Milestone 5 Report:
Final Report

Project Title: Optimal Vehicle to Grid Charging System Considering Solar, Storage, and User Privacy

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Executive Summary

This Milestone 5 report, entitled *Final Report*, provides the final commentary, lessons learned, and experimental results of vehicle-grid integration at a commercial site located at Sky Clean Energy's head office, in Markham, Ontario. This site hosts a 30 kW/100 kWh battery energy storage system (BESS), 10 kW bi-directional electric vehicle (EV) charger, and a 6 kW photovoltaic array (PV), where the objective of the project was to demonstrate the social, technical, and economic feasibility of bidirectional EV charging coupled with other distributed energy resources (DERs). From a project start date of March 2021 to its end in March 2023, this project underwent 18 days of testing to shift the peak-load of the host building to off-peak hours via its DERs, as well as 4 additional tests to demonstrate the ability the DERs to provide load reduction during simulated demand response (DR) events. To facilitate the DR events in a secure and autonomous manner, a blockchain-based smart contract was developed to handle event initiation, autonomous logging of all DER measurements (behind the meter), contractual details pertaining to the load reduction commitment, as well as dispatch/capacity compliance according to IESO Market Manual 5.5. Lastly, a potential V2G program was also developed to capture possible avenues of participation from EV owners (contract/no contract), and further developed into a web application. The web application was built on the basis of surveys from 124 EV owners across Ontario, and evaluated by another 41 EV owners by way of an online survey.

The following main points are highlighted with respect to the results and learnings of the project.

Technical

- The DERs generated a total of 3.12 MWh of energy during the measurement period of March 2022 – Feb 2023, reducing 1.75 MWh of peak load, of which the V2G contribution was 0.24 MWh.

- The developed DR algorithm successfully orchestrated control between the 10 kW V2G charger and 30 kW solar and BESS system to provide DR for simulated events of 2 hours (30 kW load reduction) and 4 hours (20 kW load reduction) while respecting capacity and dispatch constraints.

- The developed smart contract to conduct the DR event is able to validate measurements for a 4 hour DR event of 10,000 DERs in approximately 14 seconds. However, at 10,000 DERs, the smart contract returns success rates of below 90% (transactions do not complete on first try). This can be improved by the addition of more blockchain nodes on the network to help distribute the validation workload.

- The developed smart contract takes approximately 4.1 seconds to initiate a DR event on the ledger, signal the dispatch of DER, and detect the first dispatch of the DERs.

- The developed smart contract is able to implement a strict, permissioned user access system that enables EV owners to dictate which attributes of personal data can be used

by separate users within the blockchain network, with records of each access to each attribute recorded on the ledger.

Social

- In the preliminary survey of 124 EV owners from Ontario, only 4% reject participating in a potential V2G program outright, with 49% willing to participate for no incentives, and 47% willing to participate for minimum incentives (as long as money is not lost).

- When asked for the minimum incentive to participate, the most common answer was for free overall EV charging annually (42%), while 12% claimed for free home energy bills annually.

- Prior to trialing the V2G web application, 78% of respondents preferred to participate in a V2G program with no fixed contract in place, prioritizing convenience over the chance to earn more lucrative incentives. After trialing the web application, this trend reversed, with 58% of respondents preferring a fixed contract with larger incentives, and 42% preferring a no contract version.

Economical

- At current retail distribution rates, a residential V2G program is very beneficial to Local Distribution Companies (LDCs) administering it but not economically feasible for EV owners participating in the program. Based on 100 call days per year (DR events) and an incentive rate of $0.21/kWh, LDCs will net an income of $536MM over 10 years, while the EV owners will incur a loss of $1,400MM over the same period. The high current cost of bidirectional chargers ($1000/kW) is the most significant factor for the loss.

- An increase in incentive rate to $0.53/kWh or a 65% decrease in charger cost will help participants break even. However, the increase in incentive rate will result in a negative income for the administrator and higher bills for the ratepayers. The best scenario is the reduction in charger costs which would benefit all stakeholders.

- A commercial V2G program that involves an EV parking lot (EVPL) owner acting as an aggregator of EVs faces similar challenges to the residential program. Based on 100 call days per year and an incentive rate of $0.21/kWh, the LDC would net an income of $201MM over 10 years, while EV owners will net $79MM and the EVPL owners will incur a loss of $319MM over the same period. Again, the high cost of bidirectional chargers is the main reason the EVPLs are unable to break even on their investment.

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1. Introduction and Project Objectives

Traditionally, electric vehicles (EVs) have been thought of as unidirectional power loads that draw power from an electric grid to charge their onboard battery. The concept of bidirectional EV charging, or vehicle to grid (V2G), allows EVs to *discharge power from their battery to the grid*, which enables opportunities to provide grid services to power system operators (PSOs) at the transmission or distribution level. As such, EVs operating in V2G mode could be aggregated into a virtual power plant to provide demand response and ease congestion issues within the grid. Furthermore, they could be combined with other distributed energy resources (DERs) to leverage greater supply-side flexibility.

Although the concept of V2G is promising, its socio-techno-economic feasibility must be evaluated before its wide-scale adoption can begin within Ontario, with the below research questions being particularly salient:

- What preferences characterizes an EV owner's willingness to participate in V2G, whether incentive, convenience, or emissions reduction? What factors would cause an uptake in providing grid services?

- What are the technical capabilities of EVs and bidirectional chargers in terms of accuracy, response, and steady power output over time? Considering these capabilities, how does V2G fit when aggregating it with other DERs to provide demand response?

- What programs and incentive structures can be designed to introduce V2G to the public in Ontario? How feasible is the roll-out of this technology to the Ontario grid?

Funded by the IESO Grid Innovation Fund, this project, entitled "*Optimal V2G Charging System Considering Solar, Storage, and User Privacy"*, seeks to investigate the aforementioned questions by deploying a public-facing, V2G-enabled charging station in Ontario, which enables EV owners to participate in V2G and helps provide feedback that will help establish best practices for V2G in Ontario. Several objectives are discussed below:

First, a survey is designed to capture the factors that influence an EV owner's participation in V2G, and the results of the survey are used to develop a V2G program that enables the selection of several different EV session types to charge/discharge to earn incentives.

Second, a V2G enabled charger (10 kW), is deployed at the head office of Sky Clean Energy in Markham, where several tests are done to validate its accuracy and speed in responding to dispatch instructions. The V2G charger is then aggregated with other DERs on-site, including solar and battery energy storage (30 kW), to demonstrate peak shifting by arbitrage of time-of-use, as well as compliance with hourly demand response (HDR) protocols as defined by the IESO. These tests are augmented by interoperability evaluations that allow DERs to respond to a common dispatch instruction, as per the IEC-61850 interoperability standard.

Additionally, a blockchain-based smart contract is developed to demonstrate the autonomous facilitation of demand response between a PSO and a mixed aggregation of DERs. The motivation of using blockchain technology is for two purposes: (a) to ensure there is real-time penalties in place for not only HDR compliance, but also, for ensuring EV owner preferences are not violated (exceeding a certain state of charge); and (b) to ensure that any EV owner data generated, accessed, or used has proper traceability and is guided by the EV owner's consent, as enforced by Canada's privacy laws in the Personal Information Protection and Electronic Documents Act (PIPEDA) [1].

Lastly, an economic analysis is done to evaluate the feasibility of rolling out different V2G programs within Ontario, from the perspective of EV owners, general ratepayers, and local distribution companies (LDCs).

In summary, this report presents a novel look at the technology of V2G, backed by real-world testing and validation, and coupled with feasibility assessments, which together elicit several lessons learned and findings for the electricity sector in Ontario.

2. A Look at V2G Pilot Demonstrations From North America

This section lists several V2G pilots from across North America.

2.1. Canada

Organizations	LOC	Year	Project Name	Objectives
Hydro-Quebec	QC	2012-2014	Electric Vehicles: Power Exchange with the Home and the Grid	Demonstrate home backup during power outages and peak load reduction [4]
Alectra Utilities	ON	2013-2015	Powerstream Pilot	Proof of concept – first V2G charger deployment in North America [3]
Sky Clean Energy	ON	2018-Present	Sky Smart Electric Vehicle Charging Station	Assessment of the barriers to EV bi-directional charging stations and their potential to address issues such as load balancing and power security [2].
SWTCH E-Car Inc.	ON	2019-2022	Enhancing grid efficiency through a blockchain based EV charging and DER aggregation platform.	Utilizing DER aggregations with electric vehicle supply equipment to increase grid efficiency utilizing blockchain platform. [5]
Peak Power	ON	2019-Current	Peak Drive	Utilize vehicles to reduce peak demand of buildings in downtown Toronto. [6]
Blackstone Energy	ON	2020-Current	Vehicle to Grid Demand Response (V2G-DR)	Demonstrate a cost effective Vehicle-to-Grid (V2G) system that discharge during periods of peak electricity demand. [9]
Sky Clean Energy, Hero Engineering, Volta Research	ON	2021-Current	Optimal V2G Charging System Considering Solar, Storage, and User Privacy	Aggregates solar, storage, andV2G to shift peak demand, participate in demand response, and develop best practices for V2G in Ontario. [8]
Peak Power, Hydro One	ON	2021-Current	V2H for Improved Rural Reliability and Peak Reduction	Improving grid reliability for residential customers by providing back-up power during outages. [7]
Volta Research, Hero Engineering	ON	2021-Current	Improving Public Confidence for ZEVs by Exploring V2G	Raise awareness about V2G opportunities and benefits with current and prospective EV owners to help promote the uptake of ZEVs. [10]

2.2. USA

Organizations	LOC	Year	Project Name	Objectives
Hitachi	HI	2012-2015	JumpStart Maui	Demonstration of 80 V2H/G chargers for peak load reduction and frequency regulation. [12]
Electric Power Research Institute	CA	2015-2018	Distribution System V2G for Improved Grid Stability for Reliability	Exploring secure, interoperable, open standards for V2G and demonstrating relief of distribution capacity constraints. [13]
EVGo	NY	2016-Current	NYSERDA	Demonstrate participation in demand response and emergency power during outages. [14]
Transpower	CA	2017-2019	Torrance V2G School Bus	Show revenue opportunities for grid services such as frequency response and demand charges. [15]

Nuvve/UC San Diego	CA	2017-2020	Project INVENT	Demonstrate V2G fleet integration impact on the grid, including potential for grid upgrade deferral.[11]
Pacific Gas&Electric/ General Motors	CA	2022 – Current	PG&E V2X pilot	Demonstrate use cases of bidirectional charging for residential, commercial, and microgrids. [16]
National Grid/Electric Frog	RI	2021-Current	ConnectedSolutions – V2X	Demonstrate load reduction during peak events. [17]

3. Summary of EV Owner Survey for V2G Preferences

**Note: The text of this section is heavily borrowed from our journal paper [24] published as a result of this work. The IESO Grid Innovation Fund has been credited as a funder in the paper.*

3.1. Survey Design

The main objective of the EV owner survey is to capture their willingness to participate in V2X, comprising of environmental, societal, economic, and technical attributes. These attributes are then parameterized into metrics that are useful in observing trends that establish preference heterogeneity and influence the overall willingness to participate, which informs the design of the proposed V2G program.

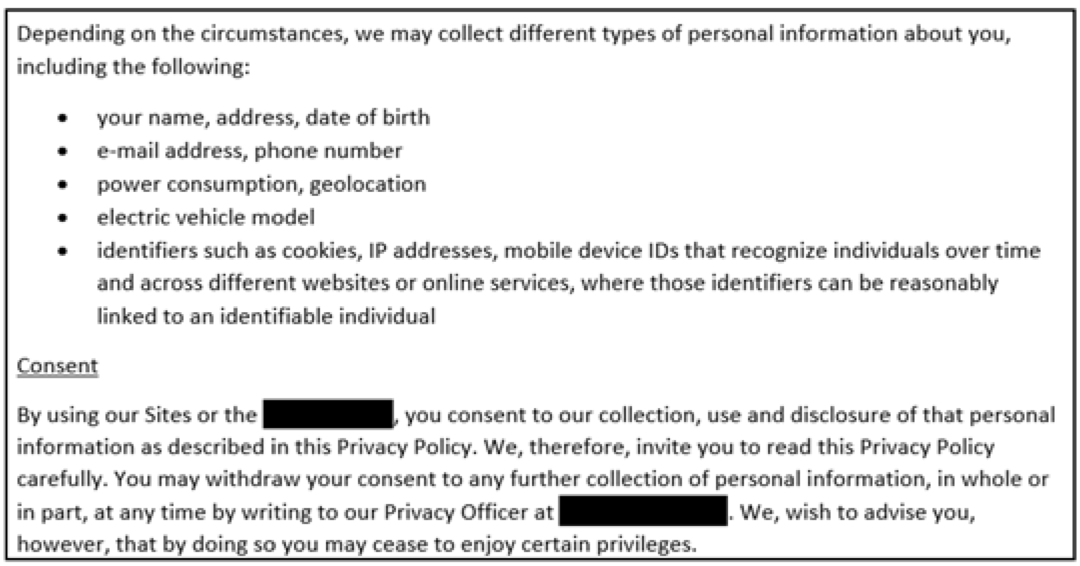
The survey is divided into four sections that ascend in order of comprehension complexity due to the general unfamiliarity of EV owners with respect to V2G [18],[19]. The first section focuses on asking general questions that establish behavioral patterns of the EV owner, such as their preferred charging location, charging frequency per week, and estimated daily plug-in-time. The responses can be interpreted to ascertain the opportunity for EV owners to participate in V2G, and predict the aggregated capacity (kW) and energy (kWh) available to participate in DR.

The second section gently introduces the concept of V2G and describes the opportunity to earn incentives for participating in exchange for energy discharged and a commitment to plug-in to a charging station for a minimum duration. Participants are also educated about the environmental opportunity for V2G in offsetting energy generation from fossil fuel based power plants. Two important parameters are introduced to the EV owner at this stage, which are the minimum driving range (MDR), and minimum-plug-in-time (MPT) [20]. The MDR is the minimum level of range that is guaranteed to be left on the EV at all times to allow it to get to its next destination, while MPT is the minimum number of hours an EV owner would be required to plug in to a bidirectional charging station per month.

The third section focuses on using the MDR and MPT parameters to introduce two different V2G program types and assess their interest in each. The first program broadly resembles a "pay as you go" program based on energy arbitrage, where EV owners would charge their EV during times when off-peak hours and discharge their EV during on-peak hours. This form of arbitrage will also result in greenhouse gas emissions savings (GHGs), as the fuel mix of Ontario is significantly cleaner during the off-peak hours as compared to on-peak hours. This program type prioritizes the convenience of the EV owner over their potential to earn incentives, since the EV owner may choose to initiate and abort an EV session without any penalty, and does not need to commit to any sort of contract with an energy aggregator or PSO. The second program is based on a fixed contract, where the EV owner would commit to a MDR and MPT, and receive payments for energy discharged (\$/kWh), as well as capacity payments for the time spent plugged in (\$/kW). If a DR event is called, the EV owner is entitled to enhanced payment for energy discharged during the DR event. However, the EV owner forfeits all monthly incentives if they do not fulfill their level of MPT, or disconnects from the charging station for a certain period of time during a DR event.

To make the programs more intuitive to understand, three separate profiles are created to characterize ranges of preference for MDR and MPT, entitled conservative, moderate, and aggressive. Without loss of generality, it is assumed that a conservative EV owner sets the MDR as two times their daily commute and the MPT at 4 hours, a moderate EV owner sets the MDR as 1.5 times their daily commute and the MPT at 8 hours, while an aggressive EV owner sets the MDR at their daily commute and the MPT at 12 hours. Monetary amounts are attached to each of the profiles and varied to observe the trade-off between convenience and desire for incentives by determining if any of the EV owners changed their desired profile type.

The fourth section revolves around data privacy, specifically pertaining to actors that may collect and disseminate data about EV owners for their own profit. For example, as shown in Figure 1, an EV network operators may gather data such as geolocation, general charging times, electric vehicle model, etc. As such, the intent of this section of the survey is to gauge whether EV owners may be aware of such data collection practices, and then to assess to what degree they are comfortable with such practices. Questions are thus asked to assess their decision to terminate a contract with an EV network operator if data is being collected, sold, or sold in exchange for a financial incentive.



Depending on the circumstances, we may collect different types of personal information about you, including the following:

- your name, address, date of birth
- e-mail address, phone number
- power consumption, geolocation
- electric vehicle model
- identifiers such as cookies, IP addresses, mobile device IDs that recognize individuals over time and across different websites or online services, where those identifiers can be reasonably linked to an identifiable individual

Consent

By using our Sites or the [redacted], you consent to our collection, use and disclosure of that personal information as described in this Privacy Policy. We, therefore, invite you to read this Privacy Policy carefully. You may withdraw your consent to any further collection of personal information, in whole or in part, at any time by writing to our Privacy Officer at [redacted]. We, wish to advise you, however, that by doing so you may cease to enjoy certain privileges.

Figure 1 - Privacy policy from EV network operator.

3.2. Discussion of Survey Results

The selection criteria to participate in the survey was for the participants to reside in Ontario, Canada, and to have driven or ridden an EV before conducting the survey. The survey was subsequently disseminated for a period of 9 months between March 2021 and December 2021, and garnered 124 responses. It is worthwhile to note that individual consent to use the survey responses for the purposes of knowledge dissemination within this report was obtained during the survey process itself, where participants indicated their consent by having an option to opt-out of the dissemination activities.

A total of 68% of EVs were from Tesla, Chevrolet, and Nissan, with Tesla accounting for 38% (models S, X, Y, 3), the Chevrolet Bolt at 19%, and the Nissan Leaf at 11%. Further observations from the survey results can be seen in Figure 2, and are discussed below.

3.2.1. General Willingness to Trial V2X Programs

As seen in Figure 2(a), there appears to be a general willingness to engage in a V2G program across respondents, with only 4% rejecting participation outright, 49% participating for a minimum incentive, and 47% participating regardless of incentives. When told that V2G had the potential to offset the use of fossil-fuel based generators, 80% of the respondents cited enhanced motivation to participate, as seen in Figure 2(b). Interestingly, when queried with respect to the minimum incentive required to participate in a V2G program, as seen in Figure 2(c), dominant responses included year-round free charging for their EV (42%), while 35% indicated that they would participate as long as they did not lose any money. Put together, the survey results indicate that the survey respondents possess a general willingness to trial V2G programs, strongly motivated by environmental benefits and financial incentives.

Qualitatively, participants were also asked the reasons they **would not** participate in a V2G program, where the top reason cited by 33% of participants was the fear of accelerated battery degradation due to frequent charging/discharging cycles, while 28% cited trust issues with the technology itself and allowing PSOs to remotely control their EV. These concerns underscore the importance of designing and deploying real-world V2G programs to mitigate these concerns.

3.2.2. Preference for V2X Program Types

EV owners indicated a strong preference for a no contract type program as seen in Figure 2(d), with 78% voting for no contract, versus 22% voting for fixed contract. To further explore the motivation to participate as a function of MDR, EV owners were asked to choose between profile types of conservative, moderate, and aggressive, as discussed previously. As seen in Figure 2(e), 55% chose the moderate profile, while 37% chose the conservative profile, with only 8% choosing an aggressive profile. Next, financial incentives were attached to the profiles in two stages, where in the first stage, the annual payout for conservatives, moderates, and aggressives was $500, $750, and $1000 respectively, while in the second stage, the annual payouts were enhanced to $750, $1000, and $1500, respectively. At the first stage, the aggressive profile reported an increase of 4 EV owners, or 3.3% of the total respondents. In the

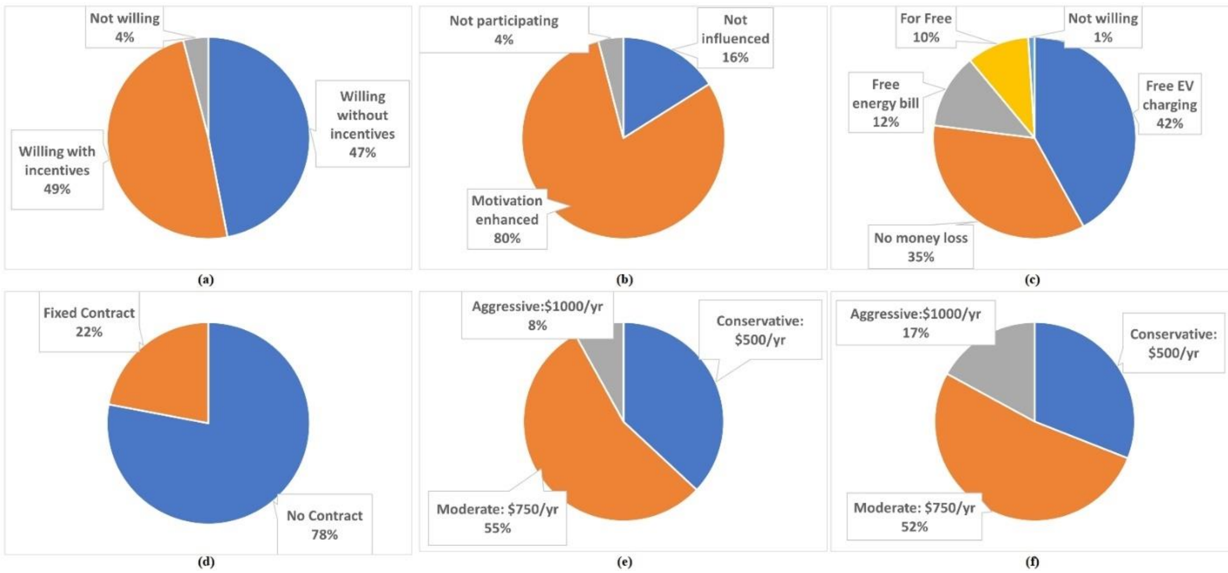


Figure 2 - EV Owner survey results showing (a) participation due to financial incentive, (b) participation due to environmental benefit, (c) minimum incentive to participate (d) preferred V2X program, (e) profiling based on MDR and (f) profiling based on enhanced MDR.

second stage, shown in Figure 2(f), the trend was observed again, where the number of EV owners switching to the aggressive profile increased by 7 (or 6% of the total respondents). By increasing the annual payout for the aggressive profile by a factor of 1.5, the number of EV owners willing to lower their MDR and offer more capacity for grid services more than doubled, from 10 to 21.

