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Design of a Conceptual Framework for the V2G Implementation

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Abstract – ***The major increases in oil prices and the rising environmental concerns are key drivers in the growing popularity of electric and plug-in hybrid vehicles. Car manufacturers understand this trend quite well and are developing new models. For the 90% of Americans who use their cars to get to work every day, the average daily commute distance is 45 km and the average daily time that cars remain parked is 22 hours. A salient feature that these vehicles have in common is the batteries, which provide good storage capacity that can be effectively integrated into the grid.***

We focus on the design of a conceptual framework needs to integrate the electric vehicles into the grid –the so-called V2G concept. The basic premise we use is to treat the battery vehicles as distributed energy resources that can act both as supply and demand resources. We assess the deployment of an aggregation of battery vehicles for the provision of frequency regulation – requiring very fast response times – and energy supply for peak shaving. We also investigate the impacts of the aggregated battery vehicle charging load on the low load generation schedules and on regulation requirements. The assessment of these impacts takes into consideration the explicit representation of uncertainty and the importance of the state of charge as a key variable in the use of the batteries for the supply and demand roles. For the framework completeness, we also explore the role of the energy services provider in the V2G integration. The role of V2G in the context of renewable resource integration is discussed. In addition, we present the need for the communications/metering system to enable the integrated battery vehicles to effectively participate in the operation of the grid and electricity markets.

I. INTRODUCTION

In July 2008, oil price reached an historical high of 147 *$* a barrel. Such high prices have pushed for the development of new transportation technologies. Those technologies include plug-in hybrid and electric vehicles, biofuel vehicles and hydrogen vehicles. Hybrid vehicles have already proven themselves to be very successful as shows the success of the *Toyota Prius* with over 510,000 sold by November 2007 in the USA. More and more customers are concerned by environmental factors and thus there is a real potential for a very high growth of plug-in and electric vehicles – which we denote by the term battery vehicles (*BV*s) in this study, as they both have on-board batteries – in the next years. Main manufacturers have understood the potential of such *BV*s and develop new models – like *Chevrolet* who plans to markets the *Volt* in 2010. All these new vehicles will need to get their energy from the electrical grid and thus will create a new load for the system. They may also represent a new resource.

We study the role of the *BV*s to the electrical grid as either a demand-side or supply-side resource. We then develop the need for aggregation and the ways to model it. Last, we present a conceptual framework for the effective implementation of the concept.

II. *BV*S AS DISTRIBUTED ENERGY RESOURCES

A. BV as a demand-side resource

Every *BV* needs to get its energy from the grid. This creates a new load for the system. A study from *EPRI* [1] shows that, for 4 million of new *PHEV*s for the Californian system – corresponding to a 25 % penetration –, the current generation capacity is already high enough to charge the *PHEV* batteries if overnight charging is done. Other sources such as [2] even suggest that the load is not high enough during the night. Compliance with the unit commitment schedules becomes difficult during low load conditions that characterize the off-peak periods. While the operator may not wish to turn off the units, there may be no choice. Charging BVs during the night can provide a solution to this problem by increasing the load to a sufficient level so that many units do not need to be turned off.

B. BV as a supply-side resource

It has already been shown that *BV*s are not suited for providing base-load power [3]. However, peak-shaving and frequency regulation applications are of high interest. In the first application, *BV*s act like pumped-storage units. Energy is stored in *BV* batteries during the night - when the price is low – and is withdrawn during peak-time – when the price is high. By acting in such as way, they provide insurance to the grid operator, who knows it can rely on fast-acting generation if it is needed. Indeed, batteries have very fast response capabilities – of the order of milliseconds – which means that one can get energy from them in a very short time. These response capabilities also make *BV*s a very strong candidate for the provision of frequency regulation services. A basic objective of the system operator is to ensure that the supply-demand equilibrium is maintained around the clock. Small imbalances lead to frequency fluctuations that need to be regulated. Frequency regulation requires small capacity quantities and the ability to either absorb or release energy. The usual disadvantage of the size of the *BV* batteries is thus not a problem as far as frequency regulation is concerned and the ability to have bi-directional transactions is of particular interest.

