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Article

The Parker project: Cross-brand service testing using V2G

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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

1. Introduction

Electrification of transportation is a key component in meeting international CO₂ 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) explore 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 [1-14].

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

33 the distribution system to acting as mobile loads in Vehicle-To-Tool applications, has vastly different
34 requirements to the abilities and performance of the EV and the electric vehicle supply equipment
35 (EVSE). Namely the support of vehicle-to-grid (V2G) and the speed with which power can be controlled
36 may determine the range of services that an EV and its EVSE may be able to provide.

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

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

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

51 This paper is organized as follows: first, related work will be described in a "State of the art" section,
52 next "Power and energy services" will describe the services identified and explored by the Parker
53 project. Then, the section "Experimental validation" will describe the components and configuration
54 used in the test-setup and present data from three different tests. Finally, the paper will conclude on
55 study presented in this paper and contemplate future work.

56 2. State of the art

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

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

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

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

76 **In [15] the authors use a statistical assessment approach to determine the potential of using**
77 **V2G for ancillary services considering constraints from car usage and local grid limits. Further in**
78 **[16] the potential is explored in terms of earnings through frequency containment reserves using**
79 **V2G enabled EVs considering driving requirements and the efficiency of the V2G chargers used.**
80 **In [17] the authors explore the earning potential for frequency regulation in the UK based on a**
81 **large dataset of real EV driving data and historical market prices. Finally the paper [18] compare**

82 the earning potential of providing frequency containment reserves both with and without the use
83 of V2G.

84 Other publications deal with the mechanisms which may be used to gain value from V2G. In
85 [19] V2G is used to prevent imbalances in the distribution grid. The suggested approach involves
86 a real-time coordination with local PV installations. In [20] a stochastic optimization model is
87 proposed to control a fleet of V2G enabled vehicles to support a reliability-oriented distribution
88 grid reconfiguration. Finally, [21] provide a review of optimization techniques which may be used
89 for EV integration.

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

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

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

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

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

109 3. Power and energy service

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

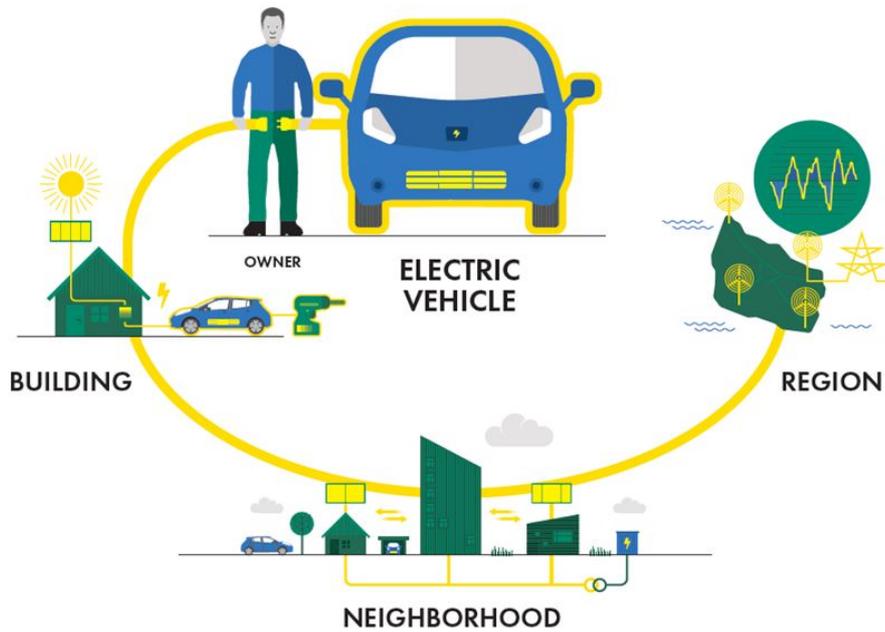


Figure 1. Vehicle-Grid Integration - possible uses of the EV

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

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

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

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

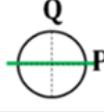
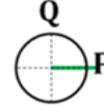
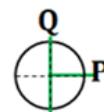
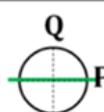
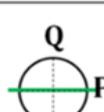
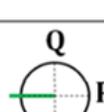
Domain	Categories	Service examples	EV+EVSE requirements	
			Controllability/Performance	
Region (Transmission) 	Power balancing	Synthetic inertia		-Fast activation -Controllable ramping rate -Bidirectional (V2G)
		Frequency containment		
Neighborhood (Distribution) 	Energy Balancing	Regulation		(no special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

Figure 2. Parker service catalog

Below follows a brief description of each category:

- **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.

