On Optimality Criteria for V2G Charging Strategies

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***Abstract*—There is a growing interest in treating EVs not only as controllable loads, but also as storage systems, which are able to reduce stresses on the grid during peak times by injecting power back, also known as Vehicle to Grid (V2G). In this paper, we formulate the problem of returning electrical load to the grid as an optimisation problem whose goal is to minimise the costs of drawing energy from the vehicles, while maintaining the effect of energy return on the environment below a safety level.**

I. Motivation

The growing interest in "green" alternatives to conventional combustion engine vehicles is driving several active areas of research, including battery design, fast charging, grid-vehicle charge balancing, and distributed charging of fleets of electric vehicles. The main advantage of plug-in electric vehicles is that they allow us to control where and when emissions are released. Another purported advantage is that, due to the assumed high penetration levels such vehicles can be used to store energy and deliver this energy back to the grid in times of need. This concept is usually referred to as vehicle to grid (V2G) and is considered as a key-point for implementing peak shaving and valley filling policies, see for example [1] and [2].

While the ability of V2G to balance the demands of the grid, the availability of renewable energy, and the needs of commuters have been extensively investigated in the literature, little attention has been paid to the design of optimality criteria and optimal strategies to draw the required power from the vehicles. In particular, given a certain demand for energy from the grid, and an oversupply of available power from the fleet of electric vehicles, the manner in which energy is drawn from the fleet of electric vehicles may have a profound impact on the environment as well as on other individual commuters. In this short paper we investigate such issues. Specific attention is paid to the various factors which have to be considered before drawing power from the EVs. These factors form a complex optimisation problem, where three key points need to be balanced: effect on the environment, inconvenience for the vehicle owner, and price.

This short paper summarises previous work of the authors [3] where several separate utility functions of interest had been proposed, and presents a new multi-criteria optimisation framework that takes into account several factors of interest at the same time.

II. Approach

Consider the following categories of willing participants in an energy exchange programme with an electricity grid: (a) full battery electric vehicles (BEVs), (b) plug-in hybrid electric vehicles (PHEVs) and (c) power stations. A goal is to supply the electricity grid with a necessary amount of energy, while choosing the energy in a way that minimises the costs derived from selling energy to the grid and the impact on the environment caused by the energy transfer.

The described problem is particularly complicated as it depends on many variables of interest such as:

- *State of Charge*: it is reasonable to take more energy from vehicles that have a higher level of battery charge;
- *Required Energy*: we can take energy from vehicles provided that enough energy remains for the next journey; the required energy for the next journey depends itself on other variables like: the *journey*, *basic power consumption per kilometre* (i.e., the average consumption depends on the vehicle), *individual driving style*, that can cause a larger or smaller energy consumption than on average, *weather conditions*, i.e., whether air conditioning or heating will be required, *usage of other electric appliances*, i.e., car navigator, radio,...
- *Presence of Charging Stations*: a vehicle can give energy to the grid even at the cost of remaining with a residual energy that is not sufficient for the next planned journey, if there are charging stations along the path; clearly, a vehicle owner might take this choice if the grid pays enough money for the V2G service;
- *Second car or second battery*: the vehicle owner has a second battery or maybe an additional car. In this case it is not convenient for the environment if the vehicle owner has to drive in fuel-mode because he sold his residual battery energy to the grid;
- *Public transportation*: availability/cost/estimated pollution of the public transportation system as an alternative to taking the personal green vehicle do have an impact on the choice of how to implement V2G strategies;

- *Probability of entering and staying in a "green zone"*: cities in some countries ban certain vehicles from densely populated areas (*Umweltzonen*) [4] to reduce pollution peaks in those areas. So the utility function should prevent the grid from taking energy from the PHEVs and BEVs that intend to travel in green zones, as they might remain without battery and be forced to reschedule their journey and eventually to travel in fuel mode.

