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The role of an Aggregator Agent for EV in the Electricity Market

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***Abstract*— An aggregator agent for electric vehicles is a commercial middleman between a system operator and plug-in electrical vehicles (EV). For the system operator perspective, the aggregator is seen as a large source of generation or load, which could provide ancillary services such as spinning and regulating reserve. Generally these services will be provided in the day-ahead and intraday electricity markets. In addition, the aggregator also participates in the electricity market with supply and demand energy bids. In this paper, the integration of these concepts in an electricity market environment is discussed through proposing a framework for the information characterization (and availability) between aggregator, system operators and clients. A specific market (the Iberian Market - MIBEL) is discussed. In the sequence, the different degrees of availability of the relevant information are identified and characterized, including the variables that are necessary to forecast.**

***Index Terms*—Aggregator agent, electric vehicles; electricity market, ancillary services, vehicle-to-grid, forecasting.**

I. INTRODUCTION

THE synergy between power system and electric vehicles (EV) became an important issue for several actors, e.g. vehicles industry, electrical utilities, regulators. For instance, according to Kempton and Tomic [1] the mechanical power of the U.S. light vehicle fleet exceeds the electric power generation of the country by a factor of 24, and Kempton and Tomic [2] show that just one-fourth of the US light vehicles converted to EV, would have a power capacity above the electric generation system (660 GW against 602 GW). In this paper the acronym EV comprises vehicles powered by batteries, a fuel cell, or a hybrid combining a gasoline engine with a generator.

Research on this topic was developed in the last decade, in particular the economic and technical problems related with the integration of EV on the electrical network and electricity markets. The vehicle-to-grid (V2G) concept was introduced in 1997 by Kempton and Letendre [3]. Under thethis concept, the electrical network could receive power from a parked EV, and in this case the charger is bidirectional (able to deliver power to the grid and also to charge the battery). This concept enhances the previous paradigm where the vehicles were just additional loads for charging batteries [4].

The authors associated to V2G the services of peak power and storage for increasing the benefits to electrical utilities, in addition to a raise in profits due to an increase in electrical energy consumption and generation units' load factor. Nevertheless, according the authors, V2G could increase the openness of electrical utilities to renewable generation, but if EV are charged during peak hours additional conventional generation units would be required. The V2G approach could be a win-win situation for both electrical utilities and EV owners.

Brooks and Thesen [5] mentioned that the V2G concept does not necessarily means that the power flow must come from the vehicle to the grid. Vehicles only with the unidirectional charge that can be controlled are also providing V2G services. Quinn et al in [6] have a different opinion: V2G is when the EV has the ability to provide electrical energy to the network, and the Grid-to-vehicle (G2V) is when the network provides electrical energy to the plug-in EV.

One of the main requirement and challenge to make feasible a massive penetration of EV plug-in with the electrical network is to design a framework for management and operation attached to the smart-grid and micro-grid concepts [7][8]. Under this framework the aggregator agent for EV plays an important role as a commercial middleman between a system operator (SO) and compound plug-in EV.

For the SO, the aggregator is seen as a large source of generation or load, which could provide ancillary services such as operating reserve or controllable load. The aggregator may contract the ancillary services directly with the system operator, but generally these services will be provided in the day-ahead and intraday electricity markets. In addition, the aggregator can participate in the electricity market with supply and demand energy bids.

Note that load aggregator is not a new actor in the electricity market. It is common to have regulated and non-regulated aggregators that buy electrical energy in the market representing several costumers. Normally, a single costumer cannot bid directly in the market, but it is represented by a company that is responsible for bidding in the market and can achieve more competitive prices. Nevertheless, EV aggregator agents are more elaborated, primarily because they can offer more services and technical flexibility than a simple load aggregator.

The EV aggregator will manage and control its EV portfolio (e.g. charging of batteries) under the smart metering development trend, however even with the possibility of collecting a large amount of information there are information gaps and also inherent uncertainties such as the drivers behavior and volatility of electrical market prices.

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The aim of this paper is to propose the theoretical basis to define and study the EV aggregator role in the electricity market. The paper describes the integration of EV in the Iberian electricity market (MIBEL) from an aggregator perspective and clarifies the different type of clients and information that an aggregator could have. Furthermore, the different degrees of availability of the relevant information are formulated in a systematic way.

The paper is organized as follows: section II presents the aggregator concept and business model according to several authors; section III presents the state-of-the-art about the economics of EV in the electricity market; section IV describes the framework for studying the aggregator role; finally, section V presents the concluding remarks.