3.2.3. Preference for Data Privacy

EV owners indicated a general acceptance of their private data being collected, as shown in Figure 3(a), where only 30% of participants responding that they were not at all comfortable with their data being collected. However, when asked if their comfort level with respect to the selling of their data, 74% of respondents stated that they were not comfortable, as seen in Figure 3(b). When further asked if they would terminate their contract with an EV network operator if their data was being sold, 63% of respondents stated that they would terminate the contract, as shown in Figure 3(c).

To gauge the level of discomfort in the selling of personal data, questions were asked with respect to if the offer of financial incentives in exchange for the data would reduce the discomfort, and what level of incentive would be required to avoid termination of a contract. As seen in Figure 3(d), the presence of a financial incentive drives 17 respondents, or 14%, to change their stance from “Termination” to “No Termination”. However, when offered different levels of compensation in Figure 3(e), 68% of respondents chose not to pick any incentive, while the next highest selection was Free EV charging year-round (20.5%). Finally, when asked if an EV network operator would offer the ability for EV owners to control what information was

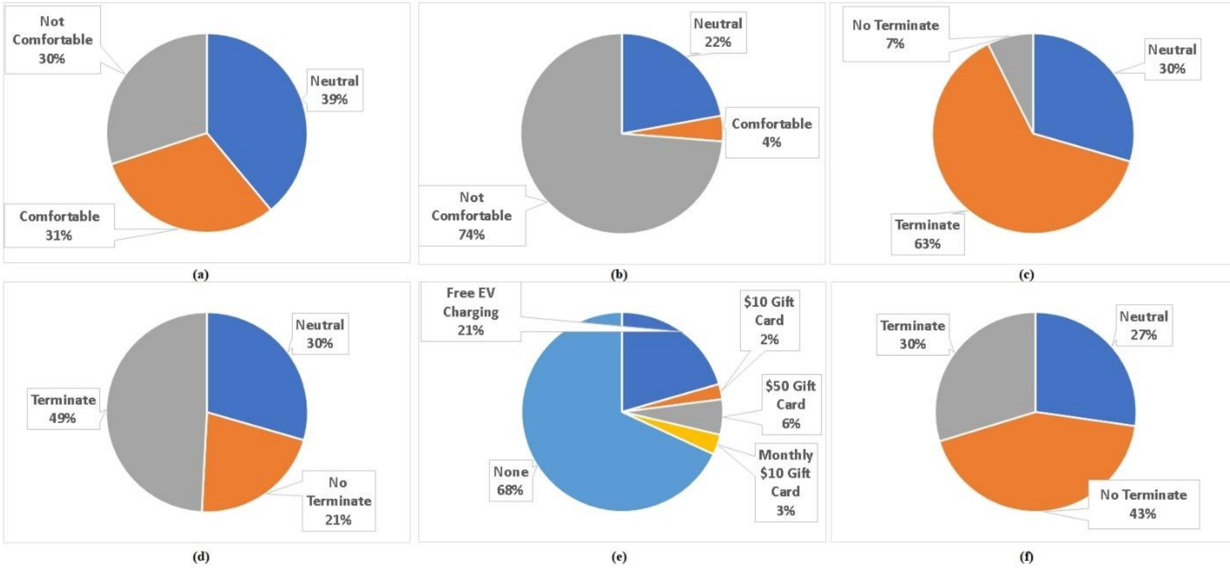


Figure 3 - EV Owner survey results showing (a) comfort level in data collection, (b) comfort level in selling of data, (c) decision to terminate if data being sold (d) decision to terminate if offered incentive for selling data (e) level of incentive required for selling data (f) decision to terminate if offered control of data to be sold.

able to be collected and sold, 43% of respondents elected to not terminate their contract, versus 30% of respondents that claimed they would not trust the EV network operator in any case.

3.2.4. Summary

In totality, it can be established that the most influential characteristic that drives an EV owner's willingness to participate in V2G is their convenience, as evidenced by the strong preference for the no contract option. However, the survey evidence also suggests that both environmental benefits and financial incentives do play a secondary role in establishing participation. Therefore, it follows that a V2G program must provide options that cater to these preferences in an intuitive manner, which includes facilitating both fixed contract and no contract options.

Furthermore, there appears to be a strong intolerance for the violation of data privacy rights, with over 70% of respondents claiming that they are not comfortable with their data being sold, and 63% of respondents claiming they would terminate their contract with an EV network operator if they found that private data was being sold. This reinforces the fact that options for granular consent should be given to EV owners with respect to their data during provision of V2G, and adequate visibility and transparency must be provided such that EV owners would be able to see actions of different actors when interacting with EV owner data. This is in line with Canada's privacy act regarding personal and private information, PIPEDA [1].

4. System Description

Henceforth, the word “system” will be used to refer to the overarching technology that controls the DERs at the demonstration facility, located in Markham, Ontario. The available DERs include a 30 kW/100 kWh hybrid solar and BESS and 10 kW bi-directional EV charger. It is worthwhile to review the objectives of the system, and by extension, the project, to better inform the rest of this section, which are summarized below:

1. Demonstrate the coordinated control of on-site DERs to realize annual peak shifting energy savings by following TOU electricity pricing.
2. Develop a DR algorithm that demonstrates the ability of a mixed aggregation of DERs to provide load reduction when called upon by a simulated DR signal, *while obeying constraints of DERs*.
3. Show the ability of a DR event to be carried out by a grid operator (either LDC or IESO) via *smart contracts* deployed on distributed ledger technology (blockchain), including event activation, dispatch, and validation.
4. Investigate the scalability of the blockchain-based DR solution by measuring the total transaction latency as a function of the number of DERs connected to the blockchain network.
5. Demonstrate the interoperability of the mixed aggregation of DERs in responding to grid operator commands as per the *IEC 61850-90-7* interoperability standard, including Remote ON/OFF and power curtailment.
6. Develop a blockchain-enabled data privacy algorithm to ensure that sensitive EV owner data cannot be accessed without the consent of the EV owner.

In view of these objectives, a block diagram of the system and its underlying subsystems can be seen in the block diagram illustrated in Figure 4.

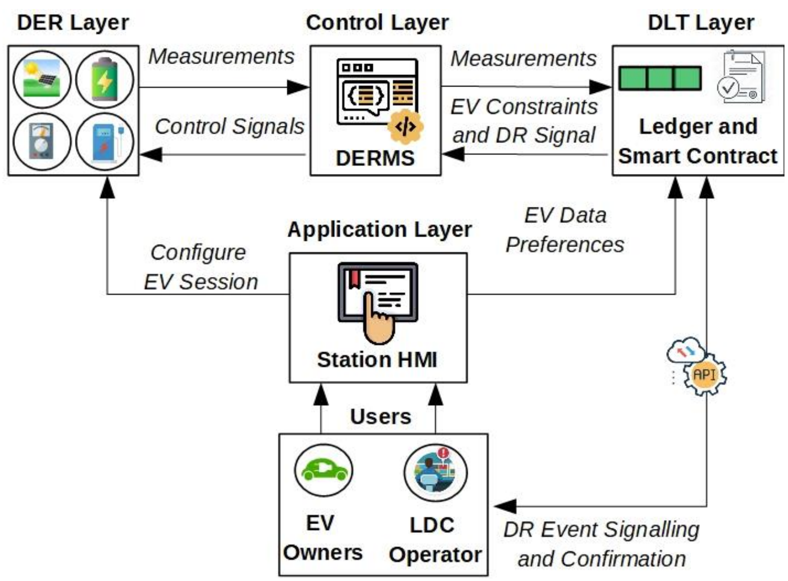


Figure 4 - System decomposed into underlying subsystems.

Before describing each subsystem, it is worthwhile to define the terms within the figure that influence the dataflow throughout the system:

- **Measurements** are data acquired directly from the DERs. The measurements will primarily be the active power consumed/generated by each DER (kW), as well as the SoC for the BESS and any connected EVs.
- **Control Signals** are dispatch instructions that represent new setpoints for the DERs that are dispatchable, which will be active power setpoints for the BESS and EVs.
- **DERMS** is a software-based, distributed energy resource management system (DERMS) that is responsible for the control and coordination of all available DERs on-site. The DERMS used in the project is developed by Hero Energy and Engineering, entitled Harmonize.
- **EV Sessions** are individual instances of an EV owner utilizing the system to either charge/discharge their EV.
- **EV Constraints** are configurable settings and limitations that govern EV Sessions, which indicate their willingness to participate in load reduction, or DR scenarios, or simply to achieve a target SoC as quickly as possible. These constraints may include an MDR, in kilometers or %, or minimum SoC that must be left on the EV at all times. The constraints may also include already agreed upon “contracts” between an EV Owner and an LDC, which specify the MDR, and MPT that an EV Owner will abide by in case of a DR Signal.
- **DR Event** is a control signal received from an LDC, which triggers all available DERs to be aggregated to provide a net reduction in load (whether generating energy, or reducing already existing loads).
- **EV Data Preferences** are preferences that govern which actors within the system workflow may access EV owner data.
- **Station HMI** is the human machine interface of the DERMS that also enables an EV owner to interact with the on-site charging station. The EV owner utilizes the Station HMI to initiate, abort, or complete an EV Session.
- **Ledger** is a part of the blockchain and is a distributed, shared database that stores EV Session data, DR Events, associated measurements, and EV Data Preferences.
- **Smart Contract** is a logic-based application residing within the DLT layer that ensures that EV Data Preferences and EV Constraints are being obeyed during EV Sessions. The smart contract also validates that the DR capacity provided by the demonstration facility was within performance standards. LDC operators may interact with the ledger and execute smart contracts to initiate a DR event by utilizing an application programming interface (API) that will be provided by the DLT layer.

With the relevant terms defined, the purpose of each subsystem can now be expanded upon.

4.1.1. DER Layer

The DER Layer consists of the physical DERs at the demonstration facility, which include:

- 100 kWh BESS, manufactured by TROES Corp Inc.
- 6 kW of photovoltaics (PV), manufactured by Canadian Solar.

- 10 kW vehicle to grid (V2G)-enabled charging station, manufactured by Coritech (VGI-30-DC). Originally rated for +/- 30 kW, however, derated to 10 kW due to system constraints.
- The BESS and PV are coupled by a power conversion system (PCS), which outputs a maximum of +/- 32 kW of active power, and is manufactured by Ideal Power (30C3)

All available DERs are standalone, which means that they require an external controller to set their setpoints and manage any errors/constraints. This is done by the DERMS.

4.1.2. Control Layer

The Control layer consists of the DERMS software, which continually acquires measurements from DERs, executes algorithms to perform optimal energy management for the facility, and manages the DERs under its command. The outputs of the DERMS are control signals that are setpoints for each of the available, dispatchable, DERs.

4.1.3. DLT Layer

The DLT, or distributed ledger technology layer, is responsible for verifying the integrity of EV charging sessions, as well as ensuring that the EV Owner data privacy preferences are being respected in accordance with the Personal Information Protection and Electronic Documents (PIPEDA) act [1]. As such, the DLT layer executes a smart contract, which contains logical functions that accept EV Session data, monitors incoming measurements to validate EV constraints, and maintains a transparent distributed ledger that can be queried by any user in case of any discrepancy. The smart contract also executes data privacy safeguards that prevent unauthorized disclosure of EV owner data by other system actors. The data privacy safeguards revolve mainly around **consent**, which gives the EV owner the ability to assign individual access control to specific data items for specific system actors. Data items could be the EV owner's name, address, charging preferences, while system actors could be DERMS providers, charging system manufacturers, LDCs, among others.

4.1.4. Application Layer

The application layer represents the interface by which a user may interact with the system, which is the Station HMI. The Station HMI is a touch-screen tablet that is located on the V2G charging station itself, and allows an EV owner to initiate, configure, and/or abort an EV Session. The Station HMI may also be used to update any preferences or contract details for their EV. It is worth noting that an API will be provided by the DLT layer such that an LDC operator may signal a DR event and monitor the performance of the on-site DERs in fulfilling the contracted DR capacity.

It is worth noting that the control layer to dispatch the DERs is provided by Hero's DERMS, entitled Harmonize, while the blockchain/DLT layer is custom developed by Hero on Hyperledger Fabric 2.2.

4.1.5. Definition of EV Session Types

Since the EVs are the only DERs that are public facing, several EV session types must be defined to enable EV owners to accomplish their objectives in an intuitive manner. These objectives may be for an EV to arrive at a desired SoC, or MDR, as quickly as possible, or, to earn revenue by providing DR capability to LDCs by either discharging power to the grid, or reducing charging consumption during DR events.

At this point, it is worthwhile to recall the two different types of V2G incentive structures that were the key findings of Milestone 1 (mentioned in the survey section in Section 2 of this document). The first was based on time-of-use (TOU), where an EV owner may charge their EV at off-peak hours, and discharge their EV at on-peak hours to realize a daily profit. This will be referred to, hereafter, as arbitrage. The second was based on a formal contract that defines MDR and MPT, where capacity and energy payments are made to the EV if it fulfills its MPT requirements and responds to DR events. It follows that the first type of incentive structure prioritizes an EV owner's convenience, and may be more conducive to EV owners that choose to engage in EV sessions that are shorter in duration and/or interruptible. On the other hand, the second type of incentive structure lends itself towards longer-term EV sessions, that may result in higher profits, but less flexibility. Thus, the following definition of EV session types seeks to reflect these objectives:

1) **Charge ONLY**: The EV owner wishes to arrive at a target SoC/MDR as quickly as possible. This session type does not support V2G, nor does it support DR, which means that the EV will charge at the maximum possible charging rate, and the EV owner may abort the session at any time. *This session type is intended for EV owners that are short on time and/or not at their usual charging location e.g., on the highway.*

2) **Discharge ONLY**: The EV owner wishes to arrive at a target SoC/MDR as quickly as possible. This session type **supports only V2G,** and means that the EV will discharge at the maximum possible discharging rate. The EV owner may also abort the session at any time. While discharging the EV may seem to qualify as provision of grid services, the EV session is interruptible, and its discharging rate is inflexible, thereby disqualifying the EV owner from contract-based incentives from the LDC. *Thus, this session type is intended for those EV owners that will configure shorter EV session durations, most probably to leverage the TOU-based incentive structure.*

3) **Grid Support:** The EV owner wishes to arrive at a target SoC/MDR by a **specific time**. This session supports **V2G, as well as the varying of charging/discharging rate** when controlling the EV.. *This session type is intended for longer session durations, such as when the EV owner is parked at home, the office, or a parking garage, and thus,*

qualifies for contract-based incentives. EV owners may still abort or interrupt a session; however, they will forfeit their incentives as a result.

4.2. Algorithm Workflow

This subsection provides workflow details, including expected results, for the time-of-use, DR, and the data privacy application.

4.2.1. Time-Of-Use Algorithm

4.2.1.1. Objective

Based on seasonal TOU pricing, dispatch controllable DERs to reduce the peak load of a building during the peak hours of electricity. As such, the BESS discharges only during peak hours. On the other hand, the EV is representative of a user in a workplace environment that is parked at the building during the hours of 8:30-5:00, and discharges power from their EV during this time. If at any point during the day, the state of charge (SOC) constraints of either DER are reached, power flow from the DER is halted.

4.2.1.2. Algorithm Details

- Maximum and minimum SOC constraints for EV are 95% and 20%, respectively.
- Maximum and minimum SOC constraints for the battery are 95% and 20%, respectively.
- BESS charges from 12AM to 6 AM until maximum SOC reached.
- BESS discharges during peak hours:
    - In Winter: BESS discharges from 8:30 AM to 11:00 and 17:00 – 19:00
    - In Summer: BESS discharges from 11:00 – 17:00
- Solar (photovoltaic – PV) generates electricity throughout the day.

The TOU tests were executed across the heating and cooling seasons to have a better reflection of seasonal variability, as shown in Table 1.

Table 1 - Test Matrix for TOU DER Control Testing

	Heating Season				Cooling Season		
Test #	Below -15˚C	-15˚C to -5˚C	-5˚C to 5˚C	5˚C to 18˚C	18˚C to 22˚C	22˚C to 26˚C	26˚C to Above 30˚C
1							

2							
3							

4.2.1.3. Intended Results

- EV and battery charge/discharge at correct times depending on TOU period and reduce building load during peak hours.
- EV and battery halt charging/discharging when SOC constraints are reached.

4.2.2. DR Algorithm

4.2.2.1. Objective

Based on contracted DR capacity, dispatch the building DERs to fulfill its contracted load reduction, while observing all DER constraints based on SOC. Facilitate the DR event via smart contract, and ensure the full automation of the event, from activation, dispatch, and validation. The test should largely follow the Standard Test Cases for Demand Response and Transactive Energy as defined by the IESO, with the calculation of the building baseline following the methodology as per IESO Market Manual 5.5, S.1.6.26.3. In addition, the DERs should be tested against both dispatch and capacity compliance.

4.2.2.2. Algorithm Details

- Maximum and minimum SOC constraints for EV are 100% and 10%, respectively.
- Maximum and minimum SOC constraints for the BESS are 100% and 10%, respectively.
- DERs should be on-site and connected during the availability window:
    - In Summer: Between 12:00 and 21:00 PM
    - In Winter: Between 16:00 and 21:00 PM
- Utilize the smart contract to send a DR activation notice approximately 2.5 hours in advance of the DR event.
- Utilize the smart contract to send a *start signal* to begin the DR event.
- DERMS begins to dispatch the DERs according to the contracted capacity (between 20 and 30 kW), the computed baseline for the building, as well as the current building load.
- Generation of solar prioritized first, then EV, then battery to cover the remaining capacity offered.
- DERMS submits measurements from all DERs, building consumption, as well as the meter at the point of common coupling to the blockchain ledger in one minute averages.
- Smart contract is used to end the DR event. DERMS returns to default DER operation.

- Immediately after the DR event has ended, smart contract is used to validate the DR event by using all measurements on the blockchain ledger. Three criteria are:
    - Dispatch Charge: Aggregate curtailment provided by DERs on-site should be within 15% of the contracted curtailment for each 5-minute interval during the DR event.
    - Capacity Charge: Aggregate curtailment provided by DERs on-site should be within 90% of the difference between the computed baseline and actual building consumption.
    - Minimum EV: To protect EV participants, ensure that EV SOC was never below the minimum SOC provided by the EV participant.

4.2.2.3. Intended Results

- On-site DERs are able to be dispatched automatically in response to a DR signal, and provided the contracted curtailment.
- Smart contracts are able to initiate a DR event, accept measurement data, and validate the DR event according to the success criteria identified above.

4.2.3. Data Privacy Application

4.2.3.1. Objective

Utilize smart-contracts and attributes of blockchain to ensure that the data of EV owners is only accessible to those individuals/organizations that the EV owner has granted **consent** to. Furthermore, implement a data history mechanism such that the EV owner may query which user accessed the data at what time, and for what purpose. Generally, this algorithm follows the Canadian privacy law as mandated by The Personal Information Protection and Electronic Documents Act (PIPEDA) [1].

4.2.3.2. Algorithm Details

- A data object defining an EV owner's user data, entitled *userData*, has the following sub-objects:
    - Personal: name and address
    - Billing: credit card details
    - EV Preferences: participation in demand response, EV make/model details, minimum driving range, minimum plug-in-time, DR contract type (fixed or no contract)
    - Access Control List: a list of objects indeed by other users and their respective organizations, defining granular access to each of the above sub-objects

- Upon an EV owner registering and filling out the details in *userData*, the *userData* is encrypted and stored on the ledger.
- A smart contract also creates another object, entitled *userDataHistory*, which is a list of objects with the following attributes:
  - Accessed By: The user that has attempted to access another user's data.
  - Access Method: The function or app that the user used to access the data.
  - Time: The time that the access request was submitted
  - Notes: additional notes about the access and the reason why the request was made
  - Granted: If the access was granted or not.
- Access control and traceability to the user's data is controlled/enforced as follows:
  - All access to *userData* will first check the credentials of the submitting user, which will reveal their user ID, and their organization. Since a permissioned blockchain is being used, authentication and validation of the submitting user's identity will occur with every request.
  - The submitting user's identity will be searched for in the Access Control List of *userData*. If the submitting user identity is found, and the sub-objects they are requesting are within the permissions specified, the *userData* is returned back to the submitting user in encrypted form. If not, the submitting user is sent back an access denied due to permissions issue message.
  - The *userDataHistory* object is updated according to the last request by the submitting user.
  - If the request was successful, the submitting user uses their private key to decrypt the data to make it readable.

4.2.3.3. Intended Results

- EV Owner is able to create their user profile on the blockchain ledger and obtain their data history at all times.
- Users with correct permissions are able to access EV owner data as defined by their consent, via the access control list.
- Users with incorrect permissions are not able to access EV owner data as defined by their consent, via the access control list.

4.3. System Screenshots

The following section shows screenshots of the various subsystems as depicted in Figure 4. A simulated version of the Station HMI can be found at this link: https://v2xhero.web.app/

4.3.1. Hero DERMS – Harmonize

This DERMS system is responsible for monitoring and dispatching the on-site DERs. A screenshot of the user interface in action is provided in Figure 5, where both EVs are charging at 10 kW each, the BESS is charging at 20 kW, while the solar is providing 5 kW of power.

Selecting the Control button on the bottom toolbar exposes three control options as seen in Figure 6, which are Time of Use, Demand Response, and Manual Control. A screenshot of the DERMS in Demand Response mode can be seen in Figure 7, where the EV connected to the ChargePoint EV charger has stopped charging, the EV connected to the V2G charger is now discharging at 10 kW, and the battery is discharging at 25 kW.

