



Article

# The Parker Project: Cross-Brand Service Testing Using V2G

Peter Bach Andersen <sup>1,\*</sup> , Seyedmostafa Hashemi <sup>1</sup> , Tiago Sousa <sup>1</sup> ,  
Thomas Meier Soerensen <sup>1</sup>, Lance Noel <sup>2</sup> and Bjoern Christensen <sup>3</sup>

<sup>1</sup> Department of Electrical Engineering, Technical University of Denmark, 2800 Lyngby, Denmark; shtog@elektro.dtu.dk (S.H.); tsousa@elektro.dtu.dk (T.S.); thms@elektro.dtu.dk (T.M.S.)

<sup>2</sup> Nuvve Corp, San Diego, CA 92106, USA; lance@nuvve.com

<sup>3</sup> Next-Dimension, Danville, CA 94506, USA; bjoern@next-dimension.ca

\* Correspondence: pba@elektro.dtu.dk

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**Abstract:** The Parker project sought to experimentally validate that contemporary series-produced electric vehicles (EVs), capable of V2G, are ready to participate in a number of advanced grid services. In such services, the timing, size and direction of power and energy exchanged between the EV battery and grid is controlled as to support either a single building, the local neighborhood or the regional power system. Vehicles purposely designed for such services are referred to as grid integrated electric vehicles (GIVs). The field of research, describing how GIVs may be used to actively support the power system, is called Vehicle–Grid Integration (VGI). The purpose of this paper is to present how the Danish Parker project has systematically categorized a range of grid services, collected in a service catalog, and then illustrate state-of-the-art EVs ability to support such services through experimental validation. Results are presented for three different tests performed in Parker; marginal emission factor charging, frequency containment reserves and a performance test for controlling power setpoints. The ultimate aim of this paper, and the Parker project, is to promote the GIV concept so that it may inform the design and capabilities of present and future EVs, EV supply equipment (EVSE) and communication standards.

**Keywords:** grid integrated electric vehicle; vehicle-grid integration; vehicle-to-grid; V2G; smart charging; electric vehicles

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## 1. Introduction

Electrification of transportation is a key component in meeting international CO<sub>2</sub> reduction commitments. The immediate effect of such electrification will be both a challenge, due to a new demand for power and energy, and an opportunity in having the vehicles become active assets that may support the power system.

The research field of vehicle-grid integration (VGI) explores not only the adverse effects of electrification in terms of grid impacts and overloading, but also the potential benefits in the form of services that electric vehicles (EVs) can bring to the power system. The California Public Utilities commission provides the following definition: “Vehicle–Grid Integration (VGI) can harness the usage characteristics of and technologies within the PEVs to allow them to serve as a grid asset, reducing operating costs for facility and vehicle owners, the utilities’ distribution maintenance requirements, and energy prices in the wholesale market”. VGI research has been documented in countless publications and R&D projects.

A service can be defined as the act of influencing the timing, size and direction of power and energy exchanged between the EV battery and an external load or electric network to provide value

not related to transportation. The nature of services, dealing with everything from loading issues in the distribution system to acting as mobile loads in Vehicle-To-Tool applications, has vastly different requirements for the abilities and performance of the EV and the electric vehicle supply equipment (EVSE). Namely, the support of vehicle-to-grid (V2G) and the speed with which power can be controlled may determine the range of services that an EV and its EVSE may be able to provide.

One of the main developments in the field of VGI is the support of V2G through direct current (DC) chargers supported by the CHAdeMO protocol. This approach, where the power conversion is left to the EVSE and the EV thereby readily may enable V2G through the CHAdeMO standard, has allowed a broader support of V2G than ever before.

The main goals of the Parker project [1] are, first, to describe the taxonomy used to systematically describe the range of services that EVs may provide, which has been collected in a service catalog—second, to present the experimental validation of state-of-the-art EVs from car companies Nissan, Mitsubishi and PSA to test their ability to provide advanced, V2G-based, services. By proving the VGI readiness of such vehicles, the authors hope to set a standard that may guide the design of future EVs to unlock their potential in supporting a stable, economic power system based on renewable energy.

This paper serves first and foremost as an introduction to the Parker project and its approach to VGI research—for a more technical and in-depth description of the test setup and methodology, we refer to the WEVJ paper [2]. This paper is a slightly modified version of an EVS31 paper [3].

The paper is organized as follows: first, related work is described in a “State-of-the-art” section, next “Power and energy services” describe the services identified and explored by the Parker project. Then, the section “Experimental validation” describes the components and configuration used in the test-setup and presents data from three different tests. Finally, the paper concludes and describe future work.