II. Aggregator Agent of EV

A. Concept

Kempton et al in 2001 [9] introduced in the literature the concept of an actor that aggregates EV. The model assumes that each EV owner cannot bid in the electricity market nor have transactions with electrical utilities due to a lower power capacity (kW rather than MW). The solution is an aggregator that serves as a middleman between EV owner and electrical utilities or electricity market. The aggregator either controls dispersed vehicles or operate with on-site vehicles (e.g. corporation's fleet). The authors identified several types of corporations that can be aggregators, for instance: local distributions companies; Energy Service Companies (ESCO); vehicle manufacturers; cell phone operators; electricity retailer.

Brooks and Cage [10] also introduced the concept of a middleman company that aggregates a large number of EV and provides a single contact point with a system operator. The authors proposed an operation where the drivers communicate their driving needs to the aggregator, and the aggregator manages all this information. With all the driving profiles the aggregator creates a ‘‘virtual power plant‘‘ where the number of vehicles expected to be plugged at any given time of the day is known, and how much electrical energy and power are expected to be available. Real time data (location, state of charge, power capacity of interconnection) would be used to update the expected availability.

The same aggregator agent is mentioned by Brooks [11], Kempton and Tomic [1], Kempton et al [12] and Guille and Gross [13].

Quinn et al [6] compared the situation with a direct communication between system operator and EV owner, and the situation with an intermediate communication between the system operator and an aggregator. The aggregator receives request signals from the system operator and transmits commands to the EV that are available and willing to sell the service. In this architecture, the aggregator can bid into in the hourly ancillary services market at any time, and the EV can engage or disengage from the aggregator as they leave or enter the charging station.

The published results show that the direct architecture has lower availability during large periods of the day, while the aggregator availability is almost 100% and can contract reserve services at any time. The direct architecture is less reliable than the aggregator reliability, mainly because depends totally from the uncontrolled behavior of EV owners, while the aggregator can control the reliability by controlling the contracted fleet size and available capacity.

B. Business Models

An aggregator needs a good business model to attract and maintain EV owners under contract. Kempton et al [9] describe a business model where the aggregator provides free replacement batteries and possible free charging or cheap charging, in exchange for being able to use the vehicle power. The advantage of this model is that the aggregator is the only entity responsible for technically managing the batteries (e.g. deep of discharge, cycling) and for the replacement.

For Brooks [11] the commercial interaction with the vehicles owners can be throughout direct payments, subsidized leases, or ownership and/or warranty of the vehicle battery pack by the aggregator.

Kempton and Tomic [2] present three possible business models. The first model corresponds to having an aggregator that manages time availability of fleet use for transportation and sells services directly to the system operator or to the electricity market. In this model the fleet is parked in a single location and connected to a single network point. The second model consists in using power from dispersed vehicles but with a business partnership with an electricity retailer company. In this case the aggregator is the retailer company which buys power from hundreds or thousands of vehicles and sells this power in the electricity market. In this model, the aggregator does not have any control over the individual vehicles, but can provide financial incentives to stay plugged when possible. In the third model, instead of an electricity retailing company, the aggregator could be a company from a different business area. The aggregator could be a battery manufacture that offers free replacement batteries in exchange for some of the profit from selling energy to the grid, or cell phone network that may provide communication functions and other services similar to the ones used for cell phones, or a distribution generation manager.

Guille and Gross [13] described the business model called ‘‘package deal‘‘ to attract and preserve EV owners with proper incentives. The aggregator provides preferential rates for the acquisition of batteries, maintenance and discount rates for charging and parking the EV. In exchange, the EV owner is constrained to plug the vehicle at times determined in the contract. If an EV owner fails to meet the contract it is penalized by loosing all discounts and/or battery maintenance, or in the limit the contract is canceled.

A different business model, from the company Better Place (www.betterplace.com), is analyzed by Andersen et al [14]. The core business consists in a creation of an Electric Recharge Grid Operator (ERGO), which has the following basic elements: a network of charging points with a smart metering infrastructure that communicates with its users and manages the charging of each vehicle; partnership with vehicle, batteries and hardware manufacturers; separate battery ownership from car ownership by offering several kinds of leasing deals for batteries or even for vehicles, e.g. paying for using the battery for a predefined number of kilometers.

The current model does not explore the V2G concept, but is expected an evolution to this paradigm.

