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Incremental profitability evaluation of V2G-enabled aFRR services for semi-public EVSE infrastructure: a case study in Belgium.

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Abstract

The current paper defines a framework for the introduction of automated frequency restoration reserve (aFRR) services enabled by vehicle-to-grid (V2G) technology into the business model of an entity owning and operating a network of semi-public EVSE (Electric Vehicle Supply Equipment). It assesses the profitability of this introduction by performing a case-study based on the real-life EV charging data from the EVSE network located in a hospital parking. From the results of the study, it is clearly visible that the introduction of V2G-enabled aFRR services has a significant positive incremental profitability, heavily dependent, however, on the plug-in ratio of EVSE network, determined by the EV user behavior.

Keywords: V2G (vehicle to grid), business model, infrastructure, electric vehicle supply equipment (EVSE), market development.

1 Introduction

1.1 Context

Recent years show a significant increase in the popularity of electric vehicles (EVs), which is generally considered a positive trend, leading to reduced pollution and a cleaner environment [1]. At the same time, the growing number of EVs on the roads brings certain challenges as well. One of these challenges is the increasing pressure on electricity grids [2]. However, EVs also become a solution for this issue by the means of vehicle-to-grid (V2G) technology [3], allowing for bidirectional energy transfer between the EV battery and the electricity grid. This opens the opportunity not only to consume and store energy in EV batteries but also to inject it back into the grid. This creates opportunities both for the grid operators, potentially benefiting from the additional solution to grid balancing issues, and for the participants of the EV charging business ecosystem, potentially benefiting from the additional revenue streams. The current paper assesses the incremental profitability of the introduction of one of grid balancing services into the business model of an entity owning, managing, and maintaining a semi-public EV charging infrastructure.

1.2 Literature overview

The vehicle-to-grid (V2G) concept was primarily introduced by the research of Kempton et. al. [4], outlining the technical and financial opportunities enabled by the bidirectional energy flow to and from the EV battery. One of these opportunities, further elaborated by a number of follow-up studies [5]–[13], is the potential application of V2G technology into energy grid balancing services.

The initial business model of the participants of the EV charging business ecosystem, managing and maintaining the network of EVSE (Electric Vehicle Supply Equipment), is mainly based on the provision of EV charging services as the core value proposition, covering the needs of the EV users as the main customer segment and receiving EV charging fees as the main revenue stream [14]–[18].

However, the V2G-enabled transformation of this business model introduces an additional value proposition : grid balancing services. The new value proposition targets a new customer segment, namely transmission system operators (TSO) (entity responsible for managing and maintaining a high-voltage electricity grid). At the same time, the currently existing main customer segment – the EV users – takes the role of the key partner, providing the EV batteries for the V2G-enabled grid balancing services [14]. Eventually, an entity managing and maintaining EVSE network (e.g. charge point operator - CPO) would take over the role of Balancing Service Provider (BSP), aggregating an EV fleet of a certain size, and providing balancing power and energy to the centralized grid [11]–[14].

According to Elia [19], the Belgian TSO, there are three types of grid balancing services designed to avoid frequency deviations from a predefined constant level (e.g. 50 Hz in Belgium):

- Frequency Containment Reserve (FCR): primary reserve, automatically fully activated within a time frame of 30 seconds in case of a significant frequency deviation and stabilizing the frequency fluctuations [20].
- Automated Frequency Restoration Reserve (aFRR): secondary reserve, automatically fully activated within a timeframe between 30 seconds and 7,5 minutes, in order to restore the frequency on the predefined level (50Hz in Belgium) [21].
- Manual Frequency Restoration Reserve (mFRR): tertiary reserve, manually activated on demand within 15 minutes, in order to restore frequency on the predefined level in case of major imbalances [22].

According to the recent study, performed by Elia [23] EVs can be mainly used to provide FCR and aFRR services, as the provision of these services requires a relatively fast automatic activation and can be performed with limited energy resources. Moreover, according to [14], the inclusion of grid balancing services into the list of their value propositions can become a significant additional revenue stream for the participants of the EV charging business ecosystem. Where prior work of this work's authors focuses on the FCR balancing service [ref FCR paper], this work focuses on aFRR blabla

1.2.1 Automated Frequency Restoration Reserve (aFRR)

From the revenues point of view, the aFRR service is particularly interesting for the entities willing to engage themselves in the energy balancing market, since it opens two additional revenue streams: balancing power capacity and balancing energy remunerations [21].

In practice, the rules and procedures related to the provision of aFRR service differ from one TSO to another. However, even though the current study focuses on the Belgian TSO Elia, the procedural differences are not critical and the results could be extrapolated to other geographical regions with minor adjustments.

It is also important to mention that the aFRR market was initially designed for large electricity-generating entities (e.g. gas and hydroelectric power plants), and still has substantial regulative barriers for small sand medium enterprises (SMEs), CPOs, and other smaller prosumers willing to participate in the provision of the service [24]. The main barriers are :

- Minimum amount of 1MW of power for capacity bid and 1MWh for energy bid [21]

- Pay-as-bid auction principle, where the TSO pays exactly the amount indicated in the elected bid. The problem with this principle is that smaller entities rarely have sufficient resources for efficient continuous market analytics and are simply not able to indicate an up-to-date adequate price [25].
- Expensive specialized metering equipment, that must be installed at every delivery point aiming to provide aFRR services [26].

However, recent years show a visible decentralization trend in the grid balancing market, indicating that these regulatory barriers can be diminished in the near future. For instance, the provision of FCR services does not require the installation of additional specialized metering equipment and requires only a standard digital meter [27]. Moreover, the FCR power capacity auctions are transferred to the pay-as-cleared principle, where all the elected bids from different BSPs receive equivalent remuneration based on the highest price from the elected bids [25]. These changes in the regulatory framework of the FCR services can be seen as the first step towards the decentralization of the whole grid balancing market, including aFRR services.