Fig. 2 also indicate 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 denote 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.

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

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

150 4. Experimental validation

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

154 4.1. Experimental setup

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

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

170 A set of services from the Parker service catalog has been selected for experimental validation.
171 Services has then been tested across all project vehicles to investigate cross-brand support. The
172 following subsections presents three different tests and describes the four EV models ability to provide
173 them.

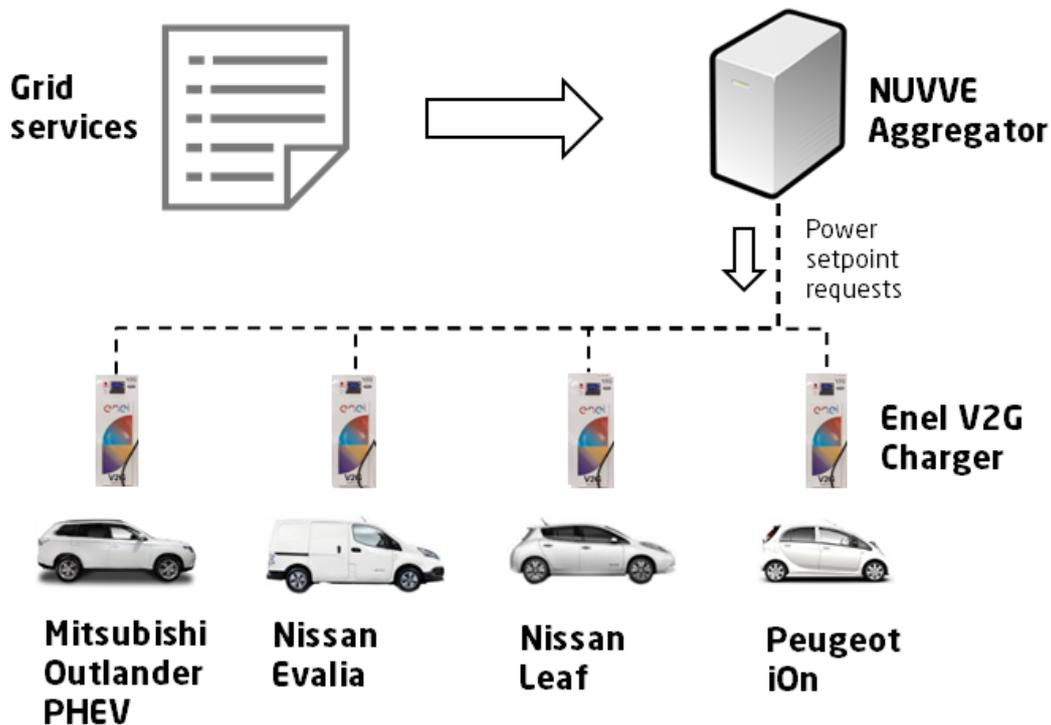


Figure 3. Parker reference configuration



Figure 4. Parker laboratory setup

174 4.2. Service - Marginal Emission Factor

175 The first service belongs to the energy balancing category and is fairly easy to provide as it does
 176 not depend on V2G nor has high requirements in regards to activation time. This service can informally
 177 be referred to as smart charging and simply postpone charging until periods where it is more suitable
 178 to consume energy. Many EVs already support static smart charging where EV owners can specify
 179 a fixed time for charging to commence, e.g. informed by a time-of-use tariff. This particular service
 180 represents a dynamic smart charging scenario where the time suitable for energy consumption may
 181 change on a frequent basis and it therefore may be more practical to leave the charging control to a third
 182 party such as an EV aggregator.

183 Specifically, this service seeks to reduce the CO_2 production caused by charging. With
 184 sufficient energy data and forecasts it is possible to identify the hours of the day where the

185 added load of EVs is likely to cause the least additional CO_2 emission considering the marginal
 186 production. A marginal emission factor (MEF) has been developed in the Parker project in
 187 collaboration with the company Tomorrow, which captures the additional CO_2 emissions of each
 188 additional unit of electricity consumed.

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

190 In Fig. 5 (top) Requested power is used to let the EVs charge in hours with the lowest MEF
 191 signal value. The majority of energy needed is charged using the 1st hour of the test - while the
 192 remainder is charged during the 4th hour. This is a result of the 1st and 4th hours having the
 193 lowest MEF value and thus offering the least CO_2 intensive energy. All cars can be seen to follow
 194 the requested power rather accurately - The vehicles with smaller batteries (Outlander and iOn)
 195 can be seen to reduce the charging power as the batteries are approaching full capacity.