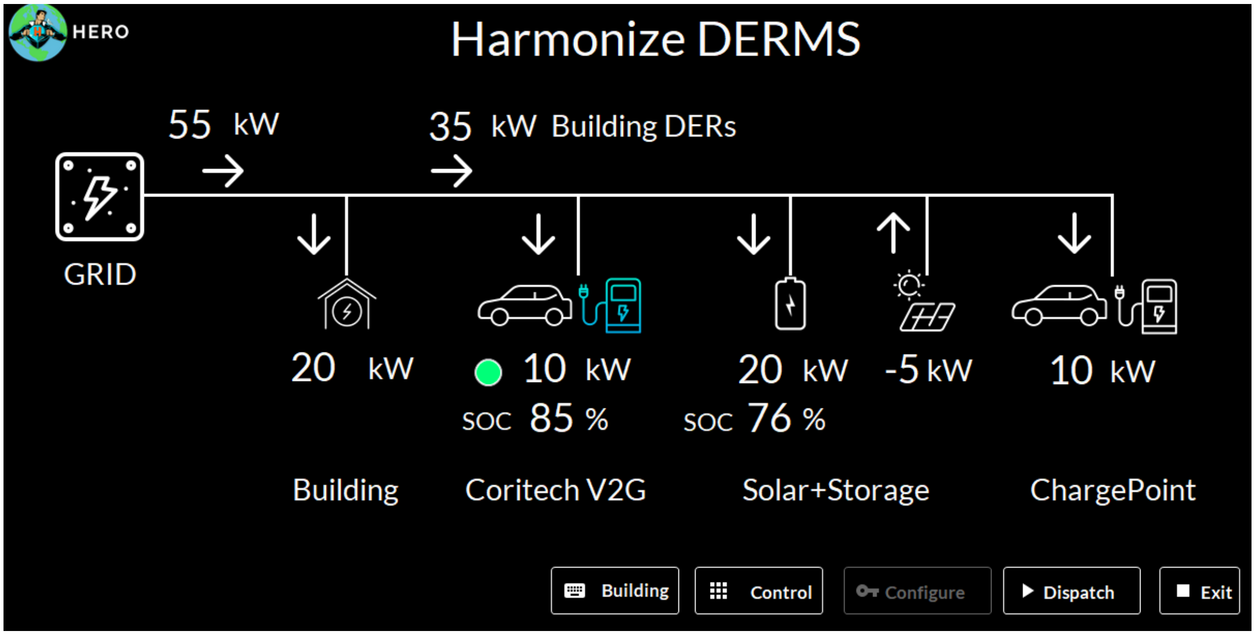


Figure 5 - Snapshot of Hero DERMS in action.

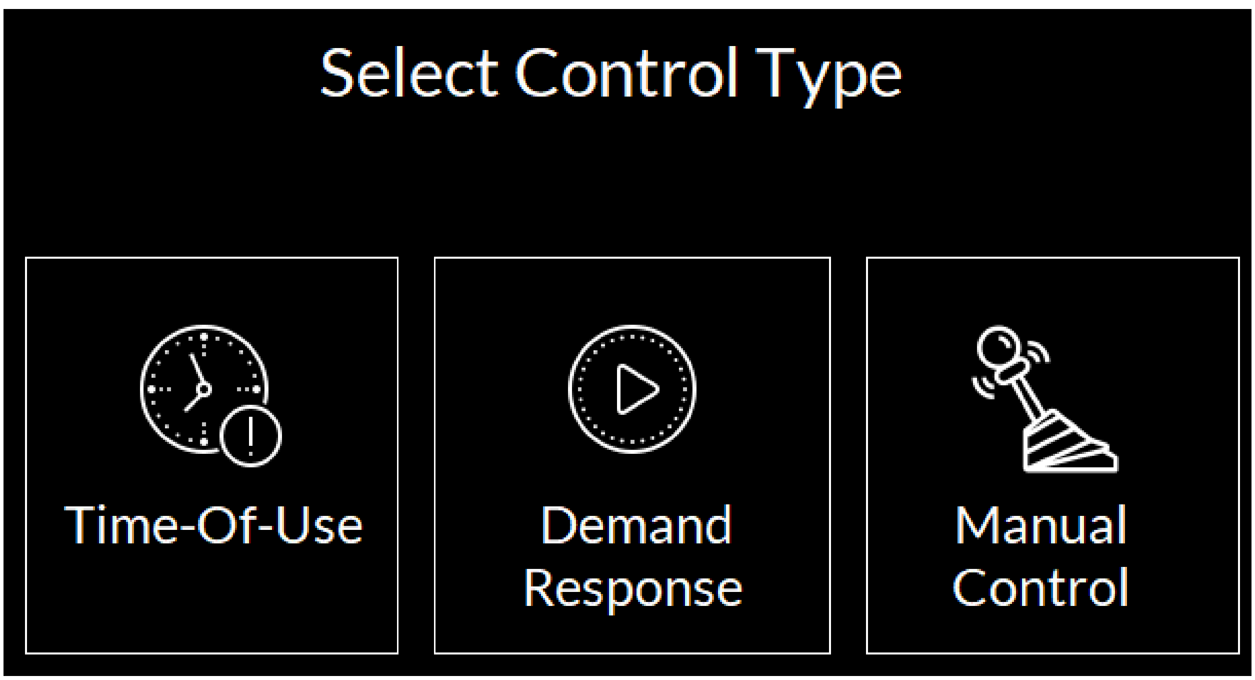


Figure 6 - Control options provided by Hero DERMS.

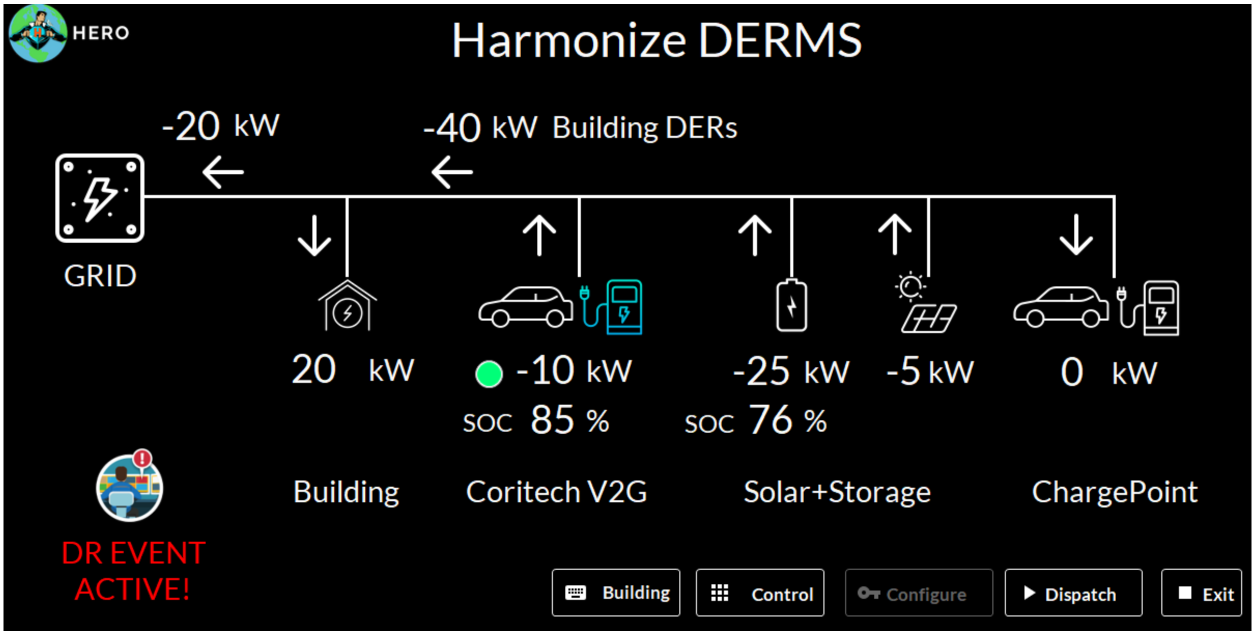


Figure 7 - DERMS dispatching DERs to meet contracted capacity of 40 kW during DR Event.

4.3.2. Station HMI

The Station HMI software is deployed on a tablet, where interaction is meant to take place with EV owners. The first screen to welcome the EV owner can be seen in Figure 8, where the EV owner can login or sign up.

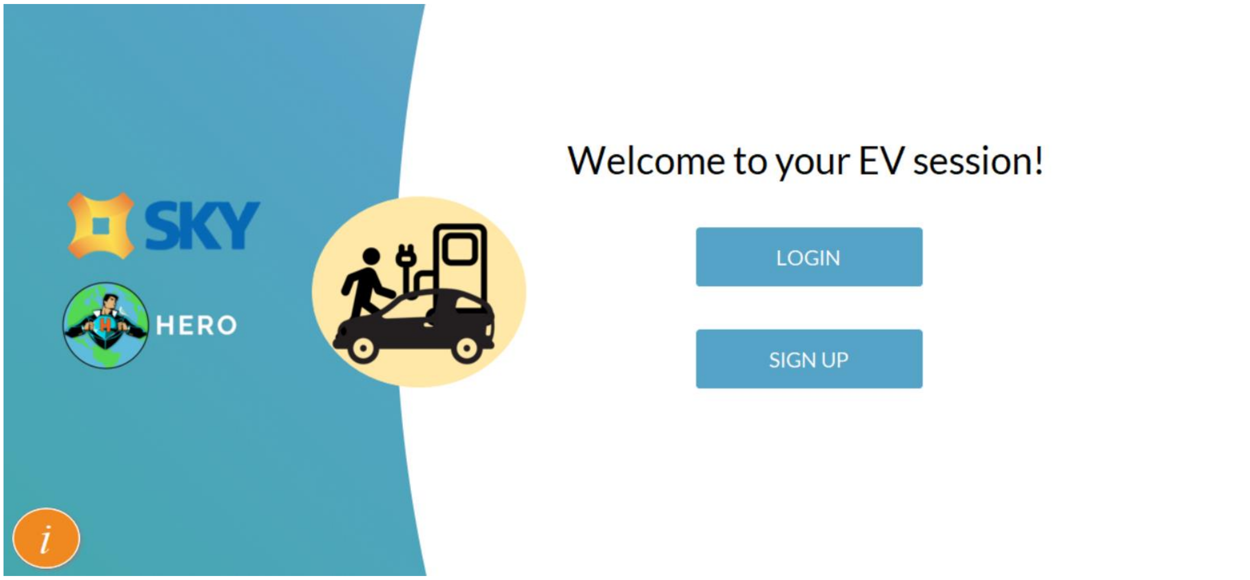


Figure 8 - Welcome screen for Station HMI.

After the EV owner authenticates, the EV owner is taken to the screen shown in Figure 9, where the EV owner can elect to have a *Quick Session* or to *Continue My Contract*. As explained in the Milestone #2 report, the quick session enables EV owners to achieve their target SOC as quickly as possible, and is meant for scenarios where the EV owner is not at their preferred charging station, and/or does not intend on having a session with a longer duration. The continuing contract option, also known as Grid Support, is meant for scenarios where EV owners may be idling at a preferred charging station (home/work), and opt to participate in demand response if such a signal is sent.

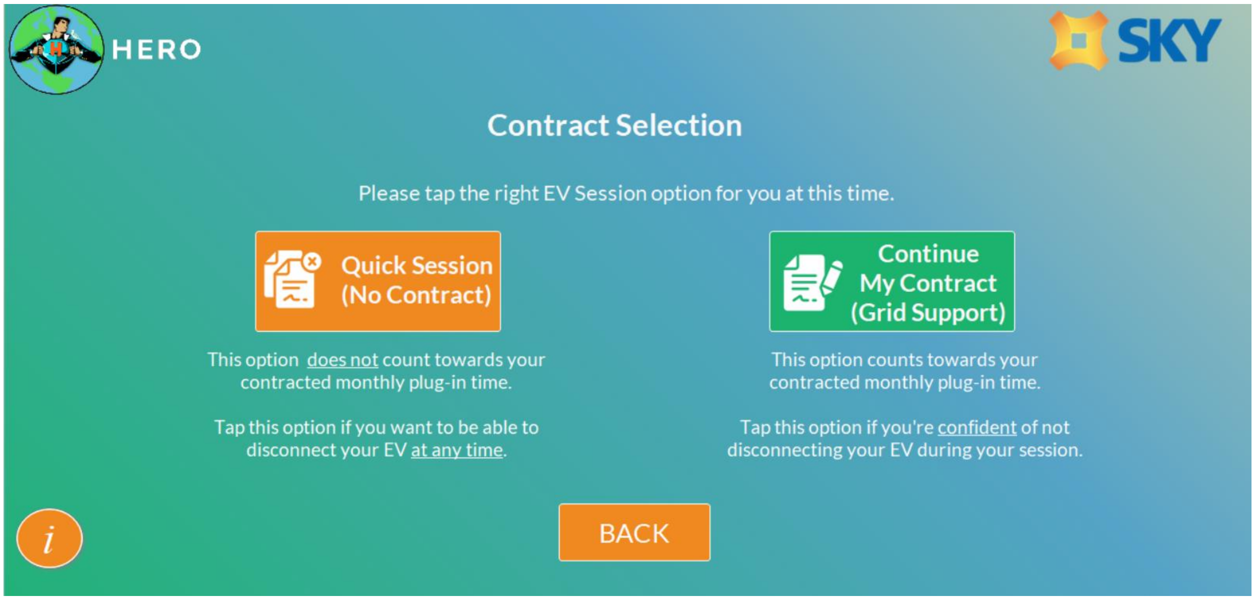


Figure 9 - Contract selection screen where EV owner can determine their contract preferences.

The subsequent screen enables EV owners to configure their session with the expected departure time and minimum battery level.

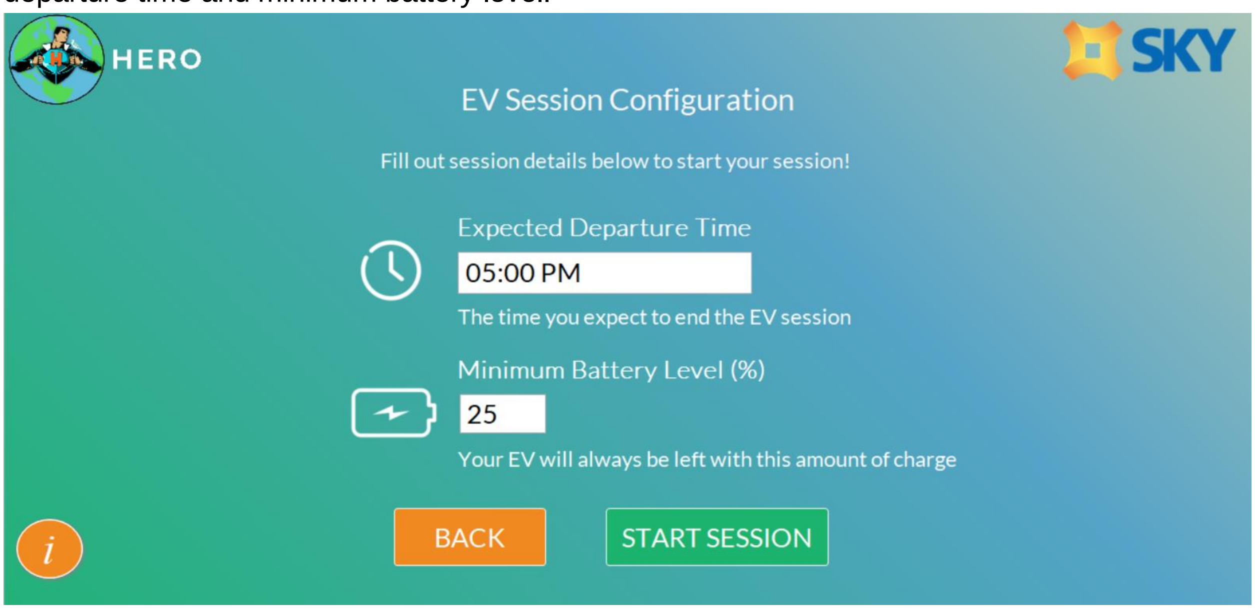


Figure 10 - EV session configuration.

The subsequent screen enables EV owners to visualize their EV session. In this case, the EV owner has opted for Grid Support mode and the EV is discharging at 10 kW, as shown in Figure 11.

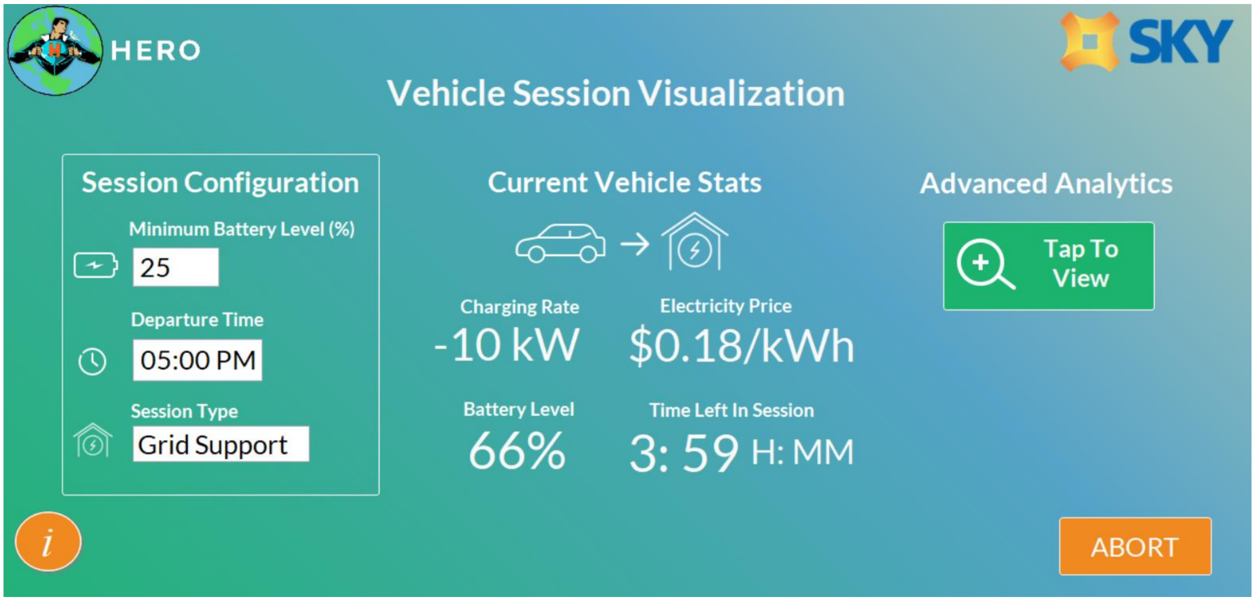


Figure 11 - EV Session visualization when discharging.

5. Experimental Results

This section provides results from real-world testing of the algorithms described in Section 4. A single line diagram of the facility is shown in Figure 12 below. In the figures shown throughout the rest of the document, measured values from the meter entitled M1 will be labeled as "Actual Consumption" and are representative of the actual load consumed by the building, inclusive of the power transfer by on-site DERs. The measured values from the meter entitled M2 will be labeled as "DER Meter", and are representative of the power transfer of the DERs on-site. Measuring these two values allows the calculation of the actual building load by subtracting the measurements of the DER Meter from the measurements of Actual Consumption.

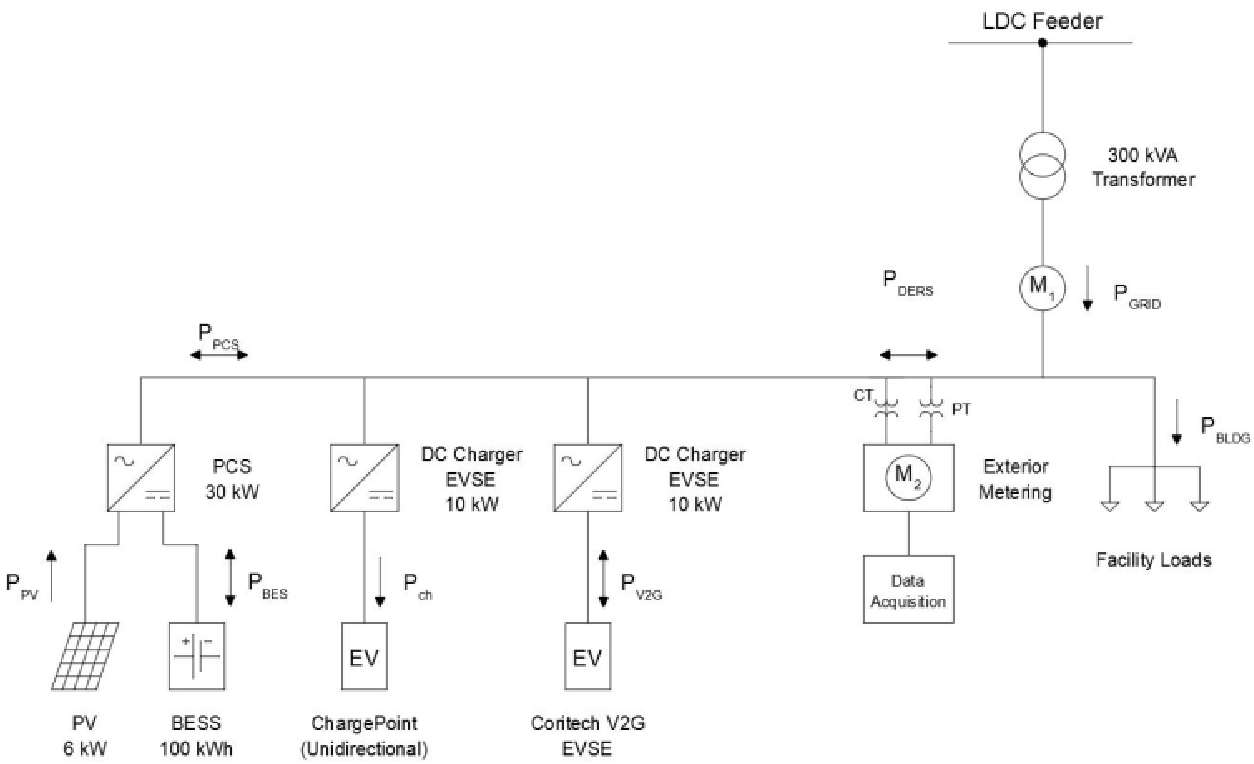


Figure 12 - Single line diagram of facility.

5.1. Testing of TOU Algorithm

Eighteen individual TOU tests were conducted between August 2022 and February 2023, as indicated by the checked entries in Table 2. It is worthwhile noting that winter weather conditions did not allow for significant tests to be conducted below -15˚C, and are omitted in Table 2.

Table 2 - Completed TOU tests.