1.3 Contribution

Since the V2G technology has not reached its maturity phase and the opportunities provided by the technology are not yet widely applied, the existing literature still lacks studies related to the profitability assessment of V2G-enabled aFRR. Therefore, the aim of the current study is to address this gap by defining the framework for the introduction of the aFRR services into the business model of an entity owning and operating an EVSE (Electric Vehicle Supply Equipment) network and assess the incremental profitability of this introduction based on a case-study of semi-public EV charging infrastructure.

2 Methodology

2.1 Model

The revenue streams of an entity owning, operating, and managing a network of EVSE is mainly represented by the fees received from the provision of EV charging services, being the core value proposition of its initial business model. The cost structure, on the opposite, comprises numerous elements, including the cost of the supplied energy, depreciation of EVSE, human resources (HR) remunerations, and others [15], [16].

As mentioned before, the introduction of V2G-enabled grid balancing services is able to diversify the list of value propositions, entering a new market with a new customer segment and creating additional revenue streams.The focus of the current study lies in the assessment of the incremental profitability of the provision of V2G-enabled aFRR, being the difference between the additional revenues and expenses caused by the introduction of the service.

The revenue generated by the provision of V2G-enabled aFRR (R_{aFRR}) consists of two components, and can be defined as follows (eq. 1):

$$R_{aFRR} = CR_{aFRR} + ER_{aFRR} , \quad (1)$$

- CR_{aFRR} : power capacity remuneration;
- ER_{aFRR} : energy remuneration.

The provision and remuneration of aFRR service are based on the auction principle. After concluding the contract with a TSO, a BSP is able to make power capacity bids on a day-ahead auction. Moreover, there are two types of power capacity auctions – “all-CCTU” and “per-CCTU”. The abbreviation CCTU means the Capacity Contracting Time Unit, being the 4 hours block when the power capacity bid made by the BSP can be activated by the TSO. Thus, in the first auction type, the bids are made for the whole 24 hours, while in the second for the 4 hours blocks beginning from midnight (e.g. 00:00 to 04:00; 04:00 to 08:00; 08:00 to 12:00, etc.). The BSP has to choose the suitable auction and CCTU(s) (in case of “per CCTU” auction) and make a power capacity bid, indicating the available amount of power it is able to provide on the next day and the price of the desired service in Euro per MW of indicated power per hour (€/MW/h). The maximum amount of power the BSP is able to bid is defined beforehand by the means of a prequalification test performed by the TSO. The bids are elected by the TSO based on the forecast balancing power necessary for the next day and the “cheapest available” principle. If the bid made by the BSP is elected, the BSP receives the remuneration for the reserved amount of power (per MW) for the reserved time period (per hour) [21].

It is also important to mention, that participation in the provision of aFRR services involves a certain risk of penalties in case of non-compliance with the contractual obligations of the BSP. The penalties can occur either due to the failure of spontaneous availability and/or activation tests performed by the TSO, or due to actual failure to provide the service during the activation. However, the maximum amount of penalty should not exceed the remuneration of the respective month. Additionally, there is also a risk mitigation opportunity, a so-called Transfer of Obligations (TO) procedure, allowing to transfer the power capacity obligations made by one BSP to another at the latest one hour before the due time, in case of any unexpected problems [21]. However, this procedure is based on agreements between the BSPs and can be costly for the demanding side.

Thus, for the V2G-enabled aFRR, the remuneration for the reserved power capacity (CR_{aFRR}) mechanism can be formulated as follows (eq. 2):

$$CR_{aFRR} = aFRR_{Capacity\ Bid} * \sum_{y=1}^{Z} Ny * Ky * T_{reserved} * (P_{plug\text{-}in} - P_{failure} * F_{failure}) - P_{TO} * C_{TO} \tag{2}$$

- $aFRR_{Capacity\ Bid}$: aFRR capacity bid (in €/MW/h) for the considered time period ($T_{reserved}$);
- y: type of EVSE (from 1 to Z) (e.g., uni/bi-directional; AC/DC; EVSE power level)
- Ny: number of EVSE type y, participating in the provision of aFRR services;
- Ky: power level of EVSE type y;
- $T_{reserved}$: reservation time period of the available BSP power capacity;
- $P_{plug\text{-}in}$: probability that the EVSE type y is going to be plugged into an EV during the reservation time period ($T_{reserved}$);
- $P_{failure}$: risk factor, indicating the probability that the BSP will fail and be penalized;
- $F_{failure}$: the multiplication factor forming aFRR penalties, being the factor to be multiplied with the price of missing MW of power the BSP was not able to deliver;
- P_{TO} : risk factor, indicating the probability of the occurrence of necessity to opt for the transfer of obligations (TO) service;
- C_{TO} : cost of TO service.

During the CCTU for which the balancing power capacity was reserved, the TSO can actually activate the bid and its activation initiates the second type of aFRR remuneration – balancing energy remuneration (ER_{aFRR}). In order to provide (for aFRR+) (or decrease for aFRR-) the necessary power capacity, the BSP has to inject (or consume, in case of aFRR-) energy into the grid during the whole activation period, while the TSO will pay for this balancing energy. The balancing energy remuneration is also based on the auction principle, but intra-day in this case. The BSP, whose power capacity bid was elected on the day-ahead, makes another intra-day energy bid, indicating the amount of energy (in MWh) and the price. In this case, the BSP receives the remuneration (cost reduction, for aFRR-) only in case of activation, based on the actual amount of MWhs injected (consumed, for aFRR-) into the TSO grid [21]. Thus, the V2G-enabled aFRR energy remuneration can be formulated as follows (eq. 3):

$$ER_{aFRR} = aFRR_{Energy\ Bid} * \sum_{y=1}^{Z} Ny * PLy * T_{activated} \tag{3}$$

- $aFRR_{Energy\ Bid}$: aFRR energy bid (in €/MWh) for the considered time period ($T_{activated}$);
- $T_{activated}$: activation time period of the available BSP power capacity.