## 2. State-of-the-Art

A 1997 publication by Prof. Kempton [4] marked the onset of modern VGI research and the exploration of V2G technology. Since this potential was first described, Prof. Kempton has led a number of scientific and commercial activities to prove that bidirectional EVs can provide power services to the power system. Willett et al. have proven how slightly retrofitted EVs, primarily based on alternating current (AC) charging, may provide power balancing on a commercial basis [5,6]. Prof. Kempton has initiated collaboration with multiple car companies proving the technical ability to support V2G across several different EV brands.

Later, inspired by the work of Prof. Kempton, the Danish Nikola project [7] sought to systematically list and investigate the services that an EV may provide to power systems by developing a first version of the service catalog described later in this paper. Nikola also sought to experimentally validate services on different brands of EVs [8] using AC chargers with dynamic power limitations using the IEC 61851 standard. The project also started the first Danish research efforts on testing frequency containment reserves (FCR) provision using V2G [9]. Finally, the project thoroughly investigated how EVs may provide local grid services through both simulation and experimental efforts [10,11].

Currently, a new generation of VGI projects has been launched, focusing on field testing using both AC and DC charging with the support of V2G. This includes the French GridMotion project [12], the Danish ACES project [13], and the California-based INVENT project [14].

These research projects, as well as others, have all contributed to the scientific state-of-the-art on investigating the potential and mechanisms for aggregating EVs for performing V2G services.

In [15], the authors use a statistical assessment approach to determine the potential of using V2G for ancillary services considering constraints from car usage and local grid limits. Furthermore, in [16], the potential is explored in terms of earnings through frequency containment reserves using V2G enabled EVs considering driving requirements and the efficiency of the V2G chargers used. In [17],

the authors explore the earning potential for frequency regulation in the UK based on a large dataset of real EV driving data and historical market prices. Finally, the authors in [18] compare the earning potential of providing frequency containment reserves both with and without the use of V2G.

Other publications deal with the mechanisms which may be used to gain value from V2G. In [19], V2G is used to prevent imbalances in the distribution grid. The suggested approach involves a real-time coordination with local PV installations. In [20], a stochastic optimization model is proposed to control a fleet of V2G enabled vehicles to support a reliability-oriented distribution grid reconfiguration. Finally, the authors in [21] provide a review of optimization techniques that may be used for EV integration.

In addition to the R&D efforts above, Copenhagen has been host to the world's first commercial V2G hub [22]. Here, the utility Frederiksberg Forsyning is collaborating with Nissan, Enel and NUVVE, and the utilities fleet of e-NV200 vans has since fall 2016 participated in the frequency containment reserve market. The Parker project is connected to this pilot through data sharing in order to promote scalability and replicability of this solution. While the commercial pilot at Frederiksberg Forsyning and the projects mentioned above illustrate the maturing of the technology, there are still neither standards that fully support VGI nor any international norm on what constitutes a GIV.

The Parker project builds on the experience and learning from previous R&D while leveraging new technological developments, specifically the V2G support from new DC chargers and CHAdeMO. The main novelty of the Parker project is that it is the first project to experimentally validate the ability to provide V2G services across several contemporary EV models.

The validation is both performed by testing some of the most demanding services today, i.e., Frequency Containment Reserves (FCR) [23], but also by using a test cycle for measuring the performance of EVs and EVSEs in responding to a power request.

The project has found that EVs, using DC chargers and the CHAdeMO 2.0 protocol, may offer demanding grid services by providing a fast, accurate and precise response to bi-directional power requests.

Parker's investigation of performance may allow us to understand how EVs may support future, even more demanding services and meet emerging grid codes [24].

### 3. Power and Energy Service

One of the objectives of the Parker project has been to suggest a systematic and comprehensive listing of the services an EV may provide. Services can roughly be divided into categories according to the geographical level at which they are aimed and can create value. Figure 1 illustrates these different domains that the EV owner may choose to actively support.

For each of the above domains, EVs can offer services that support:

- **Region**, balanced and economical power systems based on renewable energy.
- **Neighborhood**, local distribution grids and new urban energy infrastructures and communities.
- **Building**, energy-optimized buildings with local production.

The above classification, based on the geographical domain, may be more intuitive than the classical power system hierarchy—transmission system, distribution system and behind the meter. The three levels, however, still roughly corresponds to these levels of the power system.

Next, a total of six service categories are suggested and mapped to the levels above. Each category is meant to represent a logical grouping of related services. In Figure 2, these six categories, used by Parker, are listed and some examples of services are provided for each category.

