



Financial Shortfall for Electric Vehicles: economic impacts of Transmission System Operators market designs

Paul Codani, Yannick Perez, Marc Petit

► To cite this version:

Paul Codani, Yannick Perez, Marc Petit. Financial Shortfall for Electric Vehicles: economic impacts of Transmission System Operators market designs. *Energy*, 2016, 113, pp.422-431. 10.1016/j.energy.2016.07.070 . hal-01346860

HAL Id: hal-01346860

<https://centralesupelec.hal.science/hal-01346860>

Submitted on 19 Mar 2018

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Financial Shortfall for Electric Vehicles: economic impacts of Transmission System Operators market designs

Paul Codani^{a,*}, Yannick Perez^{a,b}, Marc Petit^a

^a*Group of Electrical Engineering Paris (GeePs), UMR CNRS 8507, CentraleSupélec, UPSud, UPMC, Gif-sur-Yvette, France*

^b*RITM Lab, University of Paris-Sud, Orsay, France*

Abstract

Using electric vehicles as transmission system operator reserve providing units has been demonstrated as being both a feasible and a profitable solution. However, the surveys leading to these conclusions are always conducted either without considering the transmission system operator market rules, or using the existing ones from the local system operator. Nevertheless, such rules have potentially a great impact on the electric vehicles' expected revenues, and they are likely to change within the next few years. This paper aims to assess how these rules impact the ability for electric vehicles to provide power reserves and on their expected remuneration for doing so. First, a list of the most important market rules for this use case is drawn up. Then, a simulation model is developed in order to evaluate the expected revenues for the electric vehicles. Finally, these expected revenues are computed considering various combinations of rules. A loss of revenue for electric vehicles is identified, due to the use of non-optimal rules governing grid services remuneration. Considering the French case, according to the simulation results, this financial shortfall per vehicle and per year ranges from 193€ to 593€. Market design recommendations for reserve markets are deduced from these results.

Keywords: Electric Vehicles; Frequency control; Vehicle-to-Grid; Regulation; Economics

1. Introduction

In order to cope with the objectives of reductions in CO₂ emissions in both electricity grids and transportation systems, governments' environmental-friendly

*Corresponding author:

Email address: paul.codani@centralesupelec.fr (Paul Codani)

4 policies tend to incentivize the use of alternative fuels for propelling vehicles.
5 Among the possible technical options, plug-in vehicles (EVs) driven by electric
6 motors and powered by electrochemical batteries represent a promising solution.
7 As a consequence, an increasing number of car manufacturers now have plug-in
8 hybrid and fully electric vehicles in their product lines and EV sales are expected
9 to increase significantly within the next few years [1].

10 However, EV sales are not yet following their expected trend: for instance in
11 December 2015, the EV market share only reached 1.2% in France [2], and the
12 initial forecast of having 2 million EVs on the roads by 2020 has been downgraded
13 to 500,000 [3]. EV sales are increasing slowly for three main reasons: (a) the
14 limited EV driving ranges compared with their equivalent in conventional vehicles;
15 (b) the lack of charging infrastructure; and (c) their relatively high price [4].

16 One suggested way to deal with the latter issue is to use EVs as distributed
17 storage units when they are plugged-in – in France, this entails more than 95% of
18 the time [5] – turning them into so-called Grid Integrated Vehicles (GIVs). Such
19 a GIV has a means of communication, a controllable charging rate, and, in this
20 case, is able to supply Vehicle-to-Grid power, i.e. to inject power back to the grid.
21 Under these conditions, GIVs participate in the grid system’s wide balance between
22 production and demand; they are active components of the smart grids, in which
23 demand becomes more controllable and able to follow the generation patterns.

24 According to the literature, the most profitable solution is the integration of
25 EVs into Transmission System Operator (TSO)¹ reserves [6] – mainly to provide
26 frequency regulation reserves. In this case, a fleet of GIVs is controlled by and
27 reports to a central aggregator, which is responsible for presenting the fleet as a
28 single entity in the frequency control market.

29 This solution has been intensively studied in the scientific literature, both from
30 a technical and an economic point of view. Complex multi-objective optimization
31 problems were proposed, solving linear [7] or quadratic problems [8]. Economic
32 earnings were evaluated for various areas such as Germany [9] or PJM area in the
33 United States [6], sometimes taking battery degradation into account [10]. Sim-
34 ilarly, there are several ongoing demonstration projects, in particular in the USA
35 (California, Delaware) and in Europe (Denmark) [11]. These theoretical papers
36 bear little consideration for the rules and regulations of the targeted electricity mar-
37 ket: they are either ignored in the case of technical surveys, or considered as given
38 in most economic studies. However, there is a wide diversity of electricity mar-
39 ket rules and regulations across the world and even within Europe, mainly because
40 TSOs face different technological and economic challenges, and have different

¹In the United States, TSOs are referred to as Independent System Operators (ISOs)

41 topologies and energy mixes [12]. Moreover, with the liberalization of electricity
42 markets, TSO market rules are likely to evolve within the next few years in order
43 to better support the three main energy policy pillars of the European Union (EU):
44 security of supply, sustainability, and competitiveness.

45 Thus, in a smart grid environment, electromobility could be a promising so-
46 lution not only to reduce local air pollution, but also to manage intermittent dis-
47 tributed generation (DG). For instance, reference [13] shows how solar and wind
48 sources could be coupled with EV charging load curves in France at the regional
49 scale. It has also been demonstrated that lowest costs and best voltage profiles were
50 achieved in power distribution networks by combining various DG sources with
51 EVs [14]. Similar conclusions are found at the system-wide scale [15]. However,
52 in order to achieve this potential future, integrated grids require adapted technical
53 and regulatory structures that are not complete yet. Electricity grids, and hence
54 their regulatory frameworks, have a key role to play in facilitating this transforma-
55 tion from vertically integrated systems to the emergence of new actors, services,
56 and storage technologies. In this work, the authors analyze the regulatory changes
57 that are required to align grid needs with grid users' incentives in order to promote
58 the development of electromobility.

59 More specifically, the authors assess the economic impacts of the implemented
60 market rules and regulations on the expected revenues of a fleet of GIVs providing
61 frequency regulation. In order to do so, the existing frequency regulation rules from
62 six TSOs are reviewed and a 'best combination' of existing rules with respect to
63 this solution studied is presented. Then, a simulation model which was developed
64 in a previous work is implemented [16]. This model is applied for two different
65 sets of market rules; the first one represents the current French rules, while the
66 second one is the aforementioned 'best combination'. The simulation results are
67 used to infer frequency control market design recommendations.

68 In this paper, the authors work from the perspective of EV car owners; the
69 expected revenues are entirely intended for them. The aggregator is assumed to be a
70 benevolent third party; obviously, in real life, the aggregator should earn something
71 out of these revenues, but addressing business models is beyond the scope of this
72 paper.

73 The paper is organized as follows. Section 2 presents the survey of the TSO
74 rules. In section 3, the simulation model is recalled and the data used are described.
75 Section 4 features and discusses the simulation results under two combinations of
76 rules: a best case and the current French rules. Policy considerations are inferred
77 from these results in section 5.

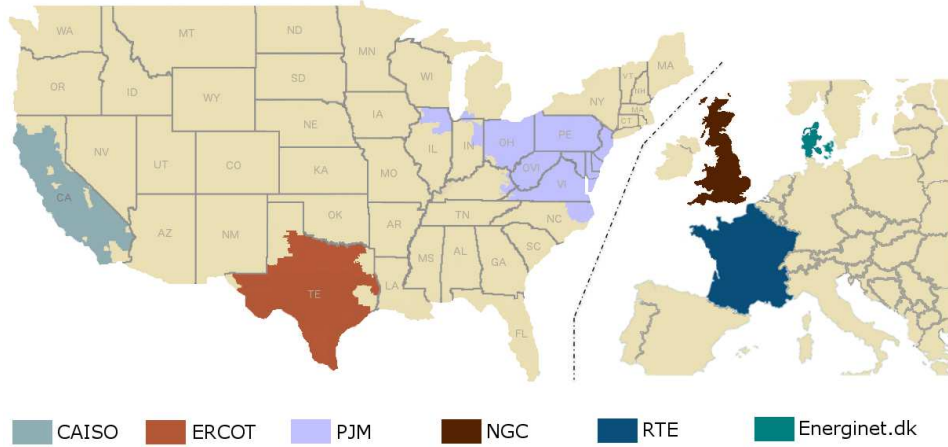


Figure 1: Maps of the six TSOs under study

2. TSO rules survey

Six TSOs are compared by screening their manuals on a list of rules and characteristics that are important for GIV deployment. The six TSOs in question, represented in Figure 1, are: Energinet.dk (Denmark), RTE (France), ERCOT (Texas, USA), CAISO (California, USA), PJM (North-East, USA), and NGC (UK). The associated regulatory manuals are [17], [18, 19, 20], [21, 22, 23, 24, 25], [26, 27, 28, 29], [30, 31, 32, 33] and [34, 35, 36].