The influence of the introduction of V2G-enabled aFRR services on the cost structure involves mainly the increase of infrastructure depreciation costs related to the difference between unidirectional and V2G EVSE prices, along with the necessary precise metering equipment to be installed on every delivery point (EVSE or EVSE hub). Thus, the additional costs related to the provision of V2G-enabled aFRR services can be defined as follows (eq. 4):

$$C_{aFRR} = \sum_{y=1}^{Z} \frac{\Delta Py}{Ly} + \sum_{m=1}^{N} \frac{Pm}{Lm} \tag{4}$$

- ΔPy : difference in price between uni- and bidirectional EVSE with comparable power level;
- Ly : useful lifetime of EVSE type y;
- m: number of aFRR delivery points (from 1 to N) in EVSE network;
- P_m : price of specialized aFRR metering equipment;
- L_m : useful lifetime of specialized aFRR metering equipment.

Defining the incremental profits for the provision of V2G-enabled aFRR service (IP_{aFRR}) as the difference between the additional revenues (R_{aFRR}) and costs (C_{aFRR}) results in the following formula (eq. 5):

$$\text{IP}_{aFRR} = \begin{array}{l} \text{aFRR}_{\ Capacity\ Bid} * \sum_{y=1}^{Z} \text{N}y * \text{K}y * \text{T}_{reserved} * (\text{P}_{plug\text{-}in} - \text{P}_{failure} * \text{F}_{failure}) - \text{P}_{TO} * \text{C}_{TO} + \\ \text{aFRR}_{\ Energy\ Bid} * \sum_{y=1}^{Z} \text{N}y * \text{K}y * \text{T}_{activated} - \sum_{y=1}^{Z} \frac{\Delta Py}{Ly} + \sum_{m=1}^{N} \frac{Pm}{Lm} \end{array} \quad (5)$$

2.2 V2G-enabled aFRR use-case

2.2.1 General provisions

In order to assess the incremental profitability of the V2G-enabled aFRR services, the current research applies the defined model, generating a case-study, based on real-life data and a set of grounded assumptions.

In general, the process of the provision of V2G-enabled aFRR services can be compared with the use of stationary batteries for similar purposes. The EV battery increases (for aFRR+) or decreases (for aFRR-) the power level of the TSO grid in case of need, while the TSO pays for the reserved capacity and the activated energy.

However, the reserved capacity bids for aFRR+ are, on average, higher than aFRR- bids, while the V2G technology allows not only to consume energy at a lower price (for aFRR-) but also to inject energy and sell it through energy bids of aFRR+ [28]. Moreover, according to the internal EV charging data, in most cases, the EVs plug in at >50% state of charge (SOC), while participation in aFRR- requires buffer space in EV battery. Finally, due to this need for additional buffer battery space, the EV is not able to charge during the CCTU outside the activation periods, solely relying on aFRR- activation periods to charge. At the same time, the expected parking time is typically longer than the time needed to charge, creating the opportunity to compensate the depleted energy for aFRR+.

Considering all the above-mentioned, the case-study generated by the current research is focused on the provision of V2G-enabled aFRR+ services.

The provision of aFRR+ can be performed in two ways, depending on the power baseline set by the BSP before the activation. Either during the activation, the BSP stops consuming energy from the grid, reducing its own power and increasing the power in the TSO grid compared to the declared baseline (while consuming), or the BSP injects energy into the TSO grid, increasing the power in grid compared to the idle-state baseline, as visualized on Fig.1:

