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USING ELECTRIC VEHICLE CHARGING STRATEGIES TO MAXIMIZE PV-INTEGRATION IN THE LOW VOLTAGE GRID

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Abstract: The role of electric vehicles (EV) in the low voltage grid has been discussed lately in many projects. An efficient energy management system for control of the charging processes while considering grid aspects is expected to raise high potential to build up Smart Grid functions. One focal point is to learn about the potential synergetic effects from EV and renewable energies regarding two main questions: (1) Is it possible to load EV batteries largely based on renewable sources – in particular PV – to guarantee positive carbon minimizing effects? (2) Can managed EV charging lead to an increased integration of fluctuating renewable energy resources in the grid? These questions can only be dealt with by keeping the status of the power infrastructure in perspective at any time – reliability of supply has to be ensured with high penetration of both EV and renewable energy resources. We used a simulative approach to follow up on these, studying the effects of charging processes for different shares of electric vehicles in the rural area of north-west Germany using characteristic grid types. Starting from these, we built up target scenarios that met our goals: Maximize PV integration, stabilize the grid and still guarantee the EV users' mobility. In this paper we present the results of scenarios with maximized PV integration and show the importance of managed charging processes to make best use of renewable feed-in for mobility purposes.

1 Motivation

There is a tremendous potential in the combination of electric vehicles (EV) and renewable energy resources: If charging management algorithms can be found, that allow charging the EV batteries with power from renewables and thus allow storing power from fluctuating resources, the effect for a sustainable mobility is promising [1]. Intelligent charging strategies that take the operational grid constraints into account are needed to maximize local renewable usage. This work, that was done within the project GridSurfer funded by the German Ministry of Economics and Technology, focuses on the effect of EV charging processes in rural grids in the north-western part of Germany. Using Smart Grid simulation techniques, varying shares of EVs and photovoltaics were analyzed regarding their effects on the power grid and the local energy mix.

2 Intelligent Charging Strategies

Mayer et al. [2] identified four stages for the integration of electric vehicles with rising demand regarding ICT. Phase I (introduction) and phase II (billing and roaming) have only reduced requirements regarding charging management, whereas with increasing amount of EV as loads in the power grid, management is needed to reduce simultaneity of the charging processes and thus take care of operational grid constraints (phase III). In phase IV, active load management and feeding-back to the grid are described. The charging management strategies evaluated in this work can be characterized using these phases.

- Uncontrolled charging (phases I and II) has no requirements for ICT-enabled charging of the EV. Charging is only started by the user by plugging in the car.
- Randomized controlled charging (phase III) aims at the reduction of simultaneity of the load processes.
- Agent-based V2G (phase IV) builds on EVs capable of feeding back to the grid, thus making the batteries accessible as local storage in the LV grid. The intelligent scheduling agent for this approach is located in the substation, thus allowing taking both local renewable generation and grid conditions into account.

In the following, randomized controlled charging and V2G are described in more detail.

2.1 Randomized controlled charging

The strategy for randomized controlled charging (Distributed Random Forecast-based Planner, short: DRFP) is a refinement of a charging strategy already discussed in [3]. It was developed with the intention to reduce the simultaneity factor of EV charging processes by shifting charging times into times of low demand or times of high feed-in from renewables. Regarding the limited ICT-integration of EV in phase III [2], the strategy was designed to generate little communication overhead.

The basic principle of DRFP is as follows: First, an EV is parked and connects to a charging point and submits both the estimated parking duration and the energy demand to the planner. After an immediate charging of the EV's battery to a minimum reserve capacity, the planner specifies the actual charging time based on a random number. The probability density function of this random number depends on a given demand / feed-in profile, e.g. the BDEW standard load profile H0 for a distribution grid dominated by domestic loads, thus statistically favouring times of low demand. Due to the randomized component of the decision process, this charging strategy comes without additional communication overhead for (de-)synchronization of multiple charging points in the same power grid segment. In case of power grids with large shares of feed-in from renewable sources, the demand / feed-in profiles have to be regularly updated based on forecast or measurement data.

2.2 Agent-based Vehicle-to-Grid (V2G)

V2G requires a significantly more elaborated ICT-integration of EV than controlled charging. Due to the EVs' ability to feed electric power back into the grid, both the possibilities and the complexity of charging strategies increase. In the context of GridSurfer, a charging strategy based on autonomous, intelligent agents was developed [4]. As depicted in **Fig. 1**, the coordinating intelligence, that is the hard- and software components that generate, submit and supervise the charging plans, has been conceptually integrated into the existing power grid infrastructure.

Located at the level of substations and/or power transformers, the intelligent agent coordinates and supervises the charging of the EVs in the respective segment of the distribution grid. This both limits the number of EV per coordinating unit and reduces the complexity of the underlying optimization problem.