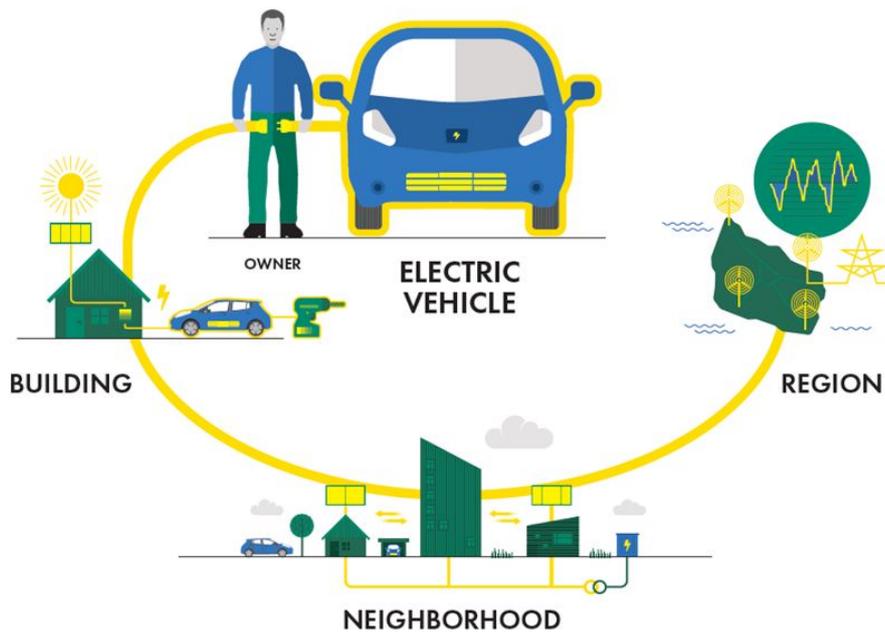


Figure 1. Vehicle-Grid Integration—possible uses of the EV.

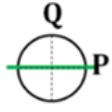
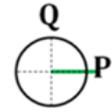
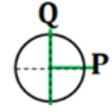
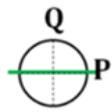
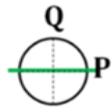
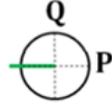
Domain	Categories	Service examples	EV+EVSE requirements Controllability/Performance
<b>Region</b> (Transmission)  	Power balancing	Synthetic inertia	 -Fast activation -Controllable ramping rate -Bidirectional (V2G)
		Frequency containment	
<b>Neighborhood</b> (Distribution)  	Energy Balancing	Regulation	 (no special performance requirements)
		Marginal emission	
	Grid contingencies	Loading issues Voltage issues	 - Reactive power capabilities
<b>Building</b> (behind meter)  	Energy Autonomy	Bilateral trading	 - Bidirectional (V2B)
		Self consumption maximization	
	Islanded operation	Back-up power Fully off-grid	 - Bidirectional (V2B) -Islanding capability
	Mobile load serving	Vehicle-to-tool Vehicle-to-Vehicle	 - Bidirectional (V2L)

Figure 2. Parker service catalog.

A brief description of each category is as follows:

- **Power balancing**, services relying on the battery and power electronics ability to provide high, instantaneous power (kW) for balancing purposes;
- **Energy balancing**, services that used the batteries' ability to consume, store and return quantities of energy (kWh) for balancing purposes;
- **Grid contingencies**, Services that support the safe and reliable operation of local distribution systems;
- **Energy Autonomy**, services that allow for energy autonomy by allowing an increasing degree of energy to be produced and consumed locally;
- **Islanded operation**, allow islanded operation when a connection to the power system is not practical or possible;
- **Mobile load serving**, services using the EV as a mobile source of power and energy where access to the power system is not practical or possible.

Figure 2 also indicates the controllability and performance needed to support each category. The circle in the figure represents 4-quadrant power control—the horizontal axis (P) is active power and the vertical axis (Q) reactive power.

The green line in the circle denotes the control that may be needed—or that may enhance the services provided.

While the authors has only denoted the need for reactive power control within the grid contingencies category (for voltage support), the ability for bidirectional active power control (V2G) will likely be useful in several of the categories.

An extended version of the Service catalog can be found in Appendix A.

The emphasis of the Parker project has been on services at the regional level, especially power balancing, as well as services aimed at the neighborhood level in the shape of local grid contingencies. A number of specific services from these categories has then been selected for experimental validation. Some of these services will be presented in the next section.

#### 4. Experimental Validation

The purpose of the experimental validation in Parker is to assess contemporary EVs ability to provide advanced and V2G-based services. These validations can be valuable to the area of Vehicle–Grid Integration as they serve as a benchmark for other, and future, brands of EVs.

