilize the Simulated Occupancy Setting 3, the Model Home 3 in the SPL,and the equipment listed in Annex C. Weather modeling will reflect a winter day.

NREL testing encompassed a series of test scenarios designed to evaluate the NeoCharge EMS system's performance and effectiveness under a range of operating conditions and home configurations. For each of these combinations of factors, a baseline test and an experimental test were conducted. The baseline test involved standard 240V electric appliances while the experimental setup utilized all the innovations described above. For each test scenario, a comprehensive set of performance metrics were collected, including:

- Real-time power consumption data at the main panel and individual circuit levels
- Indoor and outdoor environmental conditions (temperature, humidity)
- EV charging data (energy delivered, charging duration, etc.)
- Heat pump HVAC and water heater performance data (energy consumption, comfort metrics, etc.)
- Smart Splitter and CT Clamp data (power sharing, circuit utilization, etc.)

What follows is a summary of the baseline and experimental test run by the NREL team with some example results (Figures 1-4), followed by the description of the findings from these tests.

Baseline Testing:

- San Francisco Summer Baseline (Figure 1)
- Cleveland Summer Baseline
- San Francisco Winter Baseline
- Cleveland Winter Baseline (Figure 2)

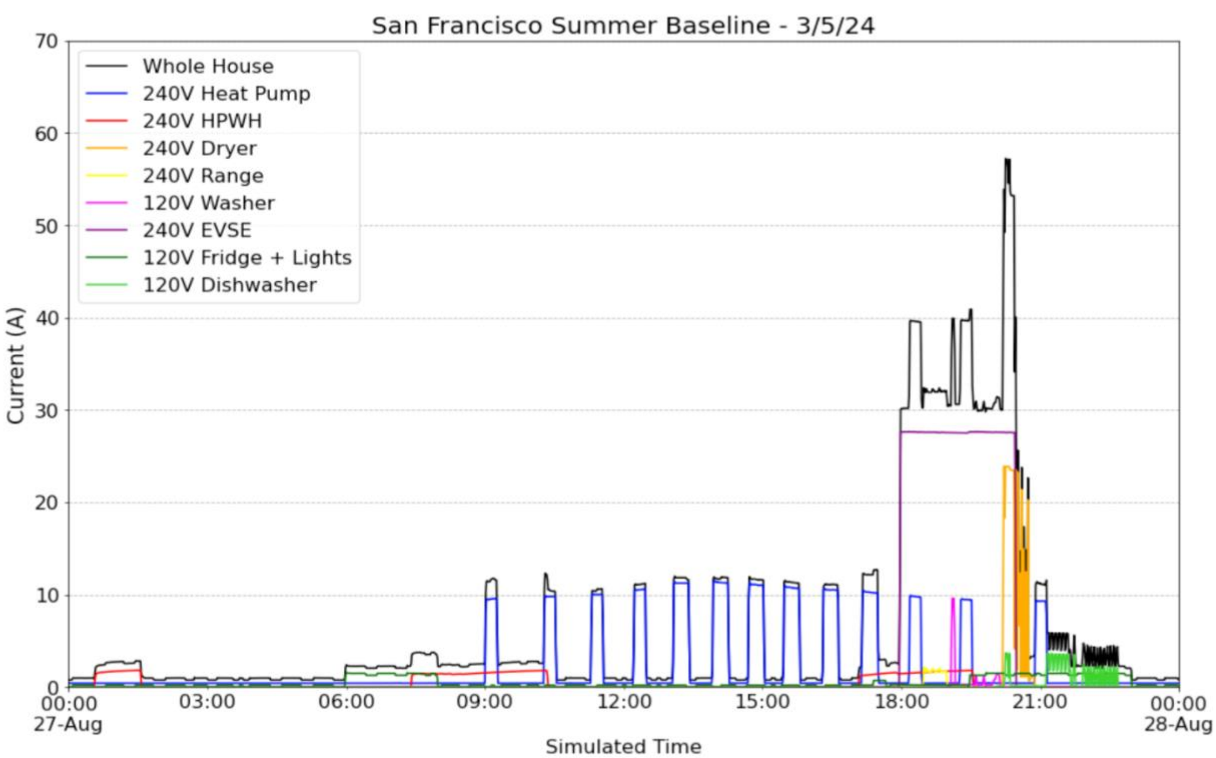

Figure 1. Appliance-level and whole home current draw for San Francisco summer baseline test