Test #	Heating Season				Cooling Season		
	Below -15˚C	-15˚C to -5˚C	-5˚C to 5˚C	5˚C to 18˚C	18˚C to 22˚C	22˚C to 26˚C	26 ˚C To Above 30˚C
1	x	✓ Jan 31 (-10˚C)	✓ Nov 14 (-3˚C)	✓ Oct 28 (9˚C)	✓ Sep 30 (18˚C)	✓ Aug 22 (23˚C)	✓ Aug 23 (28˚C)
2	x	✓ Feb 1 (-14˚C)	✓ Nov 15 (-4˚C)	✓ Nov 4 (18˚C)	✓ Oct 4 (18˚C)	✓ Aug 30 (24˚C)	✓ Aug 24 (28˚C)
3	x	✓ Feb 2 (-10˚C)	✓ Nov 16 (-3˚C)	✓ Nov 12 (11˚C)	✓ Oct 6 (22˚C)	✓ Sep 14 (22˚C)	✓ Sep 8 (26˚C)

The data from the Aug 23 TOU test is shown as an example in Figure 13 and Figure 14, where Figure 13 shows the load profile of the building with and without the onsite DERs, while Figure 14 shows measurements of the DERs throughout the day. During the off-peak hours of 0:00 to 6:00, the actual consumption is between 10-12 kW higher than the building load due to the BESS charging at this time. On the other hand, the actual consumption is lower than the building load during the peak hours of 11:00 – 17:00, where onsite DERs are able to reduce the peak energy of the building during this time by a total of 74 kWh, including reducing the building load peak from 134 kW to 122 kW at 13:03.

The operation of the onsite DERs is shown in Figure 14, where on average, the BESS charges until 6:00 at 12 kW. The EV arrives approximately at 8:30 with 92% SOC and a minimum SOC constraint of 20%, leaving a usable battery capacity of approximately 28 kWh throughout the workday, and is dispatched between 3 and 3.5 kW until the workday ends at 17:00. Similarly, the BESS discharges at approximately 12 kW from 11:00-17:00, while the PV contributes between 2 and 4 kW throughout the day.

On the other hand, results from a TOU test in the cooling season on Nov 15 are shown in Figures Figure 15 and Figure 16, respectively. Similar to the summer season test, the BESS charges during 0:00 to 6:00, however, it discharges in the on-peak hours of 7:00 to 11:00, as well as from 17:00-19:00, as seen in Figure 15. The corresponding DER contribution is shown in Figure 21, where the PV contribution is negligible, and the EV discharges from 8:30 to 17:00, apart from a brief period at 13:30 when an inverter fault on the V2G charger prevented discharge. Nonetheless, this TOU test shifted a total of 53.4 kWh from on-peak hours on the day.

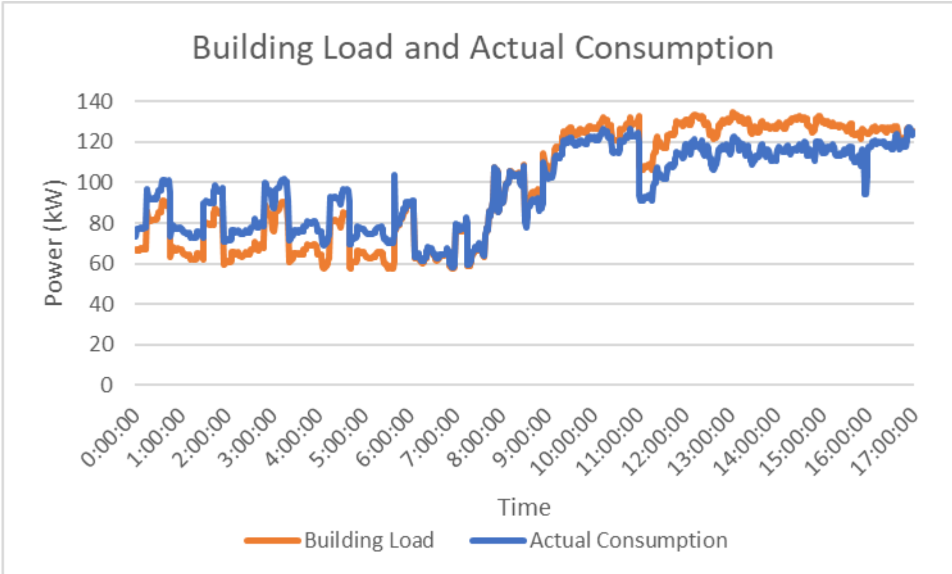


Figure 13 – Load profile of building for Aug 23 TOU test

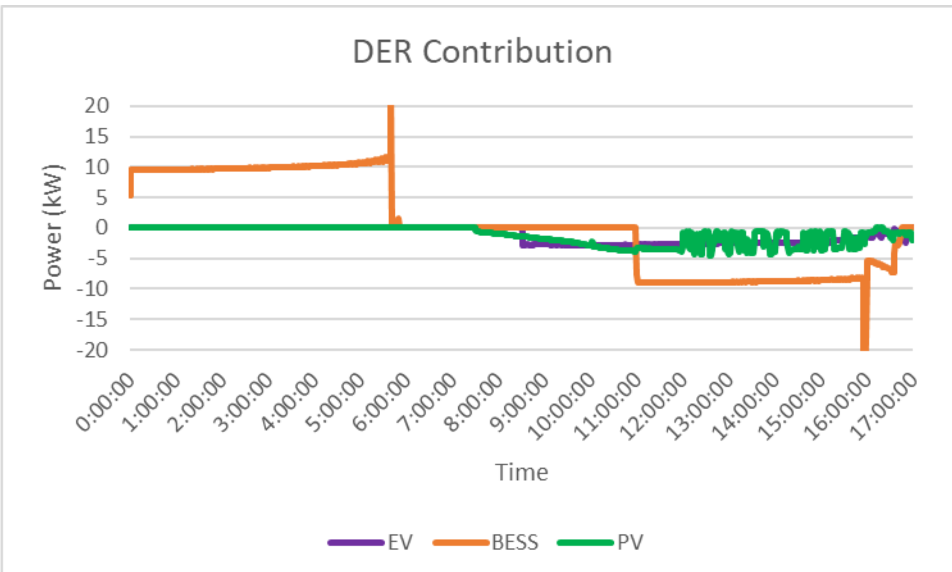


Figure 14 - Operation of DERs during August 23 TOU test

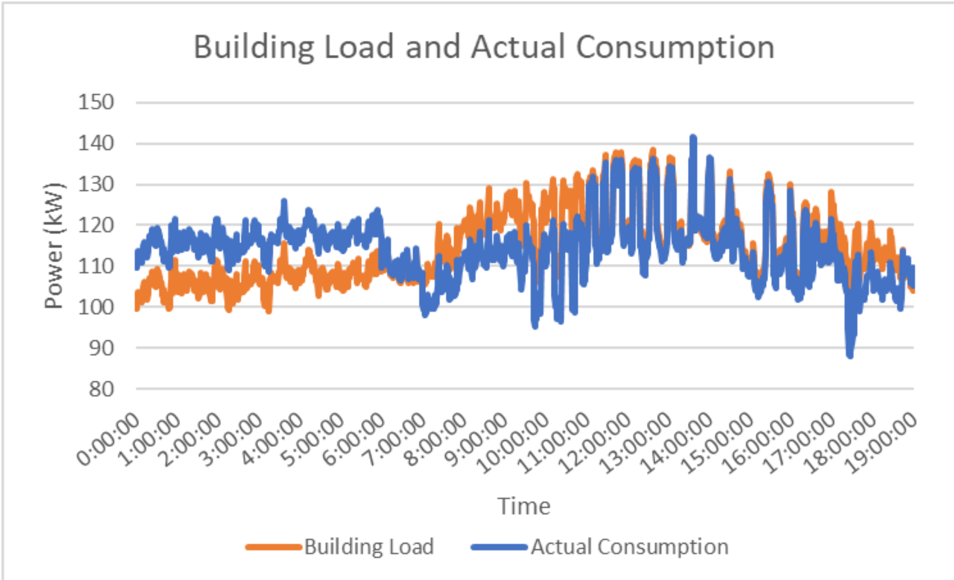


Figure 15 - Load profile of building for Nov 15 TOU test.

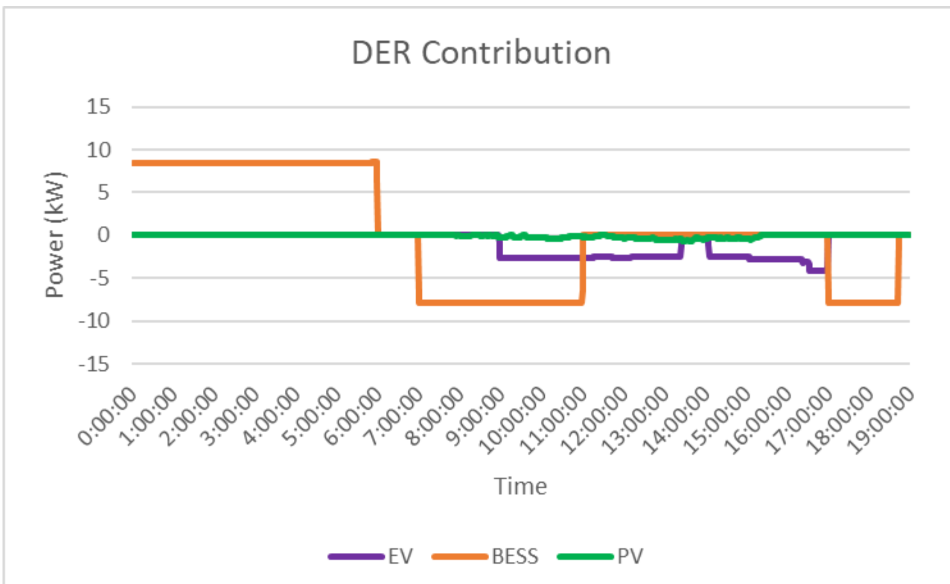


Figure 16 - Operation of DERs during Nov 15 TOU test .

5.1.1. Projected Results Against Quantifiable Outcomes

As part of this project, quantifiable outcomes were submitted during the proposal stage, which in our case, corresponded to annual metrics with respect to reducing peak demand and energy from on-site DERs. As such, a regression analysis was performed using the TOU test data that correlated daily energy consumption to average temperature for that day. Temperature regressions were developed for winter and summer for both the baseline and V2G+DERs cases, aligning with IPMVP Option C methodology. The data points and resulting regression are displayed in Figure 17.

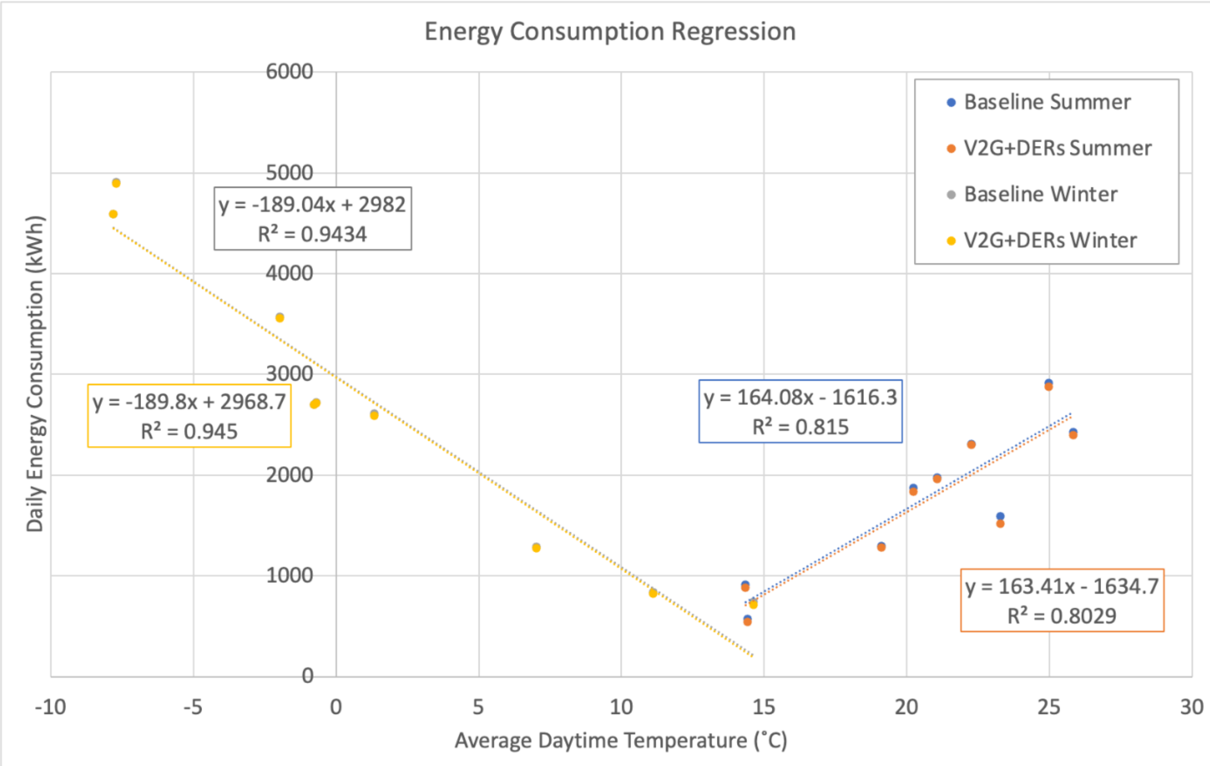


Figure 17 – Energy consumption regression analysis.

This regression analysis shows a very strong correlation of energy usage to ambient temperature for the winter, and a good correlation in the summer. Detailed irradiance data is not available for the test site, so a multi-variable regression comparing to irradiance could not be performed.

Utilizing Canadian Weather Year for Energy Calculation (CWEC) data for Toronto – Buttonville Airport (which is directly adjacent to the test site), annual performance of the V2G control system could be estimated. On an annual basis, it is estimated that the current system configuration would save the facility 8.16 MWh per year, or a net average of approximately 22.35 kWh per day.

These annual savings are in the range of expected values, as reductions in energy consumption for the facility can be attributed to the sum of the electricity produced by the 6 kW solar PV system and the electricity provided to the facility by the EV (roughly 32 kWh of usable capacity per day), less the efficiency losses of the BESS which will vary on a daily basis depending on actual usage. Notably, the inclusion of the PV and V2G systems ensures that, from the facility's perspective, net energy savings are achieved, which would not be the case if a BESS load shifting system was used on its own.

To estimate cost savings, energy versus temperature regressions were performed for each of the TOU periods for both the baseline and V2G+DERs cases, separated in to summer and winter periods. The results of these TOU regression analyses are presented in Figure 18 and Figure 19.

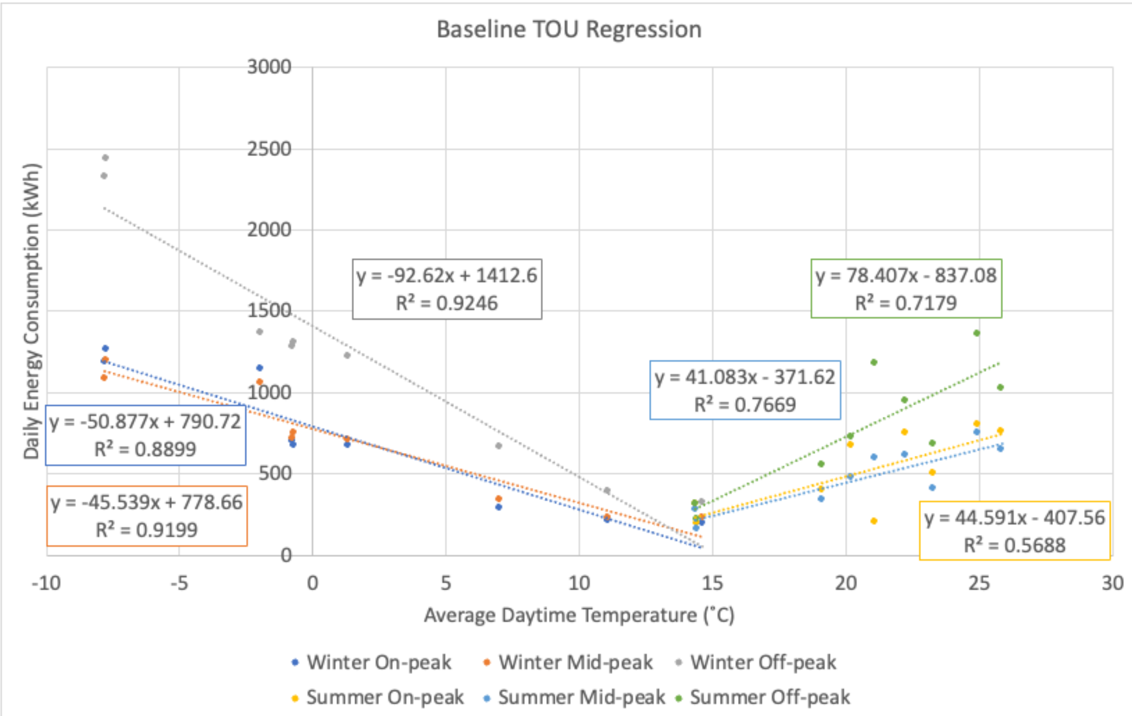


Figure 18 - TOU regression for baseline daily energy consumption

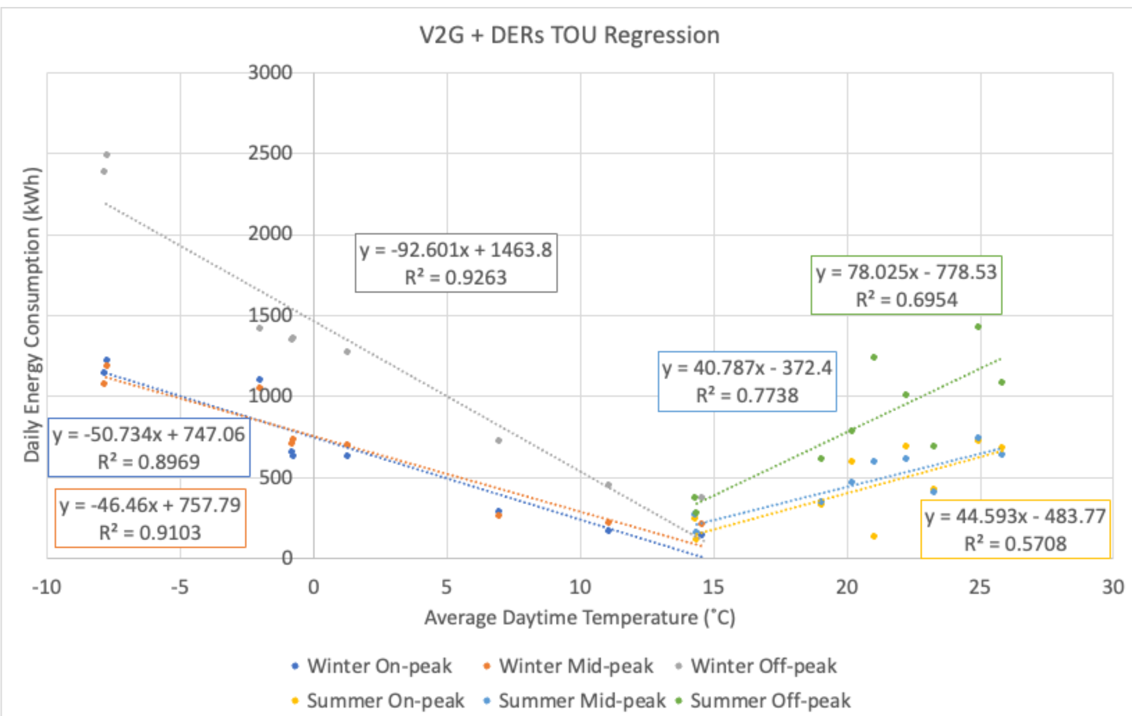


Figure 19 - TOU regression for DER operation

Extrapolating these results using the CWEC weather data for Toronto – Buttonville yielded the results shown in Table 3.

Table 3 - Estimated annual cost savings based on TOU pricing.

Period	**Baseline**	**V2G + DERs**
On-peak	$ 40,159.26	$ 36,534.48
Mid-peak	$ 28,315.94	$ 27,524.63
Off-peak	$ 38,393.96	$ 40,242.16
Total	$ 106,869.16	$ 104,301.26
Savings	-	$ 2,567.89

Table 4 compares the overall daily peak loads with and without the V2G+DERs control system. These overall numbers extend beyond the 7:00-19:00 test period and may include peaks associated with the BESS system recharging overnight. This is why certain days show an increase in peak load reduction (negative number). *It is worth noting here that the building itself is not on TOU billing, and as such, its peak values do not always align with TOU time periods*.

Table 4 - Overall daily peak load comparison.

Test Date	**Average Test Temperature (˚C)**	**Overall baseline daily peak load (kW)**	**Overall V2G+DERs daily peak load (kW)**	**Peak load reduction (kW)**
2022-08-22	21.1	158.7	159.0	-0.3
2022-08-23	25.0	162.1	171.7	-9.6
2022-08-24	25.8	134.9	131.2	3.7
2022-08-30	22.3	145.6	135.7	9.8
2022-09-08	23.3	90.6	92.7	-2.1
2022-09-14	20.2	132.2	119.6	12.6
2022-09-30	14.4	37.9	42.7	-4.8
2022-10-04	14.4	62.5	58.1	4.4
2022-10-06	19.1	102.5	102.4	0.1
2022-10-28	7.0	81.3	75.9	5.3
2022-11-04	14.6	50.6	48.3	2.4
2022-11-11	11.1	63.1	60.8	2.3
2022-11-14	1.3	133.9	129.5	4.4
2022-11-15	-0.8	141.5	141.1	0.4
2022-11-16	-0.7	152.0	149.8	2.2
2023-01-31	-7.8	221.7	216.3	5.4
2023-02-01	-7.7	235.6	232.0	3.6
2023-02-02	-2.0	213.7	211.2	2.5

As such, Table 5 displays the daytime peak loads over the TOU test period, which compares baseline and V2G-DERs peak loads between the hours of 7:00 – 19:00. In this case, all tests showed a reduction in daytime peak loads except for one on 2022-09-08*. In this case, while the peak load during the test period may have increased, it was shifted until after 17:00, because after 17:00 the BESS was allowed to recharge.

Overall these results show an average of 4.8 kW and 5.6 kW of daily peak load reduction in the summer and winter, respectively.