Based on the findings from this analysis, and on feedback from the GridOn-Wheels [37] and Nikola [38] demonstration projects, two essential and relevant sets of rules (hereafter called modules) that assemble the critical regulation for enabling the participation of GIV fleets to grid services are identified: the rules presiding over the aggregation of GIVs, and the rules establishing the payment scheme of the services provided by GIVs. The objective of this approach is to finally be able to determine a 'best combination' of frequency control rules for GIV fleets based on the authors' opinions and on the point of views of researchers involved in the aforementioned demonstration projects. The two modules are described in more detail in the two following subsections.

95 *2.1. Module 1: the rules governing the aggregation of Electric Vehicles*

96 An aggregator² has a key role in the organization enabling the provision of TSO
97 services by GIV: it is in charge of presenting a GIV fleet as a one and only body to
98 the TSO. Aggregators are necessary for the following reasons: (a) TSOs are used
99 to treating with large entities, (b) TSOs do not have the information processing
100 abilities to control numerous kW size units; they were thought up for a few multi-
101 MW size power plants, and (c) TSOs count on reliable resources, which is an issue
102 for a unique GIV. Transportation remains the priority for GIV, but from the grid
103 viewpoint, one GIV is likely to unplug at any time. Aggregators are able to deal
104 with these matters by supervising a huge amount of GIVs [39] and presenting a
105 unique, statistically-reliable entity to the TSO.

106 On the other hand, such GIV coalition should be made possible by TSO rules.
107 Here, three main rules are underlined: the smallest bidding size allowed in the
108 market, the possibility to aggregate across several Distribution System Operators
109 (DSOs), and the technical level of aggregation.

110 *2.1.1. Minimum bidding size*

111 All TSO markets require bids to have a minimum size [40]; throughout this
112 analysis, a spectrum of least bid from 100 kW to 10 MW was observed. As far as
113 GIV aggregations are concerned, this minimum-bidding value leads to a minimum
114 number of GIVs. A substantial minimum bidding value would be a challenge for
115 the development of pilot and early commercial projects, since the GIV fleet in
116 question may miss some vehicles to meet the requirement.

117 As an example, considering electric vehicle supply equipments (EVSE) of
118 3kW, and a GIV availability factor of one third for grid services' markets, 100
119 GIV would be required to meet a minimum bid value of 100kW. However, if this
120 minimum was set to 10MW, 10,000 GIV would then be needed. Comparing these
121 results with those of today's EV sales (there are approximately 50,000 EVs in
122 France [2]) shows that making an aggregation of private electric vehicles in France
123 would be extremely difficult³.

124 Even if EV penetration was more important, a significant minimum bidding
125 value would restrict the variety of possible aggregators: for instance, company
126 fleets would not be admitted as aggregators.

²An aggregator is typically a third party entity, but different stakeholders could fulfill its role: System Operators, utility companies, car OEMs, etc.

³Note that the geographical location of the EVs bears little importance here as the frequency value is the same at each node of the network.

127 *2.1.2. Possibility to aggregate across DSOs*

128 The possibility to aggregate GIV across multiple DSO technical areas is also
129 a major concern for aggregators. GIVs can potentially change their location, and
130 they may be spread across several DSO zones⁴. This problem is all the more im-
131 portant that there are numerous DSOs working with one TSO: reference [41] shows
132 that some TSOs work mainly with a single DSO (as in France, where ERDF is re-
133 sponsible for 97% of the distribution grid), but some others work with many DSOs
134 (there are, for example, more than 850 DSOs in Germany). Not being able to ag-
135 gregate across DSOs when there are so many of them would make aggregation
136 almost unfeasible. The most favorable option is therefore to allow such cross-DSO
137 aggregation.

138 More broadly speaking, according to [42], an extended cooperation between
139 the DSOs and the TSOs will be necessary to ensure a cost-efficient integration of
140 Distributed Energy Resources (DERs) in the future, and this is in particularly true
141 for GIVs.

142 *2.1.3. Operational versus financial-only aggregation*

143 Finally, a difference between operational and financial-only aggregations should
144 be made. The best form of aggregation is the operational one; it makes it possible
145 to combine bids and then for a central aggregator to directly control distributed
146 power flows. In other words, the aggregator may deaggregate the TSO request
147 among its units as it wish. In a financial-only aggregation, aggregators are only
148 allowed to merge financial bids, but the deaggregation of the TSO request is not
149 at the sole discretion of the aggregator, it is bound by the individual offers of each
150 unit.

151 Table 1 summarizes the main findings for this module. For each rule, the best
152 and the most restrictive applications that were observed throughout the TSO anal-
153 ysis are indicated.

154 *2.2. Module 2: the rules governing the remuneration scheme*

155 The provision of grid services by GIVs is a mean to lower the total cost of
156 ownership (TCO) of EVs. Indeed, the GIV fleet will earn revenues from its partic-
157 ipation in the frequency control market. As a consequence, the payment scheme of
158 these grid services is of paramount importance. GIVs should be remunerated in a
159 fair manner, and from an economic perspective, this remuneration should at least
160 cover the induced costs. Such costs include battery degradation and hardware and
161 software investments. They are beyond the scope of this paper.

⁴Registering EVSE rather than GIV may settle the issue of locational shift, but EVSE would still be spread across various DSOs.

Table 1: The Different Organizations for Module 1

<i>Rule</i>	<i>Organization</i>	
	<i>Best Option</i>	<i>Restrictive Option</i>
R1: Minimum size	100kW	10MW
R2: Aggregation across DSO	Possible	Impossible
R3: Aggregation level	Operational	Financial

162 2.2.1. Remuneration scheme: regulated or market based

163 TSOs have several means at their disposals to dispatch the power among the
164 units that are participating in a grid service. The two main ways of doing so are
165 proceeding through open markets or through regulated contracts [43]. In the former
166 solution, participating units may bid in the market as they wish. A bid is typically
167 consisted of a capacity and its price. Depending on its needs, the TSO will then
168 accept all or part of the bids. This approach ensures transparency in the dispatch
169 process. In the latter solution, the dispatch method differs from one unit to the
170 other, as each unit has its own contract with the TSO. For instance, some TSO base
171 the amount of capacity to be provided by a particular unit on its historical load
172 share.

173 Auction markets are much more appropriate than regulated approaches for new
174 innovative units such as GIV. Regulated approaches are very lengthy to change;
175 however, quick regulatory adaptations are required to integrate new resources. Fur-
176 thermore, considering a GIV fleet, some vehicles are likely to join and leave the
177 coalition at any moment; as a consequence, a fixed bilateral contract might turn out
178 to be very constraining for an aggregator.

179 2.2.2. Imperfection of the remuneration scheme

180 It is striking to point out grid services that are mandatory but not remunerated
181 by some TSOs. For instance, PJM and CAISO do not pay for primary frequency
182 control. In this case, participating in primary frequency control is mandatory for
183 all power plants, which have to bear the costs of providing this control mechanism.

184 The more imperfect the remuneration scheme and the less it compensates the
185 services provided, the less GIV fleets are able to recover the value of their flexibil-
186 ity. In the 'best combination' of rules for GIVs, all existing services are necessarily
187 remunerated.

188 On the other hand, TSOs could also benefit from improving and completing
189 their remuneration scheme. Indeed, units which have to compulsorily provide ser-
190 vices without getting paid perform usually poorly. For example, the provision of

191 primary frequency control in the US has significantly deteriorated throughout the
192 years [44], arising security concerns.

193 2.2.3. *Additional financial bonus for extreme flexibility*

194 According to the Federal Energy Regulatory Commission (FERC), present re-
195 muneration methods for TSO grid services are unfair and discriminatory [45]. This
196 is particularly due to the fact that fast ramping units (units that have the ability to
197 adapt their power setpoint rapidly) are not compensated enough considering the
198 bigger quantity of reserve capacity they supply in a brief moment in comparison
199 with slow-ramping units.

200 The FERC suggests ways to address this issue. First, all MWh that are ac-
201 tually exchanged between the grid and a unit for grid service purposes should be
202 considered in absolute value as a source of positive revenue for the unit, no matter
203 the flowing direction of the MWh. This implies that remuneration schemes in-
204 clude a utilization component (in \$/MWh) in addition to the traditional availability
205 component (in \$/MW). Fast ramping units supply more MWh than slow ramping
206 ones, thus their remuneration would be higher with the suggested payment scheme.
207 Moreover, the FERC suggests that accuracy and response time should be taken into
208 account in the payment calculation method [45], what would be beneficial to fast-
209 ramping resources.

210 GIV are able to adjust their power very quickly [46]. As a consequence, GIV
211 fleets achieve better earnings if such financial bonus is implemented by the TSO.

212 Another option would be to consider fast and slow ramping bids as two separate
213 products. A market dedicated to the trading of fast ramping bids only would be
214 created, with its own remuneration scheme which would be more adapted to fast
215 ramping units.

216 Finally, most of today's electrical grids are highly interconnected, and thus
217 may not feel an urgent need for fast-ramping products. Rather, in a first time, such
218 products may be of particular interest in case of extreme disturbances on the grid.
219 Then, as unpredictable and intermittent renewable sources' penetration increases,
220 more and more flexibility means will be required to balance production and de-
221 mand: fast ramping units may become a necessity. This has already been noted in
222 island grids, which are very responsive to grid disturbances⁵ as, for instance, in the
223 Danish island of Bornholm [47].