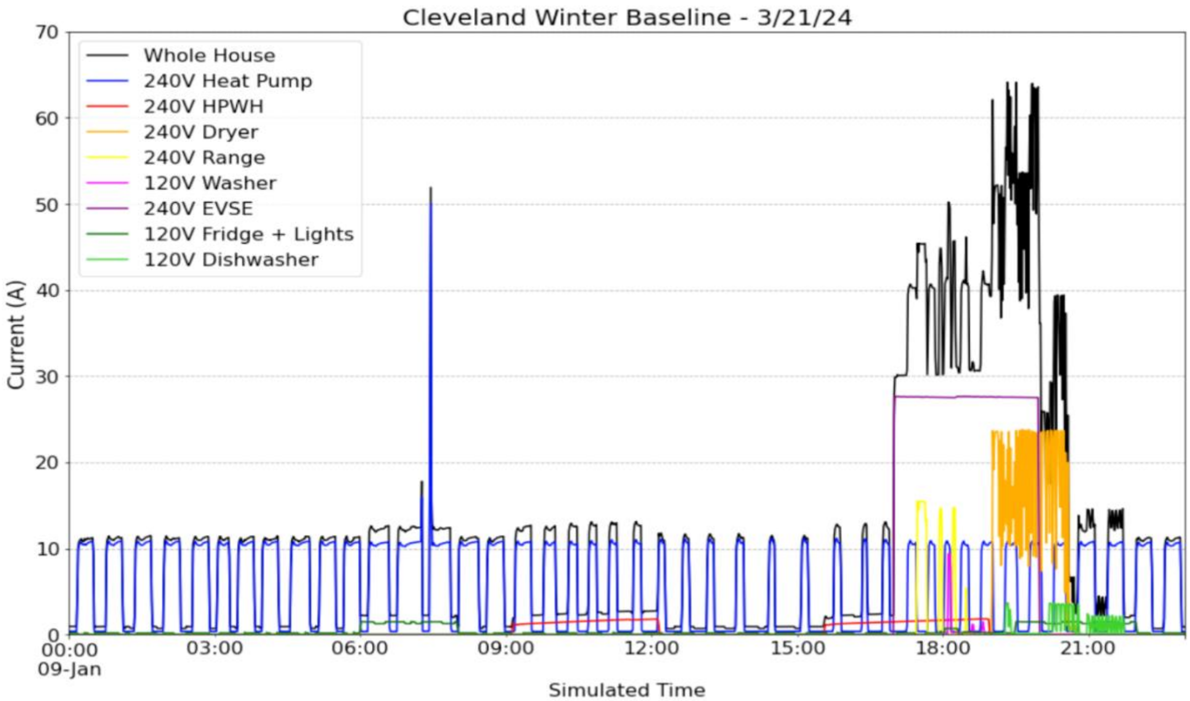

Figure 2. Appliance-level and whole home current draw for Cleveland winter baseline test

Experimental Testing:

- Cleveland Winter Experiment 1: Splitter on EVSE and dryer
- Cleveland Summer Experiment: Splitter on EVSE and dryer (Figure 3)
- San Francisco Winter Experiment: Splitter on EVSE and dryer (Figure 4)
- Cleveland Winter Experiment V2: Splitter on water heater and dryer, EVSE controlled by NeoCharge EMS.

