Economics of Vehicle-to-Grid

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Vehicle-to-Grid (V2G) is the concept of buffering energy in the batteries of electric vehicles and feeding it back into the power grid at peak demand times. The need for such a concept is justified by the fact that the power grid offers no inherent energy storage possibility and hence there has to be a fine-tuning of energy demand and supply to keep them equal at all times. Distributed energy storage, as enabled by a large number of EVs, could lower the need of auxiliary, expensive energy production capacities and thus decrease the costs drastically as well as increase the total efficiency of the system.

Figure 1 depicts the V2G concept where energy is produced in power plants and led across maximum, high, medium, and low voltage lines up to the households and/or enterprises and demand-oriented back to the grid. In Figure 2 the steady deviations between demand and supply that occur over a day are shown. A cutout of the range from 13 to 14 o'clock represents the load curve in this period in detail. It is to be recognized that the deviations are not necessarily higher in times of peak load.

The goal of the underlying investigation was to assess the potential economic profit of V2G on different energy markets in Germany like peak or balancing power, using real market data from the year 2009. To this end, the different energy markets were analyzed and a cost model for determining potential profits on these markets was developed. This comprises the definition of formulas for calculating sales, costs, and profits, and their evaluation on real energy market data. Formula 1 depicts the way total sales can be calculated while formula 2 is the same for the total arising costs.

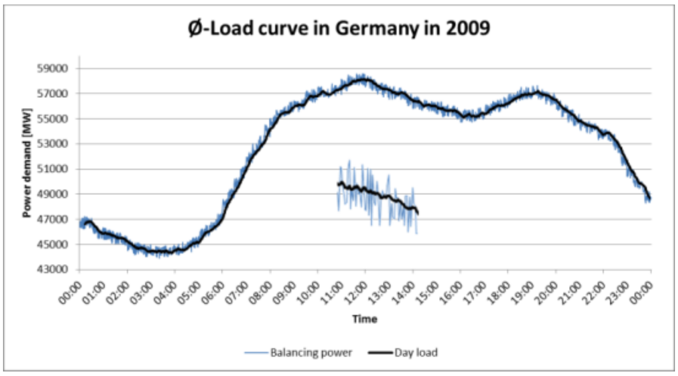

Figure 2: Average load curve in Germany in 2009.

Based on this approach, a novel software tool named V2G Profit Agent (V2GPA) was developed that allows fast, flexible, and easy-to-use evaluation of different V2G scenarios. V2GPA also supports the search of appropriate values for model parameters, to help assess V2G from the point of view of the consumers and energy companies, respectively. Thus, V2GPA is a valuable tool especially for energy companies to study the

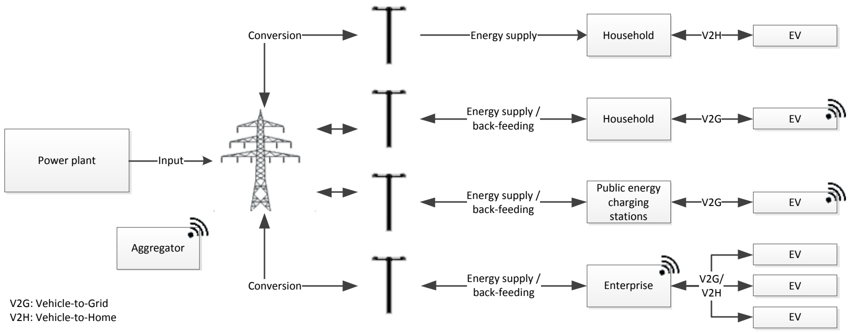

Figure 1: The V2G concept.

potential of V2G and test novel business models related to it.

$$U_{Ges} = \left(min\left\{ U \cdot I \cdot \sqrt{S},\ \frac{\left(E_{Akku} \cdot T - \frac{d_d + d_p}{F}\right)}{t_A^{max}} \cdot \eta_{el} \right\} \cdot t_L \right) (P_L + P_A \cdot V_{LA})$$

Formula 1: Total sales achievable with V2G.

$$K_{Ges} = L_L \cdot t_L \cdot V_{LA} \cdot \left(\frac{k_E}{\eta_{Umw}} + \frac{K_{Akku}^{fix} + K_{Akku}^{Arbeit}}{Z \cdot E_{Akku} \cdot T} \right) + K_0 \cdot \frac{d}{1-(1+d)^{-n}}$$

Formula 2: Total costs of V2G.

On the basis of the investigated facts, the achievable profits with V2G shown in Table 1, and the unlikelihood of the best case there has to be retained that for now and in a foreseeable future selling energy in negative direction of energy flow (V2G) only create profits in exceptional cases. In positive energy flow direction (G2V) EVs cannot only be charged for free but instead gain a profit that is between 1.621 and 4.275 € in the market of balancing power in the average case. If negative and positive balancing power cannot or may not be decoupled from each other, there have to be exact analyses under which conditions the combined use is worthwhile. For Example, in the eE-Tour case, a modified average case scenario based on real data from the eE-Tour project, a combined profit of 1.814 € can be gained for MRL.

Theoretically, V2G seems to be a feasible solution of balancing demand and supply. Challenges like user acceptance, a change in energy market prices and volumes when introducing V2G on a broad basis, or a tax income reduction when using electricity instead of oil have to be accomplished. In practice, an economic application of V2G fails in most examined scenarios because of a too high ratio of the arising costs to the attainable sales. With over 95% of the total arising costs, the variable costs due to battery wear triggered by each load/unload cycle are the highest cost driver.

The mentioned economical failure of V2G in connection with the necessity of stabilizing the grid makes it inevitable to optimize the way the transportation and the energy sector should be integrated. The transportation sector, consisting of traffic flows and traffic management strategies and the energy supply sector, consisting of management of energy resources and charging strategies inter alia, are more or less separated for the time being. Under the circumstances of a less predictable energy supply market consisting of a much higher fraction of renewable energies, these two sectors have to be integrated intelligently and economically worthwhile to cope with the challenges of a huge distributed electric vehicle fleet in future.

In further research, we will extend and adapt the developed cost model to the special needs of Singapore. Furthermore, we will develop tools with which it will be possible to study several scenarios for an e-mobility infrastructure with distributed and mobile energy demand and storage capabilities. Applications like driver assistance based on predicted traffic information will be made possible. As the next step, modeling techniques and formalisms will be developed that enable seamless composition and integration of different aspects such as battery behavior, user patters, and renewable energy sources. Taking into account potential business cases, the overall integration of electric vehicles with the environment via an ICT infrastructure will be covered and a unified approach will be guaranteed. With respect to electric vehicles and infrastructure the whole bidirectional energy supply chain will be modeled.

Type of load	**Profit in the area of… [€]**							
	…negative types of load (V2G)				**…positive types of load (G2V)**			
	Best	*Average*	*Worst*	*eE-Tour*	*Best*	*Average*	*Worst*	*eE-Tour*
PRL	4.556	-11.437	-48.078	-6.320	20.240	3.327	1.065	3.327
SRL	0	-32.507	-58.455	-20.227	22.932	4.275	765	4.275
MRL	23.627	-2.614	-7.264	-406	12.622	1.621	189	2.220
On-Peak	0	-50.319	-161.313	-66.425	---	---	---	---
Off-Peak	0	-51.283	-163.199	-68.460	---	---	---	---

Table 1: Achievable profits with V2G in Germany in 2009.