A Profitable Business Model for Electric Vehicle Fleet Owners

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***Abstract*—Fleet owners, as active participants in the decentralized energy grid, are interested in offering mobility services to the individual customers, while providing to the grid with balancing possibilities. We present a business model for the fleet owners of Electric Vehicles (EV) and prove that EVs adoption is beneficial both for the owner and the grid itself. The fleet owner's main objective is to benefit from the difference between demand and intermittent supply (from renewable energy sources), employing the Vehicle to Grid (V2G) concept. The core idea is based on the fleet owner's decision for charging the EVs during off peak hours and selling energy on the wholesale market during peak hours. This behavior leads to significant profits for the fleet and improvements in social welfare owner if the buying and selling decisions are made properly. We present a charging and discharging algorithm that converts the traditional energy consumer to an active *prosumer*, while at the same time yields significant profits for the fleet owners. Apart from the profitability for fleet owners, we show the positive impact of the proposed algorithm on the energy prices, which leads to social welfare improvement.**

I. Introduction

Electric Vehicles (EVs), as part of the decentralized energy grid, gain increasing adoption rates by individuals. They offer benefits at the societal level: lower CO_2 emissions, reduced dependency on fossil fuels (currently private transport depends to 95% on Oil according to the International Energy Agency (IEA)[1]), and high fuel efficiency. However, the adoption of EVs depends largely on the benefits they offer to individuals. The most striking benefit in this respect is lower fuel costs as compared to internal combustion engines[1], which will grow with increasing fuel costs. Nevertheless, the question remains whether these benefits are sufficient to initiate a paradigm shift from the internal combustion engine to the EV. Next to the traditional benefits associated with EVs as named above there is a much more subtle, yet significant benefit hidden in the battery of electric cars. By employing the batteries to absorb peak demands in electricity consumption as a decentralized load balancing tool for smart grids, considerable energy savings could be achieved for EV owners and society as a whole. From this we derive a business model for EV fleet owners who offer, in addition to mobility services to consumers, balancing capacity to the grid. It entails that batteries of the fleet owners EVs are charged when prices are low, and energy is sold back to the grid during peak prices. This buying and selling process will be controlled by intelligent software agents that work on behalf of fleet owners.

[1]Idaho National Laboratory, US Department of Energy, "Comparing Energy Costs per Mile for Electric and Gasoline-Fueled Vehicles", Advanced Vehicle Testing Activity, 2011. [Online]. Available: http://avt.inel.gov/pdf/fsev/costs.pdf. [Accessed: 15-Mar-2012].

II. Related Work

A fleet owner with a large quantity of EV's cannot only manage the demand side of electricity by charging his cars, but also the supply side by making additional energy available to the grid during demand peaks. This aspect is picked up by [2] with the conclusion that households can save up to 14% of their energy - while also reducing carbon emissions by 7% - and with a 48% market share social welfare would be maximized. These findings are consistent with [3] who saves 14.5% savings under similar conditions. Other research in this area, which does not account for battery degradation cost, finds that the yearly benefits are in the range of $20-120 (approximately EUR 16-96) [4] and EUR 135-151 [5]. [5] consequently investigates battery degradation costs. The author estimates that battery degradation cost range from 30 to 100 EUR/MWh. A price sensitivity analyses yields that at a price of 50 EUR/MWh for battery degradation cost, batteries are hardly used for arbitrage storage, whereas it is profitable at 10 EUR/MWh. His findings imply that the usage of Vehicle to Grid (V2G) depends on future developments in battery technology. This is supported by [6] who conclude that the future of a V2G approach lies with the developments in battery technology, and incentives for consumers to adopt EVs. [4] argue that the low yearly profits for individuals from load balancing would not to make V2G commercially successful. In contrast to this [7] see the V2G approach as a new way to make volatile renewable energy sources suitable for mainstream energy usage . They reason that volatility in renewable energy sources can be hedged against with a large amount of EV batteries. Some research even goes beyond seeing V2G as a mere a tool to regulate volatile renewable energy sources, and coin the term Virtual Power Plant [8]. A Virtual Power Plant is comprised out of the idle car batteries at battery changing points, which are connected to the smart grid. In this regard [9]'s research is relevant as they simulate the behavior of a virtual power plant integrated into current infrastructure at the example of the island of Bornholm, Denmark. They illustrate that the V2G approach is profitable when customer behavior and electricity prices are forecasted based on historical data.