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

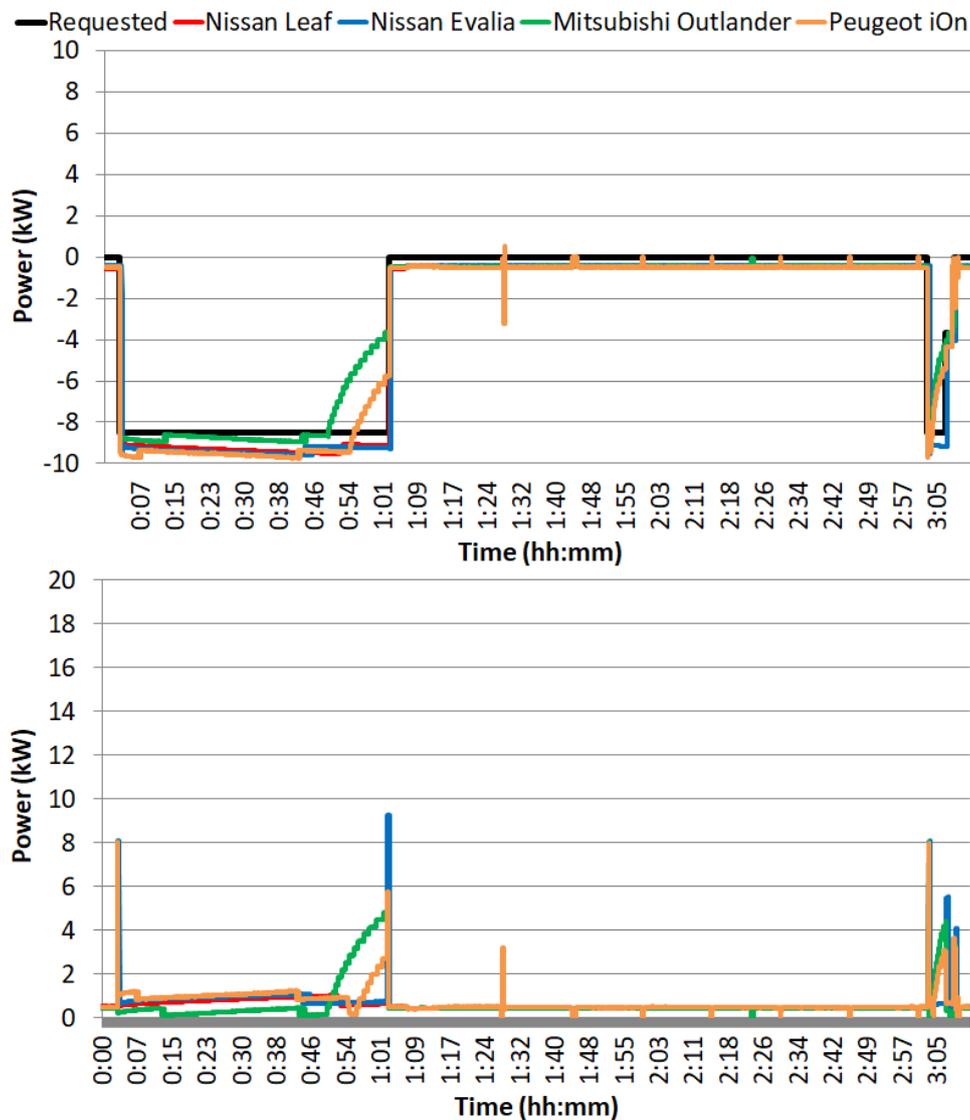


Figure 5. Parker service - Marginal Emission Factor, top: requested and provided power for service, bottom: absolute difference between requested and provided power

199 4.3. Service - Frequency Containment Reserves

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

205 FCR services has response requirements spanning from 150 sec down to 5 sec depending on
 206 the specific product provided. The ability to support V2G substantially strengthen an EVs ability to
 207 provide FCR.