##### 4.1. Experimental Setup

The main components in Parker, used to conduct the experimental validation, are four EV models: Nissan Leaf, Nissan Evalia, Mitsubishi Outlander PHEV, and Peugeot iOn, provided to the Parker project by partners Nissan, Mitsubishi Motors, and PSA. The EVSEs used are provided by project partner Enel X and are 10 kW bidirectional DC CHAdeMO chargers. All OEM vehicles are connected to the Enel EVSE and each constitutes an “EV/EVSE pair” used for testing. Since the EVSE is based on DC charging, it will contain the power electronics and inverters necessary to support V2G. i.e., for DC charging in particular, the EV cannot be seen in isolation but relies on the capabilities and performance of the EVSE connecting it to the power system.

The bidirectional powerflow between EV and EVSE is controlled through an aggregator developed by project Partner NUVVE. For each test, the NUVVE aggregator calculates and dispatches a power request that is sent to each EVSE. The EVSE then forwards the request to the EV using CHAdeMO messages. The power provided (bidirectional) by the EV is measured by a meter installed in the Enel chargers. This reference configuration is illustrated in Figure 3. The picture in Figure 4 shows the physical setup, with two Mitsubishi iOns connected to Enel X bidirectional chargers, in the PowerLabDK EVLab facility in which the tests were carried out.

A set of services from the Parker service catalog has been selected for experimental validation. Services has then been tested across all project vehicles to investigate cross-brand support. The following subsections present three different tests and describe the four EV models’ abilities to provide them.

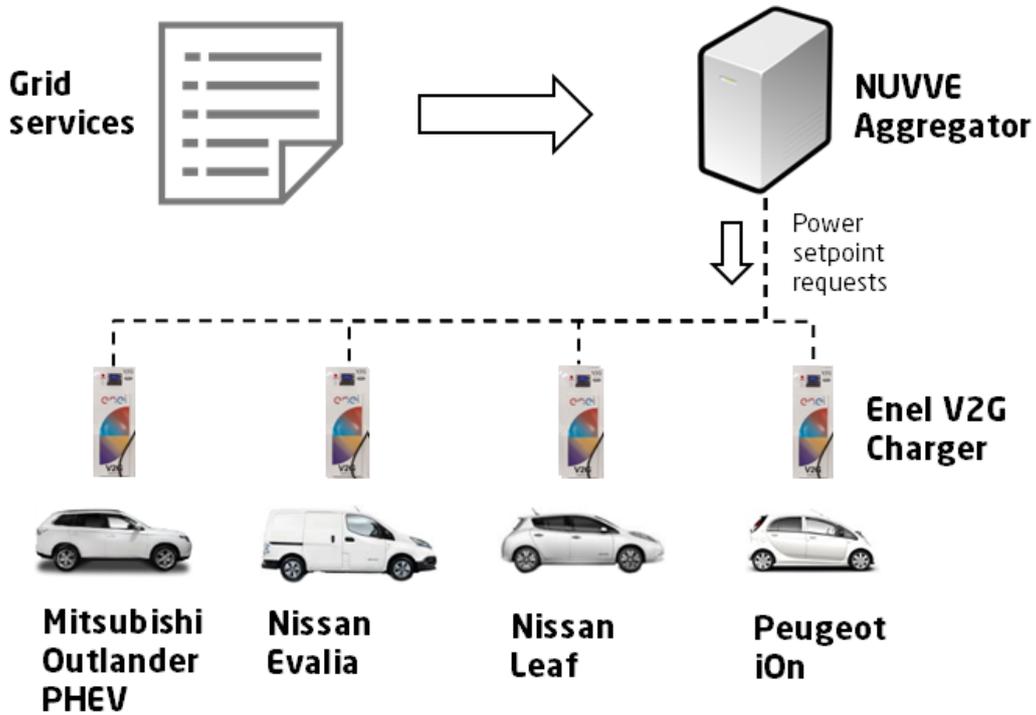


Figure 3. Parker reference configuration.



Figure 4. Parker laboratory setup.