224 Table 2 summarizes the main findings concerning the remuneration scheme,
225 and the various organizations observed. As for Table 1, the options presented in

⁵Many island networks are isolated, i.e. they are connected to other networks only through DC lines.

226 this table were identified by means of the TSO rules analysis.

Table 2: The Different Organizations for Module 2

<i>Rule</i>	<i>Organization</i>	
	<i>Best Option</i>	<i>Restrictive Option</i>
R4: Nature of the remuneration	Market Based	Regulated
R5: Imperfection of the remuneration	All grid services should be remunerated	Incomplete payment scheme
R6: Financial bonus for extreme flexibility	Set at the efficient level, or separate market created	Not Existing

227 2.3. Partial conclusion

228 Two sets of rules were identified, leading to different forms of organization. A
 229 best case, a worst case, and some intermediate cases can now be defined. Table 3
 230 sums up the findings for both modules and for all TSOs⁶. A wide diversity of TSO
 231 rules is observed.

232 To go one step further, the financial shortfall for GIVs when a ‘bad’ combi-
 233 nation of rules is implemented should be evaluated and quantified, in comparison
 234 with the ‘best combination’ for GIVs. In order to do so, a simulation model which
 235 will enable to assess the expected GIV revenues needs to be developed.

236 3. Simulation Model

237 In this section, the basics of the simulation model used to assess the economic
 238 revenues of the GIV fleet are recalled; this model has already been described in
 239 a previous work [16]. In section 2, the most important rules for GIVs providing
 240 TSO services were identified; in order to perform an economic evaluation, a par-
 241 ticular TSO service market has to be selected. The present analysis focuses on the
 242 primary frequency control (see 3.1) market. It is worth noting that GIVs could
 243 provide TSOs with other grid services, such as secondary frequency control, bal-
 244 ancing mechanisms, etc. This work focuses on primary frequency control because:
 245 (a) GIVs are very fast responding units, and the aforementioned demonstration

⁶The TSO manuals were analyzed during the years 2013-2014. Some of the rules may have changed since then; however, the overall rationale of this analysis and how it is used to compare various TSO regulatory frameworks remains valid.

Table 3: Summary of the identified rules for each TSO understudied^a

<i>Rule</i>	<i>TSO</i>					
	<i>CAISO</i>	<i>ERCOT</i>	<i>PJM</i>	<i>NGC</i>	<i>RTE</i>	<i>Energinet.dk</i>
R1	0.5MW	0.1MW	0.1MW	10MW	1MW	0.3MW
R2	Not Possible	Not Possible	Not Possible	Possible	Possible	Possible
R3	Financial	Financial	Operational	Operational	Operational	Operational
R4	Market based	Market based	Market based	Market based	Regulated	Market based
R5	Incomplete payment scheme	Incomplete payment scheme	Incomplete payment scheme	Incomplete payment scheme	All AS are remunerated	All AS are remunerated
R6	Yes	No	Yes	No	No	No

^aRules as they were in 2013 - 2014. Some of the rules may have changed since then, what would not change the rationale of the present work.

246 projects proved GIV fleets capable of providing primary control from a technical
 247 perspective [48]; (b) primary frequency control induces solicitations which are av-
 248 eragely null in energy, as shown below in Figure 4, which is very interesting from
 249 an EV perspective; (c) market clearing periods can be very short (down to an hour)
 250 for this service, which is also very interesting for a GIV fleet.

251 3.1. Primary frequency control

252 The analysis focuses on the provision of primary frequency control by Grid
 253 Integrated Vehicles (GIV). The grid frequency continuously oscillates around its
 254 nominal value (50Hz in Europe). Transmission System Operators (TSO) are re-
 255 sponsible for ensuring that the frequency deviations do not exceed a predefined
 256 range. As electricity is produced by synchronous machines, the frequency – linked
 257 to the generator’s mechanical speed – mirrors the real time equilibrium between
 258 production and demand. If the mechanical power produced by the power plants’
 259 turbines exceeds the electricity power demand, the frequency will get over its nom-
 260 inal value and inversely. Consequently, TSOs manage the frequency by means of
 261 three control levels, which aim to balance production and demand in real time.

262 The first level is called *primary* frequency control. Its objective is to end the
 263 frequency divergence, but the frequency does not retrieve its original value. Pri-
 264 mary reserve units read the frequency value by themselves, and adapt their power
 265 output to this measurement and according to specific rules [16]. References [49]

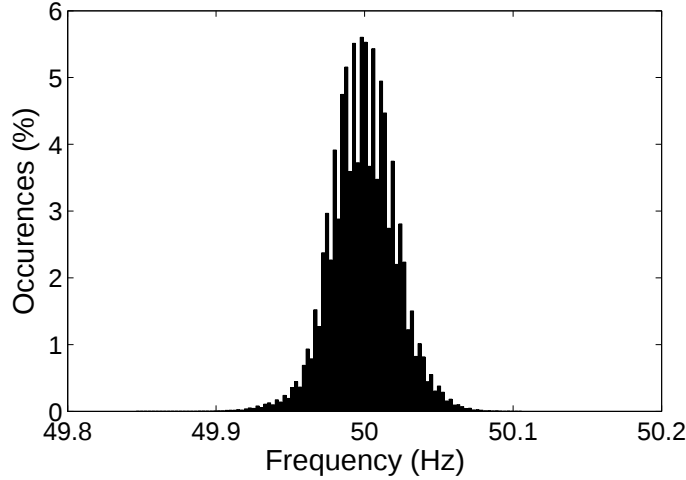


Figure 2: Distribution function of the frequency recording

266 and [50] provide more details about frequency control mechanisms from technical
 267 and economic perspectives, respectively.

268 A full month of frequency data was recorded at CentraleSupélec in April 2014
 269 by means of a frequency meter. These measurements abide by ENTSO-E (Euro-
 270 pean Network of Transmission System Operators for Electricity) requirements, i.e.
 271 they have a resolution better than 10mHz and the frequency evaluation period is
 272 1s. A summary of the frequency data set characteristics is provided in Table 4, and
 273 Figure 2 displays the distribution function of the recording used. In order to check
 274 the consistency of these measurements, their characteristics were compared over
 275 the same period of time with those of the RTE data set available on the RTE web-
 276 site [51] (which only has a 10-second time stamp, and this is it was not satisfactory
 277 for the present simulations).

278 The two data sets turn out to have very similar characteristics. In particular, the
 279 frequency is contained in the interval $[49.95\text{Hz} ; 50.05\text{Hz}]$ 97% of the time; within
 280 this interval, primary reserve units should provide less than 25% of their reserve.

281 The main limitation of the frequency recording is that it only covers one month
 282 of frequency variations; some more extreme events could have happened during the
 283 year. Moreover seasonal effects, which are not represented in this data set, might
 284 have an impact on frequency variations.

285 3.2. *GIV fleet*

286 The EV fleet model is the same as in [16]. Here, the main hypothesis are
 287 recalled, please refer to [16] for the complete justifications. All GIV are assumed

Table 4: Main characteristics of the frequency data set used, and comparison with RTE measurements

<i>Criteria</i>	<i>Author data set</i>	<i>RTE data set</i>	<i>Difference (%)</i>
Mean (Hz)	50	50	-0,002
Std (Hz)	0,02	0,02	0,4
Min (Hz)	49,9	49,9	-0,01
Max (Hz)	50,1	50,1	0
P(49,95 < f < 50,05)	0,97	0,97	-0,22

288 to have a 22kWh battery. The state-of-charge (SOC) is kept within the range $0.2 <$
289 $SOC/SOC_{max} < 0.9$ in order not to get to extreme SOC values, which could lead
290 to significant battery degradation (such phenomenon is observed at the cell level
291 [52] and may then be extended at the battery level [53]). All GIV are supposed to
292 be able to provide Vehicle-to-Grid (V2G) power, i.e. to inject power back to the
293 grid.

294 GIV have the opportunity to charge during the night, with their *primary* EVSE,
295 or at work during the day with their *secondary* EVSE. As the availability of charg-
296 ing stations at workplaces in the future is very uncertain, four scenarios are built,
297 which are detailed in Table 5.

Table 5: The four scenarios for secondary EVSE penetration levels

<i>Scenarios</i>	<i>Ratio of GIVs having an EVSE at work</i>
Scenario 1	0%
Scenario 2	25%
Scenario 3	50%
Scenario 4	75%

298 The available charging power values and their associated penetration levels at
299 home and work places are summarized in Table 6.

300 The GIV trip characteristics are based on several references: internal PSA
301 Groupe data, ministerial surveys [5] and demonstration project results [54]. The
302 data used are very consistent with the real French transportation habits; the ministe-
303 rial survey was built upon more than 35,000 observations. Similarly, PSA Groupe
304 data are very representative of their users. Demonstration project results were used

Table 6: Breakdown of Primary and Secondary EVSEs by Charging Technology Type

<i>Charging level</i>	<i>Primary EVSE</i>	<i>Secondary EVSE</i>
Slow charging A (3kW)	95%	35%
Slow charging B (7kW)	5%	34%
Intermediate charging (22kW)	0%	29%
Fast charging (43kW)	0%	2%

305 to check the consistency of the different data set, and to have real life energy con-
306 sumption values. The GIV fleet model is stochastic and dynamic: each GIV has
307 its own trip characteristics, which differ from one day to the other. GIV average
308 distance trips (D), departure time (T_d), daily number of trips (N) and seasonal en-
309 ergy consumption (E) are provided in Table 7. As GIVs are only used for the daily
310 commuting trips, there are two trips a day for each GIV. D and T_d are distributed
311 according to Gaussian distributions with mean μ and standard deviations σ .