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

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

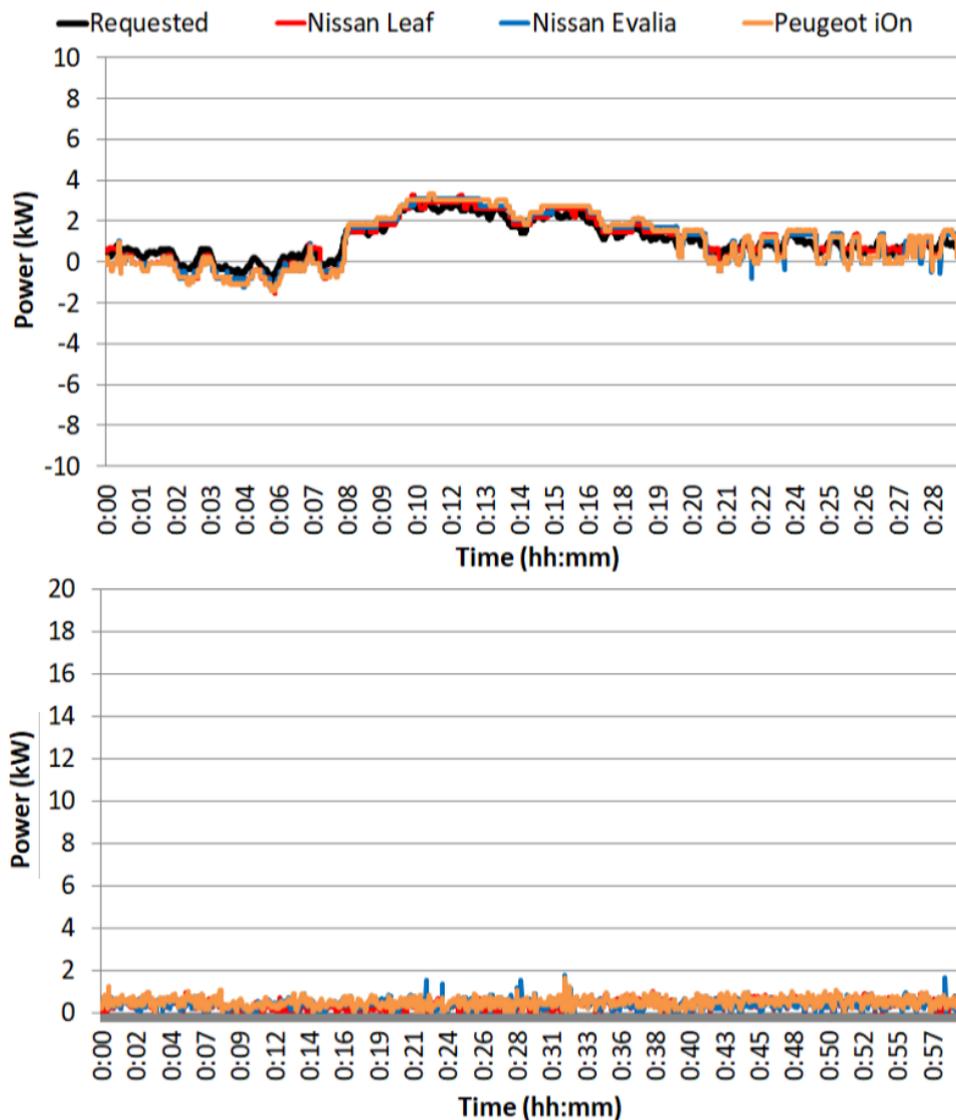


Figure 6. Parker service - Frequency Containment Reserves, top: requested and provided power for service, bottom: absolute difference between requested and provided power