III. *BV* AGGREGATION

A. The need for aggregation

The typical range for the *BV* storage is between 1 and 30 *kWh*. If we consider the full charge or discharge of a battery over 5 hours, it means that the output is in the 0.2 – 6 *kW* range. Such a capacity is of no impact to the electric power system and only represents a noise on the grid scale. Therefore, *BV*s need to be aggregated to be able to make an impact. For example, if we consider an average storage for commercial *BV*s of 15 *kWh* and an aggregation of 10,000 *BV*s, we can get a capacity of 30 *MW* if all the *BV*s are plugged to the grid. 30 *MW* is not significant for base load power but is of high interest for frequency regulation – it represents approximately 5 % of the regulation load for the *PJM* system. The aggregation can also be on the demand-side, in order to insure that the load is high enough. For both cases, there is a need for a new entity: the aggregator whose role is to form the aggregation and deal with it.

B. Modeling of a BV aggregation

The main problem in the modeling of an aggregation of *BV*s is the representation of uncertainty sources. We have to take into account various sources of uncertainty including: time of arrival, parking time, state of charge, storage of the vehicle and demand. Because of the high number of vehicles in the aggregation, we use the *Central Limit Theorem* ($N > 30$) to justify the representation of the various random variables by normal distributions. For the state of charge and the capacity, we actually use truncated normal variables in order to be sure that the values are between the physical bounds (the state of charge has to be between 0 and 1 and the storage between 0 and 30 in our case).

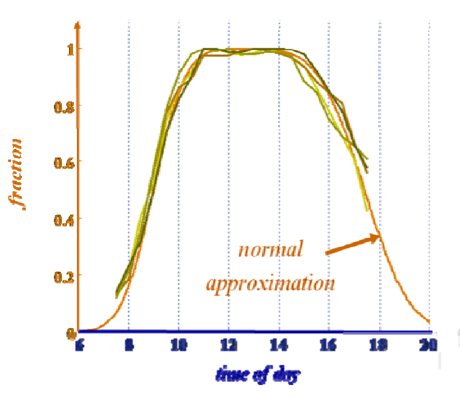

Figure 1: approximation of parking utilization

Fig. 1 represents the parking utilization as a ratio of the maximum utilization for different hours – 1 means that the parking is full, 0 that it is empty – for different parking data and for the normal approximation of the variables. We see that the modeling fits the data quite well.

IV. DESIGN OF A FRAMEWORK

In this part, we propose solutions for the main implementational issues: the design of a communication/control network and the design of an incentive program. The goal is to form a proper *BV* aggregation and to be able to control it when needed. The key players will be the *BV* itself, the *BV*s as an aggregation, the aggregator, the energy service provider (*ESP*) and the *ISO*/*RTO*.

A. Communication/Control system

Data need to be exchanged between the grid operator or the aggregator and each *BV* of the aggregation. The information flows may include the *ID* of each *BV*, the preferences/constraints of each *BV*, the parking status of the *BV*, the storage capability of the *BV* battery, the state-of-charge of the *BV* battery and the power flows from the *BV* battery to the grid. Therefore the requirements for the total amount of data to transmit are quite low. More important issues include the range of the communication system, the costs and reliability and security concerns.

The solution proposed here uses the *ZigBee* technology for communication between the *BV* and the parking lot or house. Communications between the parking lot or houses and the aggregator rely on the Internet technology. *ZigBee* offers very low costs (each transceiver costs 2 $) and a very high flexibility (up to 65,000 devices can be added to the same network). As far as *ID*s are concerned, we propose the use of *SIM* technology. This technology has proven itself to be reliable through a massive use in mobile phones. It also offers the advantage to be independent of the *BV* as one just needs to plug a *SIM* card to be identified.

B. Incentive program

An incentive program needs to be design to attract *BV* customers and retain them. It has to be sufficiently attractive for the *BV* customers to get their *BV*s charged at the right time and for them to be willing to participate on a long term.

We develop here the concept of the "package-deal". The aggregator provides this package in terms of parking facilities, service acquisition and provision, charging of *BV*s and battery service. Such a deal allows "one-stop shopping" for potential *BV* participants. The customers do not care about battery wear-and-tear as they know new batteries will be provided to them if their current batteries can no longer be used for vehicular purposes.

By signing such an agreement, the aggregator will benefit from a sizeable supply-side resource but will also be assured to sell energy to recharge the *BV*s.

V. CONCLUDING REMARKS

The integration of *BV*s helps the grid both as loads and as generation resources. *ESP*s and *RTO*s have a new player to do business with: the aggregator. The aggregators are key for the implementation of *V2G* to be successful. By signing "package deal" agreements, they have the potential for making sizeable benefits. Future work includes the design of *BV* selection technique to optimize the system performances. The major obstacle to the program seems to be the initial investment. Key players – including the government, *ESP*s and car manufacturers – have to take measures to make it happen.

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