Profit Margin of Electric Vehicle Battery Aggregator

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***Abstract*—In the light of power system decarbonization, electric vehicles are becoming an important tool to bridge the gap between traditional and low-carbon power systems. If aggregated, electric vehicle's fleet can provide flexibility to system operator. Recent literature defines aggregators as electric vehicle charger aggregators which collides with the conventional way of observing electric vehicles, as stationary chargers with connected loads/vehicles. This paper observes them as mobile batteries, not chargers. Therefore, new concept of electric vehicle battery aggregator has been defined which exploits their mobility. Battery aggregator has more information about vehicle's behavior and can maximize their flexibility provision regardless when and where they charge. New concept brings benefits to all system participants from electric vehicle owners, aggregators, and system operators to society altogether.**

***Index Terms*—Electric Vehicles, Electric Vehicle Battery Aggregator, Charging Stations, Flexibility, Batteries**

I. INTRODUCTION

Power system decarbonization enforces new operation paradigm to power system operators. Until recently, conventional generators (CG) were used to provide bulk energy and ancillary services to suppliers and system operators, respectively. Over the last two decades, share of electricity generated from variable and renewable energy sources (RES) increased drastically, while more expensive CGs gets decommissioned. Higher share of inflexible RES and decreasing number of flexible CGs leads to insufficient flexibility for ancillary services. System operators must have enough flexibility to maintain continuous operation and supply. Since the generation side cannot provide enough flexibility, system operators turned to demand side where flexibility can be extracted through demand response programs, energy storage, electric vehicles (EV) etc. In flexibility terms, EVs can be seen somewhat in between demand response and energy storage as they can change their consumption profile but also provide energy arbitrage with their batteries. EV's batteries are small in capacity and they can participate in wholesale markets jointly through new entity named electric vehicle's aggregator (EVA).

This paper will define and classify EVs interaction with power system and propose a new concept of EVA where the objective is maximization of flexibility from EVs.

A. Literature Review

This subsection is going to review recent literature related to EVA in power system research community. EVA in [1] aggregates EVs to participate in electricity and regulation markets. EVA observes only night residential charging, i.e. EVA doesn't observe specific EV's behavior throughout day instead EVA aggregates home chargers of EV users. Input parameters required from EV owners are arrival battery state-of-charge (SOC), arrival and departure times. Paper [2] explores a solution where the EVA directly controls the charging of EVs plugged-in to slow charging points (residential area) and bids for balancing reserve. Input data for EVA are targeted and initial SOC, expected and departure times. For each EV arriving to the charger availability period and charging requirement are defined. If an EV comes to charging point few times a day each new arriving is considered as a new EV. EVA in [3] participate in European style electricity and reserve markets through novel business rationale: bid maximum amount of negative reserve by EVs and use the intraday market as a backup source for charging energy. Each EV upon connection to charger submits: arrival and forecasted departure times, and SOC. EVA observes only time when EV connects to charger which effectively means it aggregates specific chargers activated only when EV plugs in.

Comprehensive stochastic optimization model of EVA in day-ahead energy and ancillary services markets has been proposed in [4]. The SOC at arrival/departure times for individual EVs are forecasted and based on EVs driving/parking profiles. All observed EVAs are positioned in the same bus connected through night hours. Such definition reveals that EVA are aggregators of EV home chargers. Paper [5] propose a model of EVA as price maker and take into account the impact of the aggregator's bids on prices using a bilevel formulation. EVs should communicate their planned trips to the EVA. The individual plans are aggregated and large fleet is defined as time-varying battery. Authors in [6] reported a bidding strategy on electricity and regulation markets where EVA tends to maximize its profit while compensating EVs for battery degradation. Each EV should inform the aggregator their availability (connection to charger). Focus of paper [7] is on the scheduling problem of EV charging in a smart charging station which operates under the mechanism of vehicle-to-vehicle (V2V). EV at charging station set the charging task, however some EVs can function as energy storage and transfer their stored energy to other EVs

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with more urgent deadlines – V2V. Authors in [8] use ADMM to decompose the EVA optimization problem. EVs and EVA solve their individual problems and message the incentive/solution/information signal between them. The input parameter is their deterministic driving/parking profile which implies that they are observing longer optimization time frames not just one parking period but they do not explain how would it be implemented in practice.