4.2. Service—Marginal Emission Factor

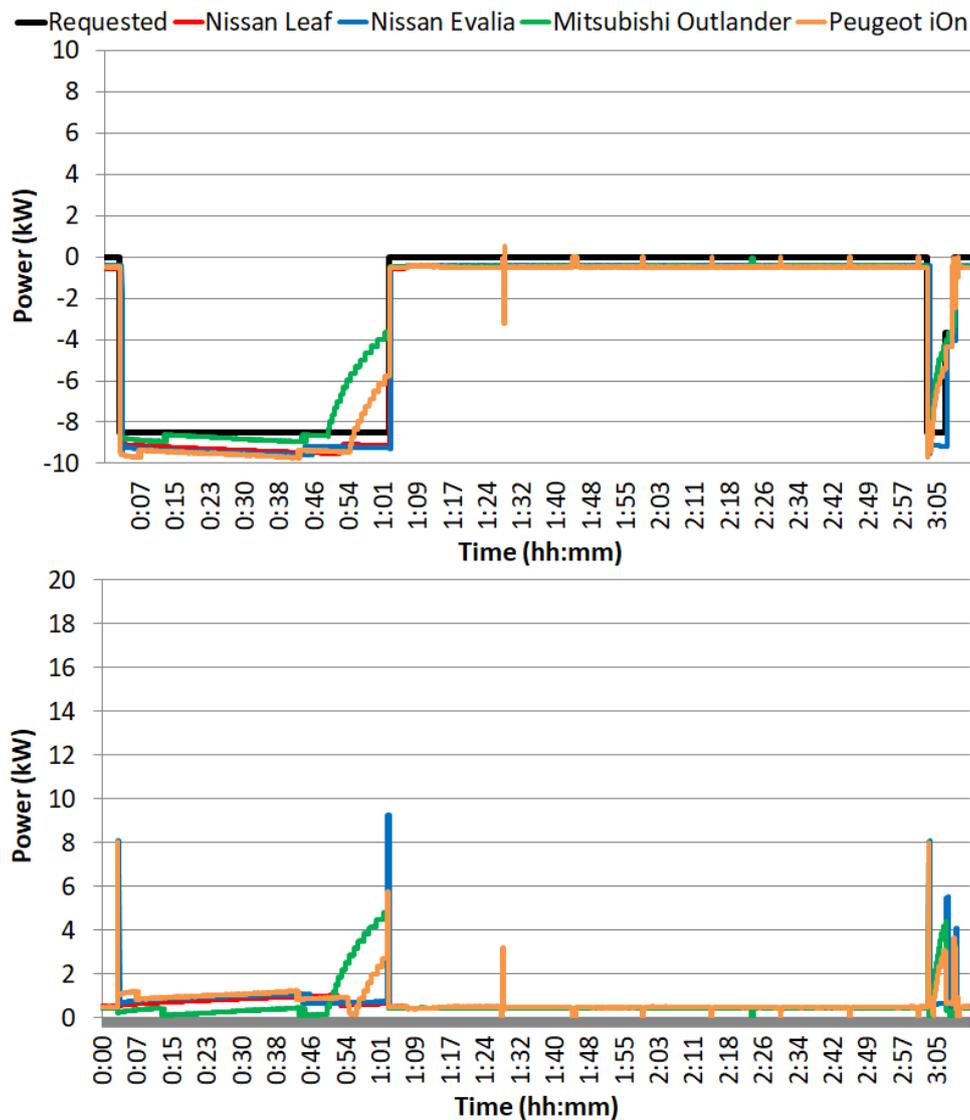
The first service belongs to the energy balancing category and is fairly easy to provide as it does not depend on V2G or have high requirements in regard to activation time. This service can informally be referred to as smart charging and simply postpone charging until periods where it is more suitable to consume energy. Many EVs already support static smart charging where EV owners can specify a fixed time for charging to commence, e.g., informed by a time-of-use tariff. This particular service represents a dynamic smart charging scenario where the time suitable for energy consumption may change on a frequent basis, and it therefore may be more practical to leave the charging control to a third party such as an EV aggregator.

Specifically, this service seeks to reduce the CO<sub>2</sub> production caused by charging. With sufficient energy data and forecasts, it is possible to identify the hours of the day where the added load of EVs is likely to cause the least additional CO<sub>2</sub> emission considering the marginal production. A marginal emission factor (MEF) has been developed in the Parker project in collaboration with the company Tomorrow, which captures the additional CO<sub>2</sub> emissions of each additional unit of electricity consumed.

The MEF is made available through a signal which has been used for the test.

In Figure 5 (top), requested power is used to let the EVs charge in hours with the lowest MEF signal value. The majority of energy needed is charged using the 1st hour of the test—while the remainder is charged during the 4th hour. This is a result of the 1st and 4th hours having the lowest MEF value and thus offering the least CO<sub>2</sub> intensive energy. All cars can be seen to follow the requested power rather accurately. The vehicles with smaller batteries (Outlander and iOn) can be seen to reduce the charging power as the batteries are approaching full capacity.

The difference between power requested by the aggregator and the power provided by the vehicles is shown in Figure 5 (bottom). While all EVs follow the requested power well, some peaks are observed due to delays in vehicle response when a change in the power setpoint occurs.



**Figure 5.** Parker service—Marginal Emission Factor, **top:** requested and provided power for service, **bottom:** absolute difference between requested and provided power.