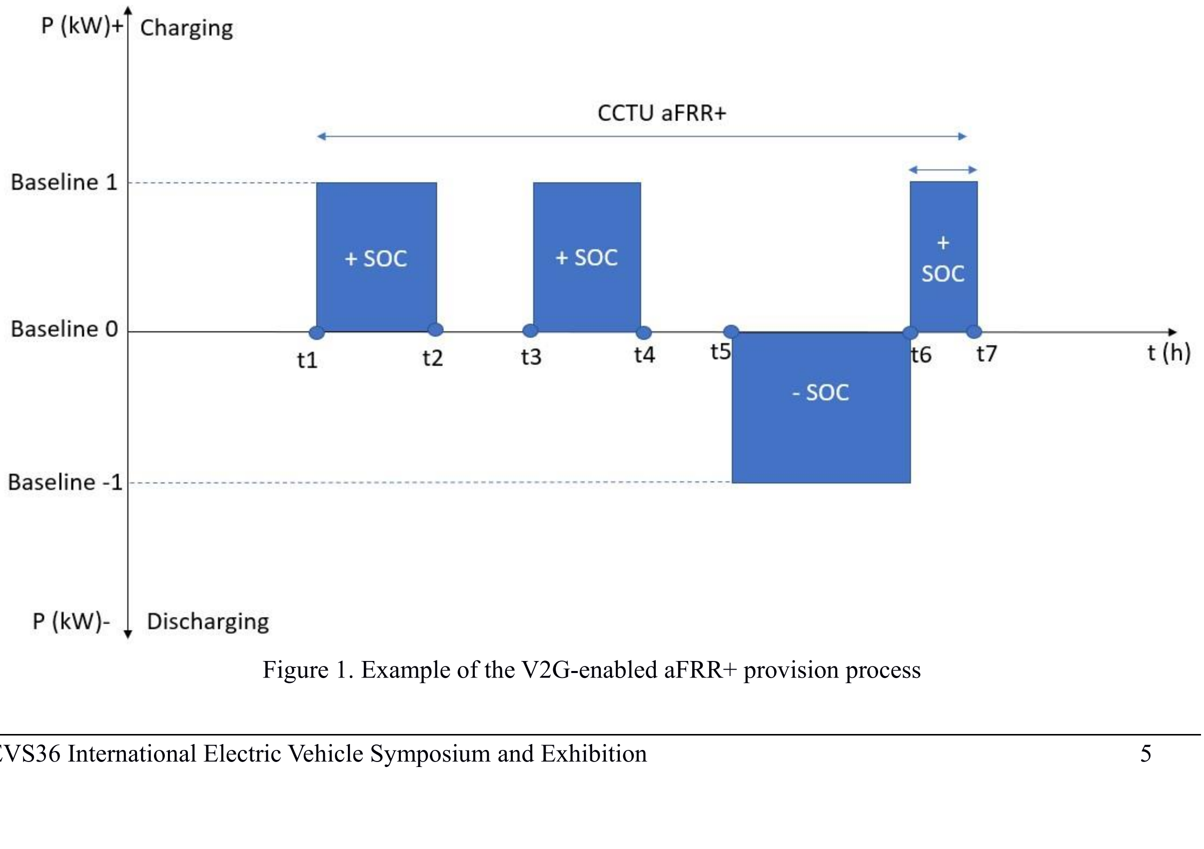

Figure 1. Example of the V2G-enabled aFRR+ provision process

Figure 1 shows an example of the V2G-enabled aFRR+ provision process with time in hours on the x-axis and power in kW on the y-axis. The reserved CCTU begins on time t1 with the declared power baseline 1. At this point, only the reservation period begins, but aFRR+ is not activated, so EVs connected to the EVSE network engaged in the provision of the service are consuming energy and increasing their SOC. On timepoint t2, the TSO activates aFRR+ and the BSP stops consuming, dropping the power baseline to 0. The activation ends at timepoint t3, and connected EVs can continue to charge until timepoint t4, when they reach 100% SOC and remain plugged-in, but idle. At timepoint t5, the TSO initiates another activation, but this time the EVs are not able to stop charging as they are idle and the power baseline is on a 0 level. Thus, the EVs begin to discharge, injecting energy into the grid. At timepoint t6, the activation ends, and EVs can begin to recharge the discharged energy, and at timepoint t7 the reserved CCTU ends. It is important to notice, that in case aFRR+ power capacity is provided by the reduction or stop of consumption, the BSP does not receive the energy remuneration, as no energy was actually injected into the grid.

What concerns the resulting SOC after the end of aFRR+ CCTU, due to the opportunity of service provision via stop or reduction of consumption, in the worst case the additional ΔSOC would be equal to 0%, meaning that the EV would remain on the same state of charge as before CCTU. Therefore, there should be created a time buffer after the CCTU to bring the EV to the SOC desired by EV user.

However, on average, the probability of occurrence of ΔSOC = 0% is less likely. By analyzing the open access data retrieved from Elia [28], the average aFRR+ activation time per CCTU (4h) is 103 minutes, while according to the internal EV charging data, an average time to reach 100% SOC is around 51 minutes (vast majority of EVs plug-in with 60-80% SOC). By subtracting 103 minutes from 4 hours, it becomes visible that there is already present a time buffer of 137 minutes of non-active time within a CCTU, easily covering the time needed to reach 100% SOC.

2.2.2 Coping with uncertainties for aFRR capacity remuneration

Besides the SOC, there is another important factor playing role. Unlike the stationary batteries, the EV batteries move together with the vehicles, while the successful provision of V2G-enabled aFRR services requires every participating EVSE to be connected to an EV during the elected CCTU. Moreover, as the capacity bids are made on the day-ahead auction, the plug-in probabilities ($P_{plug\text{-}in}$) of EVSE network for the elected CCTU should be known at least one day on beforehand. This creates an area of uncertainty, consisting of the probability to use the costly TO risk mitigation technique (P_{TO}) and the probability to fail to deliver the service and get the penalty ($P_{failure}$). Therefore, an accurate forecasting technique is of major importance for the successful implementation of the service.

The current research applies an EV charging data-driven forecasting method, allowing to limit the risk of failure. By making use of the historic EV charging data retrieved from the EVSE, meant to be engaged in the provision of V2G-enabled aFRR, the study defines a set of plug-in probabilities ($P_{plug\text{-}in}$) for every minute of the day. This allows to elect the CCTU(s) with the highest $P_{plug\text{-}in}$ and to limit risk of failure.

After defining the CCTU(s) with the highest $P_{plug\text{-}in}$, the risk could be further mitigated by the TO option. This could be done by comparing how accurately the $P_{plug\text{-}in}$ values retrieved from the EVSE, meant to be engaged in the provision of V2G-enabled aFRR, at one hour before and at the beginning of the elected CCTU(s) correspond with each other (% of correspondence) and double check by the means of statistical analysis methods (e.g. t-test; ANOVA; etc.) (BSP can opt for a TO at the latest one hour before the CCTU). The retrieved high value indicates the high accuracy of the forecast and allows to use the result of $(1 - P_{plug\text{-}in})$ as the P_{TO} value.

Finally, the probability of failure ($P_{failure}$), despite all the risk mitigation techniques, can be retrieved by calculating the joint forecasting accuracy of every CCTU timestep, adjusted for $P_{plug\text{-}in}$ at the beginning of CCTU.