Authors in [9] define the EVA as physical entity that connects to the distribution network through a main transformer. EVA is responsible for EVs charging, while maintaining the capacity constraints of its main transformer. Since the EVA is physical entity it aggregates chargers connected to its grid. Authors in [10] designed demand response strategy of smart household with incorporated EVs with vehicle-to-home and vehicle-to-grid capabilities. Household energy management's objective function is to minimize total household energy cost using EVs as source of flexibility. EVA in [11] is charging station's controller on university campus parking lots. Proposed charging strategy tends to minimize peak load curve using controlled EVs flexible charging and it is proven by results. Input parameters are current SOC, and the expected departure SOC and time. Paper [12] observes control strategies and communications requirements for system's load frequency control using EVA (defined as controllers of parking lots). The results show that frequency deviations can be decreased using EVs. Input parameters required from EV owners are battery capacity, initial and real-time SOC, as well as charging mode. Paper [13] proposes optimization framework for battery swapping station (BSS) which acts as an intermediary between power system and EV users. BSS can interact with system in bidirectional flexible manner but can also transfer energy between batteries within its battery stack if high prices occur.

Papers [14] and [15] tackle the problem of EV aggregation from the system point of view where effects of both slow and fast charging on power system has been investigated. It could be noticed that EV integration can improve power system operation if smart charging is applied or if storage is implemented into fast charging stations. On the other hand, passive charging can lower power system efficiency and increase system costs.

Based on literature review, it can be noticed that EV integration into power system is an active, prominent, and ongoing research area. Research community have high expectations for utilization of EVs to provide flexibility to power system. Impact of EVAs has been well investigated in theory, but none of the research papers tackled the issue of EVA's practical implementation.

B. *The new concept – background*

EVA has generally been defined as intermediary between EVs and market/system operator where EVA buys/sells energy/ancillary services on behalf of EVs. However, in reality, it aggregates EV chargers with connected EVs. EV can use/provide energy/ancillary services to the grid only when EV is connected to charger operated by its aggregator. EVs usually provide four input parameters to EVA: metered arrival time & SOC and preferred departure time & SOC. Based on predictions or historic profiles EVA can build demand profiles for its fleet to use them at wholesale markets. EVA defined in this manner resulted from conventional way of addressing the EVs: as any other electric load stationary connected to specific geographic location and specific socket. In fact, EVA is an electric vehicle charger aggregator and it can use only the flexibility of EV batteries within defined availability period on defined locations. EVA do not have information about EV battery SOC prior and after the connection. We argue that EVs should not be observed as conventional loads but as mobile batteries. EVA should not aggregate specific EV chargers physically located at households, parking lots or charging stations but the EVs with their batteries by themselves. The new concept of EVA is therefore named as electric vehicle battery aggregator or EVBA.

EVBA could continuously throughout day track the EV information (SOC, planed trips) as part of future internet of things concept and charge/discharge EVs on whatever charger they connect to. Charger owners/operators should allow all EVs to charge without restrictions but for additional charging fee (charging infrastructure roaming). They should be understood as infrastructure operators similar to transmission/distribution system operators and charging fee as transmission/distribution fee (tariff).

II. DEFINITIONS AND CLASIFICATIONS

To define and elaborate EVBA concept next paragraphs will provide definitions and classifications to different EV charging infrastructure, modes, services, and benefits.

A. *EV charging infrastructure types*

EVs, in contrary to their internally combusted counterparts, possess a wide range of possible charging methods. Interdependency of EV's charging and driving/parking processes can be described through three main charging infrastructure types (illustrated on Figure 1):

- Drive & Charge lanes (or on-road charging): the primary task is to drive an EV, but at the same time owner can recharge it through infrastructure installed at roadways. D&C is possible as conductive – CCL (galvanic connection) or inductive – ICL (wireless connection) energy transfer between EV and charging lane.
- Stop & Charge stations (or stop-by charging): driving with brief stops for charging through infrastructure installed next to roadways. S&C can be carried out through battery swapping stations – BSS (EVs swap empty for full battery) and Fast Charging Stations – FCS (short charging times, high charging power).
- Park & Charge lots (or parked charging): the primary task is to park an EV, but at the same time owner can recharge it through infrastructure installed at parking lots. P&C lots with high EV interchange frequency include medium chargers (medium charging times and power), while low-frequent lots include slow chargers (long charging times, low charging power).