III. Electricity Market and the Economics of EV

This section identifies and describes the services that an EV can provide to the electricity network that can also be sold in the electricity market. Note that these services can only have a significant impact if provided by a large amount of coordinated EV, e.g. throughout an aggregator agent.

A. Base and Peak Power

EV are not competitive for base load power [9], but under the right conditions (e.g. decline in the batteries costs, a small change in utility purchase rates), it can be cost-effective for an electric utility as well as for the EV owner to provide peak load [3][15].

Kempton and Tomic [1] presented formulas to compute the capacity for grid power from three types of electric vehicles. The results show that the peak power market is the least promising since the price was never high enough to justify selling peak power. Furthermore, fuel cell vehicles are more suitable to provide power during peak hours, while battery and hybrid vehicles are limited by storage to provide power during peak hours.

B. Ancillary Services and V2G

Kempton et al [9] computed the economic potential of EV for California's spinning reserve and regulation markets. Regulation reserve consists of generation synchronized with the grid to keep frequency and voltage stabilized automatic generation control (AGC). Spinning reserve is additional generating capacity synchronized with system to respond around 10 min in case of failures. These two markets are frequently known as ancillary services market. In these two services the EV present bids for having available and synchronized capacity (e.g. $/MW) and additional payments for energy sold to the network ($/MWh). Three different EV types (battery, fuel cell and hybrid) were analyzed by the authors.

One important conclusion is that some vehicles are better suited than others for different markets. The spinning reserves market shows economic viability for most vehicles, while the regulation market seems very promising for EV with battery. The net revenue for the fuel cell vehicle in the spinning reserve market was particularly larger and insensitive to fuel prices; this was because a large portion of the revenue comes from the available capacity price. The net value of battery EV for regulation services is several thousand dollars per year. This is because the battery vehicle could perform regulation function indefinitely without discharging the battery [10]. This avoids capacity issues related to battery state-of-charge and promotes less battery degradation.

Fuel cells and hybrid in motor-generator mode can only provide up regulation, which makes them not so economic attractive for regulation services.

Brooks [11] evaluated the feasibility and practicality of having EV providing the regulation service. The test was performed in a vehicle with an 18 kWh battery injecting or consuming power from the network and dispatched remotely by wireless. The economic outcome from this service beats the battery wear cost under almost all operating conditions (the cost of battery is between 20% and 60% of the gross value created) and the battery capacity increased by about 10% during the test.

Tomic and Kempton [16] analyzed the net revenue of two real fleets (100 Th!nk City and 252 Toyota RAV4) with battery EV that provide regulation reserve in four US electricity markets. Regulation up and down of the first fleet was found to be profitable in all years (with exception of 2001) of New York ISO market, but the authors found that it was more lucrative to this fleet to provide only regulation down (the EV operates just as a grid-controllable load). For the second fleet, the regulation up and down was found to be very lucrative in the New York ISO.

The analysis was extended to three additional electricity markets in US. The results show that the first fleet could provide regulation services with profit in three markets (in the other the market value of ancillary services is lower), and the second fleet presents high profits in most of the markets.

Finally, it is important to note that due to historical and technical reasons the ancillary services nomenclature and time frames for load-frequency control have significant differences of implementation in various countries; Rebours et al [17] present a survey of the reserves nomenclature and technical requirements adopted in several countries. Nevertheless, the basic principles of each type of load-frequency control are the same. For instance, regulation reserve (AGC) normally in some countries (e.g. Spain, Portugal) is the secondary control, while spinning reserve is part of the secondary control and also fast tertiary control reserve.

C. Storage

Kempton and Tomic [2] presented the storage and backup power of EV as an additional service, important to accommodate high penetration of renewable energy and compensate forecasting errors. The backup power can be provided by fuel cell and hybrid running motor generator vehicles, storage can be provided by battery vehicles or plug-in hybrids. It is foreseen by the authors a saturation in the ancillary services market (3% of the vehicles in the fleet are enough to serve the reserve needs), so the peak power and "storage market" are the next steps.

The authors see the backup and storage capability as a new service that does not exist in electricity markets. However, the current market rules in most countries already consider the possibility of having storage playing an important role as a market agent: either by combining a fleet of EV with variable energy facilities (e.g. wind farms) or selling backup power as upward operational reserve and storage as downward operational reserve.

IV. Framework for Defining the EV Aggregator Role

The objective of this section is to define a framework for studying and analyzing the EV aggregator role in the electricity market. This comprises the information that is transmitted from an EV to the aggregator, the information and communication technology (ICT) that already exists, and the relation of the EV with the SO.