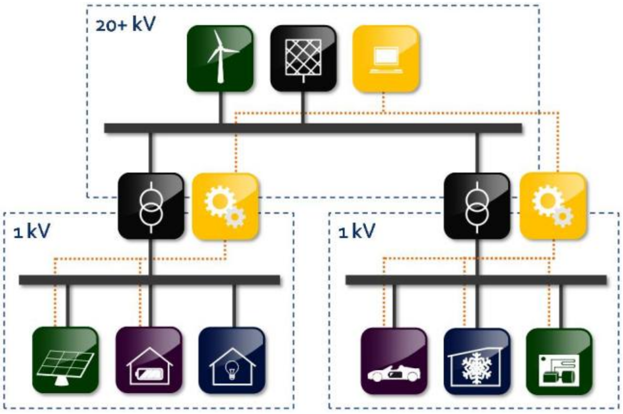

Fig. 1: Integration of the coordinating intelligence of the V2G concept.

By employing a hierarchical organization of the agent-based system, an efficient coordination across multiple voltage levels of the distribution grid is possible [5]. The agent-based V2G optimizes the residual load in regard to a given target function, e.g. the maximum levelling or maximum use of renewables, and with consideration of power grid constraints (nodal voltage levels, branch currents) [4]. As the EV users' mobility is an additional and important constraint for the usage of EV in terms of 'mobile storage systems', the V2G concept aims to guarantee the EVs' availability by ensuring a user-definable minimum reserve capacity.

3 Simulation-based Evaluation and Results

To evaluate the charging strategies introduced in section 2, a number of different scenarios were simulated and analyzed in the GridSurfer project. Therefore, different characteristic low voltage grids of the EWE Netz GmbH were examined. Below, results are presented for the rural grid type as the project GridSurfer has a special emphasis on eMobility in these rural areas. Two interrelated aspects were of special interest:

1. What contribution can EVs make with respect to an increased local usage of regenerative energy sources?
2. Can EVs be charged preferentially with "green" electricity so that they allow CO_2-efficient individual mobility?

In the different scenarios the influence factors *vehicle share*, *installed PV peak-power*, *grid type*, *EV battery capacity* and *charging/discharging power* were considered independently. The results presented here are based on the values of these factors as shown in table 1.

Table 1: Values of the considered influence factors.

Influencing factor	**Value**
EV share	50% of the households have an EV
Installed PV peak power	160kWp, shared amongst 50 plants with 3,2 kWp each
Grid type	Rural grid, EWE Netz GmbH
Charging strategies	Uncontrolled, controlled (DRFP), V2G
Battery capacity	31 kWh
Charging/Discharging power	≤ 3,7 kW single-phase, ≤11 kW three-phases

Vehicles as well as PV plants were distributed amongst the connection nodes (households) in a random fashion. For the analysis of the effects on the power grid, a load flow analysis has been performed after each simulation step [6].

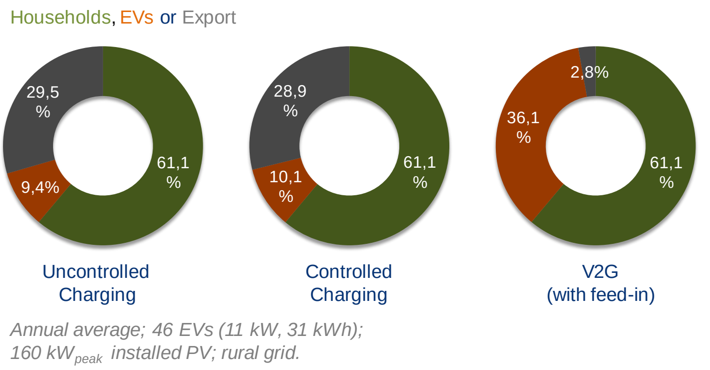

Figure 6: Usage of PV feed-in for the households, vehicles and excessive power export