Within this paper we focus on the effect of EVs in the wholesale market. We analyze past data with respect to variations in demand and supply examine their interaction effect. Unlike the retail market, where the prices are usually fixed, the wholesale market allows for benefiting from the market mechanism. Therefore, by considering the wholesale market we have a more genuine perspective on how the EV's impact demand and supply.

III. Simulation Environment and Model Description

The simulation environment is the Power Trading Agent Competition (Power TAC) [10]. Power TAC is a real world simulation that models decentralized electricity markets. The major stakeholders are generation companies, consumers, prosumers and intelligent agents acting on their behalf. They compete in the retail and wholesale market, where energy is traded as an hourly good rather than in a yearly contract. Prices may fluctuate based on demand and supply in an hourly fashion. The agents predict future prices based on historical data and weather forecasts and sell call options to use this energy. It is a complex trading environment as discussed by [11] with real time decision support from intelligent agents.

In this Power TAC based market, self-interested brokers, who are represented by intelligent software agents, buy and sell energy in the deregulated energy market with the main objective to make profit. To participate in the double auction wholesale market, suppliers submit an ”ask”, composed by the quantity they would like to sell and the lowest price they are willing to accept, for the specified timeslot. The buyers place a ”bid” with the quantity they want to buy and an indication of the price they are willing to pay at most, for the specified quantity. For both, consumers and suppliers, a market order is placed for buying and selling a certain amount of energy at the market price. Once all ”bids” and ”asks” are placed, all ”asks” for a certain timeslot are ordered by ascending price to estimate the demand curve. All ”bids” for a certain timeslot are ordered by descending price to estimate the supply function. The intercept of both functions is the clearing price that matches supply and demand.

A. Driving Profiles

Individual customers leasing EVs play a central role in this paper. We argue that this particular customer segment is of high interest in decentralized energy markets because of its particular storage features. We examine the consuming behavior of this customer group under the prism of a fleet owner who is able to aggregate the remaining storage capacity in the EVs and provide balancing services to the grid. The balancing capacity is a function of the electric cars in the fleet adjusted for consumers usage of the leased car. This means that a certain amount of every battery is reserved for the needs of people to drive the EV's. To determine the amount of the capacity to reserve, we distinguish between different consumer clusters in terms of their gender and social group. The social groups are divided into people who work 12-30 hour per week, people who work 30 hours per week and more, unemployed, students, retired, and incapacitated people. We retrieve the distance that these groups drive and the corresponding motives from the Dutch Statistical Institute[2]. Driving motives are split up into driving to work, business drives, personal care, groceries, culture and education related, visits, and sports and recreation. When analysing this data one can clearly see the peaks in driving behavior from 7 a.m. to 9 a.m. and 4 p.m. to 6 p.m. during rush hour. Furthermore we distinguish between weekdays and weekends, as the data implies that during weekends people drive less then they drive during the week. Based on this driving behavior patterns we can infer how much each car needs to be charged per day, which is added to the reserved capacity. Finally we account for the fact that an EV cannot be plugged in everywhere. Therefore we only have 90% of the capacity of all EV's at a time as indicated by [12]. An assumption for this constraint is that EV's will be the perfect substitute for an internal combustion engine vehicle in the future, as the price for EV's will decrease due to economies of scale and the range will be comparable to a regular car with advancing technology, too.