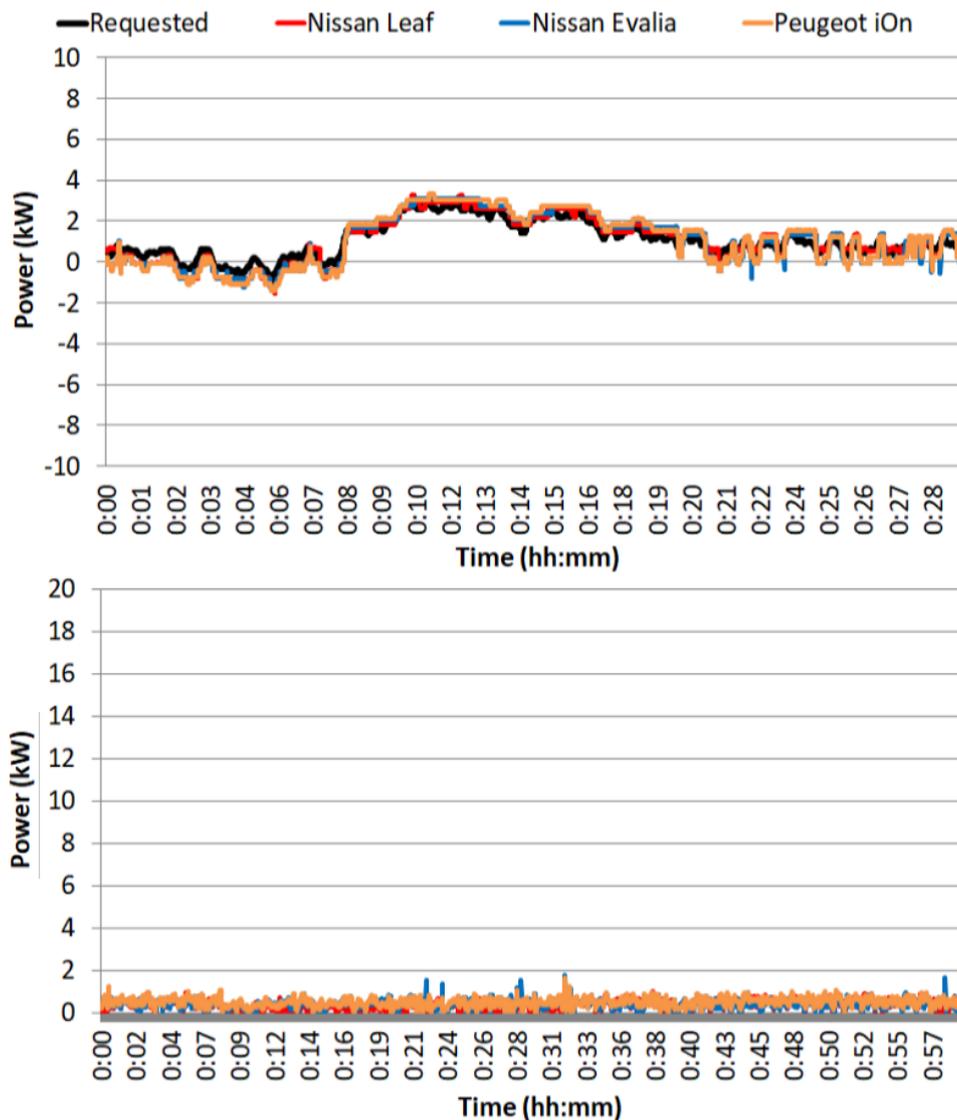
#### 4.3. Service—Frequency Containment Reserves

This service differs from the MEF test as it both utilizes V2G and requires a fast power response. To provide FCR, an aggregator would monitor the regional system frequency and dispatch a charge or discharge request to the EV according to a predefined droop function. Generally, the EVs will be set to charge if the frequency is high (according to a reference value or band), and discharge if the frequency is low.

FCR services have response requirements spanning from 150 s down to 5 s depending on the specific product provided. The ability to support V2G substantially strengthens an EV's ability to provide FCR.

This specific service is based on FCR provided in the western part of Denmark as part of the Continental Europe Regional group.

Figure 6 (top) shows the Requested power sent to all project vehicles and the corresponding response recorded by the EVSEs. It can be observed that the three vehicles participating in this test are all able to follow the bidirectional requested power set-point in a sufficiently precise and timely manner. It can be seen from Figure 6 (bottom) that no large deviations between power requested and provided occur. This is because the power setpoints change more gradually in this test (without large steps).



**Figure 6.** Parker service—Frequency Containment Reserves, **top:** requested and provided power for service, **bottom:** absolute difference between requested and provided power.