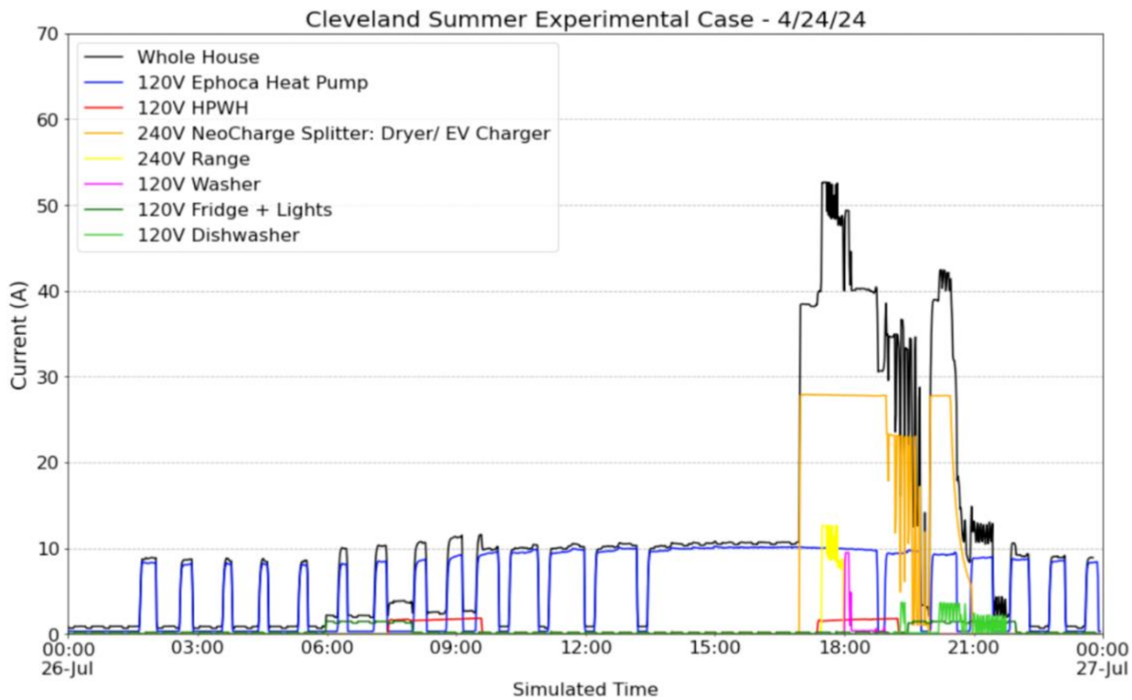

Figure 3. Appliance-level and whole home current draw for San Francisco summer experiment with splitter on EVSE and dryer

