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SwissV2G

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Abstract

A V2G system is proposed that uses voltage and frequency measured at the socket for the control algorithm of a bi-directional charger. No upfront investment or other infrastructure is required for the introduction of this system or at any time later. With a growing number of EV and PHEV the V2G effect can be measured per utility control area. This V2G system is combined with a battery rental scheme. A corresponding business model is supposed to support the market introduction of EV and PHEV.

Keywords: V2G, Infrastructure, EV, PHEV, smart grid, sodium-nickel-chloride battery

1 Introduction

When the Californian ZEV legislation [1] was still active and electricity black-outs attracted public attention to a growing instability of the electricity supply grid in California, Kempton and Letendre [2] published 1996 the concept of using electric vehicles, BEV and PHEV, as a power source for electric utilities. 2005 they supplied basic equations to calculate capacity and net revenues [3].
As millions of PHEV are parking most of the time they can be regarded as mini-power plants each handling several 10kW and in sum attaining several hundred to thousand MW. But for reasons of fuel efficiency, emissions and noise it would not be a good idea to use them for normal power generation. This is fundamentally different for Battery Electric Vehicles (BEV) and Plug in Hybrid Electric Vehicles (PHEV) which have a reasonably sized battery and which are most of the time connected to the grid. The batteries offer a distributed storage capability for grid stabilization which has monetary value. An ideal grid would have enough storage capacity so that only the average power would need to be generated. Only 1 million EV or PHEV each equipped with a bi-directional charger of 3 kW represent a power of 3 GW as load or generation. This is the power of 3 large power generation plants. Obviously this distributed power need to be managed in such a way that it supports grid stability and supply reliability instead of being connected just during the “wrong” period of the day.
The best known demonstration project was presented by AC Propulsion and is reported by Gage [4]. A communication link between the vehicle and the utility control area operator integrated the vehicle into the standard grid control process and allowed exchange of power between the grid and the vehicle in both directions. The problem areas of this concept are:

1. The installation of the communication system requires a considerable and high risk investment before a large number of vehicles are on the road
2. The effect of battery aging by the charge and discharge of power to the grid is not known and may not be balanced by the money paid by the grid operator
3. The battery owner may insist on having 100% control over his battery which is his property

In the following a solution is described for the transition from the present status of no EV or PHEV with bi-directional power connection to the grid to the desired status of a large number of vehicles being charged during off-peak periods and supporting grid stability during peak time.

2 Electricity Distribution Grid Structure and Control

The present electric transmission and distribution grid has grown historically in a centralistic way from big power generation stations to the consumers (fig.1). All customers are allocated to a "Utility Control Area" (UCA) which is responsible to plan and match supply and demand in its area which means to guarantee a socket voltage of 230 VAC ±10% which is the standard in Europe since January 1, 2009. The data required for this regulation task are the actual power and voltage at the transformers and the design capacity of the distribution grid. Both

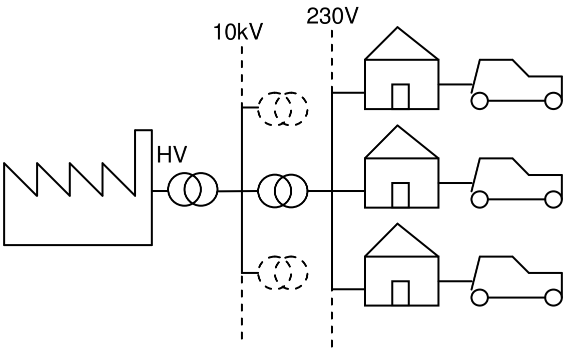

Figure 1: Grid Structure

are used to estimate the voltage drop of the line as there is no information about the voltage at every single socket. The ±10% voltage margin covers this uncertainty. The generator which acts on higher voltage levels is controlled by the frequency. This value is the same at any point in the grid and is an indicator whether the generator operates at its limit or not. Designated "regulation power plants" react on frequency variations due to load changes in the grid. In order to keep the frequency constant, the measured frequency deviation is translated into additional power or less power of several MW provided to the grid by the regulation power plants.