The optimisation problem also depends on the availability of power plants, as the electrical grid might take the required energy from increasing power plant energy production rather than taking it from vehicles. In this case, for our purposes it is important to have pollution information (e.g., in terms of CO_2 emissions), fuel and carbon costs, direct operation and maintenance costs, and production of waste material. Detailed information on the construction of convex and piecewise linear utility functions that take all the previous parameters into account can be found in reference [3].

In the V2G framework, vehicle owners must be encouraged to participate to the energy exchange programme by receiving incentives that must at least cover the expected expenses for recharging the battery (or for buying fuel/taking alternative transport means,...). Similarly, there are extra costs to allow the power plants to increase their energy production. Clearly, these are costs for the grid operator, who has interest in keeping such costs as low as possible (i.e., the grid will take energy from the EVs and the plants that will suffer such an inconvenience the least).

III. Simulations

We consider a scenario where we have two BEVs, one PHEV and a power plant. We compare five different solutions to provide the required V2G service of 18 kWh. Parameters of the utility functions of interest can be found in [3].

- In the first case, we assume that the required energy is equally taken from the three vehicles. This corresponds to conventional V2G strategies;
- In the second case, we assume that we want to take energy from the vehicles in order to minimise the production of pollution, disregarding of the cost to do so; we denote by $f_{(\cdot)}$ the utility function emissions costs for each participant;
- In the third case, we assume that we also have the possibility of increasing the energy production of a power plant to decrease the energy taken from the vehicles. Again, we do not consider the costs associated with V2G operations;
- In the fourth case, we aim at minimising the costs associated with providing the V2G service; we denote by $g_{(\cdot)}$ the utility function (price) cost for each participant;
- In the last case we minimise the money costs while guaranteeing that an emission threshold is not exceeded.

The full optimisation problem, which corresponds to the last case, is a nonlinear optimisation problem with nonlinear constraints; however, it is simple to find a solution (in this case adopting Matlab function *fmincon*, due to the convexity of the formulated optimisation problem. Results of the five optimisation problems are summarised in Table I.

TABLE I
COMPARISON AMONG DIFFERENT V2G STRATEGIES

	BEV 1	BEV 2	PHEV 1	plant 1	Total
E_i [kWh]	6	6	6	-	18
f_i [g]	72.96	≈ 0	54.4	-	127.36
g_i [\$]	25.296	18	39.68	-	82.976
E_i [kWh]	5.7648	12.1487	0.0865	-	18
f_i [g]	71.0831	≈ 0	4.7269	-	75.81
g_i [\$]	23.7248	73.7955	0.9513	-	98.4716
E_i [kWh]	-3.4737	12.1487	-0.5263	9.8513	18
f_i [g]	≈ 0	≈ 0	≈ 0	54.1822	54.1831
g_i [\$]	≈ 0	73.7955	≈ 0	33.4944	107.2899
E_i [kWh]	2.6018	3.3999	1.0751	10.9232	18
f_i [g]	45.8248	≈ 0	13.0304	60.0777	118.9509
g_i [\$]	7.97	5.78	3.53	37.138	54.4183
E_i [kWh]	1.4731	5.9017	0.2504	10.3748	18
f_i [g]	36.8356	≈ 0	6.1033	57.0612	100
g_i [\$]	4.7686	17.4152	1.2708	35.2742	58.7288

As can be seen from Table I, the second approach is more environmentally friendly than the case when equal energy is taken from all vehicles. Also, it is possible to appreciate that if a power plant is available, then it is possible to further minimise pollution and also recharge two vehicles. The result of this example suggests that it can be preferable to generate new energy than to take the available energy from the plug-in fleet. Finally, as proved in the last two lines, it is possible to keep the pollution below a desired threshold (in the example $100\ g$) and minimise the costs associated with V2G operations.

IV. Conclusion

In this paper we give a new perspective on the V2G concept. Given a certain level of demand from the grid, and a fleet of EVs and other participants, there are many ways in which this energy can be drawn from participants so as to satisfy the demands of the grid. By introducing notions of utility, either in terms of minimum pollution or minimum cost, or as a mixed optimisation, which is the main novelty of the short paper, the manner in which the energy is drawn from each participant can be uniquely defined by solving an optimisation problem.

References

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