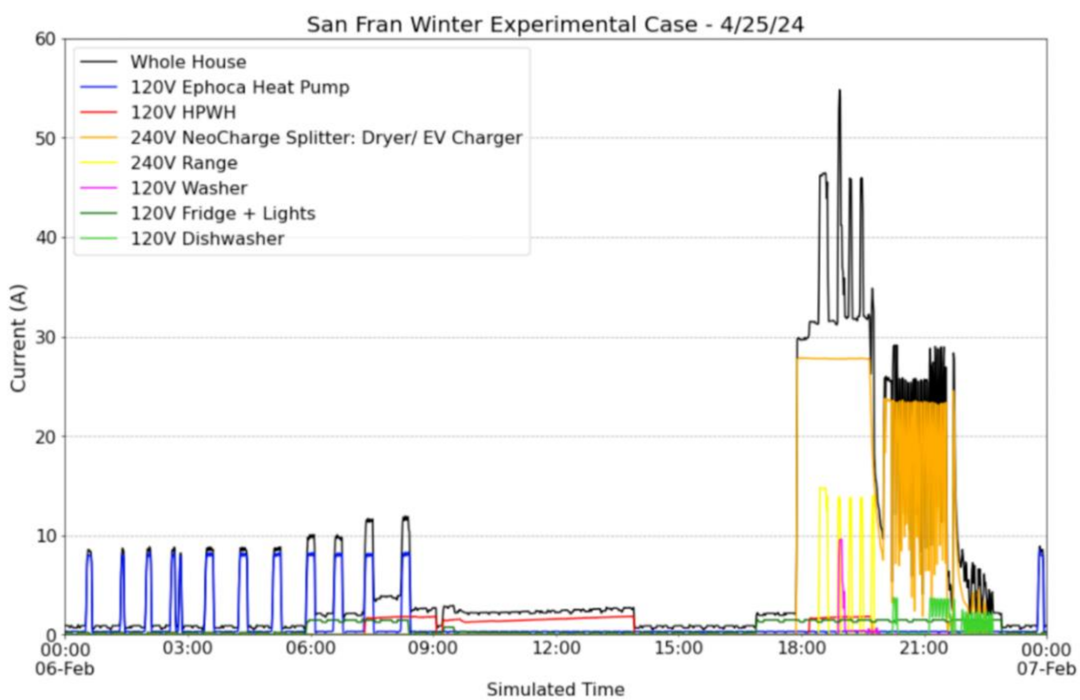

Figure 4. Appliance-level and whole home current draw for San Francisco winter experiment with splitter on EVSE and dryer

Lab Demonstration Results

The lab demonstration results provided evidence that the system was working as expected, which may help make home electrification more accessible, affordable, and scalable. The specific KPIs for the lab demonstration include software responsiveness, device-specific controls, load control, and panel safety, effectiveness in different home scenarios, and utility bill savings with load shifting. The NeoCharge EMS system exceeded the target KPIs in the performance tests completed, demonstrating its ability to effectively manage diverse electrical loads, maintain panel safety, and optimize energy consumption across a wide range of scenarios. Greater details of the solution performance in our aforementioned KPIs can be found below.

Software Responsiveness

The NeoCharge EMS demonstrated good software responsiveness during the laboratory tests. When the CT clamp detected an overload, the system quickly reduced the load from API-based devices, ensuring the panel remained within safe operating limits. The latency between the detection of an overload from the system and the EV charger load reduction was found to be between 15-23 seconds, showcasing the system's rapid response time and ability to maintain panel safety in real-time. With further adjustments, NeoCharge can continue to improve this to enable even more rapid response times for load management.

Load Control, Panel Safety, and Device Specific Controls

To rigorously test the NeoCharge EMS system's load control and panel safety features, the electric panel was effectively downsized to 70 A in software (the actual panel limit was 150A). This created a scenario to understand how our solution would work in older homes or apartments with sub-100 A panel capacity, often found in low-income and disadvantaged communities. The NeoCharge EMS system exhibited device-specific control capabilities during the laboratory tests. The system successfully throttled the Wallbox EV charger load from 28 A to 6 A via API integrations, reducing the peak energy load from 64 A to 42 A (35% reduction). By throttling the energy down, the panel was kept within safe operating limits, while ensuring the consumer received a sufficient EV charge. The system proved the ability to effectively reduce the EV charger amperage to 0 A if needed, which would control a full 28 A (50%) of the allowable 56 A panel load. The prototype NeoCharge EMS was also able to successfully throttle down charging in increments and throttle up EV charging according to the available panel capacity as seen in the Figure 5. The load management actions occur when 49 A (70%) of panel capacity was reached to ensure the total panel capacity stayed under 56 A (80%). Both times the dryer turned on (6:39 PM and 6:56 PM) the EV charger was running at a max of 28 A. With the dryer on, the max load was approaching 49 A so the NeoCharge EMS throttled the EV charging down to 16 A to keep the panel within safe capacity. Once the dryer finished, the NeoCharge EMS sensed the available load in the panel and increased the EV charger amperage to 28 A after approximately one minute. This demonstrated a unique benefit for consumers to maximize their EV charging and panel capacity.