Besides the cost of wear and tear of rechargeable batteries also the energy conversion efficiency (η) is an important cost aspect to consider when evaluating the V2G's profitability. About 3-4% of the energy is lost during the charging process of the EV as the alternating current from the grid has to be converted to direct current and subsequently be stored in the battery [13]. When energy is delivered to the grid from the EV's battery 2.4% of the energy is lost because it has to be re-converted from a direct current to an alternating current using an off the shelf solar energy inverter[3].

B. Prosumers Strategy

Demand and supply on the wholesale market vary between timeslots. This means that large fleet owners with storage capacity at their disposal can offer balancing services and benefit from this opportunity. We demonstrate the profitability of this approach with the help of an algorithm that bids energy when prices are above a certain sell threshold and charge their batteries when prices are below the buy threshold based on heuristics that approximate average consumer behavior. Both have an impact on the clearing point for that timeslot. Optimal thresholds to buy and sell are determined by the algorithm described in this sections. When large fleet owners place ”asks” on the market, supply increases. The direct consequence is that the clearing quantity increases and the price decreases. On the other hand when they place ”bids” on the market, demand increases meaning that both the clearing quantity and price increase. The magnitude of these effects on the clearing point per timeslot are estimated with the help

[2]Centraal Bureau voor de Statistiek CBS, ”CBS StatLine - Mobiliteit per regio naar vervoerwijzen en algemene kenmerken.” Centraal Bureau voor de Statistiek (Statistics Netherlands), 2012. [Online]. Available: http://statline.cbs.nl/StatWeb/publication/?DM=SLNL&PA=37637&D1=a&D2=0&D3=0&D4=1&D5=0&D6=l&VW=T. [Accessed: 10-Mar-2012].

[3]SMA Solar Technology AG, 2012. ”SUNNY CENTRAL 100 Outdoor / 100 Indoor.” [Online]. Available: http://www.sma.de/en/products/central-inverters/sunny-central-100-outdoor-100-indoor.html. [Accessed: 28-May-2012].

of the supply and demand curve as derived in the description of the simulation environment. This way every consumer that leases a car from the fleet owner will in fact be a *prosumer*, with impact both on the supply and demand curve. We train the algorithm on a historical data set derived from the Power TAC 2012 qualification rounds and maximise the revenues for all combinations of buying and selling thresholds as follows:

$$max(\sum_{i=1}^{n}(price_i \cdot qSold_i) - \sum_{i=1}^{n}(price_i \cdot qBought_i)) \quad (1)$$

where $qSold$ and $qBought$ are the quantity sold and bought respectively in the wholesale market, i stands for the timeslot and n is the last timeslot of the training set.

Under the following constraints:

$$qSold_t \leq \sum_{i=1}^{n}(C_{N,i} - C_N status_{t,i}) \quad (2)$$

$$qBought_t \leq \sum_{i=1}^{n}(C_N status_{t,i}) \quad (3)$$

where t is the timeslot, i is an individual EV, n is the total amount of EV's, C_N is the battery capacity of an EV in kWh, and $C_N status$ is the battery status in kWh.

Solving the above maximization problem we are able to define the selling and buying threshold that ensure significant profits for the fleet owner.

IV. Results & Discussion

A. Fleet Owner's Perspective

In this section a break even analysis is performed to get a better understanding of battery costs and its role in V2G. Based on the buying and selling heuristic thresholds as outlined in the previous section we can determine the revenues of this strategy on a test data set. In order to find out the break even cost we have to add battery depreciation cost for the use of the battery over its life cycles. Battery degradation cost are determined by the cost divided by the total number of life cycles, as we will discuss in more depth later. If the battery depreciation costs are higher than the arbitrage profit the fleet owner will make a loss for every kWh sold. However, if the depreciation costs for a battery are lower than the arbitrage profit, the fleet owner will make a profit. Therefore one can conclude that if battery depreciation costs are the same as the profit from the arbitrage difference, the fleet owner will break even.