Table 5 - Daytime peak load comparison.

Test Date	Average Test Temperature (˚C)	Overall baseline daily peak load (kW)	Overall V2G+DERs daily peak load (kW)	Peak load reduction (kW)
2022-08-22	21.1	142.8	137.7	5.1
2022-08-23	25.0	145.6	139.4	6.2
2022-08-24	25.8	134.9	131.2	3.7
2022-08-30	22.3	145.6	135.7	9.8
2022-09-08	23.3	90.6	92.7	-2.1*
2022-09-14	20.2	132.2	119.6	12.6
2022-09-30	14.4	37.9	34.1	3.8
2022-10-04	14.4	62.5	58.1	4.4
2022-10-06	19.1	102.5	102.4	0.1
2022-10-28	7.0	81.3	72.7	8.6
2022-11-04	14.6	50.6	42.3	8.3
2022-11-11	11.1	63.1	60.8	2.3
2022-11-14	1.3	133.9	129.5	4.4
2022-11-15	-0.8	141.5	141.1	0.4
2022-11-16	-0.7	152.0	149.8	2.2
2023-01-31	-7.8	221.7	213.4	8.3
2023-02-01	-7.7	235.6	224.6	11.0
2023-02-02	-2.0	213.7	208.8	4.9

Figure 20 displays the regression analysis that compares daytime peak loads to daily average ambient temperature. The results of extrapolating these regressions on an annual basis agree with the average peak load reductions reported above, showing an average of 5.5 kW reduced per day in the winter, and 4.9 kW reduced per day in the summer.

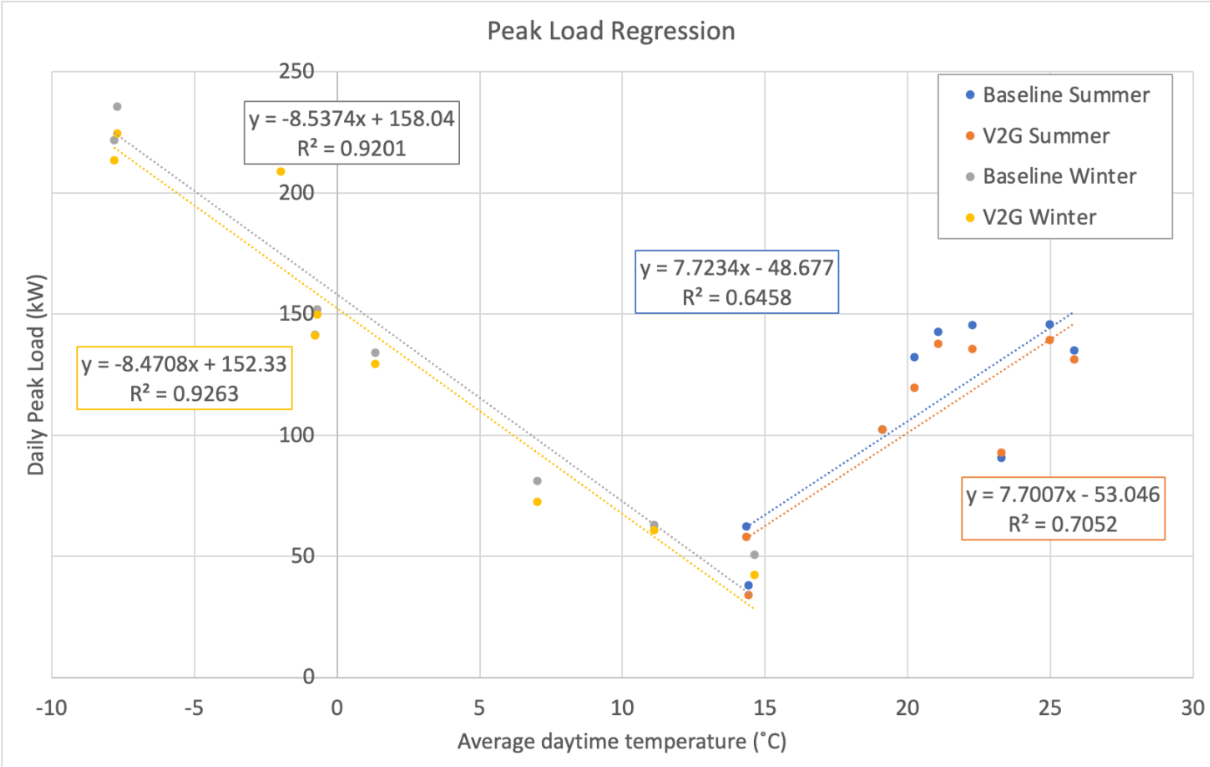


Figure 20 - Daytime peak load correlation with average daytime temperature.

5.1.2. Summary of Projected Results Against Quantifiable Outcomes

Table 6 displays the quantifiable outcomes outlined in the original project proposal, compared to calculated results from experimental work done in the project.

Table 6 - Comparison of quantifiable outcomes.

Metric	Proposal Estimate	Calculated Result
Annual Energy Savings (kWh/y)	17,633	8,157 [A]
Peak Load Reduction (kWh/day)	137	95 / 82 [B]
Max. Daily Peak Load Shifting (kW)	23.1	31 / 14 [B]
Bill Savings ($/y)	4360	$2,567 [A]
Reliability Improvement SAIFI	18.44	N/A
Reliability Improvement SAIDI	0.34	N/A

[A] Estimated via an annual regression, outlined in Section 5.1.1

[B] Maximum observed values from TOU tests, separated into Summer / Winter

It is worth noting that estimates from the proposal are not expected to line up with actual test results due to differences in assumptions of the system prior to beginning the project. For example, during the TOU experiments the solar PV system did not always operate as intended, as the PCS would often automatically switch from maximum power point tracking (MPPT) to zero power flow mode, producing zero PV generation for extended periods of time. Furthermore, when testing started, it was found that the BESS had degraded to about half the nameplate capacity (100 kWh to 54 kWh), thereby reducing its ability to provide peak shifting.

Additionally, the V2G EV charging/discharging efficiency was found to be highly variable throughout the project (i.e. the efficiency would vary with SOC and charge/discharge rate), to an extent that was difficult to quantify. Also, the assumption that the building was on TOU billing was incorrect, and this was not able to be validated before the proposal since there was limited access to energy bills during COVID-19 (the building is billed as a Class B customer). As such, the building load did not match up with TOU periods, resulting in less peak load reduction.

It should be noted that SAIDI/SAIFI metrics were submitted with the proposal but are unable to be qualified since the DERs do not provide an islanding solution to prevent system interruption.

5.2. Testing of DR Algorithm

Four tests were executed to test the DR algorithm, with the first two tests executed during the summer availability window (August 26, 2022 - 30 kW/2 Hours and August 29, 2022 - 20 kW/4 Hours), and the second two tests executed during the winter availability window (January 23, 2023 - 30 kW/2 Hours and January 24, 2023 - 20 kW/4 Hours). The results of all four tests are shown below. Note that the baseline for the building load was computed by methodology in the IESO Market Manual 5.5, S.1.6.26.3 for resources in the C&I sector.

5.2.1. DR Test #1: 30 kW/2 HRS Aug 26

The results of the first DR test of 30 kW over 2 hours are shown in Figure 21 and Figure 22, where Figure 21 shows the load reduction of the building in comparison to the building load and computed baseline, while Figure 22 shows the contribution of each DER in fulfilling the DR capacity (bid quantity) of 30 kW. A simulated activation notice was received by the DERMS at approximately 8:33 on Aug 26, while the test was started officially at 13:33.

As shown in Figure 21, the building load stayed fairly consistent throughout the test period, oscillating between 125 kW and 136 kW, while also following the computed C&I HDR Baseline as well. The DER Contribution reacts accordingly, averaging 30.4 kW of load reduction during the 2 hour period, and reducing the actual consumption of the building by 60.7 kWh. The contribution of each DER during the test can be seen in Figure 21, with the PV providing between 3 and 5 kW of production, the EV providing a steady 10 kW (its max production), and the BESS acting flexibly to make up the difference to provide the requisite load reduction.

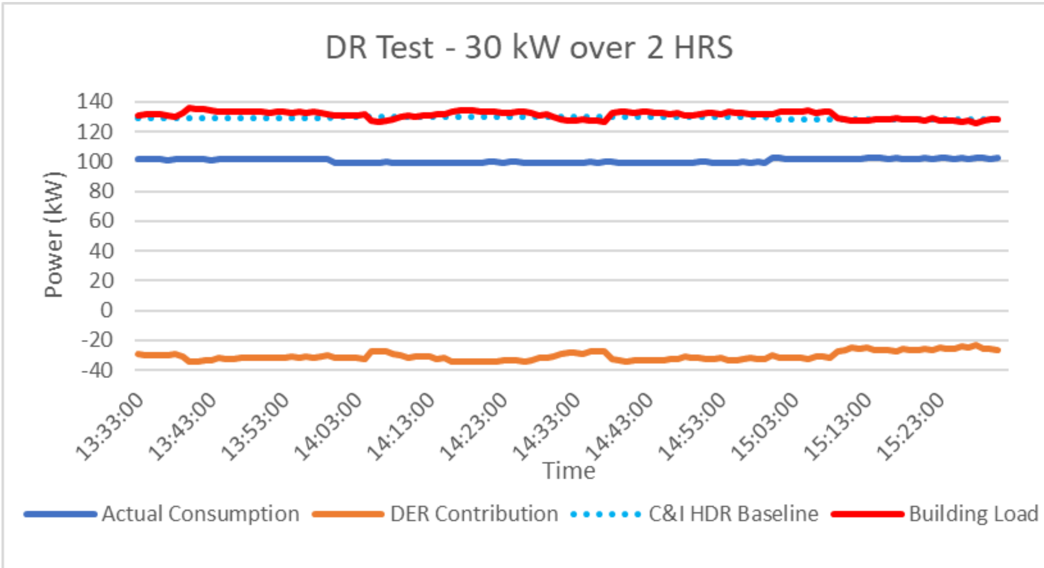


Figure 21 - Load Reduction of Building Versus Building Load on Aug 26 DR Test.

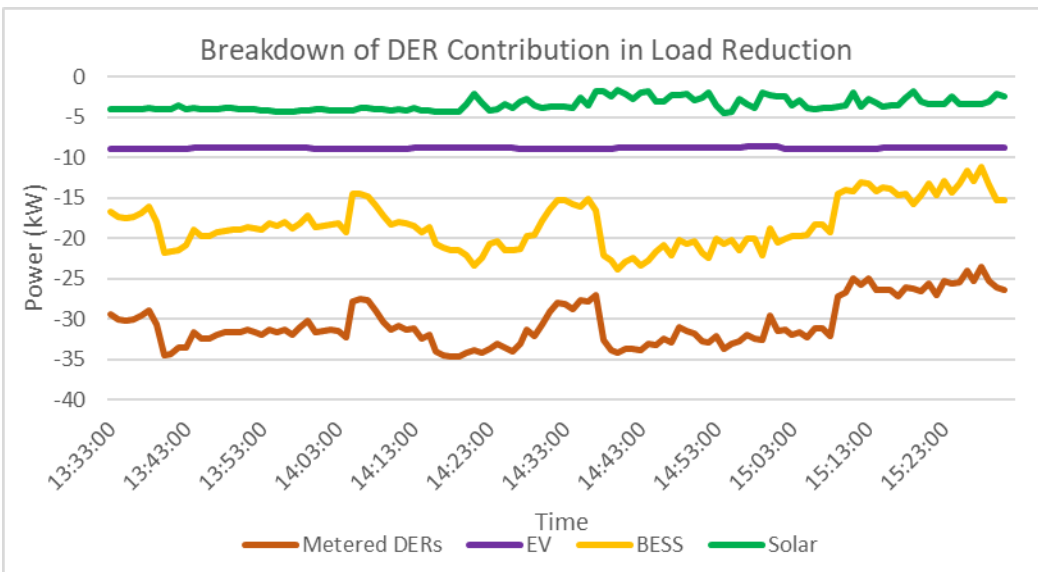


Figure 22 - DER Contribution to Load Reduction on Aug 26 DR Test.

In terms of determining compliance for dispatch and capacity charges, it is useful to refer to the interval data from the test, which is shown below in Table 7.

For evaluating dispatch charge compliance, the actual load reduction (baseline less actual consumption) of the building should be within a dead band of 15% of the total bid quantity for each interval. As such, for a bid quantity of 30 kW for each interval of the test, the acceptable range of values between 25.5 kW and 34.5 kW, which is true for each interval of the test as seen in the last column of Table 7.

For evaluating capacity charge compliance, resources must deliver at least 90% of their contracted curtailment for each interval, whereafter, the measured values are averaged over the entire activation event. The formula for evaluating the capacity charge compliance is copied from the IESO Market Manual below:

<u>Capacity Charge Assessment for C&I HDRs:</u>

A C&I HDR resource will be deemed to have failed to provide capacity if the following condition is true for the test activation event:

$$\text{Average (C\&I HDR Baseline}_i - \text{Actual Consumption}_i) < 80\% \text{ x Average (Total Bid Qty}_i - \text{Schedule}_i)$$

Where:

- "i" is an interval within the activation event.
- "C&I HDR Baseline" is the calculated C&I HDR baseline for the interval (see section 1.6.26.3.1).
- "Actual Consumption" is the measurement data for the interval.
- "Total Bid Qty" is the maximum quantity of the *demand response energy bid* converted to an interval equivalent.
- "Schedule" is the real-time constrained schedule quantity amount for the interval.

Since the activation event is simulated, there are no values for the real-time constrained schedule. As such, setting this value to zero, the average of the difference between the computed C&I HDR Baseline and the Actual Consumption should be greater than 90% of 30 kW, which is 27 kW. As seen in Table 7, the average of the difference between the Baseline and Actual Consumption throughout the event is 29.04 kW, well clear of the 27 kW mark.

Table 7 - Interval Data from DR Test on Aug 26.

Interval	Actual Consumption (kW)	C&I HDR Baseline (kW)	Baseline – Difference (kW)
1	101.27	129.13	**27.86**
2	101.33	129.13	**27.80**
3	101.29	129.13	**27.84**
4	101.39	129.13	**27.74**
5	101.45	129.13	**27.68**
6	100.09	130.31	**30.22**
7	99.25	130.31	**31.06**
8	99.23	130.31	**31.08**
9	99.28	130.31	**31.03**
10	99.30	130.31	**31.01**
11	99.25	130.31	**31.06**
12	99.19	130.31	**31.12**
13	99.31	130.31	**31.00**
14	99.39	130.31	**30.92**
15	99.26	130.31	**31.05**
16	99.34	130.31	**30.97**
17	99.38	130.31	**30.93**
18	101.39	128.27	**26.88**

19	101.84	128.27	**26.43**
20	101.80	128.27	**26.47**
21	102.00	128.27	**26.27**
22	101.93	128.27	**26.34**
23	100.22	128.27	**28.05**
24	102.09	128.27	**26.18**
		AVERAGE	**29.04 kW**
		CAPACITY CHARGE 90% LIMIT	**27.00 kW**

Lastly, for checking EV compliance, a plot of the EV SOC during the test is shown in Figure 23, where the starting SOC was 89% and the final SOC was 29%, well clear of the minimum 10% SOC constraint.

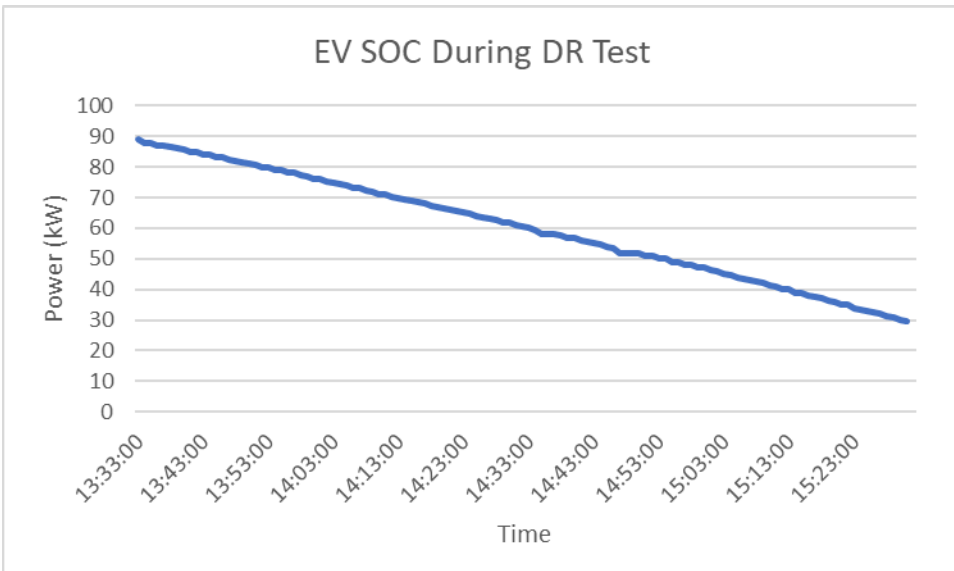


Figure 23 - EV SOC During Aug 26 DR Test.

5.2.2. DR Test #2: 20 kW/4 HRS Aug 29

The results of the second DR test of 20 kW over 4 hours are shown in Figure 24 and Figure 25, where Figure 24 shows the load reduction of the building in comparison to the building load and computed baseline, while Figure 25 shows the contribution of each DER in fulfilling the DR capacity of 20 kW. A simulated activation notice was received by the DERMS at approximately 8:17 on Aug 29, while the test was officially started at 12:14 and ended at 16:14.

In contrast to the first test, the building load stays consistently below the computed C&I HDR baseline during the test period, oscillating between 115 kW to 131 kW against a baseline of approximately 130 kW. **Due to a misunderstanding in interpreting the dispatch/compliance criteria, incorrect DER operation was executed during the test**. The interpretation of the project team was that the term HDR “resources” extended to DERs, and as such, regardless of the baseline and actual consumption values, the DER output must be within the +/- 15% deadband. As such, the DERs were still dispatched the lower the load of the building at a minimum of 17 kW, leading to an average of 17.8 kW of load reduction over the 4 hour period, reducing the actual consumption of the building by 71 kWh.

The contribution of each DER during the test can be seen in Figure 25, where the PV is noticeably intermittent due to scattered thunderstorms on the day, and provides between 0 and 6 kW of production. The EV discharges between 5 and 8 kW until the last 2 minutes of the DR event before it reaches its minimum SOC constraint, at which point the BESS has enough capacity to fulfill the DR capacity of 20 kW on its own.

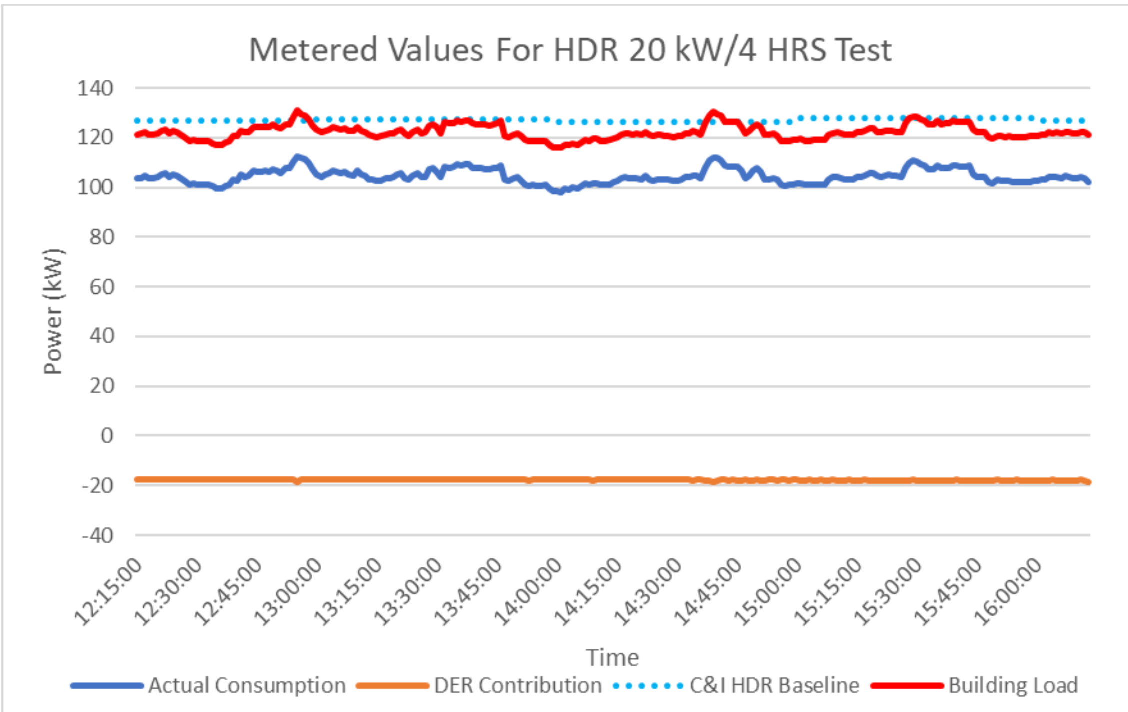


Figure 24 - Load Reduction of Building Versus Building Load on Aug 29 DR Test.