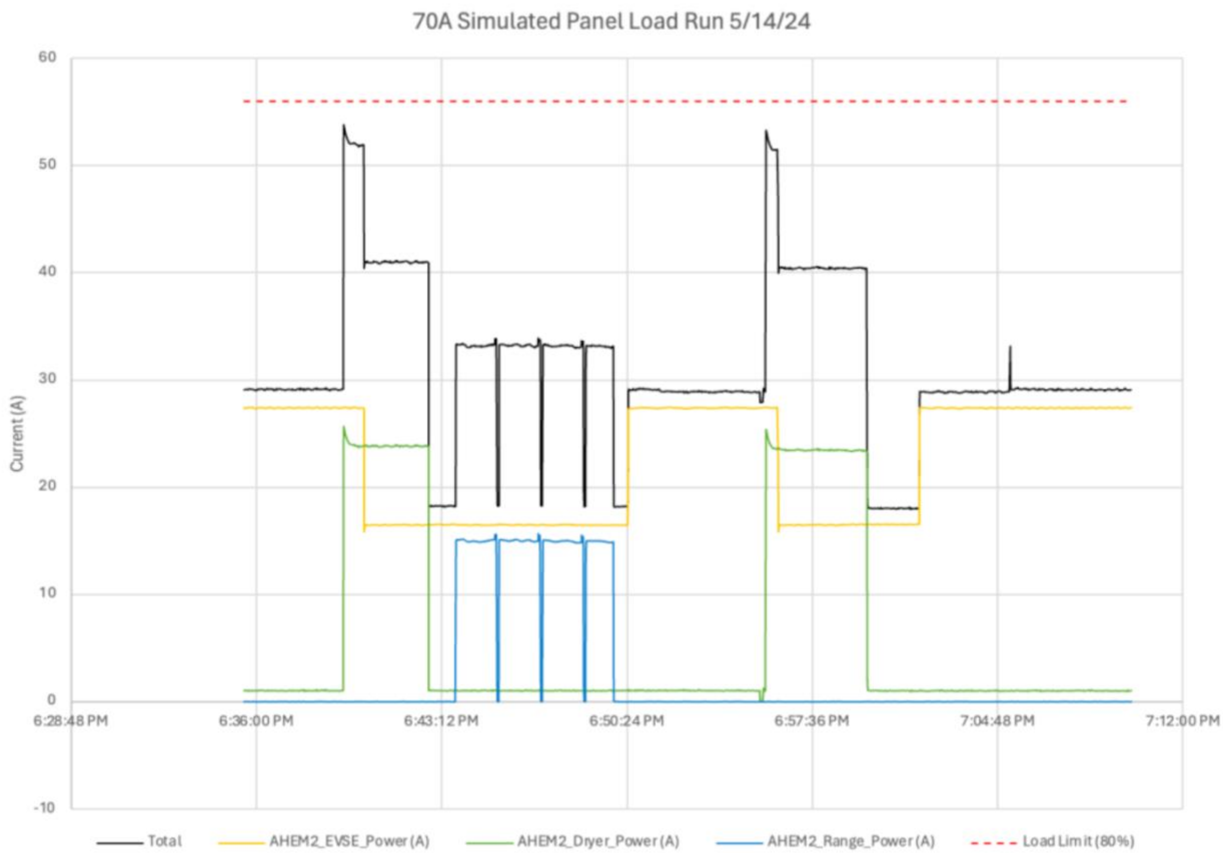

Figure 5. Current draw during an evening, high load event to demonstrate the NeoCharge load control system.

In this demonstration, the maximum controllable amperage was limited by the Nissan Leaf at NREL. The Nissan Leaf was only able to charge up to 28 A. Typically an EV charger draws up to 40 A (9.6kW), providing even more flexible load for the NeoCharge EMS.