Despite the fact that the simulation is a non-terminating system it needs to be considered as a terminating system to be able to run statistical tests on it. The warm-up period is 14 days, which is standard in the Power TAC environment. The 95 % confidence interval of the battery degradation cost has a half-width of less then 1 % with 194 replication days. We determine the battery depreciation cost per kWh (short battery cost) break even point as follows:

$$(\sum_{i=1}^{n}((price_i - bCost) \cdot qSold_i) - \sum_{i=1}^{n}(price_i \cdot qBought_i)) = 0 \quad (4)$$

here $qSold$ and $qBought$ are the quantity sold and bought respectively in the wholesale market, $bCost$ is the battery cost, i is the timeslot and n is the least replications required multiplied by the number of timeslots.

The corresponding lower confidence level is 0.059 EUR/kWh and the upper confidence level is 0.057 EUR/kWH. In other words we are 95 % sure that the break even point for battery cost lies between 0.059 EUR/kWh and 0.057 EUR/kWh. These results comply with the findings by [5] who imply that the break even point for profitability of V2G activities lies slightly above 0.05 EUR/kWh.

In order to determine the profitability of the V2G approach for large fleet owners, it is not sufficient to determine a break even point. It is desirable get an estimation of the potential profits that are associated with V2G. As the developments in battery technology are the crucial factor in determining profitability [5], but are difficult to predict, this paper considers two scenarios in battery development. For both scenarios we consider a 16 kWH *winston thunder sky* lithium ion battery. The off the shelf price of paired with the estimation that prices will decrease a third by 2017[4] results in 3800 EUR acquisition cost. In scenario 1 we expect battery technology improves in the coming years. In accordance with requirements outlined for batteries in EV's by the US Department for Energy in collaboration with the US Advanced Battery Consortium (USABC) a battery will be expected to last for 5000 life cycles[5]]. The corresponding battery depreciation cost for scenario 1 amount to 0.0475 EUR/kWh. Under this assumption fleet owners that participate in V2G trading will make a profit between 0.0095 EUR/kWh and 0.0115 EUR/kWh sold assuming a 95 % confidence interval. The market saturates when the penetration of EV's is at least 13% of all cars. At the example of Germany that would mean there are more than 5.5 million EV. In that case the fleet owner makes a profit of approximately 3.2 million EUR on a monthly basis for a market the size of Germany. Exceeding the 13% EV penetration does not yield additional profits for the fleet owner, as virtually all variation beyond the given price thresholds can be captured at that level (See Figure 1). In scenario 2 we estimate that within 10 years battery manufactures are able to bring lithium ion batteries on the mass market that have a longevity comparable to batteries that NASA built in 2005[6]. In that case a battery would last for 10000 life cycles and depreciation costs will be 0.02375

[4]Pike Research, 2011 "Electric Vehicle Batteries. Lithium Ion Batteries for Hybrid, Plug-in Hybrid, and Battery Electric Vehicles: Market Analysis and Forecasts." Navigant Consulting, Inc..

[5]D. Howell, 2009 "Progress Report for Energy Storage Research and Development 2008." US Department of Energy, Washington, D.C..

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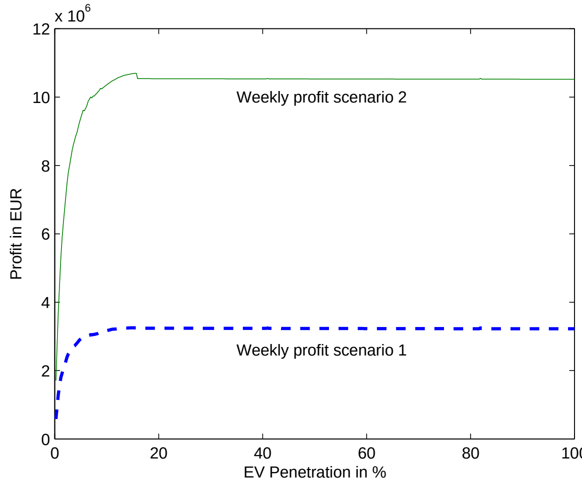

Fig. 1. Fleet owner profit for Scenarios 1 and 2 in the German market.