Table 7: Trip-related models and parameters

<i>Trip data</i>	<i>Model</i>	<i>Parameter values</i>
Daily trip numbers	Steady value	2
Trip distances	$d \sim \mathcal{N}(d_{data}; \sigma_d)$	d_{data} : internal use σ_d : 5km
Departure times	$t \sim \mathcal{N}(t_{mean}; \sigma_t)$	t_{mean} : Best adapted to usual commuting trips σ_t : 2 hours
Consumption	Steady values	c_{summer} 129Wh/km c_{winter} = 184Wh/km

312 The advantage of the modeling approach considered here is that each GIV is
313 modeled independently. Thus, extreme driver behaviors are taken into account by
314 using probabilistic distribution functions. Similarly, the availability of each in-
315 dividual GIV is used to build the overall fleet availability (*bottom-up* approach).
316 Many papers model GIV fleets as large single batteries [55], what makes it eas-
317 ier for computation, but less accurate with respect to the individual situation of
318 each GIV. For instance, using a single battery model, it would not be possible to

319 identify a GIV not capable of performing its next trip because it lacks energy for
 320 transportation, which is not satisfactory even if only one single GIV is concerned.

321 Obviously, covering only commuting trips in weekdays is not completely sat-
 322 isfactory. Future work should consist in enlarging the authors' databases in order
 323 to improve these routines. However, these trips can be considered as very repre-
 324 sentative since they account for most of the trips and kilometers driven in France
 325 [56], which makes them a good first basis for estimation.

326 3.3. Aggregator's algorithm

327 This part focuses on the aggregator's dispatch algorithm, which is used to dis-
 328 patch the power among the GIV in real time. The operating principle, based on the
 329 one described in [39], is as follows:

- 330 1. At each market clearing period, each GIV i computes its individual contribu-
 331 tion for the coming market period P_{bid_i} , and communicates this value to the
 332 aggregator. The latter, by summing up all the individual GIV contributions,
 333 deduces the total fleet power available for frequency control P_{bid} until the
 334 next market clearing period.
- 335 2. Then, within this period, the aggregator reads the frequency at each time
 336 stamp and, depending on the frequency value, calculates the power for fre-
 337 quency control that should be provided to the TSO P_{reg} according to equa-
 338 tion (1):

$$P_{reg} = \begin{cases} -\frac{f - f_0}{f_{max} - f_0} P_{bid}, & |f - f_0| < 0.2Hz \\ P_{bid}, & |f - f_0| \geq 0.2Hz \end{cases} \quad (1)$$

339 with f the grid frequency, $f_0 = 50Hz$, $f_{max} = 50.2Hz$, P_{bid} the power
 340 bid in the market, and P_{reg} the power actually provided for frequency con-
 341 trol. This equation reflects the required response of primary reserve units to
 342 frequency deviations [57].

- 343 3. The aggregator computes a scaling factor $\mu = P_{reg}/P_{bid}$.
- 344 4. The aggregator sends to all GIVs their final individual contribution $\mu * P_{reg_i}$.
- 345 5. Start back from point 1 for every new market clearing period (every hour),
 346 otherwise from point 2.

347 Figure 3 pictures the various steps of the algorithm.

348 The calculation method of each individual GIV contribution (step 1) is based
 349 on the Preferred Operating Point (POP) of this vehicle, which is equivalent to the
 350 operating point of a traditional unit (such as a power plant); it represents the charg-
 351 ing rate around which the GIV will provide frequency control. The POP calculation
 352 method is described in [16].

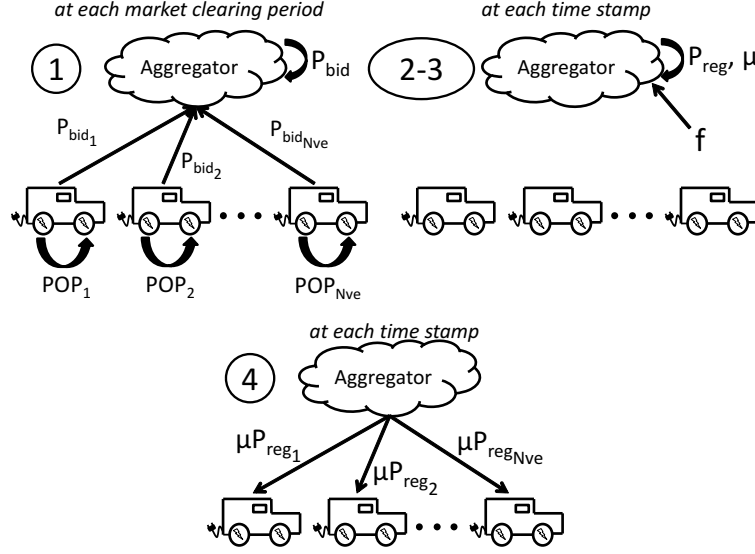


Figure 3: Dispatch algorithm operating scheme

353 The algorithm used here is a decentralized algorithm; as a consequence, it
 354 would be easily scalable to a large fleet of GIVs. Moreover, each GIV remains
 355 in control of its charging limits. Centralized algorithms perform slightly better in
 356 providing grid services, but computation time is much higher (thus they are much
 357 less scalable) and the entire decision process comes back to the aggregator.

358 3.4. Simulation parameters

359 For each EVSE power level, 100 simulations are run following the Monte Carlo
 360 approach for 100 GIVs. The simulations are performed with a one second time
 361 stamp over 5 week days. In order to compute the revenues, market prices from
 362 the Danish primary control market are used. They are provided on an hourly basis
 363 [58]. Five days of uninterrupted market prices as well as five continuous days of
 364 frequency values are arbitrarily selected from the data sets.

365 4. Results and Discussions

366 In this section, the results from simulations based on the model described in
 367 section 3 are provided, under two combinations of the rules that were detailed
 368 in section 2. First, the two selected combinations of rules are described and ex-
 369 plained. Then, the results successively for the two use cases are provided. At last,

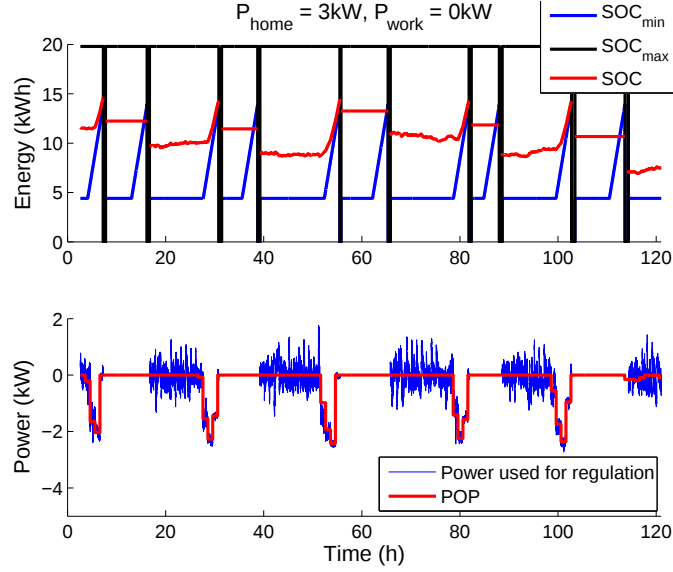


Figure 4: Simulation results for a single bidirectional capable GIV over 5 working days, with $P_{home} = 3kW$ and $P_{work} = 0kW$

the possible future evolutions of the rules are discussed by screening the ENTSO-E (European Network of Transmission System Operators for Electricity) network codes.

But beforehand, as an example, Figure 4 displays some simulation results for a GIV whose home EVSE is able to deliver 3kW, and which does not have any EVSE at workplace. The impact of the POP is noticeable: when the SOC is getting too close to its lower limit (SOC_{min}), the vehicle starts charging and always reaches its needs for transportation.

4.1. Simulation use cases

Based on the TSO analysis presented in section 2, two different representative combinations of rules are selected:

Combination A: this set of rules corresponds to the current French rules. Based on these rules, storage units are not allowed to participate in the frequency control market. RTE dispatches the required power among the production units, "based on their historical load share". In return, the latter are remunerated according to a fixed tariff amounting to 8.48€/MW for 30 minutes [19] (thus, there is no bonus for extra-flexibility). The minimum bidding size is 1MW.

388 **Combination B:** this set of rules corresponds to the 'best combination' of rules for
389 GIV fleets identified in section 2. Under this regulation, primary frequency
390 control is organized via an hourly auction market. There is no barrier to new
391 entrants, so GIV coalitions can compete like any other unit. Moreover, they
392 receive a bonus for their extra-flexibility. In order to account for this financial
393 bonus, the market prices from Energinet.dk are raised by 30% (this percent-
394 age has been observed at the UD project where a bonus is implemented by
395 PJM). The minimum bidding size is low (100kW), enabling small fleets to
396 participate in the market.