Load changes on the grid result from demand variations as well as supply variations. The variations can be instantaneous (power plant disconnecting) or in longer time units. Supply variations increase considerably with the augmenting contribution of renewable energies such as wind and PV as shown in figure 3. The power generation follows the request from the UCA and delivers energy for different cost with continuously produced base power at the lowest and unexpected peak power at the highest price. In countries with no hydro power, a few additional thermal generators run in idle mode as spinning reserve to be available for contingency if any load change appears unexpectedly. This spinning reserve is a base cost for all connected UCA and also has a considerable ecological impact.

3 SwissV2G Concept

It is the state of the art for ZEBRA batteries that the battery controller has full control over the charger by means of a PWM signal or a CAN message. The battery controller has complete information about the battery data which includes state of charge, actual current, voltage and temperature, detects end of charge and end of discharge and knows the state of health of its battery. For the swissV2G system a bi-directional charger is the sole hardware modification compared to a standard system. Like normal inverter architecture the bi-directional charger measures the grid voltage and the grid frequency which are communicated to the battery controller by a CAN message. Together with the other battery parameters they are part of the parameters of the swissV2G algorithm. Without any external communication this algorithm is designed to decide for his battery to be charged, kept on stand-by or to be discharged. Three groups of parameters are used for this decision:

- Battery parameters (SOC, charge or discharge enable)
- Grid parameters at the socket (voltage, frequency)
- Individual user parameters (section 5)

Figure 2 shows the basic logic of the algorithm with parameters taken as a reasonable example. The first check allows the driver to override the V2G function if he wishes to have 100% of his battery capacity available. The use of this function will influence the tariff which is discussed in more detail in section 5. A high grid voltage and a high frequency are indicators that the grid has overcapacity so that the battery will be charged if it is not already at 98% SOC. A low grid voltage and a low frequency are indicators for grid overload and the battery will be discharged if SOC is sufficient. If the grid voltage is in the mid range and if it is the preferred charging time of the day and if the frequency indicates that the generator is not at its limit the battery is normal charged. The cycling of the algorithm considers changing grid conditions.

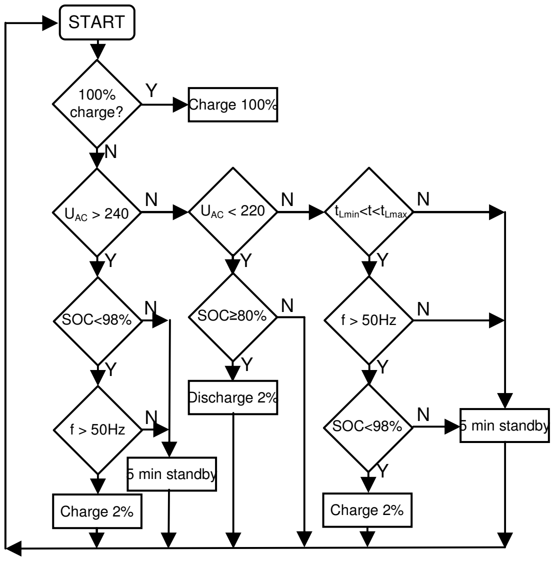

Figure 2: SwissV2G Algorithm

4 Effect on Grid Control

As the connection or disconnection of a single 3kW load has very little effect on the grid, the same applies for a single or a few vehicles equipped with a bi-directional charger and operated in the described V2G mode. But with an increasing number of vehicles the effect will smoothly start to be noticed in a statistical way. The contribution of a single vehicle does not matter but a large number does. We have to assume a slow market penetration of EV and PHEV so that the expected effect will smoothly start and should be visible by a reduced demand for unexpected regulating power in the relevant UCA as shown in figure 3. EVs are connected to the low voltage grid and therefore act mainly on the demand side as if they were household appliances. As the number of EVs grows, the effects will be visible on higher voltage levels. Having reached an available capacity of several hundreds to thousand MW, the influence of the EVs can be noticed even on the highest voltage levels.