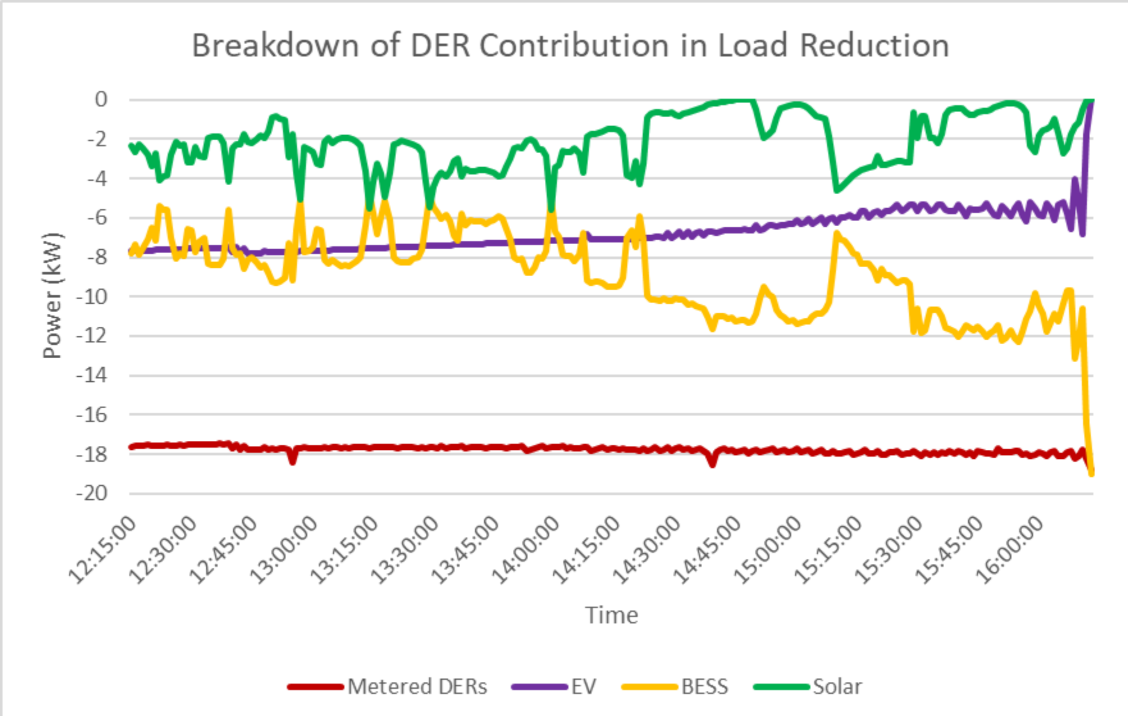


Figure 25 - DER Contribution to Load Reduction on Aug 29 DR Test.

For evaluating compliance for capacity and dispatch, interval data for the test can be seen in Table 8.

Table 8 - Interval data for DR Test on Aug 29.

Interval	Actual Consumption (kW)	C&I HDR Baseline (kW)	Baseline – Difference (kW)
1	103.82	129.68	**25.86**
2	104.92	129.68	**24.76**
3	102.72	129.68	**26.96**
4	100.97	129.68	**28.71**
5	100.78	129.68	**28.90**
6	104.65	129.68	**25.03**
7	106.61	129.68	**23.07**
8	107.65	129.68	**22.03**
9	110.53	129.68	**19.15**
10	105.36	130.31	**24.95**
11	105.61	130.31	**24.70**
12	104.57	130.31	**25.74**
13	103.39	130.31	**26.92**
14	104.40	130.31	**25.91**
15	105.79	130.31	**24.52**
16	107.02	130.31	**23.29**
17	108.91	130.31	**21.40**
18	107.58	130.31	**22.73**

19	105.27	130.31	**25.04**
20	101.92	130.31	**28.39**
21	100.09	130.31	**30.22**
22	99.02	128.89	**29.87**
23	100.90	128.89	**27.99**
24	101.43	128.89	**27.46**
25	103.48	128.89	**25.41**
26	103.51	128.89	**25.38**
27	102.99	128.89	**25.90**
28	103.73	128.89	**25.16**
29	107.90	128.89	**20.99**
30	109.70	128.89	**19.19**
31	106.00	128.89	**22.88**
32	104.86	128.89	**24.03**
33	101.35	128.89	**27.54**
34	101.11	130.88	**29.78**
35	102.16	130.88	**28.72**
36	103.51	130.88	**27.37**
37	105.03	130.88	**25.86**
38	104.58	130.88	**26.30**
39	107.45	130.88	**23.44**
40	108.64	130.88	**22.24**
41	108.20	130.88	**22.68**
42	107.83	130.88	**23.05**
43	103.36	130.88	**27.52**
44	102.57	130.88	**28.31**
45	102.21	130.88	**28.68**
46	103.51	129.58	**26.07**
47	104.02	129.58	**25.56**
48	103.52	129.58	**26.06**
		AVERAGE	**25.45 kW**
		CAPACITY CHARGE 90% LIMIT	**18.00 kW**

In terms of dispatch compliance, the acceptable range of values for load reduction (baseline subtract actual consumption) is between 17 and 23 kW, which the building delivers only in 9 of the 48 intervals due to the misinterpretation mentioned above.

For evaluating capacity charge compliance, the average of the difference between the computed C&I HDR Baseline and the Actual Consumption should be greater than 90% of the 20 kW DR capacity contracted, which is 18 kW. As seen in Table 8, the average of the difference between the Baseline and Actual Consumption throughout the event is 25.45 kW, well clear of the 18 kW mark.

Lastly, the EV SOC compliance check result can be seen in Figure 26, where the minimum SOC value is 10%, and equal to the minimum EV SOC constraint.

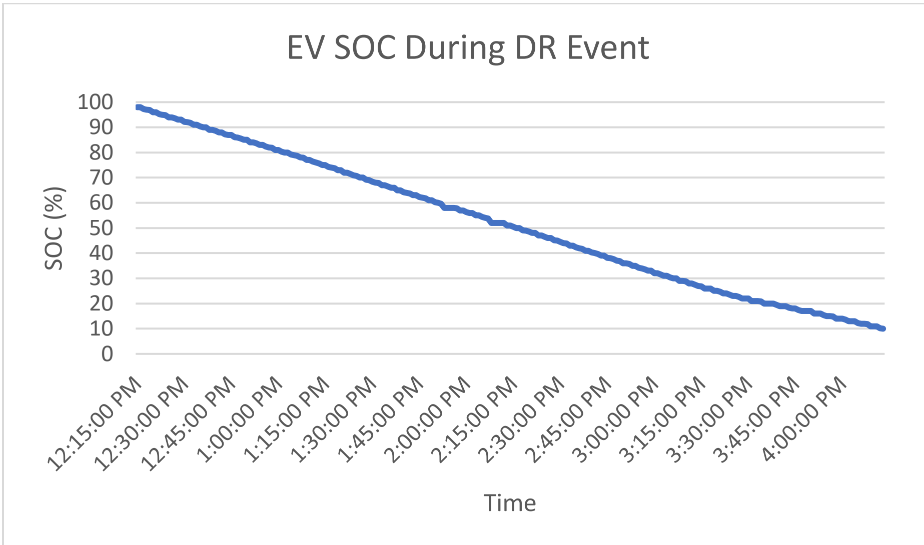


Figure 26 - EV SOC During DR Event on Aug 29.

5.2.3. DR Test #3: 30 kW/2 HRS Jan 23, 2023

The results of the third DR test are in Figure 24 and Figure 25, where Figure 24 shows the load reduction of the building in comparison to the building load and computed baseline, while Figure 25 shows the contribution of each DER in fulfilling the DR capacity of 30 kW. The test was officially started at 17:00 and ended at 19:00.

As seen in Figure 24, the building load stays 20-25 kW below the computed C&I HDR baseline during the test period, oscillating between 100 kW to 120 kW against a baseline of approximately 135 kW. The DER contribution reacts accordingly, oscillating between 1 and 10 kW to complete the requisite load reduction of 30 kW. Since much of the load reduction demanded by the DERs is less than 10 kW, the EV is able to discharge and meet the need by itself, with the BESS operating in short bursts when needed, as shown in Figure 25.

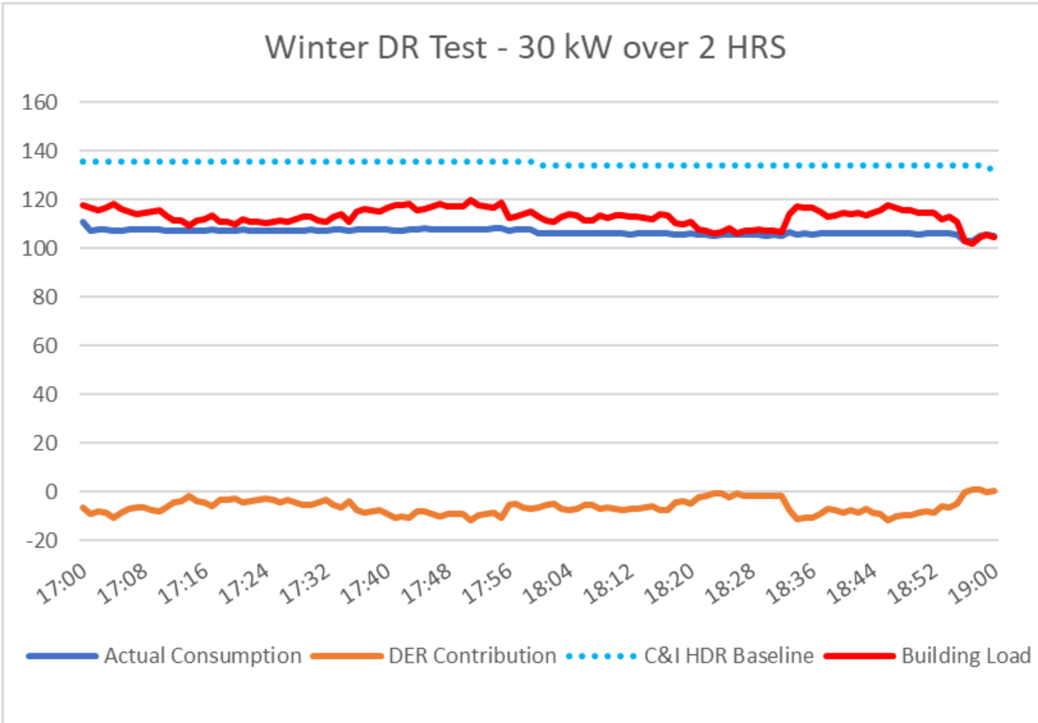


Figure 27 - Load reduction of building versus building load on Jan 23 DR test.

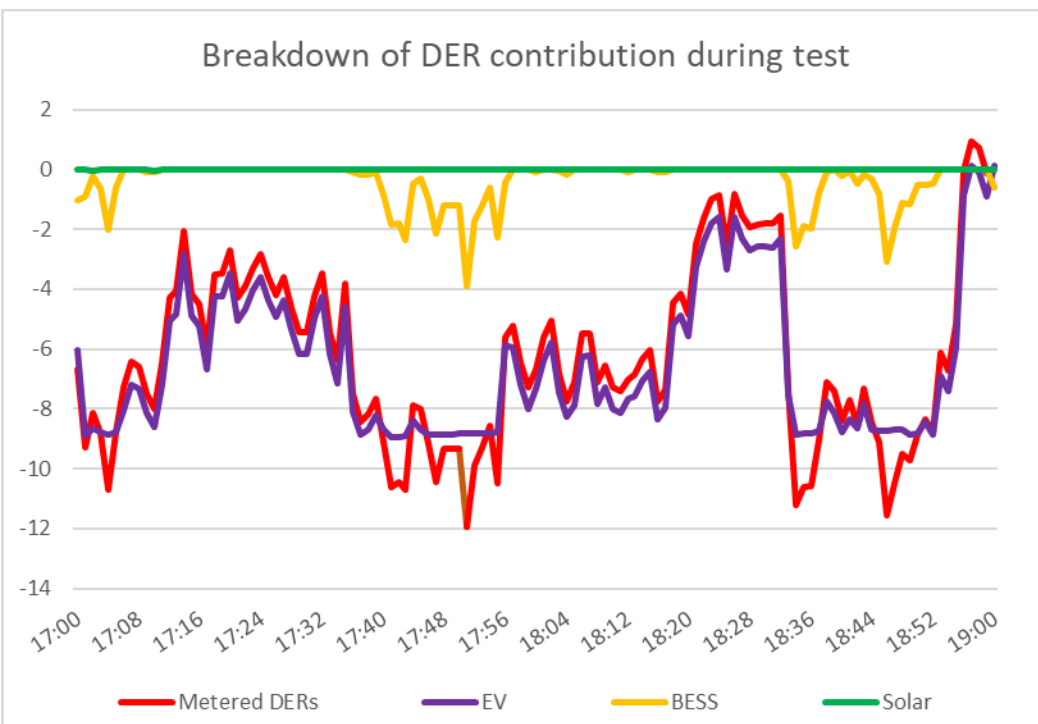


Figure 28 - DER contribution to load reduction on Aug 29 DR test.

For evaluating compliance for capacity and dispatch, interval data for the test can be seen in Table 8.

Table 9 - Interval data for DR Test on Jan 23.

Interval	Actual Consumption (kW)	C&I HDR Baseline (kW)	Baseline – Difference (kW)
1	108.13	135.37	**27.24**
2	107.56	135.37	**27.81**
3	107.35	135.37	**28.02**
4	107.28	135.37	**28.09**
5	107.27	135.37	**28.10**
6	107.29	135.37	**28.08**
7	107.39	135.37	**27.98**
8	107.50	135.37	**27.87**
9	107.49	135.37	**27.88**
10	107.87	135.37	**27.50**
11	107.78	135.37	**27.59**
12	107.56	135.37	**27.81**
13	106.03	133.89	**27.86**
14	106.04	133.89	**27.86**
15	106.06	133.89	**27.83**
16	105.85	133.89	**28.04**
17	105.45	133.89	**28.45**
18	105.53	133.89	**28.36**
19	105.61	133.89	**28.29**
20	105.95	133.89	**27.94**
21	106.09	133.89	**27.80**
22	106.10	133.89	**27.80**
23	105.91	133.89	**27.98**
24	104.40	133.89	**29.50**
		AVERAGE	**27.99 kW**
		CAPACITY CHARGE 90% LIMIT	**27.00 kW**

In terms of dispatch compliance, the acceptable range of values for load reduction (baseline subtract actual consumption) is between 25.5 kW and 34.5 kW, which the DERs are able to deliver in all 24 intervals of the test, as seen in Table 9.

For evaluating capacity charge compliance, the average load reduction during the test is 27.99 kW as compared against the minimum of 27 kW. Lastly, the EV SOC compliance check result can be seen in Figure 29, where the minimum SOC value observed during the test is 49%, well clear of the 10% minimum EV SOC constraint.

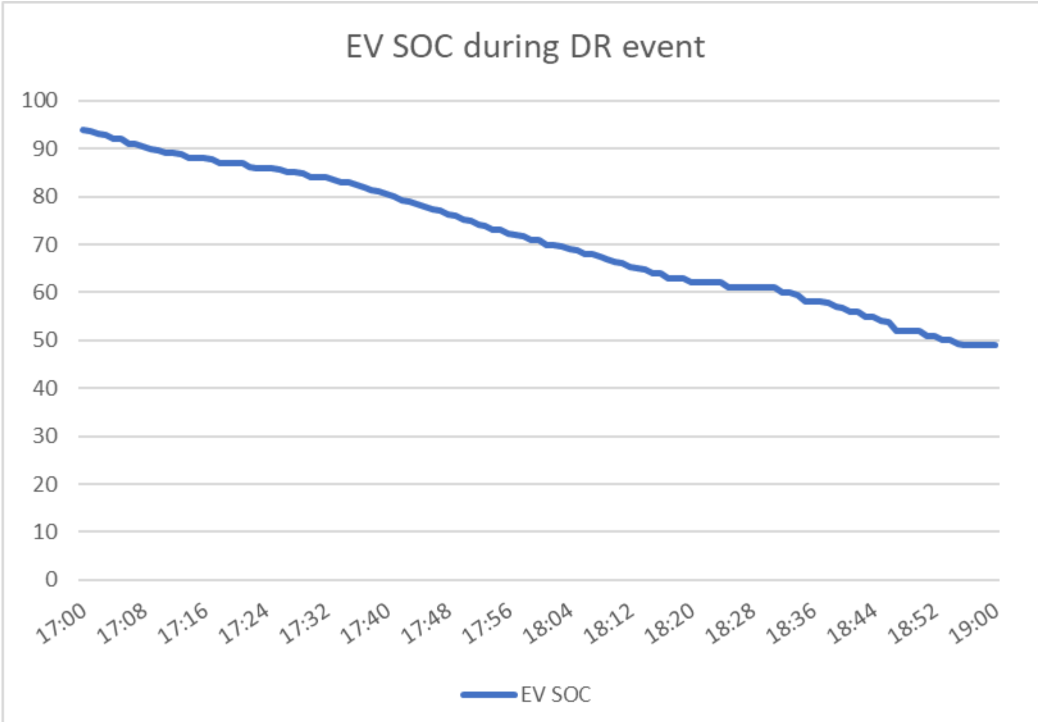


Figure 29 - EV SOC During DR Event on Jan 23.

5.2.4. DR Test #4: 20 kW/4 HRS Jan 24, 2023

The results of the fourth DR test are in Figure 30 and Figure 31, where Figure 30 shows the load reduction of the building in comparison to the building load and computed baseline, while Figure 31 shows the contribution of each DER in fulfilling the DR capacity of 20 kW. The test officially started at 16:08 and ended at 20:08.

As seen in Figure 30, the building load stays in line with the computed C&I HDR baseline from the start of the test period until 18:40, with the EV and BESS delivering the requisite load reduction of approximately 20 kW as seen in Figure 31. However, at 18:40, there is a sudden drop in the consumption of the building, with a reduction of approximately 68 kW as compared to the baseline. At this point, the DERs stop discharging, only to pick back up at 19:40 when the building load exceeds the baseline.

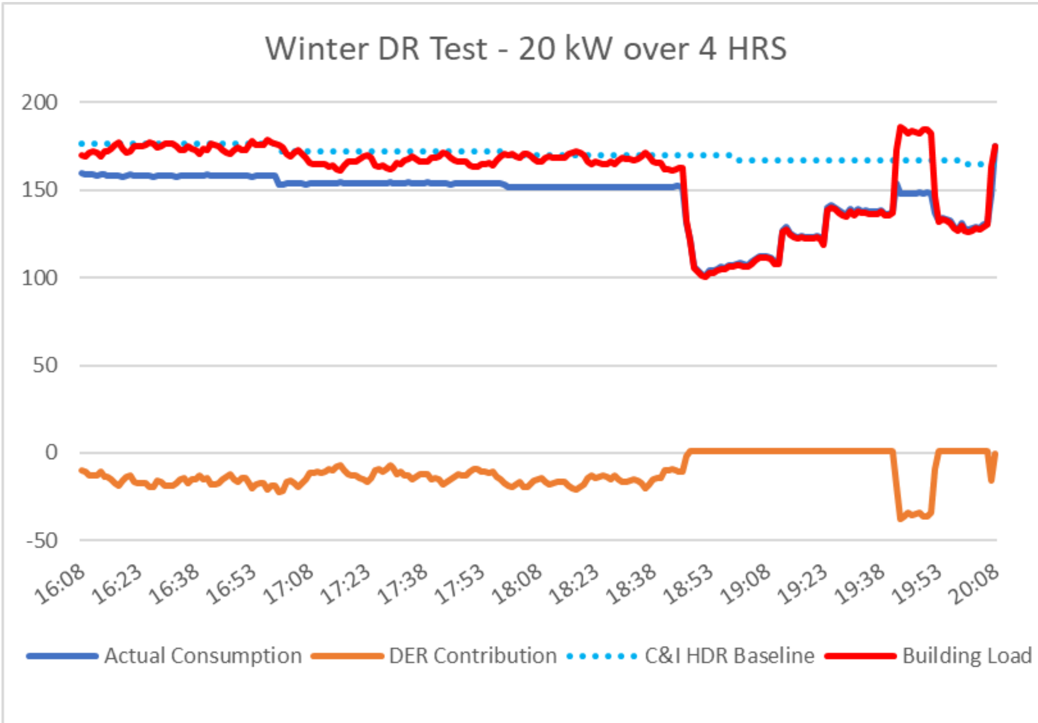


Figure 30 - Load reduction of building versus building load on Jan 24 DR test.

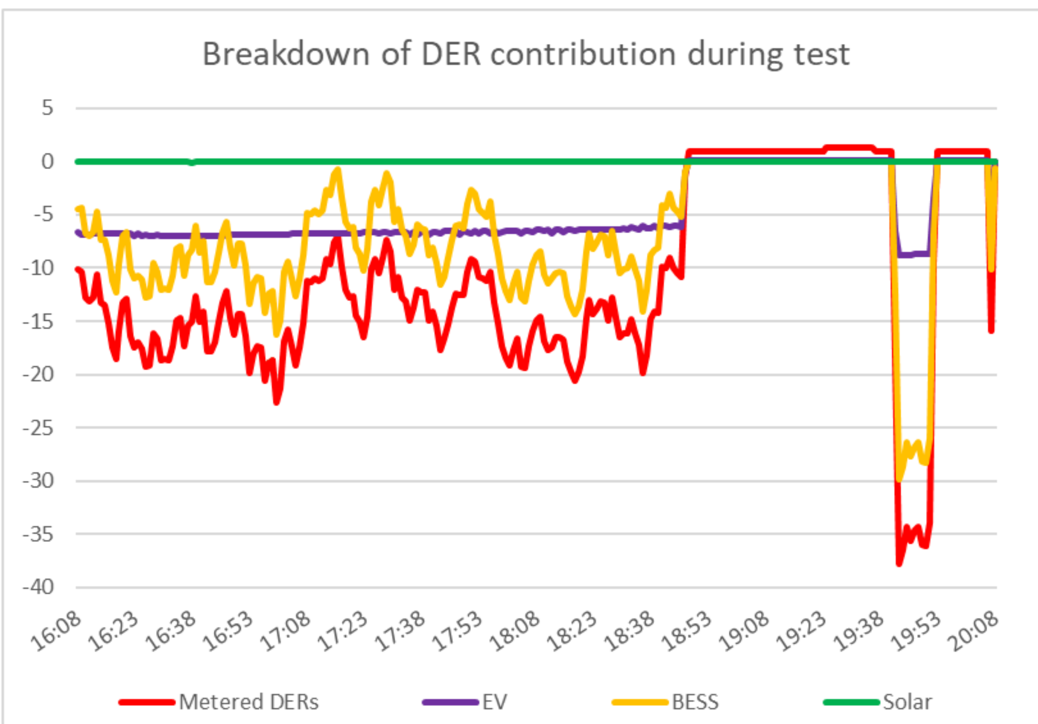


Figure 31 - DER contribution to load reduction on Jan 24 DR test.

For evaluating compliance for capacity and dispatch, interval data for the test can be seen in Table 10.

Table 10 - Interval data for DR Test on Jan 24.