2.2.3 Values of the model parameters

After outlining the general provisions of the case-study and describing the methods for coping with uncertainties, it becomes relevant to define the values for a number of parameters actually participating in the calculations:

Table 1: Values of the model parameters

	Parameter	Symbol	Value	Units
External data source	EVSE type	y	V2G charger	/
	EVSE power level [29]	Ky	0,01	MW
	Difference between uni- and bidirectional EVSE price [12], [29]–[31]	ΔPy	3000	€
	aFRR capacity bid [28]	$aFRR_{Capacity\ Bid}$	65,07	€/MW/h
	aFRR energy bid [32]	$aFRR_{Energy\ Bid}$	282,60	€/MWh
	CCTU time [21]	$T_{reserved}$	4	h
	Average activation time per CCTU [33]	$T_{activated}$	103	minutes
	EVSE useful lifetime [16], [34]	Ly	10	years
	Metering equipment cost [35]	Pm	2000	€
	Metering equipment useful lifetime [35]	Lm	10	years
	Failure factor [21]	$F_{failure}$	1,3	/
EV charging data	Plug-in probability during CCTU	$P_{plug-in}$	[0,136; 0,99]	/
	Probability of failure	$P_{failure}$	[0,009; 0,32]	/
	Probability of TO	P_{TO}	[0,01; 0,864]	/
Assumptions	Cost of TO	C_{TO}	1,2*Capacity remuneration	€
	EVSE network size	Ny	250	Units

As it is shown in Table 1, the values of the parameters are divided into three subgroups. The first subgroup represents the values retrieved from external data sources. The second represents the ranges of probabilities retrieved by the means of calculations from the available charging dataset and are discussed in more detail in the results of the study (Section 3). The third subgroup are the values being part of the assumptions list designed explicitly for the current case-study.

2.2.4 Design and assumptions of the case-study

The current research assesses the annual incremental profitability of the V2G-enabled aFRR+ services, by the means of a case-study of semi-public EVSE infrastructure located in a hospital parking. The case-study is built up on the real-life EV charging data filtered for the workdays only, assuming the highest probability for EVs to remain plugged-in for a longer period of time during working hours. Moreover, the current case-study generates results of participation in only one CCTU per day, namely CCTU 4 (12:00 – 16:00) as the one with the highest plug-in probabilities and lowest risk of failure.

Being the application of the model defined in Section 2.1, the case-study adopts the following assumptions:

a) The costs of TO are defined by the means of bilateral contracts between the BSPs, and are therefore not disclosed. The current study assumes this cost to be 120% of the capacity remuneration, as slightly lower than the one applicable for penalties.
b) The average EV battery capacity of the EVs charging at the respective EVSE is 50 kWh.
c) The provided case-study does not include any bidding strategies, assuming all the power capacity bids are to be elected based on the average market price.

2.2.5 Scenarios

As it becomes clear from the previous sections, the successful implementation of the V2G-enabled aFRR services is heavily dependent on the EV user charging behavior, determining the $P_{plug-in}$ at a certain point in time. Therefore, the current study provides three different modeling scenarios, considering different types of behavior and interactions with EV users, which affect the $P_{plug-in}$ and its derivatives (P_{TO}; $P_{failure}$):

- <u>Scenario 1: Natural behavior.</u> The EV user agrees to the fact that his/her EV is going to be used for V2G-enabled aFRR services (or is unaware of this fact), but does not change his/her charging behavior and acts naturally. This scenario is based purely on historical real-life data of EV charging patterns determining $P_{plug\text{-}in}$, P_{TO}, and $P_{failure}$. The EV user is not bound by any obligations and is able to unplug the EV at any time. At the same time, the EV user receives no shared revenues from the provision of V2G-enabled aFRR services.
- <u>Scenario 2: Binding contract.</u> The EV users receive binding day-ahead contracts, offering 20% of aFRR+ capacity revenues for the permission to use their EV batteries for grid balancing purposes. In this case, the EV would be plugged-in and blocked during the period of 6 hours, beginning 1 hour before the elected CCTU (allowing to opt for the TO option in case of emergency) and ending 1 hour after the CCTU (securing the reaching of 100% SOC for the EV after the provision of the service). In case of violation of contract terms (e.g. not plugging in or unplugging in before the contractually defined moments), the EV user pays the penalty equivalent to the penalty the BSP would receive for missing MW (securing the BSP from losses in case of contract violation). This allows reaching the situation when $P_{TO} = P_{failure} = 0$. This can be seen as another risk mitigation method, cutting out the additional expenses related to uncertainties, by sharing 20% of capacity revenues with the EV users.
- <u>Scenario 3: Non-binding contract.</u> The EV users receive non-binding day-ahead contracts, offering 20% of aFRR+ capacity revenues for the permission to use their batteries for grid balancing purposes. This contract type is a non-binding commercial offering, that does not involve any penalties in case if the EV user is not plugged-in during the defined period of time. Thus, in the worst case, the violation of the contract terms by the EV user means receiving no remuneration. In this scenario, 20% of the contracted users are on average assumed to violate the non-binding contract, creating losses related to TO and penalties for the BSP. This scenario can be seen as another risk mitigation method, less efficient than the one described in Scenario 2 in absolute terms for the BSP, but also less binding, and thus, more attractive for EV users. In this case, the P_{TO} and $P_{failure}$ are limited to 20% of their initial value.

3 Results

Before proceeding to the actual results of the study, determining the incremental profitability of the V2G-enabled aFRR+ services for an entity owning, managing, and maintaining EVSE infrastructure, it is important to discuss the results of the $P_{plug\text{-}in}$ calculations and its derivatives, playing a crucial role in the successful implementation of the service. By making use of the method described in Section 2.2.2 and a real-life dataset retrieved from the EVSE network located in a hospital parking, the current study has defined the $P_{plug\text{-}in}$ distribution, presented in Fig. 2:

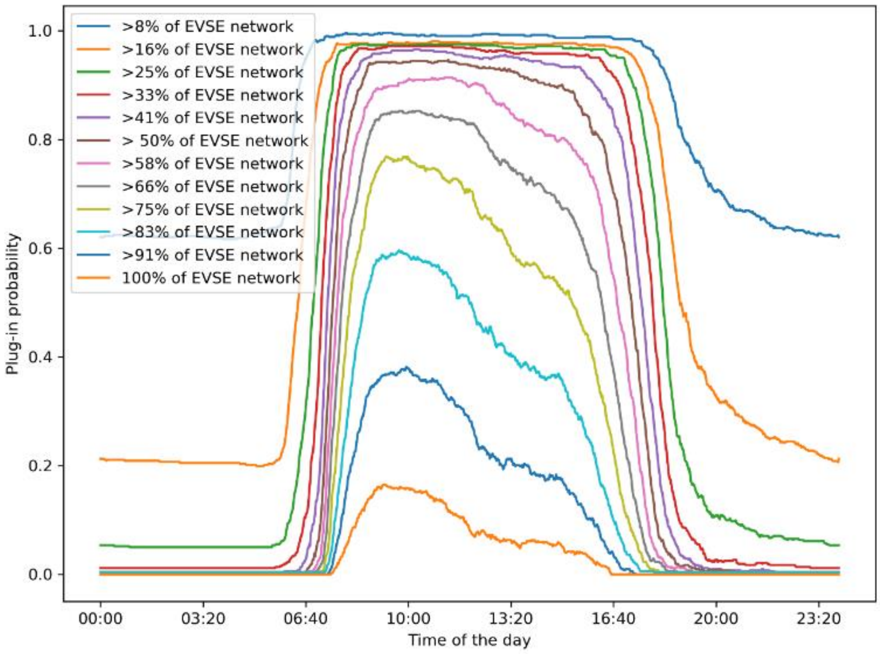

Figure 2. Plug-in probabilities of EVSE network during the working daytime.

Figure 2 shows the $P_{plug\text{-}in}$ (y-axis) of EVSE network during the time of the day (x-axis). Every curve on the graph represents the probability that at least a certain percentage of EVSE network (indicated in the legend) is connected to an EV (and can be potentially used for grid balancing) at a certain point of time. First, and quite obvious observation with regard to the location and the nature of the given EVSE network, the $P_{plug\text{-}in}$ drastically increase around 07:00 and decrease around 17:00, indicating the average working hours of the hospital. This observation points directly out that the CCTU for the provision of grid balancing services should be elected within this timeframe. Considering the given conditions, there are two options regarding the CCTU choice: CCTU 3 (08:00 – 12:00) and CCTU 4 (12:00 – 16:00). However, there is also another point of attention, namely P_{TO}. As mentioned before, the BSP can opt for TO at the latest 1 hour before the elected CCTU, while the $P_{plug\text{-}in}$ values at 07:00 and 08:00 have significant differences, making the TO forecast inaccurate. At the same time, the $P_{plug\text{-}in}$ values at 11:00 and 12:00 match each other very well. Therefore, the optimal risk-limiting choice is to opt for CCTU 4 (12:00 – 16:00) in this case.

Another important observation is that the higher percentage of EVSE network is considered, the lower is the chance to have this percentage simultaneously plugged-in to EVs. However, the the $P_{plug\text{-}in}$ density up to 50% of EVSE network engagement remains quite high. In any case, the value of EVSE network engagement into the provision of the service is one of the most important factors influencing its profitability. The incremental profitability of V2G-enabled aFRR+ service for every EVSE network engagement level and every scenario defined in Section 2.2.5 is provided on Fig. 3:

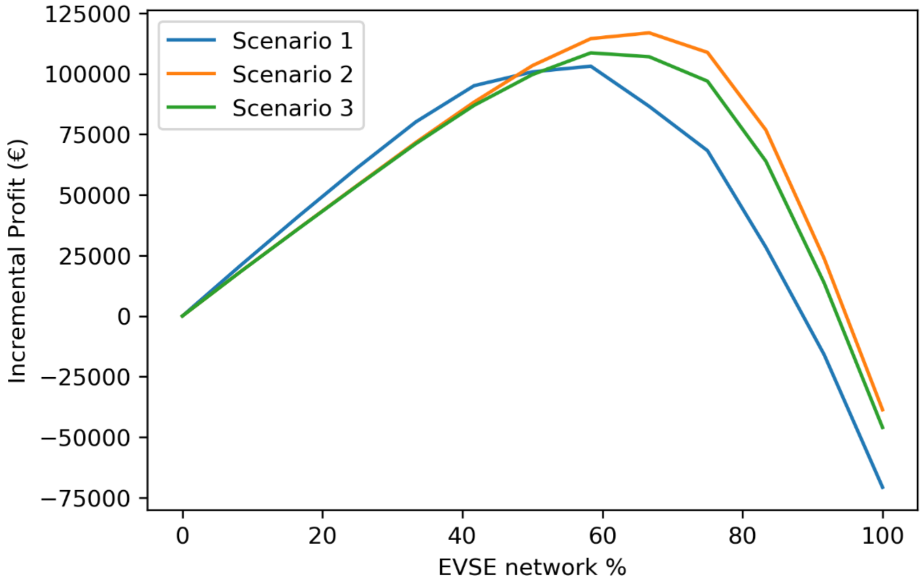

Figure 3. V2G-enabled aFRR incremental profit in function of EVSE network % engaged in the provision of the service.

It is noticeable from Figure 3, all the modeled scenarios show a positive incremental profit (indicating that additional revenues outperform the additional expenses) growing until reaching the engagement of 60% (70% for Scenaro 3) of the EVSE network into aFRR+ services. These results are particularly interesting in light of the previously conducted research on the profitability of the provision of EV charging services only [13], showing negative profitability results (namely, – € 76 738) for this EVSE network size (250 EVSE units) caused by the high fixed costs and electricity prices for smaller consumers. At the same time, it is clearly visible from Fig. 3, that the incremental profits from the provision of V2G-enabled aFRR+ services are able to cover these losses, allowing to reach the break-even point on this, relatively small, network size.