The panel capacity for most of the baseline testing, and even more so for the experimental testing of the design solution, never reached the limits of the panel. However, in a modified test run with baseline appliances for Cleveland Winter usage, the EMS system detected the panel load had approached 80% of its capacity and successfully throttled down the amperage of the EV charger from 21 A to 6 A. This test further demonstrated the NeoCharge EMS's load shift ability. The tests above illustrate the performance, safety, and flexibility of NeoCharge EMS in reducing peak power demand and shifting critical home load across various climate scenarios, home energy devices, and panel sizes. The consistent results demonstrate the system's ability to optimize energy usage and maintain panel safety in a wide range of residential settings.

Although not demonstrated in the laboratory tests, the NeoCharge EMS system is also capable of shutting off one side of the smart splitter in case the panel becomes even more overloaded, loads on the Smart Splitter range from 24 A to 40 A, allowing more additional shiftable load. However, the tests found that this feature was not necessary, as the system effectively maintained the panel within its capacity, even for 100 A panels, which are common in the US.

Effectiveness of Design Solution in Different Home Scenarios

The NeoCharge EMS system's ability to effectively manage various loads and employ the "Watt Diet" approach to maintain safe panel capacity levels has significant implications for its scalability and potential impact. By demonstrating its versatility and adaptability to different housing types, vintages, and climate zones, the NeoCharge EMS combined with the Watt Diet approach positions itself as a universal solution for home electrification that can be deployed rapidly and cost-effectively across the U.S. housing stock.

Three baseline tests were completed with NREL, and none of the tests reached the total 80A panel capacity limit for a 100 A panel. The highest max whole-home one-minute interval power measurement was for the Cleveland Summer Baseline which was 68 A (16.2 kW). Comparing the Cleveland Summer Baseline test to the Cleveland Summer Experiment test, which used power-saving technology and low-voltage appliances, the peak one-minute power was reduced by 15 A (Figure 6). HVAC power was reduced by 5 A. Additionally, in the experiment scenarios, power was shared between the Dryer and EVSE, reducing maximum one-minute current by 23 A on that circuit.

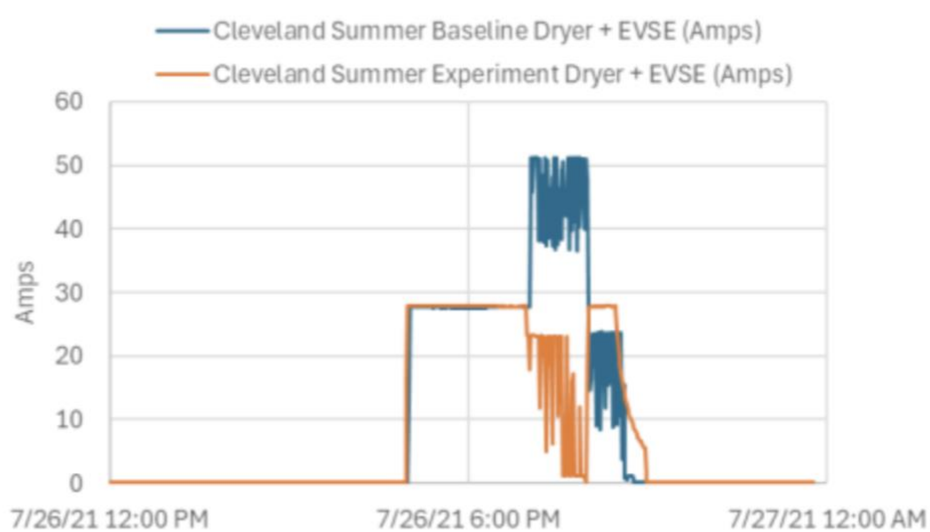

Figure 6. Current draw reductions for Dryer and EVSE using load control device

The 120V solutions performed similarly to their 240V counterparts under almost all conditions. Only during peak heating and cooling demand did the 120V HVAC unit show any signs of differing in performance. In this situation, the lab data shows that the unit takes slightly longer to hit setpoints (Figure 7).