397 A simplistic view of these two combinations of rules is presented in Table 8.

Table 8: Combinations of rules under study

<i>Rule</i>	<i>Combination A: current RTE rules</i>	<i>Combination B: best setting for GIVs</i>
R1: Minimum Size	N/A	100kW
R2: Possibility to aggregate across DSOs	Possible	Possible
R3: Aggregation Level	Not Possible	Telemetry
R4: Nature of the remuneration	Regulated	Market-based
R5: Consistency of the remuner- ation scheme	All grid services are remunerated	All grid services are remunerated
R6: Bonus for extra flexibility	Not existing	Set at the efficient level

398 4.2. Comparison of combinations A and B: results

399 Under the combination of rules A, GIVs are not allowed to participate in the
400 frequency control market; aggregation of distributed energy resources are not al-
401 lowed to join in this regulated market. Even if they were, GIV fleets would have
402 a very limited remuneration because: (a) RTE dispatches the reserve among the
403 units based on their historical load share and (b) the payment scheme is a regu-
404 lated tariff set for long periods of time. Moreover, the minimum bidding amount
405 is rather high, which could prevent early adopters (such as small company fleets)
406 from entering the market.

407 As for combination of rules B, earnings per power level of charging station
408 are provided in Table 9. Week-end revenues are not reflected in these findings,

409 which only cover working days, so the actual GIV remuneration would be more
 410 important over one year. Results are much dependent on the EVSE power level,
 411 as the remuneration scheme is based on €/MW. A typical GIV owner, with a 3kW
 412 domestic plug and no EVSE at work could earn 130€/year. On the other side, a
 413 GIV owner with a 7kW charging station at home and a 22kW charging station at
 414 work could earn up to 1,448€/year.

Table 9: Average earnings per vehicle and per year depending on the EVSE power level for combination of rules B

<i>EVSE power level (kW)</i>		
<i>Primary</i>	<i>Secondary</i>	<i>GIV revenues / year (€)</i>
3	0	180
3	3	310
3	7	505
3	22	1,346
7	0	474
7	3	543
7	7	780
7	22	1,448

415 If the results are averaged per charging station for the entire fleet and for the
 416 different scenarios (based on Tables 5 and 6), the average yearly revenues per EV
 417 and for each scenario may be computed. Results are featured on Table 10.

Table 10: Average earnings per GIV and per year for each scenario and for combination B

<i>Scenario</i>	<i>Average yearly GIV revenues (€)</i>
Scenario 1	149
Scenario 2	251
Scenario 3	353
Scenario 4	456

418 These expected revenues shed some light on the loss of revenues for GIVs due
 419 to the implementation of restrictive TSO rules. Under the combination of rules
 420 A, GIVs are merely not allowed to participate in the frequency control regulated

market (so their revenues amount to 0). Under the combination of rules B, they can expect to earn between 193€ and 593€ a year.

4.3. Possible future evolutions of the market rules understudied

In order to anticipate future changes in the rules in Europe, the ENTSO-E network codes (which are still at the draft step) are screened [59, 60, 61, 62, 63]. These documents pave the way for future European TSO regulation. The suggested rules in the network codes are compared with the best combination of rules for GIV fleets that was found in this survey. Results are presented in Table 11.

Table 11: Identified best combination of rules for GIVs compared to ENTISOE guidelines

<i>Rule</i>	<i>Best Combination of ENTISOE Proposals rules for GIVs</i>	
R1: Minimum Size	100kW	Not addressed
R2: Possibility to aggregate across DSOs	Possible	Not clearly defined, but TSOs and DSOs should make all endeavors and cooperate in order to ease the participation to DSR
R3: Aggregation Level	Telemetry	Status of <i>aggregator</i> defined. Telemetry aggregation considered for FCR up to 1.5MW
R4: Nature of the remuneration	Market Based	Market Based
R5: Consistency of the remuneration scheme	All AS should be paid	All AS should be paid
R6: Bonus for extra flexibility	Set at the efficient level / separate market created	DSR VFAPC should be implemented

According to this table, ENTSO-E proposals are pushing TSO regulation in the correct direction to enable the participation of GIVs in the TSO reserve markets, although, based on the structure found, it seems that they could go one step further towards the best combination of rules for GIVs. If the future development of the network codes maintain the same approach, the incentives of grid operators, electricity service providers and GIV users should be aligned. Integrated grids need a regulatory framework addressing simultaneously grid services, grid technology innovations and grid users.

437 5. Conclusions

438 The presented simulation results show that, under the ideal market design for
439 GIV fleets, GIVs could achieve significant earnings. The Total Cost of Ownership
440 of GIVs could be notably reduced. Obviously, our simulation model is quite simple
441 and does not take into account the myriad of parameters TSOs have to deal
442 with. Still, considering the identified diversity of existing TSO rules, the results
443 indicate possible improvements in the TSO market rules, which are listed below.
444 These possible improvements could be investigated further by each TSO, or by the
445 European association ENTSO-E.

- 446 1. A legal framework and a formal status for distributed storage units could be
447 considered in TSO rules. Indeed, in most of the rules that were analyzed,
448 there were no special considerations regarding storage units, which there-
449 fore have to abide by both producer and consumer rules and requirements.
450 As a consequence, rules do not seem to be adapted to them yet. For in-
451 stance, energy costs were not considered in this survey because payments for
452 frequency control are based on availability (€/MW). Nevertheless, because
453 GIVs constantly charge and discharge, it would be much more beneficial
454 for them to be granted net metering. Similarly, compliance tests, ongoing
455 validation procedures, etc. could be defined specifically for storage units,
456 bearing in mind their particular technical characteristics.
- 457 2. The rules could ease and encourage the building of coalitions of small dis-
458 tributed units. Such aggregations would have a single entry point from the
459 TSO perspective (even if non-material), which would enable them to dis-
460 patch the power flows among the distributed units as they wish, thus maxi-
461 mizing the aggregations' ability to bid in the electricity markets. Moreover,
462 the minimum number of GIV required in the coalition could be kept low in
463 order to foster early adopters and thus technology deployment. Several rules
464 have an impact on the minimum number of GIVs in the aggregation: the
465 minimum bidding amount, which could be kept as low as possible, and the
466 possibility to aggregate GIVs across various Distribution System Operators.
- 467 3. All grid services could be remunerated in a fair and transparent manner, so
468 that no grid service would be left unremunerated, as is the case with primary
469 frequency control in some regions today. Adapted markets could be imple-
470 mented for the provision of all grid services. Markets increase transparency
471 in the sense that they enable participating units to clearly understand the
472 clearing price formation, and the reserve allocation method. The remunera-
473 tion level should not be discriminatory and, for example, extra bonus for
474 fast ramping units could be considered as a way to incentivize these fleets to
475 provide the services needed.

476 The best combination of rules for GIVs provide a roadmap for electricity grids
477 and their regulatory frameworks to evolve towards an efficient grid integration of
478 plug-in vehicles. Both TSOs, because they could take advantage of new efficient
479 reserve providing units, and GIV owners, because they could lower their TCO,
480 would benefit from an evolution of the rules towards the identified best combination
481 for GIVs. The simulation results show that GIV owners could be involved in the
482 process thanks to the financial incentives calculated from the simulations; without
483 customers' involvement, it would not be possible to develop such solutions.

484 There are several challenges in having TSOs changing their rules towards the
485 identified best combination. First, changing TSO rules is a lengthy process that
486 should be carried out thoroughly. Indeed, TSO costs are reflected in electricity
487 tariffs for end users, thus any change in the rules that could have an impact on
488 electricity bills should be deeply analyzed and validated by the local regulation
489 commission. Any market design correction should not result in other unexpected
490 market disruption. Then, because the priority of TSOs is the security of supply,
491 i.e. to serve all their customers at all times. Considering this fact, some TSOs
492 might be reluctant to change towards rules which could improve competitiveness or
493 sustainability, but whose impact on the security of supply is considered uncertain.
494 Nevertheless, ENTSO-E network codes will come into effect in a near future, and
495 TSOs will have to comply with these new requirements.

496 Future work could consist in going one step further by conducting a similar
497 analysis on the technical parameters of the frequency market rules. For instance,
498 simulations could provide insights into the relevant market clearing period value
499 (which was arbitrarily set to one hour in this survey) or on whether UP and DOWN
500 products should be procured jointly or separately. Furthermore, the provision of
501 other grid services (such as secondary control, balancing mechanisms, etc.) by GIV
502 fleets could be investigated. Multidisciplinary approaches should be considered,
503 taking into account economics, technical and regulatory aspects.

504 **Acknowledgments**

505 Paul Codani benefits from the support of the Chair "PSA Peugeot Citroen Auto-
506 mobile: Hybrid technologies and Economy of Electromobility", so-called Armand
507 Peugeot Chair led by CentraleSuplec, and ESSEC Business School and sponsored
508 by PEUGEOT CITROEN Automobile.