A. Interface with the System Operator

The massive integration of EV will create challenges in the distribution network, such as congestions in feeders and active losses. Therefore, the distribution system operator (DSO) sees the aggregator agent as an important actor in the distribution grid operation. Moreover, the transmission system operator sees the aggregator as a source of regulating and spinning reserve, either as a load or as load-generation resource.

However, in an electricity market environment, the scenario where the system operator controls the period and power level of EV charging is not possible from the regulatory point of view. Even from an ICT perspective it is very demanding to directly control millions of EV. Therefore, the communications will be performed from the system operator to the aggregator, and then from the aggregator to each EV.

Presently, there are already ICT that allow the communication between an aggregator and each EV. For instance, Coulomb Technologies (www.coulombtech.com) created a ChargePoint Network of electric vehicle (EV) charging stations with smart metering technologies. These stations are in permanent communication with the ChargePoint Network Operating System (CPNOS). The CPNOS bi-directional communications with the stations enabling functions such as remote diagnostics and demand side management. Another example is Gridpoint (www.gridpoint.com) who developed ICT that controls the flow of electricity between the network and the EV, enabling smart charging and V2G. In the Gridpoint technology the connectivity module receives and transmits commands to control the EV charging when connected to the electrical network [18][19].

B. Different Charging Modes and V2G

The battery charging is envisioned to be performed in two ways: with the option of adjusting the charging rate (e.g. fast and slow) or only with the possibility of having "charging on" or "charging off" (constant rate). Either way, there are different methods for charging an EV. The following modes can be considered:

- dumb charging [7], or charge anywhere/anytime [18], or opportunity charging [20]: the EV is not controlled by the aggregator and the charging is only defined by the owner and starts when the EV is immediately plugged;
- dual tariff charging [7] or charging during a time window [18]: consists in having different prices for peak and off-peak hours (e.g. more attractive to charge during night);
- smart charging embedded in the microgrid and multi microgrids concept [7]: consists in a active management system where the aggregator has complete control over the EV and is a link between the DSO and the EV owners. This mode requires adjustable battery charging rates and assumes that the DSO requires direct services from the aggregator;
- manual on/off charging [18]: stops charging during emergency events;
- charge only at a particular location or type of location [18][19]: the EV is limited to charge on "work" or "home" based on the preference transmitted by the owner;
- time-centered charging [18]: turn on the charges at a determined time instant for each EV to center the charging (e.g. line up with the cheapest hour);
- energy availability signal [19]: the control scheme charges the EV based on the real-time available generation, where the load (demand) follows the electrical energy generation (supply) signal;
- energy price signal [19][20]: the charge will only start based on the price that the EV owner is willing to pay;
- renewable energy signal [20]: consists in charging at a fast rate when there is an high penetration of renewable energy and at a slow rate in periods with lower penetration.

Some of these charging methods can be used when the EV has the V2G mode. Actually, this mode is an extension of the previous ones and with full control of the charge/discharge rates. For instance, the energy price signal mode can be extended to include a price threshold above which the EV starts injecting power into the grid. Another possibility, suggested in [18], is to synchronize EV charging with regulating reserve.

C. Charging Locations and Metering Devices

It is assumed that the EV will be only charged at residential, charging stations and public places. Probability, it will be also possible to charge/discharge the EV at work.

The charging modes described in the previous section are only possible in some charging locations. In charging stations it is only possible to perform the following charging modes: opportunity charging, dual tariff and manual on/off charging. Moreover, it is an open matter if the V2G mode is possible in a charging station. When parked at home or at work, depending on the ICT and electrical network infrastructure, all the charging modes are possible. Public places can also have almost all charging modes and V2G.

The electrical energy consumption and injection activity requires metering systems, and two solutions can be considered: residential smart meters (which now are being widely installed) or on-board metering devices. Note that with V2G mode it is required to have bi-directional communications, and the meters at home will be more advanced in ICT since it is expected that most EV will only be plugged during the night at home.

D. Available Information

The available information can be divided in two groups: static and dynamic information.

Static information consists in the EV type, battery characteristics, and charging location characteristics.

In [16] it is stated that the important variables are: the power capacity (kW) of the electrical connections and wiring, and the kWh capacity of the battery. Moreover, for an aggregator it is also important to have information about the battery's charging. Fell et al [21] identified the following variables: normal charging level (charging rate in the absence of any control signal); duration (period of time for going from almost discharge to full charge); maximum charge rate; rate of change (maximum rate of change in charging rate). It is also important for an aggregator to have associated to each EV an ID.