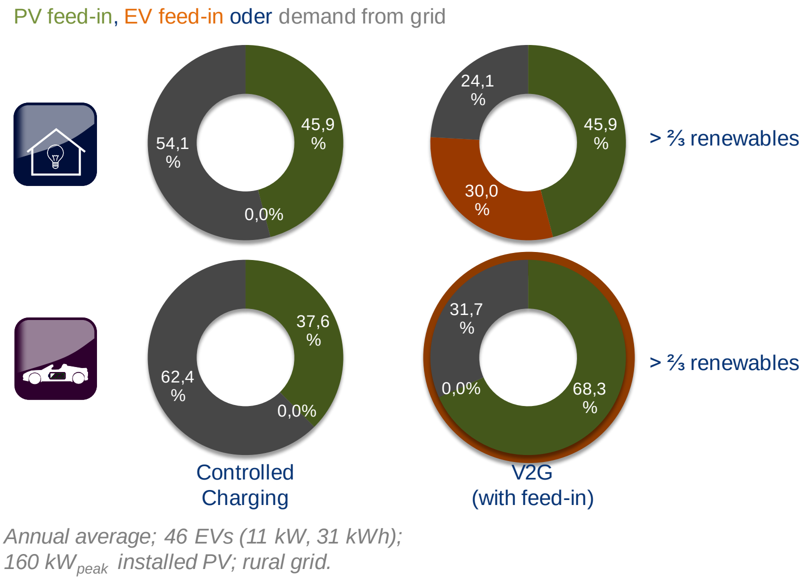

Figure 7: Coverage of household and vehicle energy demand by PV feed-in, vehicle feed-back and grid supply

Figure 6 depicts the average annual values for the local usage of PV feed-in, split into usage within the households themselves, vehicle charging and export into the higher voltage level grid. While about 61% of the annual PV feed-in can be used directly to cover household loads, uncontrolled charging allows the EVs to run on 9% locally generated renewable energy. The controlled charging allows shifting the charging slots partially into favorable times, increasing the share of renewable energy marginally to 10%. This surprisingly low increase can be explained by the fact that the vehicles do not feed energy back into the grid and thus can only use the PV power to cover their driving energy and are merely shiftable loads. From the distribution grid's perspective, the controlled charging is useful nonetheless, as the simultaneity factor is reduced and the chances for overloading the grid resources can be reduced. In the case of V2G capable EVs, the full potential of using the vehicles as "mobile storages" can be exploited: An annual average of about 36% of the local PV feed-in can be buffered in the vehicles' batteries and be used in particular for covering the vespertine and nocturnal household loads. Moreover, it happens that EVs are charged partially by using power provided by discharging other EVs, inasmuch this does not violate the mobility needs of their owners. By doing so, the vehicles can make a substantial contribution to the usage of electricity provided by renewable energy sources in close proximity.

In addition to the results discussed so far, **figure 7** depicts the coverage of the energy demand of households and vehicles. Due to the only marginal differences in controlled and uncontrolled charging, the latter is not shown. In the case of controlled charging (without V2G) the households can cover about 46% of their annual energy demand via the local PV feed-in; the remaining share is covered by drawing power from the subordinate grid level. For the vehicles, the share of “green” energy is somewhat lesser, as often the vehicles are not at home in times of maximum PV feed-in but rather at work [3]. In the V2G case, further 30% of the household’s demand can be covered by the energy that is fed-back by the vehicles. Also, the vehicles themselves can increase their share of renewable energy clearly to 68%. This can be explained partly by the better scheduling of the charging slots by the agents but especially because of the fact that EVs arriving home later can be charged by the batteries of those vehicles that were available for charging in more favorable times. In this sense, the presented V2G strategy represents a *cooperative charging strategy*, which maximizes the usage of energy provided by PV plants in close proximity.

4 Conclusion and Outlook

This work discussed the potential of different charging strategies of electric vehicles with respect to their potential for exploiting renewable energy produced in close proximity to the demand. The concepts of uncontrolled and controlled charging require an ICT-based integration with growing complexity of the ICT integration. The charging strategies’ performance has been evaluated based on a simulation of different scenarios using the *mosaik* framework, which allows a composition of different models to a full Smart Grid simulation. For the explicit analysis of the effects on the power grid (omitted due to length restrictions) a power flow analysis tool based on open source components has been created that can be configured using CIM compliant grid topologies.

Controlled charging reduces the simultaneity factor of charging vehicles. However, it barely increases the usage of locally generated PV feed-in. Hence, EVs can only be seen as flexible loads with a high potential for DSM measures. In contrast, V2G-enabled EVs open up a huge potential to store electric energy from renewable resources. We were able to satisfy both the EVs’ and the households’ power demand by more than two thirds in the described scenario without violating the voltage bands or endangering the electrical equipment from a stationary point of view. However, we cannot make any assertions for the transient (sub-second) behavior of the power grid. For that reason, modern equipment like FACTS should be object of further research.

Future work will focus on the further development of the *mosaik* framework. Apart from refining the underlying simulation models, we aim at a hierarchical composition of existing scenarios (e.g., composing medium voltage grids from several low voltage grids). Another important goal is the integration of standardized communication protocols like OPC/UA and the CIM or IEC 61850 with simulated energy systems to control these systems during the simulation. In this way, we aim at evaluating control strategies and intelligent agents based on standardized interfaces and software-in-the-loop simulations.

5 Acknowledgements

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