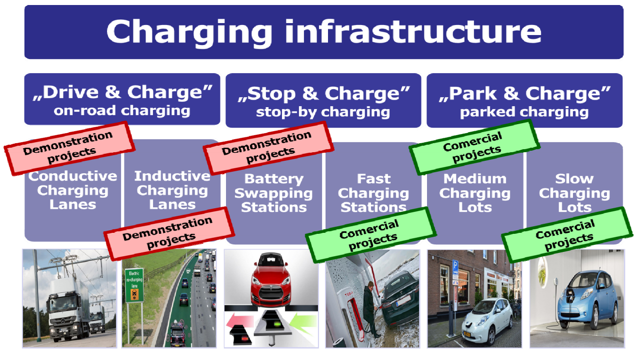

Figure 1. EV's charging infrastructure types

B. *EV charging modes in regards to EVSE flexiblity*

Each EV requires energy for motion, however EVs usually do not spend all energy for their trips and have spare energy or power capacity which can be used to sell flexibility services to system operator. Five main modes of power interchange between EV's and power grid can be identified:

- Uncontrolled or fixed power charging:
  - EVs charge at maximum power since plugged-in until fully charged (D&C, FCS, and P&C);
  - Batteries charge at maximum power since stocked-in battery stock until fully charged (BSS);
- Unidirectional controlled grid charging:
  - Grid-to-Vehicle (G2V): EVs charge according to aggregator's instructions (D&C, P&C);
  - Grid-to-Station (G2S): FCS charge controllable through energy storage as a buffer, but each of EVs within the station is charged uncontrollable (FCS);
  - Grid-to-Battery (G2B): Batteries charge according to BSS operator's instructions (BSS);
- Bidirectional controlled grid charging/discharging:
  - Vehicle-to-Grid (V2G): EVs charge or discharge according to aggregator's instructions (D&C, P&C);
  - Station-to-Grid (S2G): FCS charge/discharge controllable through energy storage, but each of EVs within the station is charged uncontrollable (FCS);
  - Battery-to-grid (B2G): batteries charge/discharge according to BSS operator's instructions (BSS);
- Controlled without grid charging:
  - Home-to-Vehicle/Vehicle-to-home (H2V/V2H): EVs charge/discharge using energy generated or stored in household (Slow Charging Lots);
  - Vehicle-to-Vehicle (V2V): EVs function as energy storage and transfer their stored energy to other EVs with more urgent deadlines (D&C, P&C);
  - Battery-to-Battery (B2B): Batteries function as energy storage and transfer their stored energy to other batteries with higher SOC (BSS).
- Controlled charging with additional services:
  - Vehicle-for-Grid (V4G): EV's charging/discharging flexibility is used for grid-specific ancillary services such as voltage control (D&C, P&C);

C. *EV's flexiblity services*

EVs can provide flexibility services utilizing controlled charging modes listed in Subsection II. B. In this paper, flexibility services are defined as the use of EV's controllable charging/discharging ability to change power rates at grid connection point. In general, these services are all actions beside basic charging (whose purpose is to increase the SOC to and to ensure energy for mobility) and they can be:

- Up regulation achieved through:
  - If charging – charging power decrease,
  - If discharging – discharging power increase,
  - If idle – start discharging,
- Down regulation achieved through:
  - If charging – charging power increase,
  - If discharging – discharging power decrease.
  - If idle – start charging.

D. *EVA types*

EVA can act on different markets with different objective functions. In general, EVA can act as:

- Conventional supplier of EV chargers: Chargers are regarded as any other load (fixed charging) and EVA buys energy for them in energy-only markets;
- Flexible supplier of EV chargers: EVA supplies EVs (energy-only market) and use charger's flexibility (controlled charging) to balance its own stochasticity;
- EV charger aggregator – BRP balancing: EVA supplies EVs (energy-only market) and use charger's flexibility (controlled charging) to provide balancing services to other participants (balance responsible parties – BRP);
- EV charger aggregator – System balancing: EVA supplies EVs (energy-only market) and use charger's flexibility (controlled charging) to provide balancing ancillary services (regulation and reserve markets);
- EV charger aggregator – Grid services: EVA use charger's flexibility to provide grid-specific ancillary services (voltage/reactive power control, black start…).