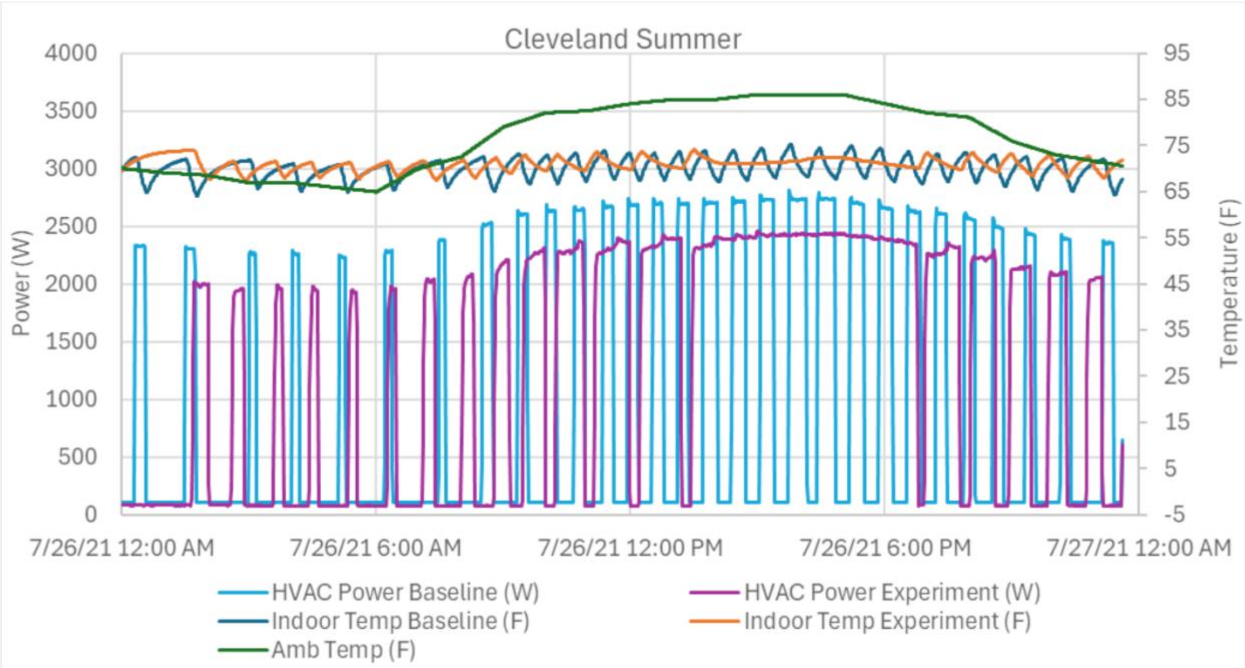

Figure 7. Power usage of Ephoca AIO unit and indoor and outdoor temperature during the Cleveland Summer simulated weather conditions

The system's consistent performance in maintaining total demand within the capacity of existing electrical panels, even in scenarios with high electrification loads, underscores its potential to enable widespread electrification without requiring major infrastructure upgrades. This is particularly important for older homes, low- and moderate-income households, and historically underserved communities, where the cost and complexity of electrical panel upgrades often pose significant barriers to electrification.

Task 5: Return of loaned equipment

Redwood Energy will arrange for return of loan equipment at the end of the project and will facilitate shipping of loaned equipment.

Redwood Energy arranged for the return of loan equipment at the end of the project. Loaned equipment will be returned in August 2024.

Task 6: CRADA final report

This report serves to meet the requirement for the CRADA Final Report with preparation and submission in accordance with the agreement's Annex A – Statement of Work.

References: None

Subject Inventions Listing: None

ROI#: None