The static information is not difficult to obtain by an aggregator and it is essential for the technical management.

Dynamic information consists in electricity market prices, EV status, signals from the system operator, preferences of the EV owner (e.g. charging time), driving constraints of the EV owner (e.g. travel schedule), electrical energy consumed and injected by each EV.

With the current ICT developed GridPoint and Coulomb Technologies it is possible to have in real-time the following information: parking status, battery state of charge (SOC), power flows from the EV battery to/from the grid, measured value of metered quantities and location.

It is also possible to have summary data of each EV that allows performance evaluation by time period, travel or charging session. Additionally, the current ICT also provides information about travels, such as: departure location and time; arrival location and time, distance, SOC in departure and arrival, fuel consumption (for hybrid EV). Note that this type of information could raise some ethical and confidentiality concerns.

The electricity market prices are publicly available and normally can be found in the market operator website. Furthermore, the ICT of GridPoint and Coulomb Technologies already allow sending in real-time the market prices to the EV.

Finally, valuable information for an aggregator is the EV owner's preferences and constraints. This information could be divided in two groups. First, the contract between the aggregator and the EV owner establishes minimum standards for quality of supply and also the flexibility that the aggregator has in control the EV. Then, the EV owner can define a driving schedule for the next day or current day by communicating the following: minimum desired SOC level, scheduled battery SOC for the next day or travel, battery SOC needed for next travel, departure and arrival time instants, expected distance to travel.

E. Framework for the Aggregator Activity and Role

Even without V2G it is possible to offer ancillary services, such as downward spinning and regulating reserve. In fact, this represents a change in the paradigm, moving from "generation following demand" into "demand following generation".

Therefore, the interaction between the system operator (SO) and the aggregator is performed as follows: the SO publishes the requirements of ancillary services; the aggregator presents in the market bids for its services (e.g. regulating reserve); the SO buys, in the market, services from the EV aggregator; during the operational period the SO sends signals to the aggregator requesting the contracted services and the aggregator is responsible for controlling the charging of each EV to comply with the commitment.

It is expected that the aggregator will provide the services by managing the combination of several EV, and sending to the SO the aggregated MW and MVAR load in each network node. And it is the responsibility of the aggregator to offer the rate of change required to meet the market commitments. Hence, the aggregator needs to define groups of clients with similar characteristics. The following groups of clients can be considered:

- **Type 1, uncontrollable load**: comprises clients that frequently plug the vehicle in charging stations, that are traveling constantly (e.g. taxis, postal services), or that just are willing to pay anything to charge the vehicle (price taker). These clients will only use the opportunity and dual tariff charging mode. The aggregator does not have control over the charging location, time and charging rate of these clients, consequently these clients cannot offer any service and the aggregator is just a simple electricity retailer.
- **Type 2, partially-controllable load**: comprises clients with known charging location and time (with an inherent uncertainty), such as a bus or a deliver van; the aggregator has no control over the charging rate. These clients can use the manual on/off, dual tariff, time centered and at a particular location charging modes. The aggregator cannot use these clients to provide regulating reserve services, but has information of where and when these loads will be connected for charging; therefore the aggregator can manage the charging period of these loads and curtail the load in case of emergency.
- **Type 3, controllable load**: comprises clients with known charging location and time (with an inherent uncertainty), and with controllable charging rate. The essential requirement is the possibility of controlling the charging process; the aggregator may not know the departure and arrival time of the EV. These clients can use the active management, time-centered, electrical energy availability signal, electrical energy price signal, and renewable energy signal charging modes. With these clients the aggregator can provide downward regulating and spinning reserve.
- **Type 4, controllable resource**: comprises clients of type 3 that have V2G mode. With these clients the aggregator can provide several ancillary services, such as upward and downward regulating reserve. With V2G it is assumed that the aggregator has a specified quantity of battery SOC, in the contract, to use as V2G.

The key issue for an aggregator in providing ancillary services is to forecast the aggregation capacity, or in other words, the number of EV of type 3 and 4 that are plugged in each hour. The clients of type 4 can also be used to sell electrical energy in the market. Note that the vehicle type (fuel cell, hybrid or battery) is also important.

The commercial relation between aggregator and clients of Type 3 and 4 is more involved. Two issues must be considered: how is the EV owner remunerated for the supplied services? How to deal with the battery wear out problem? Different options exist for solving these two problems, and some were already presented in section II. B, but the simplest solutions consist in offering a discount in the electricity tariff (for the ancillary services provided) and a discount in battery replacement or battery leasing.