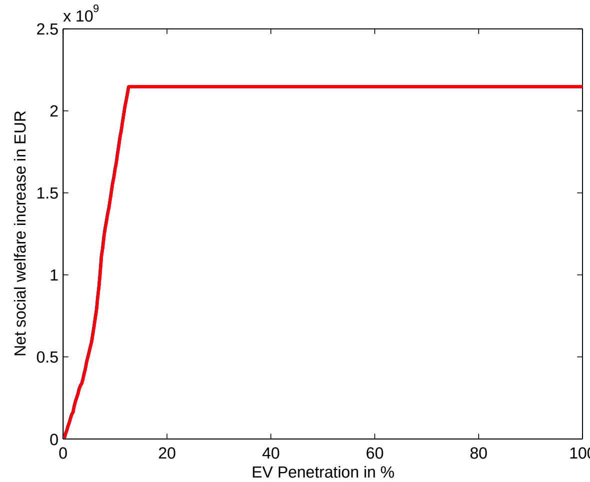

Fig. 2. Annual Social Welfare Improvement (at the example of Germany).

EUR/kWh. In scenario 2 fleet owners would earn between 0.03325 EUR/kWh and 0.03525 EUR/kWh. At the saturation level of 13% this translates into approximately 10.6 million EUR earnings on a monthly basis for a market the size of Germany (See Figure 1).

B. Societal Perspective

Besides the benefits for fleet owners there are also benefits for consumers when fleet owners participate in V2G trading. As fleet owners make additional energy available to the market, the demand decreases and the supply increases, which has the effect that the clearing price decreases. However, when fleet owners charge their EV's for V2G purposes the demand increases, while supply remains the same, which has an adverse effect on the clearing price. It is not intuitively clear which effect is stronger. Therefore the prices for electricity are measured in a regular Power TAC simulation and then the results are compared with a paired t-test to the same simulation, but with V2G. The comparison suggests that the average wholesale price is significantly lower when V2G is available. The magnitude of the price difference is a function of the fleet size up to the point where the market is saturated. Also social welfare plateaus at an EV penetration of 13%. If 13% of all cars in Germany were EV's that would be used for V2G the average price for electricity would decrease significantly, creating social welfare of on average EUR 2.1 billion annually ($p < 0.01$). Also for social welfare it holds that an EV penetration exceeding 13% does not yield additional benefits, as virtually all variation beyond the given price thresholds can be captured at that level (See Figure 2). If the price is weighted by the quantity sold per timeslot the decrease is significant ($p < 0.01$). Previous research has not been able to prove this welfare on the societal level, as they focused on benefits for individual traders at the retail level.

TABLE I
RESULT SUMMARY

Break-even battery cost	0.059 EUR/kWh
Scenario 1 (Battery cost are 0.0475 EUR/kWh)	EUR 3.2 monthly million profits for fleet owner*
Scenario 2 (Battery cost are 0.02375 EUR/kWh)	EUR 10.6 monthly million profits for fleet owner*
Net social profit	EUR 2.1 billion for society on annual basis*

* assuming a 13 % EV penetration, a market the size of Germany.

V. CONCLUSION

Increasing volatility in energy prices will create room for new business models in the future. This research presented a V2G business model where fleet owners charge EV's during off peak hours and sell energy back to the grid on the energy wholesale market during peak hours and profit arbitrage differences. A crucial cost factor in the business model are the depreciation cost for batteries over its life cycle. A break even analysis in form of a simulation revealed that once depreciation costs for batteries drop below 0.057 EUR/kWh the business model will be profitable. An EV penetration of 13% saturates the market. Depending on the developments in battery technology fleet owners could make profits ranging from 3.2 and 10 million EUR on a monthly basis. Simultaneously evidence suggests that there are large welfare gains for society as a whole. For a country with an electricity consumption like Germany these welfare gains amount to EUR 2.1 billion annually.

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