The SwissV2G-algorithm has a very rough picture of the grid status and translates the locally measured parameters into a charging or discharging activity of the battery. These energy flows of a large number of vehicles are supposed to act in favor of the grid by decrease of volatility and peaks. The algorithm is the synthesized information of many measurements on different plugs and grid categories, and is therefore something like a "decentralized intelligence" which acts by its big number in favor of the system. This is expected to be just opposite to the historically observed effects of increasing installed wind-power on the necessary regulation capacity: As long as renewable energies have been below a certain percentage compared to the thermal bulk power production, there was no or little effect observed on the regulation capacity. Irregular production of renewable energy was covered by other stochastic production and demand variations. With increasing renewable energy supply, the necessary regulation capacity increased as shown in figure 3. SwissV2G introduction is expected to show the same effect in the opposite direction so that the degree of regulation power will be reduced.

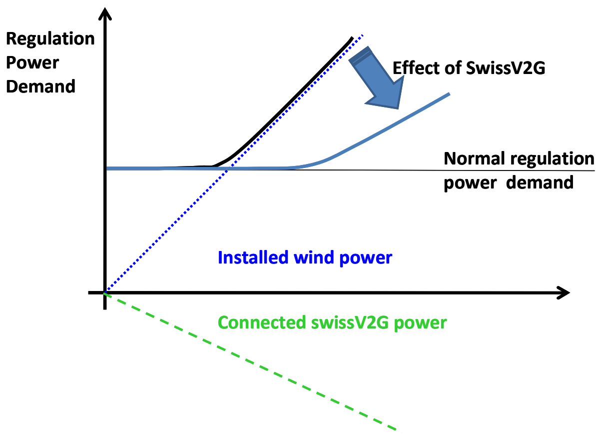

Figure 3: Reduction of grid regulation power demand by swissV2G

SwissV2G will not interfere with the traditional control processes, as described in Chapter 2 and therefore they do not need to be changed. The SwissV2G algorithm in each EV or PHEV does not need centralized and exact grid status information, and nevertheless contributes to grid stabilization. In order to be sure of its positive contribution to grid stability, the data are continuously analyzed and evaluated by the UCA operator to discover any effect as soon as possible. In case of deviations corrective actions by modification of the V2G algorithm parameters are possible. In this way it is a quasi self-adjusting system without any start-up investment. It is planned to run computer simulations in the near future for parameter optimization of the V2G algorithm and to avoid any surprise as far as possible. Even controlling tests are possible by a moderate change of the limits for additional power or reduced power inserted into an UCA. This SwissV2G concept also is open for any future smart grid concept when ever it will be introduced.

5 SwissV2G Business Model

As soon as bi-directional chargers are available on the market and the swissV2G algorithm is included in the battery controller software the system can be introduced. The vehicles can be connected to every standard household socket. Obviously all existing sockets are connected to the grid and to a well established payment system so that no upfront investment or other installation is required for the start.

5.1 Incentives

From a fleet-test with 60 electric vehicles [5] we know that different persons have a very different charging behavior if they do not receive any direction. For this reason incentives are built into the individual user parameters of the algorithm in order to influence the user behavior in the desired way:

1. The cumulated time of grid connection over a year valued with the time during each day is registered and recorded. The contract is made for a certain predetermined value and cleared with the measured value once a year.
2. The contract also determines the amount of energy made available from the vehicle. As examples it could be 20% of a 30 kWh EV battery = 6 kWh or only 5% of a 10 kWh PHEV battery =0,5 kWh. The user who makes more energy available to the grid receives a higher payment.

5.2 Monetary Value

The monetary value paid to the EV and PHEV users is calculated from the measured reduction of energy cost per UCA. This cost reduction is expected because less high cost peak power need to be purchased. This system is flexible to be matched to changing energy market conditions.

5.3 Combination with Battery Rental

This swissV2G concept is planned to be combined with battery rental for the following reasons:

- The vehicle sticker price excludes the price for the battery which is financed over time. This sticker price reduction will support and accelerate EV and PHEV introduction
- The battery rental fee can be financed by the price difference between fuel and electricity plus the monetary value of V2G regulation power
- The individual battery risk is reduced to a statistical risk which is covered by an insurance concept
- Any concern of constrained control on the own battery is avoided because the battery is owned by the rental company

The combination of the swissV2G concept with battery rental offers a business model which combines the advantages of grid stability support with incentives for EV and PHEV introduction without any upfront and risky investment.

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