The clients of type 1 are loads that act arbitrarily, and sometimes these clients can mitigate possible deviations from the market bids.

Assuming that each EV and charging point has an ID there is no need to have an on-board meter. The meters installed at home (one for EV and the other for home electricity consumption), charging stations and other locations are enough for measuring the power flows. The current state-of-the-art in ICT allows without difficulty to deal with this amount of information (internet traffic is an example). The only requirement is to have certified meters. This solution is the cheapest and can also lead to an industry standard.

The relation between the aggregator and the EV owner requires that clients of Type 2-4 must have a battery management system on-board. According to Bradford [22] each vehicle is unique when it comes to battery management. The off-board solution is more complex and expensive to incorporate into charging points and could lead to incorrect charging algorithm. Therefore, the on-board solution is better because it is not necessary to have charging point for EV and batteries of different types. The main challenge now is to have standards for the communication protocol.

The aggregator can have real-time information (described in section IV. D) from all type clients. However, from the clients of type 2-4, the driving preferences and constraints are also important information for an aggregator, in particular for the participation in the electricity market. Four degrees can be established for this information:

- **Degree A**: there is no information available about driving schedule and charging preferences for the next day or hours;
- **Degree B:** the EV owner when plugs the EV defines how much to charge, the available period for charging, and the minimum battery SOC level for the next day or hours;
- **Degree C**: the EV owner at night sends to the aggregator a travel schedule for the next day or hours;
- **Degree D**: information about travel schedule, minimum battery SOC level, departure and arrival time, when and how much to charge the battery is available.

For supplying regulation reserve the aggregator receive in real-time from each EV and send the SO the following information: status, frequency, capacity in MW, voltage. This information can be provided as a single controllable block for each control area.

V. Participation in the Iberian Electricity Market

As a development of the preceding ideas, this section describes the participation of an aggregator agent in the Iberian Market with the present market rules, as well the decision support tools that the aggregator will need.

A. Day-ahead and Secondary Reserve Market

1) Operation

The Iberian market is organized in a sequence of markets where each day is divided in 24 hours. The first market to be cleared is the day-ahead market. The bids reception closing time for day D+1 is 10:00 of day D (CET time), and the matching results for day D+1 is known at 11:00. An EV aggregator in the day-ahead market can present simple bids (energy [MWh] and price [€/MWh]) for purchasing and selling electrical energy.

After the constraints management, the system operator performs the evaluation of the reserve requirements, publishes the system requirements of upward and downward secondary control (or regulation) and then opens a period for the reception of secondary reserve bids. The aggregator submit their offers indicating the offer of increase or decrease in power together with the price (for capacity, in €/MW) at which they are prepared to provide this service. Note that the primary control reserve is mandatory and not remunerated.

Fig. 1 depicts the procedure that can be followed by an aggregator for participating in the day-ahead market.

At time step t_A the aggregator forecasts the total EV electrical energy consumption (load), the total battery SOC (divided by client type), and the number of EV plugged (divided by client type) in each hour of day D+1.

At time step t_P the aggregator forecasts the spot and balancing prices for the next day. Finally, at time step t_B the aggregator based on the forecasted load, SOC, EV availability, and market prices defines the hourly bids for buying and selling electrical energy in the day-ahead and ancillary services market.

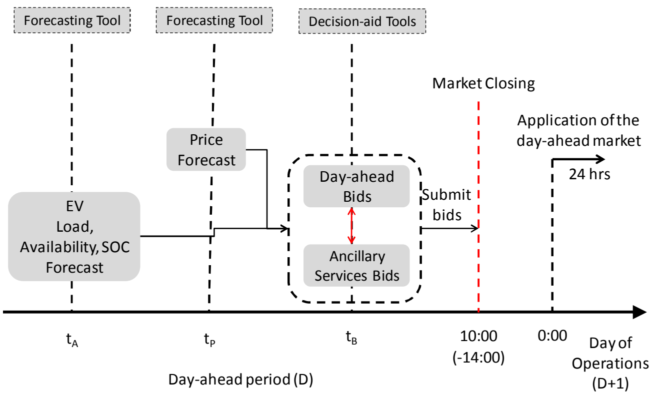

Fig. 1. Timeline of day-ahead market and aggregator market bidding.

2) Information Availability and Forecast

Besides the uncertainty in the market prices, the aggregator also faces uncertainties in the EV owner's behavior and preferences.