509 We would like to thank the research teams of the GridOnWheels and Nikola
510 projects for their valuable inputs. In particular, the authors gratefully acknowledge
511 the contributions of Willett Kempton (University of Delaware), Bjoern Christensen
512 (Nuvve), Ole Jan Olesen (Nikola project) and Olivier Borne (CentraleSupélec). At

513 last, the authors would like to thank Martin Hennebel (CentraleSupélec) for helping
514 with the frequency data set.

515 References

- 516 [1] International Energy Agency, Global EV Outlook (2013).
517 URL [https://www.iea.org/publications/
518 globalevoutlook{_}2013.pdf](https://www.iea.org/publications/globalevoutlook{_}2013.pdf)
- 519 [2] Avere, Plus de 22 000 véhicules électriques immatriculés en France
520 en 2015 !, [http://www.aver-france.org/Site/Article/
521 ?article_id=6424&from_espace_adherent=0](http://www.aver-france.org/Site/Article/?article_id=6424&from_espace_adherent=0), Last Accessed
522 April 4th, 2016 (January 2016).
- 523 [3] RTE, Bilan prévisionnel de l'équilibre offre-demande d'électricité en
524 France, [http://www.rte-france.com/sites/default/
525 files/bilan_complet_2014.pdf](http://www.rte-france.com/sites/default/files/bilan_complet_2014.pdf) (2014).
- 526 [4] Board on Energy and Environmental Systems; Division on Engineering and
527 Physical Sciences; Transportation Research Board, Overcoming Barriers to
528 Electric-Vehicle Deployment, National Academies Press, Washington, D.C.,
529 2013. doi:10.17226/18320.
530 URL <http://www.nap.edu/catalog/18320>
- 531 [5] Commissariat Général au Développement Durable, Les véhicules électriques
532 en perspectives, [http://www.developpement-durable.gouv.
533 fr/IMG/pdf/ED41.pdf](http://www.developpement-durable.gouv.fr/IMG/pdf/ED41.pdf), Last Accessed Julyst, 2016 (2011).
534 URL [http://www.developpement-durable.gouv.fr/IMG/
535 pdf/ED41.pdf](http://www.developpement-durable.gouv.fr/IMG/pdf/ED41.pdf)
- 536 [6] W. Kempton, J. Tomić, Vehicle-to-grid power fundamentals: Calculating ca-
537 pacity and net revenue, *Journal of Power Sources* 144 (1) (2005) 268–279.
538 doi:10.1016/j.jpowsour.2004.12.025.
- 539 [7] E. Sortomme, M. a. El-Sharkawi, Optimal Scheduling of Vehicle-to-Grid En-
540 ergy and Ancillary Services, *IEEE Transactions on Smart Grid* 3 (1) (2012)
541 351–359. doi:10.1109/TSG.2011.2164099.
- 542 [8] S. Vandaël, T. Holvoet, G. Deconinck, S. Kamboj, K. Willett, A comparison
543 of two V2G mechanisms for providing ancillary services at the University of
544 Delaware, in: *IEEE International Conference On Smart Grid Communica-
545 tions, IEEE, Vancouver (Canada), 2013*, pp. 211 – 216.

- 546 [9] D. Dallinger, D. Krampe, M. Wietschel, Vehicle-to-Grid Regulation Reserves
547 Based on a Dynamic Simulation of Mobility Behavior, *IEEE Transactions on*
548 *Smart Grid* 2 (2) (2011) 302–313. doi:10.1109/TSG.2011.2131692.
- 549 [10] S. Han, S. Han, K. Sezaki, Economic assessment on V2G frequency regula-
550 tion regarding the battery degradation, in: 2012 IEEE PES Innovative Smart
551 Grid Technologies, ISGT 2012, 2012. doi:10.1109/ISGT.2012.6175717.
- 552 [11] P. Bach Andersen, R. Garcia-Valle, W. Kempton, A comparison of electric
553 vehicle integration projects, in: 2012 3rd IEEE PES Innovative Smart Grid
554 Technologies Europe (ISGT Europe), no. 081216 in 1, IEEE, 2012, pp. 1–7.
555 doi:10.1109/ISGTEurope.2012.6465780.
- 556 [12] V. Rious, J.-M. Glachant, Y. Perez, P. Dessante, The diversity
557 of design of TSOs, *Energy Policy* 36 (9) (2008) 3323–3332.
558 doi:10.1016/j.enpol.2008.05.010.
- 559 [13] P. Codani, P. L. L. Portz, P. Claverie, M. Petit, Y. Perez, Coupling local re-
560 newable energy production with electric vehicle charging: a survey of the
561 French case, *International Journal of Automotive Technology and Manage-*
562 *ment* 16 (1) (2016) 55. doi:10.1504/IJATM.2016.076443.
563 URL <http://www.inderscience.com/link.php?id=76443>
- 564 [14] H. Fathabadi, Utilization of electric vehicles and renewable energy
565 sources used as distributed generators for improving characteristics
566 of electric power distribution systems, *Energy* 90 (2015) 1100–1110.
567 doi:10.1016/j.energy.2015.06.063.
568 URL [http://linkinghub.elsevier.com/retrieve/pii/](http://linkinghub.elsevier.com/retrieve/pii/S0360544215008191)
569 [S0360544215008191](http://linkinghub.elsevier.com/retrieve/pii/S0360544215008191)
- 570 [15] M. Carrión, R. Zárate-Miñano, Operation of renewable-dominated power
571 systems with a significant penetration of plug-in electric vehicles, *Energy* 90
572 (2015) 827–835. doi:10.1016/j.energy.2015.07.111.
573 URL [http://linkinghub.elsevier.com/retrieve/pii/](http://linkinghub.elsevier.com/retrieve/pii/S0360544215010063)
574 [S0360544215010063](http://linkinghub.elsevier.com/retrieve/pii/S0360544215010063)
- 575 [16] P. Codani, M. Petit, Y. Perez, Participation of an Electric Vehicle fleet to
576 primary frequency control in France, *International Journal of Electric and*
577 *Hybrid Vehicles* 7 (3). doi:10.1504/IJEHV.2015.071639.
- 578 [17] Energinet.dk, Ancillary services to be delivered in Den-
579 mark Tender conditions, [https://www.energinet.dk/](https://www.energinet.dk/SiteCollectionDocuments/Engelske%20dokumenter/)
580 [SiteCollectionDocuments/Engelske%20dokumenter/](https://www.energinet.dk/SiteCollectionDocuments/Engelske%20dokumenter/)

581 El/8871-11%20v3%20Ancillary%20services%20to%
582 20be%20delivered%20in%20Denmark%20-%20Tender%
583 20conditions.%20Valid%20from%203%20October%202012.
584 pdf (2012).

585 [18] Reseaux de Transport d'Electricite, Mémento de la sûreté du système
586 électrique, [https://eco2mix.rte-france.com/uploads/](https://eco2mix.rte-france.com/uploads/media/pdf_zip/publications-annuelles/memento_surete_2004_complet_.pdf)
587 [media/pdf_zip/publications-annuelles/memento_](https://eco2mix.rte-france.com/uploads/media/pdf_zip/publications-annuelles/memento_surete_2004_complet_.pdf)
588 [surete_2004_complet_.pdf](https://eco2mix.rte-france.com/uploads/media/pdf_zip/publications-annuelles/memento_surete_2004_complet_.pdf) (2004).

589 [19] Reseaux de Transport d'Electricite, Documentation Technique de Référence
590 Chapitre 4.1 - Contribution des utilisateurs aux performances du RPT,
591 [http://clients.rte-france.com/htm/fr/mediatheque/](http://clients.rte-france.com/htm/fr/mediatheque/telecharge/reftech/30-06-05_article_4-8__v1.pdf)
592 [telecharge/reftech/30-06-05_article_4-8__v1.pdf](http://clients.rte-france.com/htm/fr/mediatheque/telecharge/reftech/30-06-05_article_4-8__v1.pdf)
593 (2011).

594 [20] Reseaux de Transport d'Electricite, Documentation technique de référence
595 Article 8.10: Modèle de contrat de participation aux services système (2011).
596 URL [http://www.rte-france.com/uploads/](http://www.rte-france.com/uploads/Mediatheque{_}docs/offres{_}services/reftech/03-02-11{_}complet.pdf)
597 [Mediatheque{_}docs/offres{_}services/reftech/](http://www.rte-france.com/uploads/Mediatheque{_}docs/offres{_}services/reftech/03-02-11{_}complet.pdf)
598 [03-02-11{_}complet.pdf](http://www.rte-france.com/uploads/Mediatheque{_}docs/offres{_}services/reftech/03-02-11{_}complet.pdf)

599 [21] Electric Reliability Council of Texas, Nodal Protocols Section 8: Per-
600 formance Monitoring, [http://www.ercot.com/mktrules/](http://www.ercot.com/mktrules/nprotocols/current)
601 [nprotocols/current](http://www.ercot.com/mktrules/nprotocols/current) (2012).

602 [22] Electric Reliability Council of Texas, Nodal Protocols Section 6: Ad-
603 justment Period and Real-Time Operations, [http://www.ercot.com/](http://www.ercot.com/mktrules/nprotocols/current)
604 [mktrules/nprotocols/current](http://www.ercot.com/mktrules/nprotocols/current) (2013).