215 4.4. Active power performance test

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

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

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

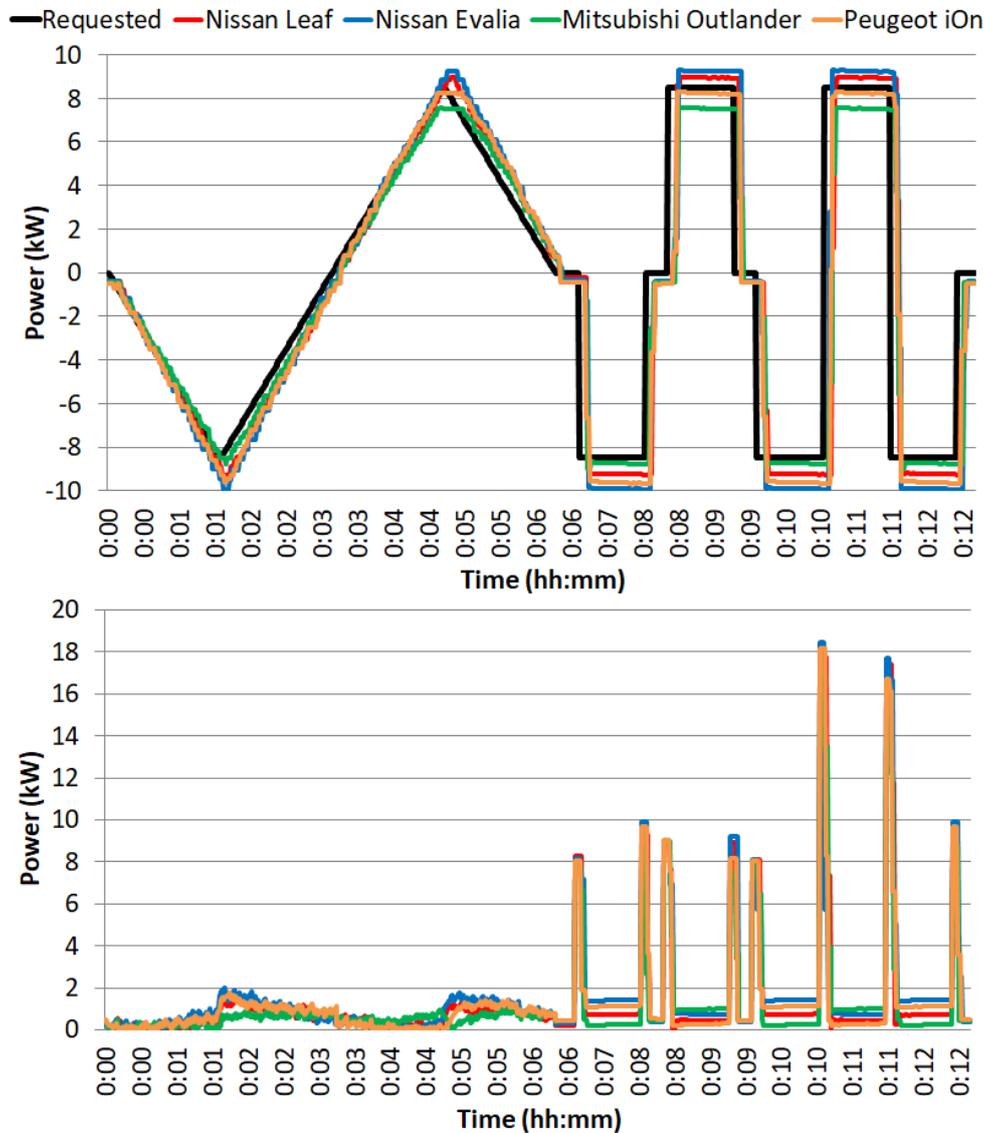


Figure 7. Parker performance test - active power, top: requested and provided power for test, bottom: absolute difference between requested and provided power

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

229 5. Conclusion

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

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

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

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

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

259 **Author Contributions:** methodology, P.B.A., S.H., T.S., T.M.S., L.N. and B.C.; data curation, L.N., B.C. and P.B.A.;
260 visualization, P.B.A.; project administration, P.B.A.; writing—original draft preparation, P.B.A.; Writing - review &
261 editing, P.B.A., S.H., T.S., T.M.S., L.N. and B.C.

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264 Abbreviations

265 The following abbreviations are used in this manuscript:

266	EV	Electric Vehicle
	EVSE	Electric Vehicle Supply Equipment
	FCR	Frequency Containment Reserves
267	GIV	Grid Integrated Electric Vehicles
	V2G	Vehicle-To-Grid
	VGI	Vehicle-Grid Integration

268

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325 **Appendix A**

The Parker “VGI service catalog” 2.0

Domain	Categories	Service examples	Short description	EV+EVSE requirements		USER Incentives
				Controllability/Performance		
Region (Transmission)	Power balancing	Synthetic inertia	Mimics inertia of rotating machines		-Fast activation -Controllable ramping rate -Bidirectional (V2G)	Availability payment
		Frequency containment	Keeps the frequency in a desired window			
Neighborhood (Distribution)	Energy Balancing	Wholesale energy	Provide responsiveness to varying energy prices		(no special performance requirements)	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.			
Building (behind meter)	Grid contingencies	Loading issues	Mitigate overloading of transformers and cables in LV network. Can also include phase load balancing.		-Reactive power capabilities	Savings on connection costs / compensation from utility
		Voltage issues	Mitigate over- or undervoltages in LV network			
Building (behind meter)	Energy Autonomy	Bilateral trading	Local peer-to-peer trading of energy.		- Bidirectional (V2B)	Savings/indep endence
		Self consumption maximization	Ensure the highest possible utility of locally produced energy			
		Back-up power	Sustain a small power system temporarily disconnected from the grid.			
Building (behind meter)	Islanded operation	Fully Off-grid	Sustain a small power system permanently disconnected from the grid.		- Bidirectional (V2B) -Islanding capability	Security of supply / independence
		Mobile load serving	Vehicle-to-tool Vehicle-to-Vehicle			

Figure A1. Full Parker service catalog