EVBA concept can efficiently incorporate all above-mentioned types depending on market design and regulation.

III. NEW CONCEPT

Charging at any infrastructure type described in Subsection II. A. depends on the same EV's SOC. However, based on current EVA definition, different aggregators (FCS/BSS operators or slow charger aggregators) act independently one from another and act as competitors. The idea is to create EVBA business model with the insight into charging at all infrastructure types and by doing so extracting maximum benefits from EV battery's flexibility.

A. The core of EVBA concept

Benefits of charging an EV at slow/medium charging lots (SCL or MCL) versus FCS are multiple: lower power rates – lower battery degradation, off peak charging – lower charging energy, charging at one's backyard – no need for travel to charge, long charging times – high possibility to provide flexibility services… For this reason, slow/medium charging should be used for bulk energy charging, while other infrastructure types are supplementary when additional motion energy is required. SCL/MCL are usually part of other consumer facilities and they are controlled within their smart environment (smart households, buildings, parking lots etc.). It's not quite clear how an EVA can aggregate chargers (sockets) within other's property. That's why each charger should have its own independent metering so energy for/from EV can be exactly defined. When using charger metering several problems arise. How to execute billing if EV charges on charger that is not his property since supplier relates to chargers not EVs? How to include charging on different charging infrastructure in EVA's future demand forecasts? How to pay for or forecast an EV's flexibility services? Our solution to these questions is to implement metering on EV's batteries and to aggregate batteries itself, not their chargers, which is the core of EVBA concept.

In such design, SOC of batteries is tracked down by EVBA on continuous basis and EVs long-term flexibility could be utilized. For example, consider a case of a single EV illustrated on Figure 2 and Figure 3. Figures are representing EV's driving/parking/charging profile through three adjacent days. Areas represent EV's availability to charge, while red lines represent EV's SOC for the case of uncontrollable charging (it doesn't provide insight in EV's SOC profile when used for flexibly services). Exemplary EV uses three charging infrastructure types: home-charger (where it parks every night), a work-charger (where it parks during workhours), and a FCS (on road to its favorite restaurant where it recharges every couple of days). Home-charger is EV owner's property, work-charger is EV owner company's property and FCS is of private recharging company. Under conventional EVA concept, home and work chargers would utilize EV's flexibility just during EV's parking hours on that specific charger without knowledge of charging and discharging outside that specific parking period. Different charging periods are illustrated with different colors on Figure 2 and each of them is independent from each another. EV's cannot charge bulk of their power when energy prices are low (for example at weekends) or provide extra flexibility when flexibility prices are high since they do not record the history and do not *predict* the future. The also do not have information about SOC behavior due to driving and charging on FCS. In EVBA concept, EVs would optimally charge on different chargers while observing longer period. EVBA can track SOC information in all green areas of Figure 3. Since, EVBA have continuous information about battery's behavior stochasticity will decrease radically while forecasting and scheduling becomes far more efficient.