605 [23] Electric Reliability Council of Texas, Nodal Protocols Section 4: Day-Ahead
606 Operations, [http://www.ercot.com/mktrules/](http://www.ercot.com/mktrules/nprotocols/current)
607 [current](http://www.ercot.com/mktrules/nprotocols/current) (2013).

608 [24] Electric Reliability Council of Texas, Nodal Protocols Section 3: Man-
609 agement Activities for the ERCOT System, [http://www.ercot.com/](http://www.ercot.com/mktrules/nprotocols/current)
610 [mktrules/nprotocols/current](http://www.ercot.com/mktrules/nprotocols/current) (2013).

611 [25] Electric Reliability Council of Texas, Nodal Protocols Section 16: Registra-
612 tion and Qualification of Market Participants, [http://www.ercot.com/](http://www.ercot.com/mktrules/nprotocols/current)
613 [mktrules/nprotocols/current](http://www.ercot.com/mktrules/nprotocols/current) (2013).

- 614 [26] California Independent System Operator, Rules for net metering (2013).
 615 URL http://www.dsireusa.org/incentives/incentive.cfm?Incentive{_}Code=CA02R
 616
- 617 [27] California Independent System Operator, Tariff Clar-
 618 ifications to Implement Pay for Performance Reg-
 619 ulation, [http://www.caiso.com/Documents/](http://www.caiso.com/Documents/TariffClarifications-ImplementPay-PerformanceRegulation.pdf)
 620 [TariffClarifications-ImplementPay-PerformanceRegulation.](http://www.caiso.com/Documents/TariffClarifications-ImplementPay-PerformanceRegulation.pdf)
 621 pdf, Last Accessed July 1st, 2016 (2013).
 622 URL [http://www.caiso.com/Documents/](http://www.caiso.com/Documents/TariffClarifications-ImplementPay-PerformanceRegulation.pdf)
 623 [TariffClarifications-ImplementPay-PerformanceRegulation.](http://www.caiso.com/Documents/TariffClarifications-ImplementPay-PerformanceRegulation.pdf)
 624 pdf
- 625 [28] California Independent System Operator, Non-Generator Resources
 626 - Regulation Energy Management - Frequently Asked Ques-
 627 tions, [https://www.caiso.com/Documents/FrequentlyAskedQuestions-](https://www.caiso.com/Documents/FrequentlyAskedQuestions-NonGeneratorResourceRegulationEnergyManagementMarketSimulation.pdf)
 628 [NonGeneratorResourceRegulationEnergyManagementMarketSimulation.pdf](https://www.caiso.com/Documents/FrequentlyAskedQuestions-NonGeneratorResourceRegulationEnergyManagementMarketSimulation.pdf)
 629 (2011).
 630 URL [\url{https://www.caiso.com/Documents/](https://www.caiso.com/Documents/FrequentlyAskedQuestions-NonGeneratorResourceRegulationEnergyManagementMarketSimulation.pdf)
 631 [FrequentlyAskedQuestions-NonGeneratorResourceRegulationEnergyManagement](https://www.caiso.com/Documents/FrequentlyAskedQuestions-NonGeneratorResourceRegulationEnergyManagementMarketSimulation.pdf)
 632 pdf}
- 633 [29] California Independent System Operator, Proposal for participation of non-
 634 generator resources in California ISO ancillary services markets, [http://](http://www.caiso.com/246f/246fb968171e0.pdf)
 635 www.caiso.com/246f/246fb968171e0.pdf (2009).
- 636 [30] PJM Interconnection, Manual 1: Control Center and Data Exchange Require-
 637 ments, [http://www.pjm.com/~media/documents/manuals/](http://www.pjm.com/~media/documents/manuals/m01.ashx)
 638 [m01.ashx](http://www.pjm.com/~media/documents/manuals/m01.ashx) (2013).
- 639 [31] PJM Interconnection, Manual 10: Pre-Scheduling Operations, [https://](https://www.pjm.com/~media/documents/manuals/m10.ashx)
 640 www.pjm.com/~media/documents/manuals/m10.ashx (2013).
- 641 [32] PJM Interconnection, Manual 11 : Energy & Ancillary Services, [http://](http://www.pjm.com/~media/documents/manuals/m11.ashx)
 642 www.pjm.com/~media/documents/manuals/m11.ashx (2013).
- 643 [33] PJM Interconnection, Manual 12: Balancing Operations, [http://www.](http://www.pjm.com/~media/documents/manuals/m12.ashx)
 644 [pjm.com/~media/documents/manuals/m12.ashx](http://www.pjm.com/~media/documents/manuals/m12.ashx) (2012).
- 645 [34] National Grid, Balancing code 3: Frequency control process, [http:](http://www2.nationalgrid.com/uk/industry-information/electricity-codes/grid-code/the-grid-code/)
 646 [//www2.nationalgrid.com/uk/industry-information/](http://www2.nationalgrid.com/uk/industry-information/electricity-codes/grid-code/the-grid-code/)
 647 [electricity-codes/grid-code/the-grid-code/](http://www2.nationalgrid.com/uk/industry-information/electricity-codes/grid-code/the-grid-code/), Last Ac-
 648 cessed April 4th, 2016 (2012).

- 649 [35] National Grid, CUSC - Section 4 Balancing Services, <http://www2.nationalgrid.com/uk/industry-information/electricity-codes/cusc/the-cusc/>, Last Accessed April 4th,
650
651 2016 (2012).
652
- 653 [36] National Grid, Grid Code Chapter 06 - Connection conditions, <http://www2.nationalgrid.com/uk/industry-information/electricity-codes/grid-code/the-grid-code/>, Last Ac-
654
655 cessed April 4th, 2016 (2013).
656
- 657 [37] GridOnWheels project, Gridonwheels project webpage, <http://grid-on-wheels.com>, Last Accessed July 1st, 2016 (2016).
658
659 URL <http://grid-on-wheels.com/>
- 660 [38] Nikola project, Nikola project webpage, <http://www.nikola.droppages.com/>, Last Accessed April 30th, 2016 (2016).
661
662 URL <http://www.nikola.droppages.com/>
- 663 [39] S. Kamboj, W. Kempton, K. S. Decker, Deploying Power Grid-Integrated
664 Electric Vehicles as a Multi-Agent System, 10th Int. Conf. on Autonomous
665 Agents and Multiagent Systems - Innovative Applications Track (AAMAS)
666 1 (Aamas) (2011) 2–6.
- 667 [40] E. Koliou, C. Eid, J. P. Chaves-Ávila, R. a. Hakvoort, Demand response
668 in liberalized electricity markets: Analysis of aggregated load participa-
669 tion in the German balancing mechanism, *Energy* 71 (2014) 245–254.
670 doi:10.1016/j.energy.2014.04.067.
671 URL [http://linkinghub.elsevier.com/retrieve/pii/](http://linkinghub.elsevier.com/retrieve/pii/S0360544214004800)
672 [S0360544214004800](http://linkinghub.elsevier.com/retrieve/pii/S0360544214004800)
- 673 [41] K. Knezovic, M. Marinelli, P. Codani, Y. Perez, Distribution grid services
674 and flexibility provision by electric vehicles: A review of options, in: 2015
675 50th International Universities Power Engineering Conference (UPEC),
676 IEEE, Staffordshire (UK), 2015, pp. 1–6. doi:10.1109/UPEC.2015.7339931.
677 URL [http://ieeexplore.ieee.org/lpdocs/epic03/](http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=7339931)
678 [wrapper.htm?arnumber=7339931](http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=7339931)
- 679 [42] Electric Power Research Institute, The Integrated Grid, Tech. rep., Elec-
680 tric Power Research Institute, [http://www.epri.com/Our-Work/](http://www.epri.com/Our-Work/Pages/Integrated-Grid.aspx)
681 [Pages/Integrated-Grid.aspx](http://www.epri.com/Our-Work/Pages/Integrated-Grid.aspx) (2014).
682 URL [http://energy.gov/sites/prod/files/2015/03/f20/](http://energy.gov/sites/prod/files/2015/03/f20/EPRIIntegratedGrid021014.pdf)
683 [EPRIIntegratedGrid021014.pdf](http://energy.gov/sites/prod/files/2015/03/f20/EPRIIntegratedGrid021014.pdf)