The main sources of uncertainty are: departure time instant, arrival time instant, distance, and preferences (e.g. when and how much to charge the battery).

This information is not available for all types of clients and also for all market sessions. Table I presents the degree of information that is available in the day-ahead market by client type, the variables that are essential to forecast, and a qualitative level of uncertainty.

The total load, EV availability and battery SOC can be forecasted with standard techniques used in load and wind power forecasting. Note that the aggregator must associate a bid (quantity and price) to a transmission network node. Therefore it must produce forecasts by network node.

TABLE I
AVAILABLE INFORMATION FOR THE DAY-AHEAD MARKET

	Degree of Information	Forecast	Uncertainty
Type 1	A	total load	the drivers behavior is very unpredictable but the aggregation of EV decreases the uncertainty **(very high)**
Type 2	D	-	the uncertainty is in departure and arrival time instants **(very low)**
Type 3 and 4	A	total load, EV availability and battery SOC	the behavior of these clients is very similar along days and weeks, in particular with aggregated EV **(moderate)**

3) Decision-making Phase

The decision-making could be divided in two phases: i) the aggregator must define ex-ante which markets are more probable to provide a higher net income, or in alternative, which vehicles (or how many vehicles) should be aggregated to increase the profit in a predefined market, e.g. determine if it is attractive to sell peak power; ii) the aggregator must decide how much electrical energy to buy and sell at each hour of both day-ahead and ancillary services market. The aggregator must also evaluate the trade-off between the opportunity of charging the EV with downward reserve and the risk of not being assigned to provide this service in the necessary level.

Based on the forecasts, the aggregator must define periods where it is possible to manage the charging (load) by moving charging from one hour to other. The EV forecasted load gives an estimative of the total required battery SOC of the EV owners (information degree B), which means that the aggregator can move this electrical energy along the hours but in the end (when the vehicle is unplugged) the battery SOC should match the EV owner' preference. Hence, for the day-ahead bids the aggregator must do a roughly estimate of the load, that can be later corrected in the intraday market.

The forecasted battery SOC (separated by clients of type 3 and 4) informs the aggregator about how much peak power or ancillary services can provide.

Following the idea proposed by Ugedo et al [23], the bids for day-ahead and ancillary services market cannot be independent. A decision model that distributes the generation and load resources of an aggregator agent between the two markets, taking into account cost, risk and other criteria, is necessary. The output is the hourly electrical energy bid curves (demand and supply) for the day-ahead, and the upward and downward secondary reserve bids (power and capacity price) for the ancillary services market.

B. Intraday and Tertiary Reserve Market

1) Operation

In addition to day-ahead market, the Iberian market has six intraday market sessions organized as an adjustment market. Table II presents the six intraday sessions from which results new prices and schedules.

TABLE II
INTRADAY MARKET SESSIONS

Session	1	2	3	4	5	6
Opening	16:00	21:00	01:00	04:00	08:00	12:00
Closing	17:45	21:45	01:45	04:45	08:45	12:45
Final Program	19:20	23:20	03:20	06:20	10:20	14:20
Time Horizon	28 h	24 h	20 h	17 h	13 h	9 h
Period	21-24	1-24	5-24	8-24	12-24	16-24

After clearing the secondary reserve market, the system operator defines a minimum amount of tertiary reserve that must be bid to the tertiary reserve market in order to replace the secondary reserve in use. The tertiary reserve market is normally performed in each intraday market. The agents can only present offers for the delivered energy (in €/MWh).

It is not mandatory the presentation of the bids in the intraday market, but it is foreseen that the aggregator will use this market to correct the bids with updated information.

Fig. 2 depicts the procedure that can be followed by an aggregator for participating in the intraday session number 2. The same procedure as in Fig. 1 is used, the input data being "refreshed" with the new forecasts, with additional information from EV owners and with the schedule decided in the previous intraday market session.