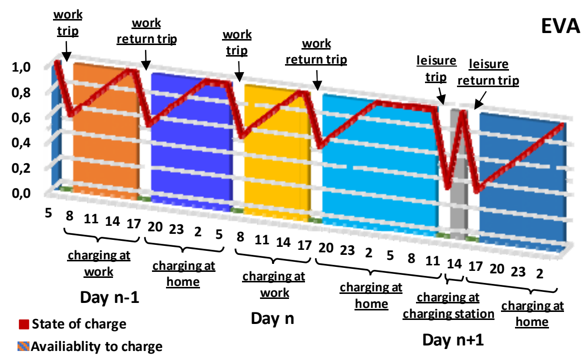

Figure 2. EV's driving/parking/charging behavior under conventional EVA

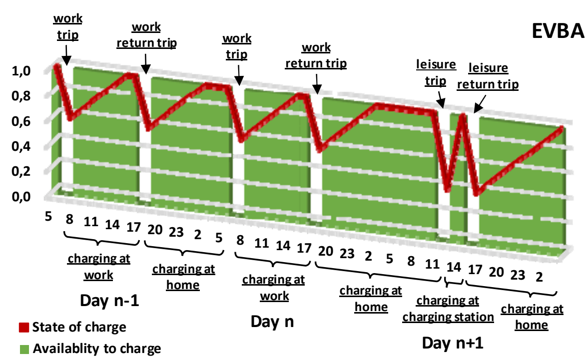

Figure 3. EV's driving/parking/charging behavior under EVBA

B. Additional business opportunities of EVBA concept

Nowadays, many companies worldwide offers EV charging services through their own or through roaming on others' charging infrastructure. There is also many ICT platforms offering mapping and information about charging infrastructure as well as optimal EV routing to closest and cheapest chargers. Such activities require detail information about EVs planned trips and battery characteristics. Since EVBA already handle all those data for its clients, a service of optimal EV routing is easily implemented to its algorithms.

Even though charging at FCS is more expensive and more degrading, it is sometimes required as supplementary to SCL/MCL due to three reasons:

- Unexpected trips before EV has been charged as planned and scheduled;
- Insufficient charging times at SLC/MCL (business EVs, e.g. taxis), requires additional energy to finish activities;
- Insufficient driving range, EV's battery is depleted before the end of the trip (e.g. intercity trips).

Investments in FCS are slow and usually executed by companies whose primary goal is not to earn through EV charging but to attract customers for their core business (commercial sector, energy companies, EV manufactures, city authorities…). Since EVBA have EV's detail information, they would be ideal company to site, size and invest in FCS at most frequent routes. It can provide competitive edge to EVBA and increase the number of its clients.

The same idea applies for charging lanes and BSS. The former is still in its early stage of development, while the latter have conceptual issues. The BSS advantages are short swapping times and lower battery degradation rate. In BSS concept all the batteries are BSS property. BSS needs to have significant number of batteries to even start its operation which makes capital-intensive to invest in BSS. Another issue is that BSS doesn't allow charging outside BSS facility due to degradation reasons which is not appealing neither to EVAs nor to EV users. If an EV wants to recharge its battery by a dozen percent, the swapping process is the same as for the empty battery. Insufficient battery standardization between various battery and car manufactures is a big issue as well.

Using EVs to provide flexibility services often collide with the problem of battery degradation. Capital cost of buying an EV is high where one of the most expensive parts is battery. EV's users are unwilling to lend their batteries to aggregator for flexibility services even if the charging would be cheaper because, eventually, they would end up with destroyed battery. Since EVB concept base itself on strong control of EV's batteries, the opposite interaction of EV's users and EVBA would be extremely beneficial: the EVBA should participate in EV owner's investment costs by buying the battery and effectively lending it to EV owner for mobility. The benefits of such model would be multiple:

- EV owner's investment costs are significantly decreased and EVs become accessible to wider range of users;
- EV owners do not have to coupe up with battery charging and degradation (EVBA takes over);
- EVBA acquires batteries for the whole fleet which leads to lower battery costs due to volume discounts;
- EVBA receives continuous information about battery conditions and could easily perform on-line monitoring and diagnostics effectively becoming ideal battery maintenance company and prolonging battery lifetime;
- EVBA can offer battery swapping due to degradation and swap EV's battery when battery's maximal capacity falls under certain value;
- After battery capacity drops under values usable for mobility in EVs, EVBA can second-use them as stationary storage (especially within its own FCS to lower the peak demand and costs);
- Since, the main BSS obstacles are solved (ownership and battery degradation), EVBA could invest in BSS at frequent FCS locations and increase its revenues.

IV. Conclusion

New concept of EV aggregator, named electric vehicle battery aggregator – EVBA has been proposed and demonstrated. EVBA aggregates EV batteries, hence long-term EV flexibility can be most efficiently utilized. Continuous information exchange takes place between EVs and EVBAs. Efficient EVBA integration and design can bring benefits to different system participants. Existing EV owners can experience cost savings, new EV users can be stimulated, while their EVBAs can exploit new business opportunities. Grid operators can increase grid efficiency, while system operators can carry out more efficient system balancing. In general, society benefits are twofold: decarbonization of power (increased feasible RES penetration levels) and transportation system (increased attractiveness of electrification process).

Future research will focus on EVs and EVBAs modeling in stochastic electricity and ancillary services market environment where the benefits of EVBA versus conventional EVA will be demonstrated.

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