- 684 [43] R. Raineri, S. Rios, D. Schiele, Technical and economic aspects of
685 ancillary services markets in the electric power industry : an inter-
686 national comparison, *Energy Policy* 34 (1010750) (2006) 1540–1555.
687 doi:10.1016/j.enpol.2004.11.015.
- 688 [44] J. W. Ingleson, S. Member, E. Allen, D. E. Interconnection, A. Beta, Tracking
689 the Eastern Interconnection Frequency Governing Characteristic, *Power and*
690 *Energy Society General Meeting 2010 IEEE* (2009) 1–6.
- 691 [45] FERC, Order 755 - Frequency Regulation Compensation in the Organized
692 Wholesale Power Markets, [https://www.ferc.gov/whats-new/](https://www.ferc.gov/whats-new/comm-meet/2011/102011/E-28.pdf)
693 [comm-meet/2011/102011/E-28.pdf](https://www.ferc.gov/whats-new/comm-meet/2011/102011/E-28.pdf) (2011).
- 694 [46] P. B. Andersen, M. Marinelli, O. J. Olesen, C. A. Andersen, G. Poilasne,
695 B. Christensen, O. Alm, The Nikola project intelligent electric vehicle
696 integration, in: *IEEE PES Innovative Smart Grid Technologies, Europe,*
697 *IEEE*, 2014, pp. 1–6. doi:10.1109/ISGTEurope.2014.7028765.
698 URL [http://ieeexplore.ieee.org/lpdocs/epic03/](http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=7028765)
699 [wrapper.htm?arnumber=7028765](http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=7028765)
- 700 [47] Yu Chen, Zhao Xu, J. Ostergaard, Frequency analysis for planned islanding
701 operation in the Danish distribution system - Bornholm, in: *2008 43rd*
702 *International Universities Power Engineering Conference, IEEE*, 2008, pp.
703 1–5. doi:10.1109/UPEC.2008.4651467.
704 URL [http://ieeexplore.ieee.org/lpdocs/epic03/](http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=4651467)
705 [wrapper.htm?arnumber=4651467](http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=4651467)
- 706 [48] W. Kempton, V. Udo, K. Huber, K. Komara, S. Letendre, S. Baker, D. Brun-
707 ner, N. Pearre, A Test of Vehicle-to-Grid (V2G) for Energy Storage and
708 Frequency Regulation in the PJM System, *Tech. rep.* (2009).
709 URL [http://www.udel.edu/V2G/resources/](http://www.udel.edu/V2G/resources/test-v2g-in-pjm-jan09.pdf)
710 [test-v2g-in-pjm-jan09.pdf](http://www.udel.edu/V2G/resources/test-v2g-in-pjm-jan09.pdf)
- 711 [49] Y. G. Rebours, D. S. Kirschen, M. Trotignon, A Survey of Frequency and
712 Voltage Control Ancillary Services Part I : Technical Features, *IEEE Trans-*
713 *actions on Power Systems* 22 (1) (2007) 350–357.
- 714 [50] Y. G. Rebours, D. S. Kirschen, M. Trotignon, A Survey of Frequency and
715 Voltage Control Ancillary Services Part II : Economic Features, *IEEE Trans-*
716 *actions on Power Systems* 22 (1) (2007) 358–366.
- 717 [51] *Reseaux de Transport d’Electricite, RTE Frequency Data Set, Webpage,*
718 <https://clients.rte-france.com/lang/fr/visiteurs/>

719 vie/vie_frequence.jsp, Last Accessed July 1th, 2016 (2016).
 720 URL https://clients.rte-france.com/lang/fr/visiteurs/vie/vie_frequence.jsp
 721

722 [52] I. Bloom, B. Cole, J. Sohn, S. Jones, E. Polzin, V. Battaglia, G. Henriksen,
 723 C. Motloch, R. Richardson, T. Unkelhaeuser, D. Ingersoll, H. Case, An accel-
 724 erated calendar and cycle life study of Li-ion cells, *Journal of Power Sources*
 725 101 (2) (2001) 238–247. doi:10.1016/S0378-7753(01)00783-2.

726 [53] I. Fernández, C. Calvillo, A. Sánchez-Miralles, J. Boal, Capacity fade and
 727 aging models for electric batteries and optimal charging strategy for electric
 728 vehicles, *Energy* 60 (2013) 35–43. doi:10.1016/j.energy.2013.07.068.

729 [54] Cross-border Mobility for EVs, Online publications, <http://crome.forschung.kit.edu/francais/57.php> (2013).
 730
 731 URL <http://crome.forschung.kit.edu/francais/57.php>

732 [55] S. Izadkhast, P. Garcia-Gonzalez, P. Frias, An Aggregate Model
 733 of Plug-In Electric Vehicles for Primary Frequency Control,
 734 *IEEE Transactions on Power Systems* 30 (3) (2015) 1475–1482.
 735 doi:10.1109/TPWRS.2014.2337373.
 736 URL <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6871408>
 737

738 [56] CGDD, La mobilité des Français, panorama issu de l’enquête
 739 nationale transports et déplacements 2008., <http://www.developpement-durable.gouv.fr/IMG/pdf/Rev3.pdf>,
 740 Last Accessed Julyst, 2016 (2010).
 741
 742 URL <http://www.developpement-durable.gouv.fr/IMG/pdf/Rev3.pdf>
 743

744 [57] Union for the Co-ordination of Transmission of Electricity, Operation
 745 Handbook, Tech. Rep. June, Union for the Co-ordination of Transmission of
 746 Electricity (2004).
 747 URL [www.pse.pl/uploads/kontener/542UCTE_Operation_](http://www.pse.pl/uploads/kontener/542UCTE_Operation_Handbook.pdf)
 748 [Handbook.pdf](http://www.pse.pl/uploads/kontener/542UCTE_Operation_Handbook.pdf)

749 [58] Energinet.dk, Energinet.dk market clearing prices, <http://energinet.dk/EN/El/Engrosmarked/Udtraek-af-markedsdata/Sider/default.aspx> (2013).
 750
 751 URL <http://energinet.dk/EN/El/Engrosmarked/Udtraek-af-markedsdata/Sider/default.aspx>
 752
 753

- 754 [59] European Network of Transmission System Operators for Elec-
755 tricity, Network Code on Operational Security, [https://www.](https://www.entsoe.eu/major-projects/network-code-development/operational-security/Pages/default.aspx)
756 [entsoe.eu/major-projects/network-code-development/](https://www.entsoe.eu/major-projects/network-code-development/operational-security/Pages/default.aspx)
757 [operational-security/Pages/default.aspx](https://www.entsoe.eu/major-projects/network-code-development/operational-security/Pages/default.aspx), Last Accessed
758 July 1st, 2016 (2013).
759 URL [https://www.entsoe.eu/major-projects/network-code-development/](https://www.entsoe.eu/major-projects/network-code-development/operational-security/)
760 [operational-security/](https://www.entsoe.eu/major-projects/network-code-development/operational-security/)
- 761 [60] European Network of Transmission System Operators for Elec-
762 tricity, Network Code on Demand Connection, [https://www.](https://www.entsoe.eu/major-projects/network-code-development/demand-connection/Pages/default.aspx)
763 [entsoe.eu/major-projects/network-code-development/](https://www.entsoe.eu/major-projects/network-code-development/demand-connection/Pages/default.aspx)
764 [demand-connection/Pages/default.aspx](https://www.entsoe.eu/major-projects/network-code-development/demand-connection/Pages/default.aspx), Last Accessed July
765 1st, 2016 (2012).
766 URL [https://www.entsoe.eu/major-projects/network-code-development/](https://www.entsoe.eu/major-projects/network-code-development/demand-connection/)
767 [demand-connection/](https://www.entsoe.eu/major-projects/network-code-development/demand-connection/)
- 768 [61] European Network of Transmission System Operators for Elec-
769 tricity, Network Code on Electricity Balancing, [https://www.](https://www.entsoe.eu/major-projects/network-code-development/electricity-balancing/Pages/default.aspx)
770 [entsoe.eu/major-projects/network-code-development/](https://www.entsoe.eu/major-projects/network-code-development/electricity-balancing/Pages/default.aspx)
771 [electricity-balancing/Pages/default.aspx](https://www.entsoe.eu/major-projects/network-code-development/electricity-balancing/Pages/default.aspx), Last Accessed
772 July 1st, 2016 (2014).
773 URL [https://www.entsoe.eu/major-projects/](https://www.entsoe.eu/major-projects/network-code-development/electricity-balancing/)
774 [network-code-development/electricity-balancing/](https://www.entsoe.eu/major-projects/network-code-development/electricity-balancing/)
- 775 [62] European Network of Transmission System Operators for Electricity, The
776 Harmonised Electricity Market Role Model (2011).
777 URL [http://www.ebix.org/Documents/role{_}model{_}](http://www.ebix.org/Documents/role{_}model{_}v2011{_}01.pdf)
778 [{_}v2011{_}01.pdf](http://www.ebix.org/Documents/role{_}model{_}v2011{_}01.pdf)
- 779 [63] European Network of Transmission System Operators for Electricity,
780 Network Code on Load-Frequency Control and Reserves, [https://www.](https://www.entsoe.eu/major-projects/network-code-development/load-frequency-control-reserves/Pages/default.aspx)
781 [entsoe.eu/major-projects/network-code-development/](https://www.entsoe.eu/major-projects/network-code-development/load-frequency-control-reserves/Pages/default.aspx)
782 [load-frequency-control-reserves/Pages/default.aspx](https://www.entsoe.eu/major-projects/network-code-development/load-frequency-control-reserves/Pages/default.aspx),
783 Last Accessed July 1st, 2016 (2014).
784 URL [https://www.entsoe.eu/major-projects/](https://www.entsoe.eu/major-projects/network-code-development/load-frequency-control-reserves/)
785 [network-code-development/load-frequency-control-reserves/](https://www.entsoe.eu/major-projects/network-code-development/load-frequency-control-reserves/)