Interval	Actual Consumption (kW)	C&I HDR Baseline (kW)	Baseline – Difference (kW)
1	158.69	176.49	**17.81**
2	158.22	176.49	**18.27**
3	158.28	176.49	**18.22**
4	157.95	176.49	**18.55**
5	157.91	176.49	**18.59**
6	158.01	176.49	**18.48**
7	158.17	176.49	**18.33**
8	158.09	176.49	**18.41**
9	158.08	176.49	**18.42**
10	158.01	176.49	**18.48**
11	153.46	172.00	**18.54**
12	153.59	172.00	**18.41**
13	153.87	172.00	**18.13**
14	153.97	172.00	**18.03**
15	153.68	172.00	**18.32**
16	153.83	172.00	**18.17**
17	153.99	172.00	**18.01**
18	153.97	172.00	**18.03**
19	153.85	172.00	**18.15**
20	153.57	172.00	**18.43**
21	153.80	172.00	**18.20**
22	153.68	172.00	**18.32**
23	151.54	170.12	**18.58**
24	151.61	170.12	**18.51**
25	151.62	170.12	**18.50**
26	151.60	170.12	**18.52**
27	151.63	170.12	**18.49**
28	151.71	170.12	**18.41**
29	151.57	170.12	**18.55**
30	151.57	170.12	**18.55**
31	151.78	170.12	**18.34**
32	132.71	170.12	**37.41**
33	102.96	170.12	**67.16**
34	106.12	170.12	**64.01**
35	107.93	166.96	**59.03**
36	111.80	166.96	**55.16**
37	119.68	166.96	**47.28**
38	123.44	166.96	**43.51**
39	125.72	166.96	**41.24**
40	138.55	166.96	**28.41**

41	138.23	166.96	**28.72**
42	137.51	166.96	**29.45**
43	144.77	166.96	**22.19**
44	148.28	166.96	**18.68**
45	140.15	166.96	**26.80**
46	130.67	166.96	**36.29**
47	128.07	166.96	**38.89**
48	139.16	166.96	**25.5**
		AVERAGE	**25.85 kW**
		CAPACITY CHARGE 90% LIMIT	**18.00 kW**

In terms of dispatch compliance, the acceptable range of values for load reduction (baseline subtract actual consumption) is between 17 and 23 kW, which the building is able to deliver in all 33 out of 48 intervals of the test, as seen in Table 11. However, the failure to abide by dispatch compliance is not caused by incorrect DER operation, as was observed in the second DR test, but a sudden, unexpected drop in building load. Further work should be done on this edge case to determine how DERs, or flexible loads, might be used to mitigate such a scenario, including charging the batteries of EVs or BESSs.

For evaluating capacity charge compliance, the average load reduction during the test is 25.85 kW as compared against the minimum of 18 kW. Lastly, the EV SOC compliance check result can be seen in Figure 32, where the minimum SOC value observed during the test is 28%, well clear of the 10% minimum EV SOC constraint.

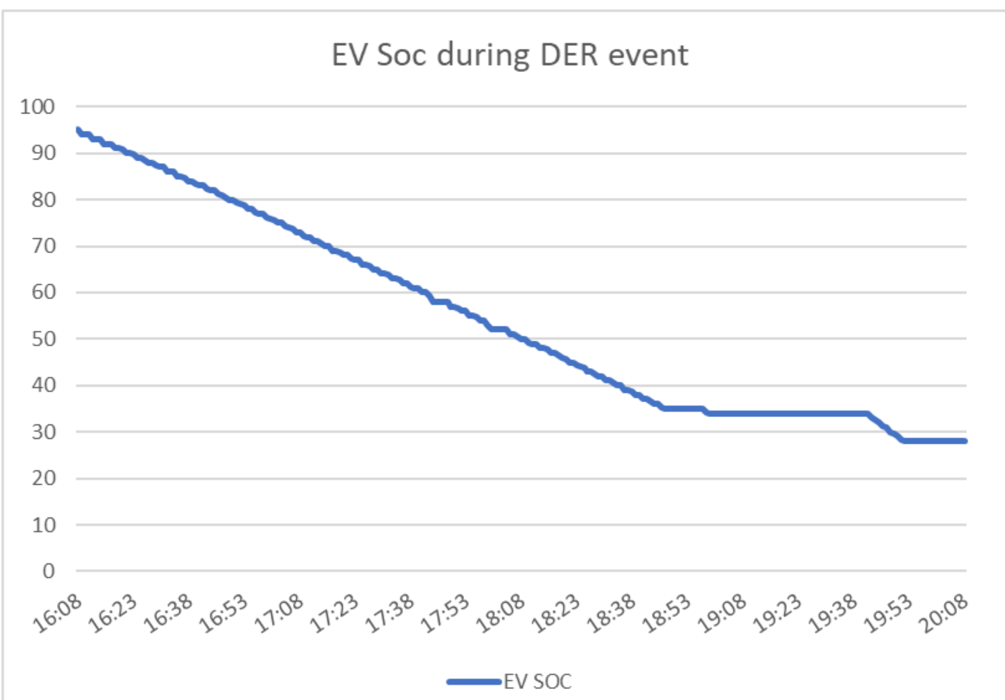


Figure 32 - EV SOC during DR Event on Jan 24.

5.2.5. Blockchain Integration of DR Testing

The aforementioned 4 tests were conducted as per the Testing Workflow listed in Section 4.2.2, where a smart contract was used to initiate, execute, and validate the results of a DR event for all participants, namely a PSO, an aggregator of DERs, and EV owners. The smart contract was developed using Hyperledger Fabric 2.2, and exposed several web-based functions that enabled the automated handling of a DR event. The functions within the smart contract and a short description of each is discussed below:

- *createDemandResponseEvent* – this function is called by a PSO and accepts an event start time and end time. Upon completion, the function creates a unique ID for the DR event and stores it on the shared ledger.

- *submitBid* – this function is called by aggregators and accepts a bid for each unique DR event in the form of hourly-based contracted capacities, in kW. Upon completion, the function adds this bid to the ledger, alongside all other bids for this DR event.

- *submitMeasurements* – this function is called by DERMS software and submits to the ledger measurements for each DER, as well as the meter that measures the point of common coupling between each facility governed by the aggregator, in one minute intervals. This function also records the SOC of each EV participating in DR. In this way, the ledger possesses all measurements needed to conduct validation of the DR event for each participant.

- *validateDR* – this function is called by a PSO when the DR event has **finished**. Upon completion, the function evaluates all measurements submitted by each aggregator for each facility it governs against the dispatch, availability, and minimum SOC constraints. It posts the results of this evaluation to the ledger, indexed by the correct ID of the DR event, where the PSOs may see the result.

A scalability analysis of the validateDR function is included in Section 5.5 to evaluate the amount of time it takes for the smart contract to validate the performance of each facility as a function of the number of DERs it controls.

For results with respect to real-world testing, the average time taken between calling the *createDemandResponseEvent* and beginning to see ramp up to full generation at the facility site (solar and battery generating 30 kW, V2G generation 10 kW), was **4.1 seconds.**

5.2.6. Projected Results Against Quantifiable Outcomes (DR)

In the quantifiable outcomes, the line item associated with the DR tests is the maximum peak load reduction, which is set at 50 kW. Upon reflection, this outcome does not wholly reflect the testing executed for the DR tests. First, the value of 50 kW was set when two EVs were available for testing during the DR period, and hence, the load reduction of the absence of charging (10 kW), coupled with the 40 kW available from the solar/storage and V2G unit, would comprise of the 50 kW. As it turns out, only one EV was available for testing, reducing the maximum reduction potential to 40 kW.

Second, the maximum instantaneous peak load reduction value of 40 kW does not include components of time, where DR events can be anywhere between 1-4 hours. Considering a usable capacity of the EV of 32 kWh (roughly 80% of the 40 kWh battery), and approximately 50 kWh of the BESS, the load reduction attributed to DERs could sustain only for a little over 2 hours. Instead of a simple instantaneous metric, timing components should have been included to better guide the testing, similar to HDR bid quantities.

On this note, the project team was advised to conform to HDR testing procedures midway during the project, which is not necessarily in line with the testing procedures originally documented in the IESO DR Test Cases (as of November 2021), where references to baselines are not mentioned. For future work, HDR bid quantities should be included within the quantifiable outcomes, where the bid quantities should be chosen carefully after looking at baseline data.

Lastly, upon testing the BESS after inverter repairs in the summer of 2022, it was found that the BESS had half the usable capacity of its nameplate (54 kWh against 100 kWh). As a result, the quantifiable outcomes for DR had to change from 30 kW/4 HRS, to 20 kW/4HRS and 30 kW/2HRS. As seen in the four DR tests, the DERs were largely successful in delivering the contracted HDR capacity.

5.3. Interoperability Testing

The interoperability evaluation of the system validates that the system is able to receive standardized control requests from power system operators and dispatch DERs accordingly. As such, the information models and inverter functions from the IEC 61850 interoperability standard will be used within this evaluation [21]. Specifically, the functions for inverter-based functions PC1: Connect/Disconnect and PC2: Adjust Maximum Generational Level Up/Down will be evaluated. Is it worthwhile to mention that while there are other functions, such as adjusting power factor and reactive power, these are not available on the bidirectional EV charger, and as such, they are not included in the evaluation.

The IEC 61850 standard allows for multiple DERs to be aggregated into one *logical device*, and this logical device can then be associated to various *logical nodes* that represent data/functions that are specific to those devices. The IEC 61850-90-7 standard introduces a logical node for DERs referred to as *DRCC*, which is DER Supervisory Control, and allows operating points and functions to be set on DERs by power system operators. For this evaluation, the DRCC logical node will be used to test the inverter functions listed above, with the bidirectional EV charger and battery/solar system will be aggregated as a single logical device. A table of setpoints and expected outputs for the interoperability test is given below in Table 11. The dispatch logic is similar to the logic used in the demand response cases (dispatch EV first, then supplement the rest with battery/solar).

Table 11 - Test plan for interoperability evaluation.

Setpoints/Command	Expected Total Power Output (kW)	EV (kW)	Battery/Solar (kW)
ON	0	0	0
-5 kW	-5	-5	0
-10 kW	-10	-10	-10
-20 kW	-20	-10	-10
-30 kW	-30	-10	-20
-40 kW	-40	-10	-30
OFF	0	0	0

To facilitate the test, a simulated IEC 61850 Client was developed, which represents a typical client application that would be used in a control room. A corresponding IEC 61850 Server was integrated into the DERMS, and command requests were sent between the client/server applications using the Manufacturing Message Specification (MMS) protocol. The client application could then send the setpoint/command in Table 11 via MMS, which would be received by Hero DERMS, and in turn, dispatch the DERs.

The results of the interoperability evaluation can be seen in Figure 33, which shows the time-series power measurements of each individual DER, along with their total power output. Each setpoint/command is cycled through at 30 second intervals, and it can be seen that the total DER output matches the expected total power output in Table 11. The ON/OFF commands result in a total power output of 0 kW, while the power commands from -5 kW to -40 kW result in the correct dispatch of the EV, battery, and solar.

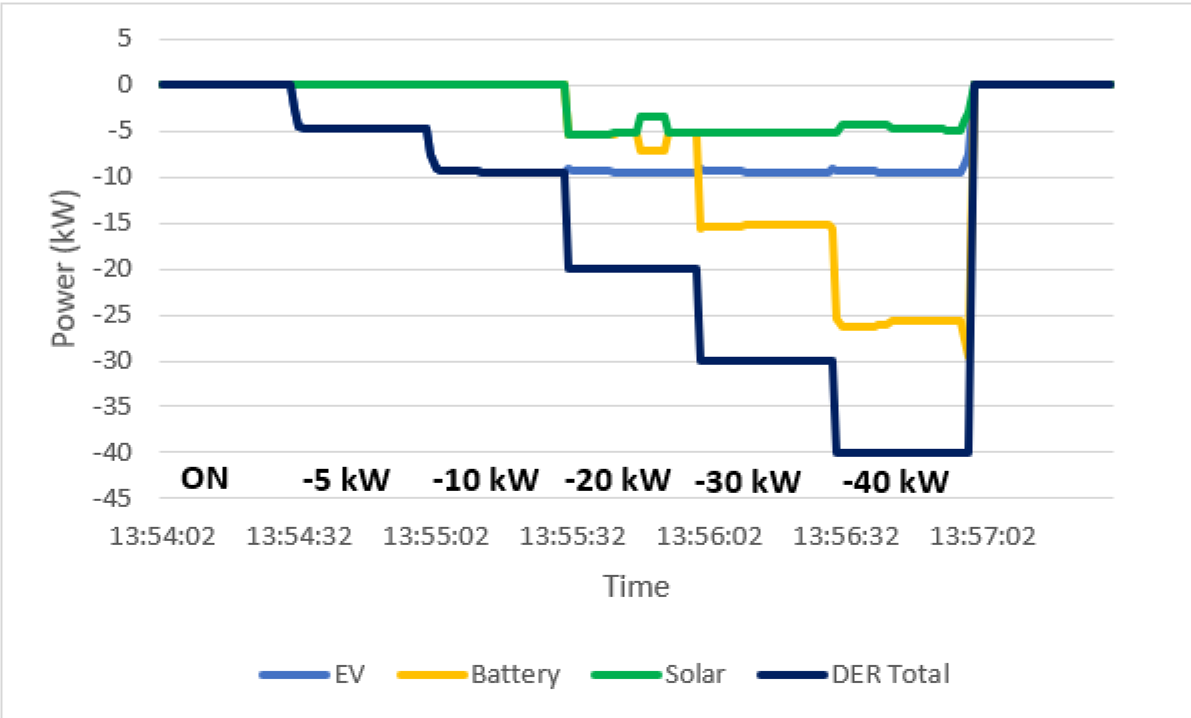


Figure 33 - DER operation during interoperability test.

5.4. Testing of Privacy Algorithm

Three test cases are executed to validate the ability of the system to protect EV owner data, which are: (1) registering the EV owner's details on the network; (2) accessing the EV owner's data from an authorized user; (3) accessing the EV owner's data from an unauthorized user. The smart contract functions involved in the testing are *createUserData, getUserDataHistory,* and *getUserData*.

5.4.1. Register New EV User

Input: userData object with name "EV Owner A" and Access Control List that includes "LDC X" as an organization, with access to personal and billing data, but not EV preference data.

Action: Call the *createUserData* function with the "EV Owner A" userData object as the payload

Output: OK message received from the smart contract. To verify, the *getUserDataHistory* function is called and a record of the user creation can be found. **Test is successful**.

5.4.2. Access User Data From Authorized User

Input: Login credentials as “LDC X”, list of data attributes requested (personal and billing).

Action: Log in to the system with “LDC X” credentials. Call the *getUserData* function, requesting to access the personal and billing data of “EV Owner A”.

Output: Function returns the personal and billing data of “EV Owner A”. Additionally, the calling of the *getUserDataHistory* function shows a new record that documents the data request and approval just made by LDC X for EV Owner A.

5.4.3. Access User Data From Unauthorized User

Input: Login credentials as “LDC X”, list of data attributes requested (personal, billing, EV preferences).

Action: Log in to the system with “LDC X” credentials. Call the *getUserData* function, requesting to access the personal, billing, and EV preferences of “EV Owner A”.

Output: Function returns **access rejected message**. Additionally, the calling of the *getUserDataHistory* function shows a new record that documents the data request and rejection just made by LDC X for EV Owner A.

5.5. Scalability Testing (Blockchain)

The scalability evaluation of the system revolves around measuring the transaction latency of the blockchain component when participating in a demand response event. As such, two functions of the demand response smart contract are evaluated, which are the submitMeasurements and validateDR functions. The submitMeasurements function allow an aggregator to submit DER measurements to the ledger during a demand response event, while the validateDR function checks all measurements for all aggregators and determines if they were compliant during the event.

To facilitate the testing, a virtual testbench application was created to simulate a variable number of aggregators and an associated number of DERs per aggregator. The test bench application launches concurrent connections to the blockchain ledger, and begins to call the submitMeasurements function to submit DER measurements to the ledger. Timestamps before and after the function is executed are measured, and the difference between the two represents the total transaction latency. In this trial, the number of aggregators is fixed at 10, while the number of DERs per aggregator varies from 100 to 10,000, resulting in between 5839 to 589039 bytes of data being transmitted to the ledger by one call of the submitMeasurements function. On the other hand, the transaction latency of the validateDR function is measured by submitting measurements from an entire DR event to the ledger, and then evaluating only the time it takes to process the data and determine compliance for all the aggregators. Again, the number of aggregators is fixed at 10, while the number of DERs per aggregators is varied from 100 to 1000. In both tests, the transaction success rate is also logged, where a transaction is deemed a success if it successfully makes it on to the ledger, and failure otherwise.

The smart contract is developed in Hyperledger Fabric 2.2, and is deployed on a single workstation with i7-6700HQ Processor (2.60GHz) and 8 GB RAM, running Ubuntu 20.04.4. The number of nodes in the network is fixed at 2.

The results of the submitMeasurements testing can be seen in Figure 34, where the latency per transaction grows from approximately 5 seconds at 100 DERs to 14 seconds at 10000 DERs. However, the success rate of the transactions, which is above 90% until 5000 DERs, dips to 81% when the DERs approach 10000. This indicates that while the latency of the system at 10000 DERs is acceptable at 14 seconds (considering demand response intervals are in 5 minutes), the success rate is not ideal. Nevertheless, the success rate can be improved with the introduction of more nodes on the blockchain network.

The results of the validateDR function testing can be seen in Figure 35, where the transaction latency hovers around 5 seconds between 100-500 DERs and rises to 5.8 seconds at 1000 DERs, which, again, are acceptable speeds considering that DR intervals execute every 5 minutes.

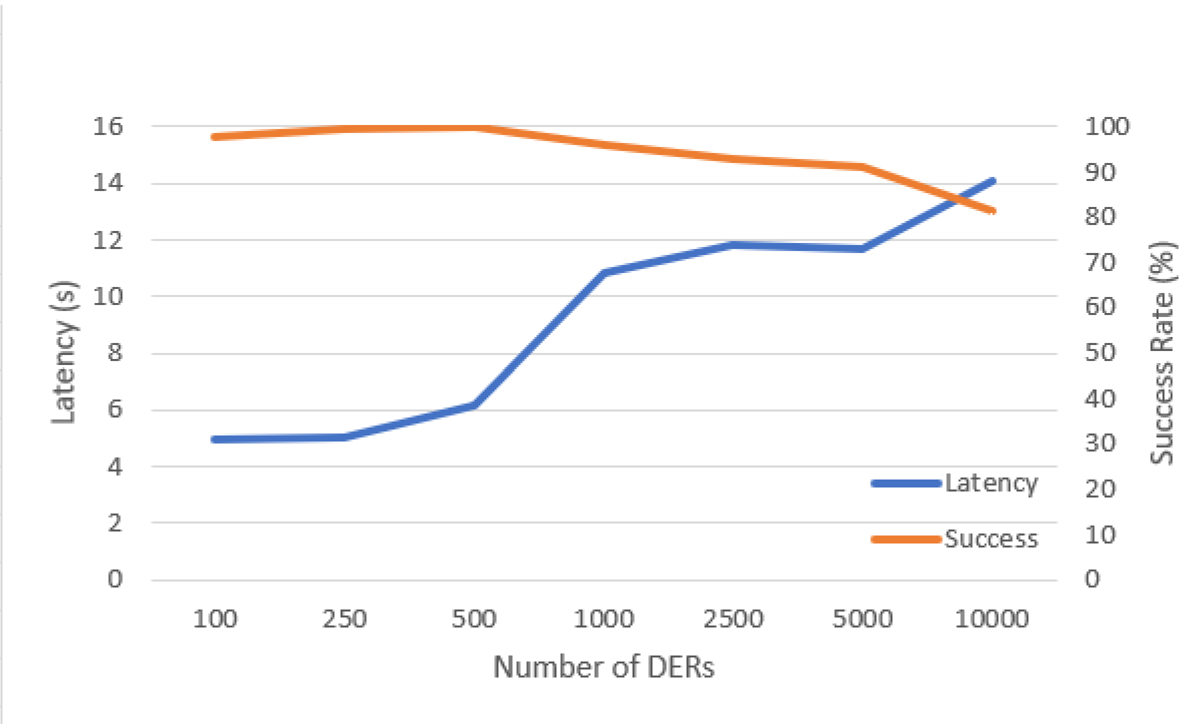


Figure 34 - Latency results of submitMeasurements function.

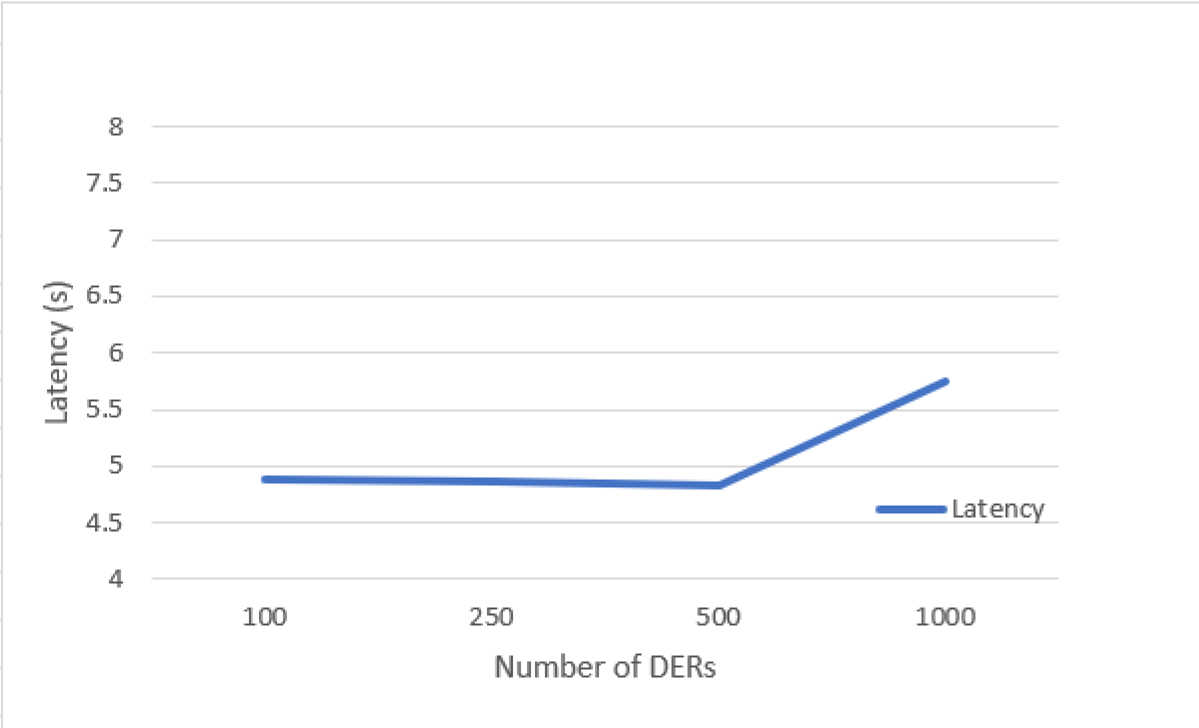


Figure 35 - Latency results of validateDR function.

