Two Alternative Approaches for Modelling a Portfolio of Electric Vehicles

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***Abstract*— This paper describes two alternative optimization approaches, global and divided, for supporting the participation of an electric vehicles (EV) aggregator in the day-ahead spot market. The two optimization approaches are formulated as linear optimization problems, and the difference is on how information about EV is represented. The global approach uses aggregated (or total) values of the EV variables, while the divided approach uses individual information from each EV.**

Keywords: electric vehicles; aggregator; electricity market; forecasting; optimization.

I. Introduction

The participation of electric vehicles (EV) in the electricity markets will probably follow the same scheme of household's consumers. Aggregation entities (also known as load-serving entities) will serve as intermediaries between the loads (EV in this case) and the system operators (TSO and DSO) and market operators [1]. These entities aggregate a portfolio of EV under contract and purchase electrical energy for satisfying the EV charging requirements in the electricity market.

The EV aggregation agent is a concept already adopted in business models for electrical mobility. For instance, in Portugal the industrial network MOBI.E is implementing a charging network accessible to all users [2]. The business model includes aggregation agents that users may liberally choose. In this model, the aggregator is a simple electricity retailer for electrical mobility. A more elaborated aggregator model, comprising the possibility of controlling directly the charging process of each EV is being explored in this paper. This type of EV aggregator enables the smart-charging approach. Moreover, the EV aggregator may also present offers for ancillary services (namely reserve), which will increase its retailing profit and decrease the charging tariffs for the EV drivers [3].

Many algorithms were developed for supporting the EV aggregator participation in the day-ahead spot and reserve market [4][5]. The major limitation is the assumption that there is complete knowledge of all the EV variables (such as driving routes) involved in the problem. In fact, it is necessary to forecast these variables. Furthermore, it is crucial to have an operational management phase where the aggregator manages (or dispatch) the EV charging, in order to avoid penalizations due to deviations from the bid values.

This paper covers the gap between optimization and forecasting phases, and studies the impact of EV information modeling in the optimization algorithms. Two alternative approaches are discussed and tested: one that uses aggregated values of the EV variables (named global), and another that uses individual information from each EV (named divided). Both approaches solve the same problem; the difference is on how information about EV is modeled in the optimization phase.

II. Aggregator Framework and Chain of Algorithms

A. Aggregator Framework

Two different groups of clients are foreseen for the EV aggregator: inflexible EV, which is a client who does not allow the aggregator to control the charging process, being the aggregator just an electricity provider; flexible EV, which is a client who allows the aggregator to control the charging process (bidirectional communication). The charging requirement of a flexible client must be satisfied, but presents a degree of freedom regarding when this load can be supplied.

The aggregator represents the EV drivers in the electricity market and retains a profit that depends on its bidding strategy and charging control strategy. However, it does not have any control over the individual EV driving behavior, so the driver needs must still be respected and are the main priority. The benefits for the aggregator are the possibility of increasing its retailing profit by minimizing the cost of purchased electrical energy. In exchange, the aggregator offers cheap retailing prices or a discount in the monthly electricity bill, in particular for flexible loads.

For the inflexible EV clients, the aggregator only buys electrical energy for charging these clients. The interaction is unidirectional and just for billing purposes.

B. Chain of Algorithms

For the short-term time horizon (up to 48 hours ahead), the aggregator participates with buying bids in the spot market.

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The aggregator for each hour of the next day, based on forecasted variables, defines the bids for the day-ahead spot market. The optimized decisions related with these markets are performed on a daily basis and the bids are not discriminated by EV.

The optimization process can use as input the EV information represented with two alternative approaches (depicted in Fig. 1):

- global approach: the variables related with each EV are aggregated and the optimization model determines the "optimal" bids entirely based on summed values of EV availability and consumption. The EV individual information is not included in the bidding phase;
- divided approach: the variables related with EV behavior are forecasted for each EV and the optimization model based on this information computes the optimal charging for each EV. The bid is equal to the sum of the optimized individual charging.

The bids resulting from the day-ahead optimization phase are the input of an operational management algorithm. The operational management is discriminated by EV and takes advantage of the EV fleet flexibility. This flexibility allows different combinations of charging profiles for achieving a matching between consumed electrical energy and accepted bids. The inputs are the following: accepted bids from the day-ahead market session; expected end of charge time interval and charging requirements of the EV, communicated by the drivers that are plugged-in. Based on this information, the algorithm optimizes the individual EV charging to comply with the market commitments and satisfy the EV drivers charging requirements.