Furthermore, after reaching the peak, the incremental profits begin to fall, eventually becoming negative at above 90% of network engagement. This behavior is explained by the lowering $P_{plug\text{-}in}$ that goes along with increasing network engagement (clearly visible on Fig. 2), and rising P_{TO} and $P_{failure}$ as result. Moreover, even though the potential penalty is capped by the power capacity revenues, the negative incremental profit is caused by the additional expenses related to the provision of the service.

It is also noticeable that at lower EVSE network engagement values (up to 50%), Scenario 1 (blue curve) is more profitable than the other. This can be explained by the lower P_{TO} and $P_{failure}$, causing smaller expenses compared to the EV users' remuneration. However, after 60% of EVSE network engagement, Scenario 1 shows a strong negative trend, reaching negative values faster than other scenarios. The reason is that the BSP in Scenario 1 does not mitigate the P_{TO} and $P_{failure}$ by the means of contracts with EV users and bares more risks when the plug-in probability of the chosen percentage of EVSE network begins to fall.

4 Conclusions

The current research has defined the framework for the introduction of the V2G-enabled aFRR services into the business model of an entity owning and operating EVSE network and used the defined framework for the assessment of its profitability based on a case-study of EVSE infrastructure located on a hospital parking.

From the performed analysis based on real-life data and a set of modeling assumptions, it becomes clear that the introduction of V2G-enabled aFRR services into the business model of an entity owning, managing, and operating a network of semi-public EVSE can have a significant positive incremental profitability.

However, it is important to bear in mind that the provision of aFRR services is heavily related to the plug-in probability of the EVSE network, influencing the potential network engagement into the service and the probability of costly risk mitigation techniques and penalties. As is visible from the results of the case study, the profits increase up to 60-70% of the EVSE network engagement in aFRR service, having relatively high simultaneous plug-in probability. Up to this level, the increasing additional revenues are able to cover the expenses. On the higher levels of network engagement, the simultaneous plug-in probability of the network is significantly lower resulting in a higher probability of TO, penalties, and diminishing profitability as result.

By comparing different scenarios from the case-study, it becomes clearly visible that above 50% of EVSE network engagement, it becomes more profitable to conclude contracts and share profits with the EV users. Even non-binding contracts (assumed to be violated in 20% of cases), partially mitigate the penalty and TO risks born by the BSP and increase profitability at the higher levels of EVSE network engagement.

Finally, it should be pointed out that even though the defined framework is applied on the semi-public EVSE network in the current research, its application (with minor adjustments) can be extrapolated to the public and private EVSE infrastructures as well. However, the results of these use-cases can be significantly different, being interesting topics for future research.

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References

[1] International Energy Agency, "Electric Vehicles," Sep. 2022. https://www.iea.org/reports/electric-vehicles (accessed Apr. 11, 2023).

[2] R. Abousleiman and R. Scholer, "Smart Charging: System Design and Implementation for Interaction between Plug-in Electric Vehicles and the Power Grid," *IEEE Transactions on Transportation Electrification*, vol. 1, no. 1, 2015, doi: 10.1109/TTE.2015.2426571.

[3] B. K. Sovacool, J. Axsen, and W. Kempton, "The Future Promise of Vehicle-to-Grid (V2G) Integration: A Sociotechnical Review and Research Agenda," *Annual Review of Environment and Resources*, vol. 42. 2017. doi: 10.1146/annurev-environ-030117-020220.

[4] W. Kempton, J. Tomic, S. Letendre, A. Brooks, and T. Lipman, "Vehicle-to-Grid Power: Battery, Hybrid, and Fuel Cell Vehicles as Resources for Distributed Electric Power in California," *Fuel Cell*, vol. IUCD-ITS-R, no. June, 2001.

[5] F. Gonzalez Venegas, M. Petit, and Y. Perez, "Active integration of electric vehicles into distribution grids: Barriers and frameworks for flexibility services," *Renewable and Sustainable Energy Reviews*, vol. 145. 2021. doi: 10.1016/j.rser.2021.111060.

[6] H. Ali, S. Hussain, H. A. Khan, N. Arshad, and I. A. Khan, "Economic and Environmental Impact of Vehicle-to-Grid (V2G) Integration in an Intermittent Utility Grid," in *2020 2nd International Conference on Smart Power and Internet Energy Systems, SPIES 2020*, 2020. doi: 10.1109/SPIES48661.2020.9242992.

[7] E. Sortomme and M. A. El-Sharkawi, "Optimal combined bidding of vehicle-to-grid ancillary services," *IEEE Trans Smart Grid*, vol. 3, no. 1, 2012, doi: 10.1109/TSG.2011.2170099.

[8] D. Steward, "Critical Elements of Vehicle-to- Grid (V2G) Economics," *Nrel*, no. September, 2017.

[9] S. Cundeva and A. Dimovski, "Vehicle-to-grid system used to regulate the frequency of a microgrid," in *17th IEEE International Conference on Smart Technologies, EUROCON 2017 - Conference Proceedings*, 2017. doi: 10.1109/EUROCON.2017.8011151.

[10] K. Knezović, M. Marinelli, P. Codani, and Y. Perez, "Distribution grid services and flexibility provision by electric vehicles: A review of options," in *Proceedings of the Universities Power Engineering Conference*, 2015. doi: 10.1109/UPEC.2015.7339931.

[11] O. Borne, "Vehicle-to-grid and flexibility for electricity systems: from technical solutions to design of business models," Université Paris Saclay, Paris, 2019.

[12] B. K. Sovacool, J. Kester, L. Noel, and G. Zarazua de Rubens, "Actors, business models, and innovation activity systems for vehicle-to-grid (V2G) technology: A comprehensive review," *Renewable and Sustainable Energy Reviews*, vol. 131. 2020. doi: 10.1016/j.rser.2020.109963.