4.4. Active Power Performance Test

The last test does not represent a specific service but is rather designed to measure the performance of the vehicles and EVSEs. The test cycle suggested here consists first of a continuous and then a step-wise variation of charging power set-points and can be said to be the most demanding of the three tests. This cycle allows for a measurement of, for instance, set point granularity (continuous portion) and response times (step-wise portion).

It can be seen in Figure 7 that the provided power closely followed the request setpoint. Short deviations occur (seen as spikes in the absolute difference between request and response) due to a response delay.

A separate publication [24] elaborates on how the performance of the vehicles may be quantified using this test.

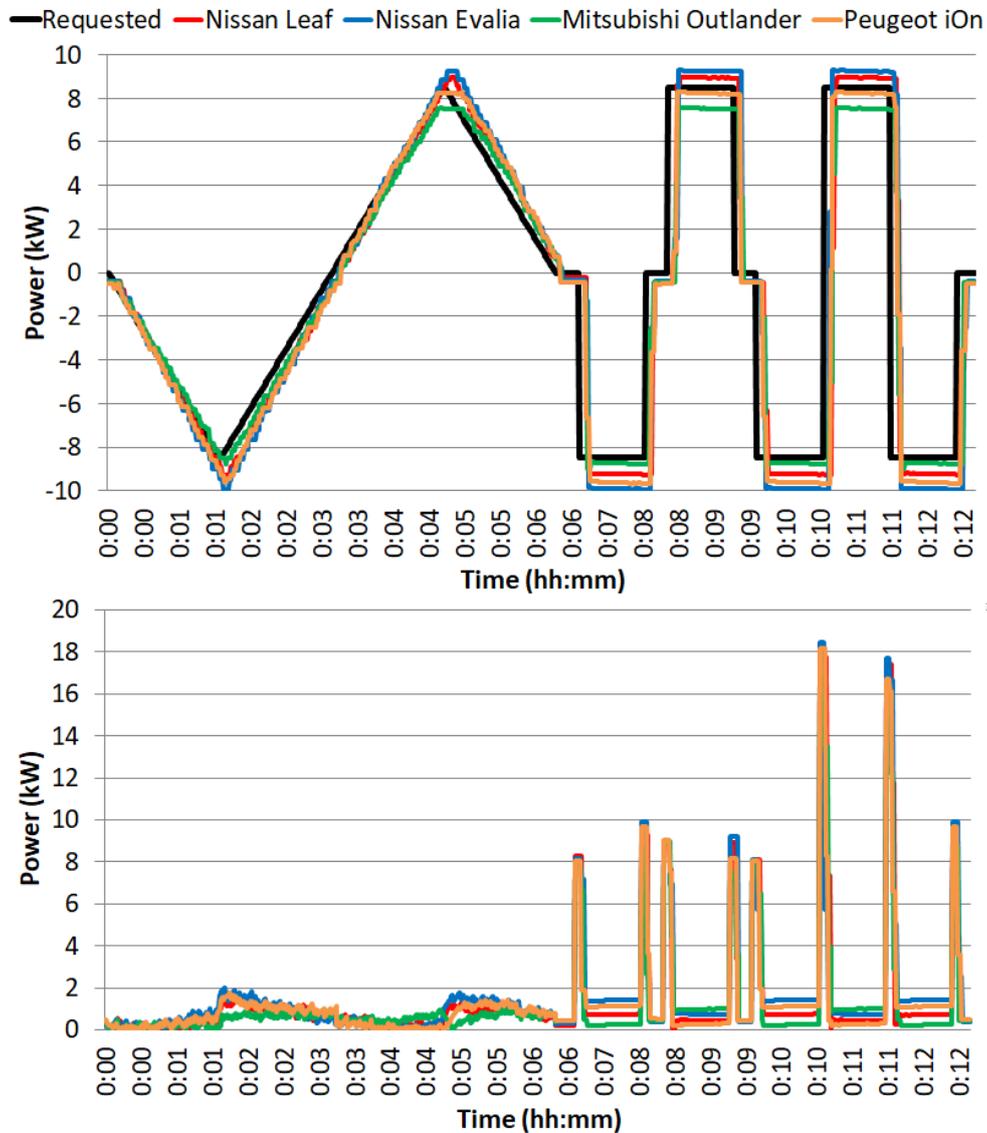


Figure 7. Parker performance test—active power, top: requested and provided power for test, bottom: absolute difference between requested and provided power.

Based on the tests conducted in Parker, including the three above, the project has been able to conclude that the vehicles are ready and able to provide advanced grid services relying on a fast and bidirectional exchange of power.