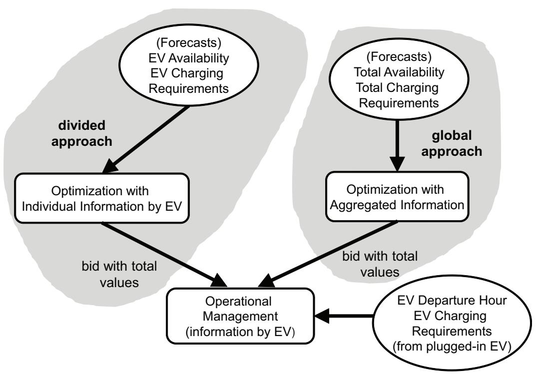

Figure 1. Chain of algorithms for the participation in the day-ahead spot market.

An important part of this model chain consists in forecasting algorithms for the electric energy consumption from EV and availability periods for charging. The load forecasting task is common in problems related with power systems and electricity markets. However, this problem is different because the aggregator controls the EV consumption, which means that the classical approach of forecasting the consumption in each time interval cannot be strictly followed. The proposed approach in this paper is to forecast the charging requirements. The charging requirement of each EV is the electrical energy needed to get from the initial SOC (i.e. when the EV plugs-in for charging) to the target SOC defined by the EV driver for the next trip. The aggregator then distributes this quantity (following an optimization strategy) by the time intervals of the plugged-in period.

III. CASE-STUDY RESULTS

A case-study using the rules and data of the day-ahead Iberian spot market was used for comparing the two alternative approaches. The total cost (cost of purchasing electrical energy plus penalizations due to deviations from planned) was computed for both approaches. Fig. 2 depicts the total cost for 100 samples obtained from a sampling process based on [17]. The objective is to evaluate the optimization results for different market data randomly sampled. The two approaches are compared with the situation where all the EV are inflexible.

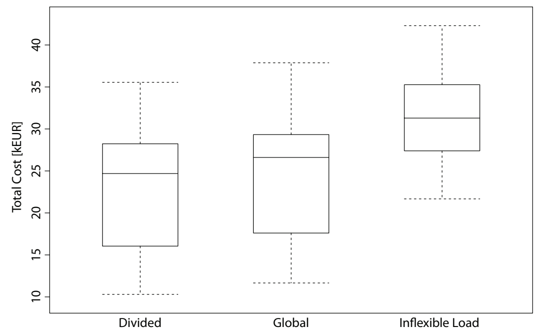

Figure 2. Total cost for the divided, global and inflexible approach.

The approach with the lowest total cost is the divided approach, followed by the global approach. The median of the total costs is 24.69 k€ for the divided approach, 26.60 k€ for the global and 31.29 k€ for the inflexible load. This translates to a 26.7% total cost decrease in the divided approach compared to the inflexible load, and a 17.6% decrease in the global approach. Note that the inflexible approach presents a high total cost because the EV are not controlled by the aggregator and charge in expensive hours.

REFERENCES

[1] R.J. Bessa and M.A. Matos, "Economic and technical management of an aggregation agent for electric vehicles: a literature survey," Europ. Trans. on Elect. Power, vol. 22, pp. 421-570, May 2012.

[2] MOBIE May 2012. [Online] http://www.mobie.pt

[3] R.J. Bessa, M.A. Matos, F.J. Soares, and J.A. Peças Lopes, "Optimized bidding of a EV aggregation agent in the electricity market," IEEE Trans. on Smart Grid, vol. 3, pp. 443-452, Mar. 2012.

[4] E. Sortomme and M.A. El-Sharkawi, "Optimal charging strategies for unidirectional vehicle-to-grid," IEEE Trans. on Smart Grid, vol. 2, pp. 119-126, Mar. 2011.

[5] D. Wu, D.C. Aliprantis, and L. Ying, "Load scheduling and dispatch for aggregators of plug-in electric vehicles," IEEE Trans. on Smart Grid, vol. 3, pp. 368-376, Mar. 2012.

[6] M. Herrera, L. Torgo, J. Izquierdo, R. Pérez-García, "Predictive models for forecasting hourly urban water demand," J. of Hydro., vol. 387 141-150, 2010.