[13] A. Gончearuc, N. Sapountzoglou, C. De Cauwer, T. Coosemans, M. Messagie, and T. Crispeels, "Profitability Evaluation of Vehicle-to-Grid-Enabled Frequency Containment Reserve Services into the Business Models of the Core Participants of Electric Vehicle Charging Business Ecosystem," *World Electric Vehicle Journal*, vol. 14, no. 1, 2023, doi: 10.3390/wevj14010018.

[14] A. Goncearuc, N. Sapountzoglou, C. De Cauwer, T. Coosemans, M. Messagie, and T. Crispeels, "An integrative approach for business modelling: Application to the EV charging market," *J Bus Res*, vol. 143, 2022, doi: 10.1016/j.jbusres.2021.12.077.

[15] A. Goncearuc, N. Sapountzoglou, C. De Cauwer, T. Coosemans, M. Messagie, and T. Crispeels, "Business model quantification framework for the core participants of the ev charging market," *World Electric Vehicle Journal*, vol. 12, no. 4, 2021, doi: 10.3390/wevj12040229.

[16] C. Madina, I. Zamora, and E. Zabala, "Methodology for assessing electric vehicle charging infrastructure business models," *Energy Policy*, vol. 89, 2016, doi: 10.1016/j.enpol.2015.12.007.

[17] Capgemini, "A focus on the EV charging infrastructure ecosystem and emerging business models," 2019. [Online]. Available: https://www.capgemini.com/wp-content/uploads/2019/02/Capgemini-Invent-EV-charging-points.pdf

[18] C. De Cauwer, A. Guillemot, G. Cragues, J. Van Mierlo, T. Coosemans, and M. Messagie, "Towards EU-wide Interoperability of charging infrastructure for electric vehicles - The Belgian Case," in *31st International Electric Vehicle Symposium and Exhibition, EVS 2018 and International Electric Vehicle Technology Conference 2018, EVTeC 2018*, 2018.

[19] Elia, "Keeping the balance," 2023. https://www.elia.be/en/electricity-market-and-system/system-services/keeping-the-balance (accessed Apr. 11, 2023).

[20] Elia, "Terms and Conditions for balancing service providers for Frequency Containment Reserve (FCR)," 2020. https://www.elia.be/-/media/project/elia/elia-site/public-consultations/2020/20200317-tc-bsp-fcrfinal-consulten.pdf (accessed Aug. 15, 2022).

[21] Elia, "Terms and Conditions for balancing service providers for automatic Frequency Restoration Reserve (aFRR)," Apr. 2020. Accessed: Apr. 11, 2023. [Online]. Available: https://www.elia.be/-/media/project/elia/elia-site/electricity-market-and-system---document-library/balancing---balancing-services-and-bsp/2020/20200303_tc-bsp-afrr_en.pdf

[22] Elia, “Terms and Conditions for balancing service providers for manual Frequency Restoration Reserve (mFRR),” Apr. 2019. Accessed: Apr. 11, 2023. [Online]. Available: https://www.elia.be/-/media/project/elia/elia-site/public-consultations/20191004_terms_and_conditions_mfrr/tc-bsp-mfrrfeb2020.pdf

[23] Elia, “Using electric vehicles to balance the network.” https://innovation.eliagroup.eu/projects/v2g/ (accessed Aug. 23, 2022).

[24] D. Lauinger, F. Vuille, and D. Kuhn, “A review of the state of research on vehicle-to-grid (V2G): Progress and barriers to deployment,” in *European Battery, Hybrid and Fuel Cell Electric Vehicle Congress*, Mar. 2017.

[25] Elia, “Remuneration of mFRR and aFRR capacity: pay-as-bid & pay-as-cleared,” 2020. Accessed: Apr. 11, 2023. [Online]. Available: https://www.elia.be/en/public-consultation/20200901_public-consultation-on-the-study-on-pay-as-bid-vs-pay-as-cleared

[26] Elia, “Technical documentation concerning the provision of ancillary services,” 2021. Accessed: Apr. 11, 2023. [Online]. Available: https://www.elia.be/-/media/project/elia/elia-site/electricity-market-and-system/system-services/how-to-become-provider-documents-technical/technical-requirements-for-private-measurement-devices-final-v3_28102021.pdf

[27] Elia, “Market Facilitation.” https://innovation.eliagroup.eu/innovation-pillars/market-facilitation/ (accessed Aug. 18, 2022).

[28] Elia, “Individual aFRR capacity bids,” 2023. Accessed: Apr. 14, 2023. [Online]. Available: https://opendata.elia.be/explore/dataset/ods125/information/

[29] Izvia, “Bornes de recharge V2G Entreprise,” 2022. https://www.izivia.com/bornes-electriques-lieu-de-travail/bornes-de-recharge-V2G-entreprise (accessed Aug. 21, 2022).

[30] Indra, “Vehicle-to-Grid (V2G) Chargers,” 2022. https://www.indra.co.uk/v2g (accessed Aug. 11, 2022).

[31] Alfen, “EV charging stations,” 2022. https://alfen.com/en-be/ev-charging-stations (accessed Aug. 23, 2022).

[32] Elia, “Individual incremental balancing energy bids (Historical data),” 2023. Accessed: Apr. 14, 2023. [Online]. Available: https://opendata.elia.be/explore/dataset/ods068/information/

[33] Elia, “Activated balancing energy volumes per minute (Historical data),” 2023.

[34] C. Nelder and E. Rogers, “Reducing EV Charging Infrastructure Costs,” 2020. Accessed: Aug. 23, 2022. [Online]. Available: https://www.researchgate.net/profile/Chris-Nelder/publication/338660434_Reducing_EV_Charging_Infrastructure_Costs/links/5e2237d6299bf1e1fab9ed9c/Reducing-EV-Charging-Infrastructure-Costs.pdf

[35] Elia, “General technical requirements for private measurement,” 2021.

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