5.6. Summary of Real-world Energy Metrics

Across all tests executed during this project, the DERs contributed a total of 3.12 MWh of energy towards the building, with the EV contributing 0.62 MWh (20%), the PV contributing 1.3 MWh (41%), and the BESS contributing 1.2 MWh (39%). Of the 3.12 MWh of energy contributions from the DERs, 1.75 MWh were during peak hours (56%), with the EV contributing 0.24 MWh (14%), the BESS contributing 0.92 MWh (52%), and the PV contributing 0.60 MWh (34%). Given an annual emissions factor for the Ontario electricity system of 0.031 kg CO_2eq/kWh [22], the total emissions reductions during peak hours is approximately 54 kg.

With respect to battery degradation, this metric was measured from March 2022 to Feb 2023 by the LeafSpy mobile application, which returns the state of health (SOH) as calculated by the vehicle itself. It is worthwhile mentioning that the EV was driven for over 15,000 km during this time period, in addition to discharging its battery at other locations. A timeline of the SOH observations is shown below, where over the course of roughly 11 months, the SOH degraded from 92.42% to 91.54%, for a total of 0.88%. It is difficult to ascertain the effect of the bidirectional charging on the EV with such a small sample window, however, it is interesting to note that a study of 6000 EVs in [23] found that the average SOH loss per year was between 2-3%, well above the 0.88% experienced by the EV in this project.

Table 12 - Observations of EV battery SOH.

Day	SOH (%)	Odometer (km)
03/16/2022	92.42	19,200
04/05/2022	92.37	21,005
08/24/2022	91.89	27,623
09/30/2022	91.75	29,625
10/28/2022	91.63	30,902
11/26/2022	91.56	32,255
12/22/2022	91.55	32,751
01/15/2023	91.56	33,228
02/05/2023	91.54	34,201

6. Summary of Feedback of V2G App

The simulated V2G app was launched on November 28, 2022, with an accompanying survey to elicit feedback for the user experience in participating in the proposed EV session types. The survey has garnered 41 responses thus far (Feb 2023), and responses will continue to be gathered for another 6 months. The survey results are summarized below.

6.1. Understanding session motivations and configuration

The first six questions of the survey were meant to gain insight with respect to EV owner's understanding of the EV session types proposed and whether the app was able to explain the motivation of the session types in an intuitive manner. The survey results in Figure 36 show that respondents found the app useful and were able to understand the differences between the proposed EV session types. When asked if an explanation for each of the session types were provided, 80% of respondents answered with either “Agree” or “Strongly agree” (Figure 36a), in addition to 77% of respondents answering the same when asked if they understood the motivation behind the EV sessions themselves (Figure 36b).

When asked if they were able to understand how their battery level would change during the quick support EV session, 37% of respondents answered with “Strongly agree”, and 45% answered with “Agree” (Figure 36c). Correspondingly, when asked the same question with respect to the extended support EV session, the numbers dipped to 32% and 27%, respectively, with “neutral” (20%) and “disagree” (18%) being other popular answers. These answers indicate that the workflow for the extended support EV session was much less intuitive for the respondents, and needs to be explained further in the app. This trend is reinforced when EV owners are asked if the configuration of the quick support and extended support sessions were easy, where 84% of respondents answered “strongly agree” or “agree” for quick support (Figure 36e), and only 70% for extended support (Figure 36f).

6.2. Evaluating session preferences and willingness to participate

The second six questions focus on evaluating preferences for session types and eliciting reasons for participation in V2G programs based on these session types Figure 37. When asked if the analytics during session operation were intuitive and followed their understanding of how the EV session type would be conducted, 22.5% of respondents answered with “strongly agree”, while 55% of respondents answered with “agree” (Figure 37a). These results show that the app was generally received well and delivered to the expectation of the user. Furthermore, when asked if they would ever support in a grid support EV session option, 70% of respondents stated that they would participate (Figure 37b), with 57% preferring the extended support option, and 43% preferring the quick support option (Figure 37c). This finding is in contrast to the first survey, where 75% of respondents had stated that they would prefer a session type with no fixed contract, akin to the quick support option. When asked, qualitatively, the reason for their preference, those in favor of extended support mentioned (a) higher revenue opportunity and (b) ease of configuration since their schedule is largely fixed.

From the educational point of view, when asked if the app was helpful in helping understanding V2G, 72% of respondents stated “agree” or “strongly agree” (Figure 37d), with 70% of respondents reporting an increased motivation to participate V2G programs rolled out by the utility because of the learnings from the app (Figure 37e). Lastly, when asked the main reason why they would participate in such a program, dominant responses included “incentives” (50%), “emission reduction” (20%), and “home backup” (20%).

6.3. Conclusion of Survey Results

From the survey results, three main takeaways can be realized:

1) While the app is largely intuitive for users and they generally understood the motivation behind V2G, there was a significant drop-off in understanding when users operated the extended support option. This option, while complex, should still be explained thoroughly to the user so that they may understand its true use.

2) After trying the app, the fixed contract option (extended support) was preferred over a no contract option (quick support), by a margin of 57% to 43%. In the initial survey, the no contract option was the dominant preference, by a margin of 75% to 25%. The reasons stated for the extended support was the higher revenue opportunity and ease of configuration to integrate V2G with their daily schedule.

3) The app has motivated EV owners to understand V2G and participate in future programs rolled out by system operators or electric distributors, with 70% of respondents reporting an increased sense of motivation to participate. The dominant reason for their participation, at 50%, is for the incentives received from the program.

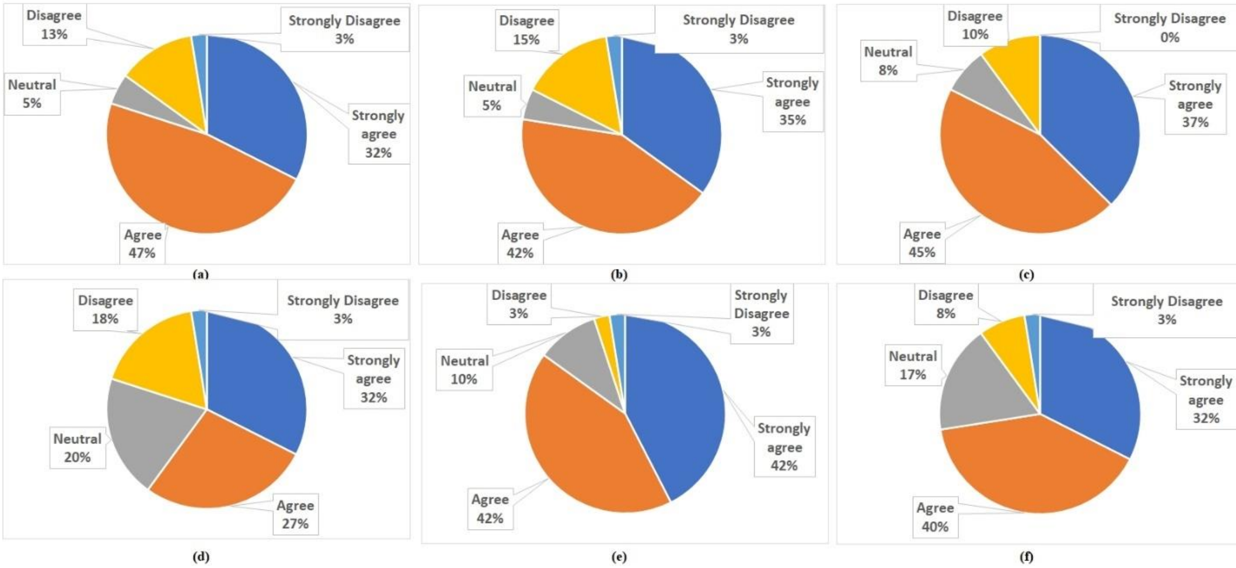


Figure 36 - Survey results for: (a) explanation of EV sessions; (b) motivation of grid support; (c) understanding of quick support; (d) understanding extended support; (e) configuration of quick support; (f) configuration of extended support.

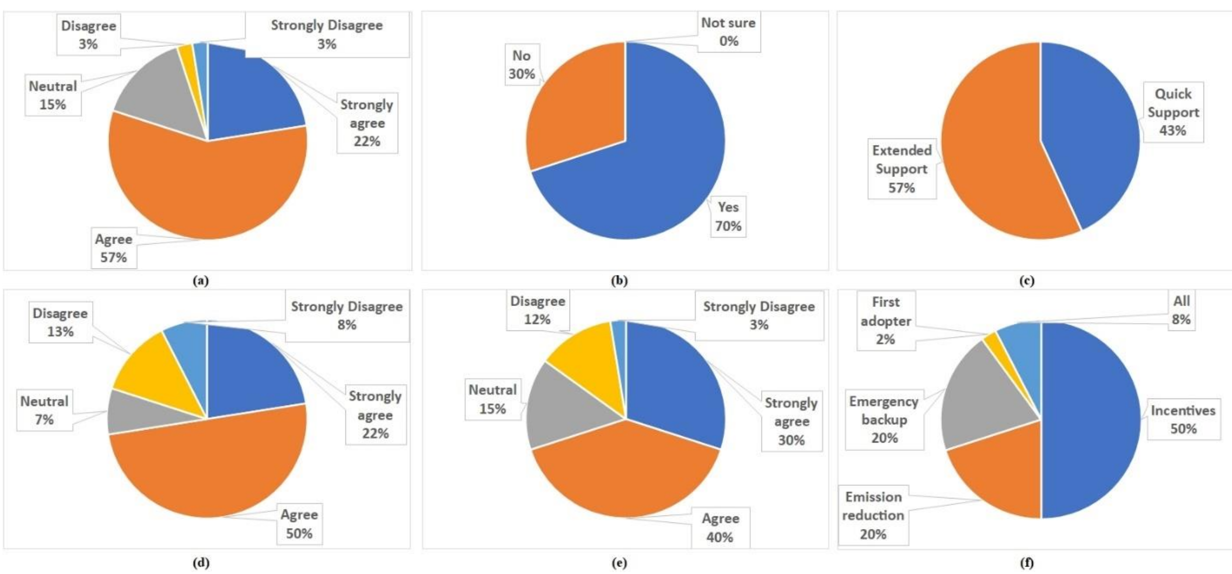


Figure 37 – Survey results for: (a) analytics intuitiveness; (b) engage in grid support; (c) session preference; (d) enhanced learning; (e) increased motivation; (f) engagement reason.

7. Summary of Economic Analysis of V2G Adoption in Ontario

This section includes a summary of an economic analysis completed for V2G adoption in Ontario. For the full report, please refer to the report entitled "Feasibility Analysis for V2G Programs in Ontario", which is submitted as a separate report to fulfill the deliverables as part of this project.

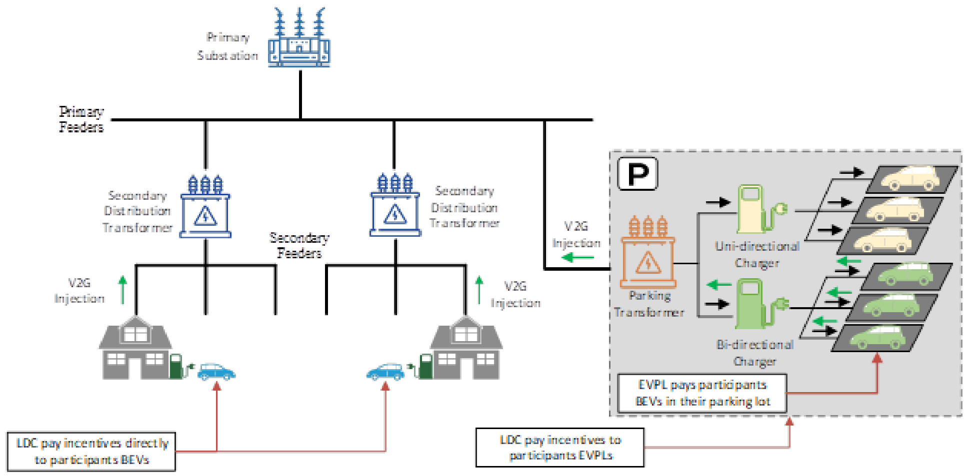


Figure 38 - Depiction of residential and commercial V2G programs.

The aforementioned report investigates the financial viability of introducing both residential and commercial V2G programs for the purpose of providing peak shaving in Ontario, as shown in Figure 38. For the residential program, it is assumed that the LDC is the administrator and interacts with EV owners directly. For the commercial program, it is assumed that EV parking lot (EVPL) owners invest in bidirectional charging infrastructure, and act as aggregators between the LDC and EV owners. Both EVPL and EV owners are treated as program participants, where the LDC is the program administrator.

The study considers several factors that influence the overall net benefits of the proposed V2G programs, such as the net Benefits–Costs Ratio (BCR) for each stakeholder, including the LDC (administrator), ratepayers (those not participating in the program), and program participants (EV and EVPL owners). Several case studies are presented to investigate the impact of adopting the proposed V2G programs in Ontario. A summary of the main findings is given hereunder.

For the residential V2G program:

- The program is generally beneficial to the LDC in the form of avoided distribution system capacity cost and reduced peak energy cost, while having minimal effect on Ontario ratepayers when the incentive is set to the on-peak TOU price of $0.21/kWh. The incentive of $0.21/kWh is the highest ever on-peak rate in Ontario's history.

- The costs endured by program participants outweigh the benefits received. The current market price of bi-directional chargers ($1000/kW) [25] makes it difficult for the program participants to recoup their investment unless incentives exceed the on-peak TOU price.

- The BCR for the program participants and the ratepayers are inversely proportional, which means that the ratepayers benefits decline after the program participants benefits start to increase (BCR goes below one for ratepayers once it exceeds one for the program participant).

- An increase in incentive rate to $0.53/kWh or a 65% decrease in charger cost will help participants break even. However, the incentive rate increase will result in a negative income for the administrator and higher bills for the ratepayers. The best scenario is the reduction in charger costs which would benefit all stakeholders.

- Based on 100 call days per year and an incentive rate of $0.21/kWh, the program administrator is expected to net an income of $536MM over 10 years, while the participants will incur a loss of $1,400MM over the same period.

- It is imperative to obtain an accurate estimation of V2G impact on distribution system deferral since a low impact means that there is no benefit for the program administrator.

For EVPL V2G program:

- The results of the EVPL program show that it benefits its administrator and EV owners while having no effect on Ontario ratepayers.

- EVPL members' expenditures exceed the benefits received. Similar to the residential program, the high cost of bi-directional chargers is the primary reason that their BCR is less than one BCR.

- An increase in the incentive rate to $0.48/kWh or a 75% decrease in charger cost will help EVPL members break even. However, the incentive rate increase will result in a negative income for the administrator and higher bills for the ratepayers. The best scenario is the reduction in charger costs which would benefit all stakeholders.

- Based on 100 call days per year and an incentive rate of $0.21/kWh, the program administrator is expected to net an income of $201MM over 10 years, while EV owners will net $79MM and the EVPL owners will incur a loss of $319MM over the same period.

8. Conclusion

This project investigated the socio-technical-economic feasibility of V2G within the context of its adoption within the Ontario electricity sector. Based on feedback from a survey of 124 EV owners, several new EV session types and incentive structures for V2G programs were developed, including the provision of non-contract and fixed contract discharge to enable EV owners to arbitrage, or provide contracted demand response support to PSOs. These session types were developed into a prototypical web application, where initial feedback suggests that there is general willingness to participate in a V2G program and receive incentives in return for DR services.

With respect to the technical aspect, several tests were executed to observe its ability to couple with other DERs (100 kWh BESS and 6 kW PV) and provide peak-shifting and contracted demand response support to the grid. Over the entire duration of the project, the DERs combined to generate 3.12 MWh of energy towards the building, with 1.75 MWh of energy shifted at peak hours. The DERs also participated in successful HDR testing, where they reduced the building load by 30 kW over a 2 hour time period, and 20 kW over a 4 hour time period. A blockchain-based smart contract was developed to initiate the DR event, collect behind the meter measurements from DERs, integrate with a DERMS to dispatch the DERs, and validate the measurements against capacity/dispatch charges as per HDR protocols from the IESO. The average time taken to initiate the DR event and first receive power injections from the DERs was found to be approximately 4.1 seconds.

From an economic standpoint, two separate V2G programs were studied, where one focused on the residential space, while the other focused on the commercial space with EV parking lot owners acting as aggregators of EVs. In both cases, it was found that while the programs are very beneficial to LDCs and standard ratepayers, the participants that must invest the cost of owning/installing bidirectional chargers (EV owners in the residential program, EV parking lot owners in the commercial program) fail to recoup their investment by a large margin. The cost of bidirectional chargers, currently around $1000/kW [25], must reduce by approximately 65% for the participants to break even.

From the social standpoint, a survey of 124 EV owners established that there was general interest and willingness to participate in V2G programs, motivated by incentives, and a desire to decrease greenhouse gas emissions. When asked to choose between program types that were no-contract (pay as you go) or fixed-contract (scheduled), 78% of respondents preferred the no-contract type. Additionally, the survey results showed a strong intolerance for the unauthorized selling of personal data of EV owners, with over 64% of respondents stating that they would terminate their contract with an EV network operator if unauthorized selling of data occurred.

In summary, the outputs of this project show that V2G can indeed be a reliable, flexible non-wire alternative that is capable of providing several services to the grid and realizing increased energy efficiency. The next steps are for more pilots to be launched to determine its real-world efficacy in Ontario's future plans for decarbonization.

8.1. Lessons Learned

1) Warranty and compatibility.

One of the biggest barriers to having users try the technology on-site at the building with their own vehicles was unanswered questions regarding warranty. Currently, only three vehicles are compatible with the ChaDeMo charging protocol for bidirectionality, those being the Nissan LEAF, Mitsubishi Outlander, and Kia Soul [26]. Yet, a careful perusal of their owner manuals does not reveal warranty policies, conditions, or best practices with respect to bidirectional use. Although the project team did recruit over 10 volunteers to test their vehicles on-site, this limitation should be mitigated before further attempts at pilots. In our case, we were able to volunteer our own Nissan LEAF for testing and demonstration, and further developed a simulated app such that feedback could be elicited with respect to the proposed V2G program.

2) Location matters

Our V2G contract defines a minimum driving range for the EV owner, as well as a minimum plug in time that the EV owner must plug in to receive capacity payments. If they are plugged in during a demand response event, they get availability payments as well. However, given that EVs are a mobile resource, there is currently no consideration given to the fact that congestion occurs in different parts of the grid, which is a function of time, and location. In retrospect, contract design should have looked into these dimensions instead of an abstract plug-in-time, which might not be helpful if the EV owner plugs in only at off-peak hours and in locations that do not have congestion.

3) Test plans should be ironed out before proposal acceptance.

Our project proposal contained testing for DR events, however, the methodology for validation was not quite clear. In the middle of the project, we were asked to conform to HDR methodology, which requires an understanding of the building load profile to establish a baseline consumption for the building. We did not have access to this data, and as such, had to recreate algorithms and perform internal analysis to organize the DER dispatch and establish realistic load reduction commitments, respectively. While this step resulted in a more realistic and useful approach, the availability of the full protocol at the beginning of the project would have been beneficial.

4) Power electronics in inverters are still vulnerable.

The inverters for both the hybrid solar/BESS system and the V2G charger were damaged and required repair to internal transistors. This involved extra expenditure and delays to the data collection and testing phases. One of the learnings from the inverter manufacturers was to ensure that the doors to the physical system were sealed completely shut to ensure proper ventilation. Additionally, any inverters enclosed within a cabinet should be outfitted with a ventilation system adept at mitigating challenges posed by weather in Ontario (cool, dry winters and warm, humid summers).

5) Discharging efficiency is variable

When reviewing data from TOU testing, it was found that the discharging efficiency of the EV varied between 70% and 90%, and trended towards the lower part of that range when the setpoint was lower (less than 3 kW). This is in contrast to literature, where the discharging efficiency is usually modelled as a constant between 85% to 95%. Considering that the efficiency is quite low at lower setpoints, in hindsight, it would be better for the EVs to discharge in shorter bursts and higher setpoints during the TOU tests (7 kW for 4 hours) instead of throughout the day (3.5 kW for 8 hours).

8.2. Future Work

1) Investigation of power quality and harmonics

The meters installed at the facility as part of this project are revenue grade, power quality meters that measure total harmonic distortion and other power quality metrics. It is important to review this data and conduct experiments to determine if harmonics from the inverters of the hybrid solar/BESS and V2G chargers are within the IEEE limits. Additionally, at higher setpoints, the transformer that interfaces these two inverters to the rest of the building begins to output erratic noises, which again, could be a function of the increase in harmonics. This will be investigated in future projects.

2) Pilot with ChaDeMo and CCS vehicles

As of May 2022, the CCS charging standard has approved use cases for bidirectional charging, and our discussions with V2G charging station vendors indicate that they have begun to adopt the standard. We will be pursuing further research and pilots by expanding the technology developed in this project and aggregating both ChaDeMo (LEAF, Outlander) and compliant CCS vehicles to provide demand response and other grid services to the IESO controlled grid. We then intend on taking the results of the pilot into a well-formed program that can be administered by the IESO and/or LDCs.

3) Find a reliable formulation for discharging efficiency

Considering the yearlong data logged as part of this project, we are in a unique position to discover what factors influence the discharging efficiency the most, whether setpoint, temperature, or SOC of the EV. This is a critical piece to determining the total useable capacity of an EV, at scale, for the IESO or LDC controlled grid, and plays a part in the establishment of any V2G program.

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