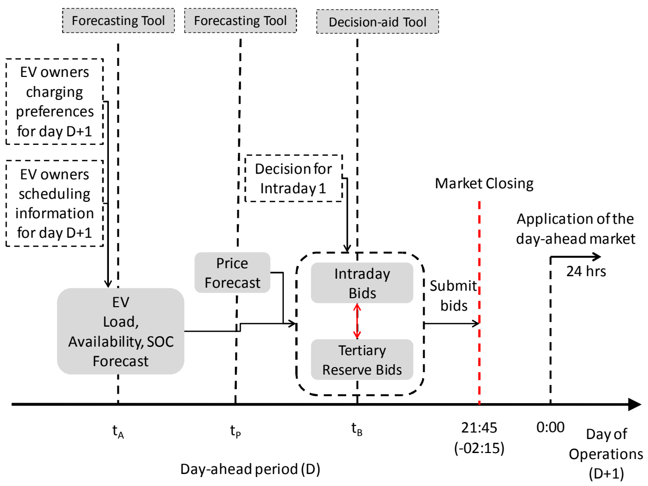

Fig. 2. Timeline of intraday session 2 and aggregator market bidding.

2) Information Availability and Forecast

Since the intraday market sessions are close to the operational time, the aggregator must have information for each EV in order to manage the fleet charging and go to the intraday market if necessary. Table III presents the degree of information that is available in the intraday market sessions 2-6 by client type, the variables that are essential to forecast, and a qualitative level of uncertainty.

It is important to stress that the aggregator may not need information degree C and D. The alternative is to derive typical profiles for classes of EV owners. The clustering approach described in [24] and conceived to build typical load diagrams can be extended to extract load, SOC and plug-in typical patterns of EV. Consequently, to each EV will be assigned a profile and the market bidding and charge management will be based on this profile. This allows a reduction of the computational demand and complexity because establishing the charging for thousand of EV can be computationally heavy and complex.

TABLE III

AVAILABLE INFORMATION FOR INTRADAY SESSIONS 2-6

	Degree of Information	Forecast	Uncertainty
Type 1	A	total load and EV availability	both variables are difficult to forecast, but real-time information can be useful **(very high)**
Type 2	D	-	the uncertainty is in departure and arrival time instants **(very low)**
Type 3 and 4	B	typical daily profile (by weekday, EV technology and user) for availability and SOC	the uncertainty is in departure, arrival, and distance **(low)**
	C	typical daily profile (by weekday, EV technology and user) for load	the uncertainty is in the EV owners preferences **(low)**
	D	-	uncertainty in departure and arrival time instants **(very low)**

3) Decision-making Phase

Similar to the day-ahead market, the bids in the intraday and tertiary reserve market should be decided in a joint decision process.

The major concern when the aggregator participates in the intraday market is to correct the bids made in the previous market session. For instance, if the amount of energy forecasted for the intraday session is larger than the amount of energy contracted for the daily session (or in the previous intraday session), the aggregator makes every effort to sell this surplus of energy in the intraday (obtaining a positive income). Conversely, if the amount of energy forecasted for the intraday session is smaller than the amount of energy contracted for the daily session, the producer must buy the deficit of energy from the pool at an higher price (making a negative income) to avoid imbalance penalties.

Since the intraday markets are close to the operational period, the aggregator based on current status of each vehicle change the bids. For instance, if a vehicle is plugged with a partially charged battery and provides up and down regulation, then it can switched only to down regulation mode to charge the battery without any cost and even gaining money by providing the service.

VI. CONCLUDING REMARKS

This paper presented the conceptual basis to define and characterize the EV aggregator role in the electricity market. Moreover, this basis can be useful to design new markets and rules to accommodate the EV as a flexible load and generation resource.

The ideas described in this paper are already feasible with the current ICT, and the only concern is the trade-off between benefits and costs of the smartgrid paradigm. However, there are several phases in this EV development trend, and the clients that offer controllable load and generation (V2G) will only appear a few years (3 or 4) before the massive integration of hybrid and battery EV. Therefore, the EV aggregator in its first years will be mainly simple load aggregator and electricity retailer.

Finally, new market designs and services are foreseen to include the particular characteristics of EV and also to cope with the integration of new ICT. Therefore, a change in the electricity market is expected, in order to include new products such as peak shaving, load curtailment, load response to prices, local voltage control, loss reduction at the low voltage level, and load shedding due to congestion in feeders. Note that most of these markets do not require the V2G mode.

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Ricardo Bessa received his Licenciado (five years) degree from the Faculty of Engineering of the University of Porto, Portugal (FEUP) in 2006 in Electrical and Computer Engineering. In 2008 he received his Master degree in Data Analysis and Decision Support Systems on the Faculty of Economy of the University of Porto (FEP). Currently, he is a researcher at INESC Porto in its Power Systems Unit and a PhD student of the Doctoral program in Sustainable Energy Systems (MIT Portugal) at FEUP. His research interests include wind power forecasting, data mining, decision-aid methods and electric vehicles.

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