## 5. Conclusions

This paper has described how the Parker project has sought to systematically list, and then test, EV services towards a number of contemporary unmodified electric vehicles using bidirectional DC chargers.

The experimental validation showed a good performance for the vehicles tested (Nissan Leaf, Nissan Evalia, Peugeot iOn, Mitsubishi Outlander PHEV) and can serve as a benchmark for upcoming car models and standards. The reaction time were measured to 5–6 seconds (including communication delays) using an aggregator—down to a few seconds when controlling charger and car directly. Ultimately, the performance depends on the design of the power electronics as well as the software and protocols used to control it. The project concludes that V2G capability works well for a number of contemporary EVs today, using a DC V2G charger and CHAdeMO 2.0, but further work is needed to make such capabilities universal.

It is important to stress that V2G is currently only available in series-produced EVs through novel DC chargers and use of the CHAdeMO 2.0 protocol. Besides V2G, other capabilities, such as reaction time when altering a power setpoint, granting access to battery State-Of-Charge (SOC), and vehicle identification through the EVSE, need to be considered to fully support VGI services. For the broadest possible support, these capabilities need to be available through both DC and AC charging and be implemented in all international charging interfaces and standards—in Europe, most notably in the ISO/IEC 15118 and CCS standard.

While the Parker project has successfully proven the V2G readiness of the participating vehicles, further improvements may further extend the number of services that EVs can offer. By decreasing the response and activation time of the EV-EVSE pair, even more time-critical power balancing services may be provided. In addition, adding new capabilities such as reactive power provision and islanding support would extend services that EVs can provide. A main recommendation of the Parker project is to pursue a common definition of a grid integrated vehicle. i.e., the capabilities and performance that an EV should possess to be able to claim V2G and grid readiness.

The vehicles and chargers in Parker can be seen as a first generation of equipment that has been designed with power services in mind—representing a stride forward for the field of Vehicle–Grid Integration.

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## Abbreviations

The following abbreviations are used in this manuscript:

AC	Alternating Current
DC	Direct Current
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FCR	Frequency Containment Reserves
GIV	Grid Integrated Electric Vehicles
V2G	Vehicle-To-Grid
VGI	Vehicle–Grid Integration

Appendix A

### The Parker “VGI service catalog” 2.0

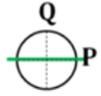
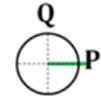
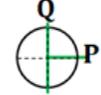
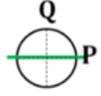
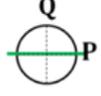
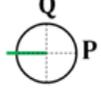
Domain	Categories	Service examples	Short description	EV+EVSE requirements	USER
				Controllability/Performance	Incentives
<b>Region</b> (Transmission) 	Power balancing	Synthetic inertia	Mimics inertia of rotating machines	 <ul style="list-style-type: none"> <li>-Fast activation</li> <li>-Controllable ramping rate</li> <li>- Bidirectional (V2G)</li> </ul>	 Availability payment
		Frequency containment	Keeps the frequency in a desired window		
	Energy Balancing	Wholesale energy	Provide responsiveness to varying energy prices	 <ul style="list-style-type: none"> <li>(no special performance requirements)</li> </ul>	 Savings on energy costs / Renewable-based charging
Regulation	Balances energy schedules/portfolios				
Marginal emission	Defer charging based on the energy sources that will cover marginal consumption in a given hour.				
<b>Neighborhood</b> (Distribution) 	Grid contingencies	Loading issues	Mitigate overloading of transformers and cables in LV network. Can also include phase load balancing.	 <ul style="list-style-type: none"> <li>- Reactive power capabilities</li> </ul>	 Savings on connection costs /compensation from utility
		Voltage issues	Mitigate over- or undervoltages in LV network		
	Energy Autonomy	Bilateral trading	Local peer-to-peer trading of energy.	 <ul style="list-style-type: none"> <li>- Bidirectional (V2B)</li> </ul>	 Savings/Independence
Self consumption maximization	Ensure the highest possible utility of locally produced energy				
<b>Building</b> (behind meter) 	Islanded operation	Back-up power	Sustain a small power system temporarily disconnected from the grid.	 <ul style="list-style-type: none"> <li>- Bidirectional (V2B)</li> <li>-Islanding capability</li> </ul>	 Security of supply /Independence
		Fully Off-grid	Sustain a small power system permanently disconnected from the grid.		
	Mobile load serving	Vehicle-to-tool	Provide a mobile power-source for equipment during in-field use.	 <ul style="list-style-type: none"> <li>- Bidirectional (V2L)</li> </ul>	 Access to mobile power source
Vehicle-to-Vehicle	Provide energy directly from one vehicle to another				

Figure A1. Full Parker service catalog.

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