ENERGY MANAGEMENT OF PRIVATE HOUSEHOLDS WITH ELECTRIC VEHICLES AS ACTIVE CONSUMERS IN THE GERMAN RESEARCH PROJECT 'WELL2WHEEL'

Peter FRANZ
TU Darmstadt – Germany
peter.franz@e5.tu-darmstadt.de

Bernd M. BUCHHOLZ
NTB Technoservice – Germany
bernd.buchholz@ntb-technoservice.com

Volker BUEHNER
EUS GmbH – Germany
volker.buehner@eus.de

Bernhard FENN
HSE AG – Germany
bernhard.fenn@hse.ag

Lutz-Wolfgang TIEDE
Continental – Germany
lutz-wolfgang.tiede@continental-corporation.com

Jutta HANSON
TU Darmstadt – Germany
jutta.hanson@e5.tu-darmstadt.de

ABSTRACT

The extensive increase of renewable energies has led to fundamental changes in network planning and control for the system operators in Germany. New challenges for network stability (congestion, voltage limits) will occur, since the penetration of electric vehicles is expected to rise in the next years. For economic reasons the existing potentials of flexibility in networks should be activated in advance to avoid expensive grid expansion.

Within the German research project 'Well2Wheel' effects of a high penetration of electric vehicles are analysed and practical solutions for an optimised integration are developed. In combination with an automated energy management, private households with electric vehicles can act as active consumers. The energy demand can be shifted autonomously, corresponding to the requirements of the local network. This is shown in the project by the example of the low-energy building 'SurPLUShome'.

INTRODUCTION

In Germany the share of renewable energies in the gross electricity generation has increased rapidly during the last years up to nearly 26 % in 2014 [1]. This extensive increase of renewable energies has led to fundamental changes in network planning and control for the system operators. Since most of the renewable generation units are installed in the lower voltage levels, the Distribution System Operators (DSOs) have been affected at first. The same applies in the case of a rising penetration of electric vehicles (EVs). By the rollout-plans of the government in Germany to have at least one million EVs until 2020, new challenges for network stability (congestion, voltage problems) are expected to occur. Fast charging of EVs will further increase problematical voltage deviations which already occurred in the last years in the opposite direction because of the installation of distributed energy resources (DERs). Especially networks in rural areas with generally long feeders were not designed to transmit high powers. Even a small number of simultaneous charging processes of EVs can bring these networks to their limits. Furthermore, it becomes more difficult to balance feed-in and energy consumption, when the maximum generation by photovoltaics (PV) is around noon and EVs are mainly charged in the evening hours after work. For economic reasons, existing potentials of flexibility in the networks should be activated first to reduce cost for grid expansion.

The German research project 'Well2Wheel' analyses the effects of EVs on the distribution networks and tries to develop practical solutions for an optimised integration. It started in May 2013 and is funded by the German ministry for the environment. The project is rolled out by seven partners of industry and research in the supply area of the utility HSE AG close to Frankfurt (fig. 1).

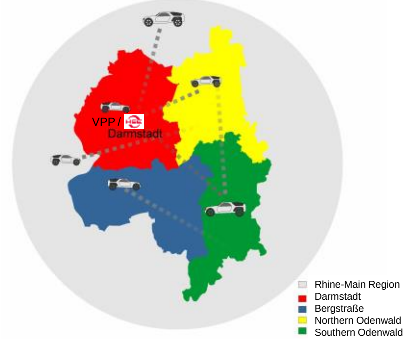

Figure 1: Supply area of HSE and regional grid zones [2]

VIRTUAL POWER PLANT

A virtual power plant (VPP) in the network control centre in Darmstadt represents the core of the project. It pools generation units, flexible loads and energy storages by data exchange and remote control. Via ICT-infrastructure 10 MW hydropower, 2,5 MW photovoltaics, 9 MW wind power plants, 6,8 MW block heat power plants and a total of 16 MW of flexible loads, like heat pumps and cooling systems, are connected to the VPP. The available storage capacity consists of lithium-ion and redox-flow batteries. Additionally around 50 EVs will also be integrated in the VPP until the end of the project.

Depending on the selected business case, an algorithm in the VPP is calculating time-variable traffic light tariffs which are representative for variable electricity tariffs in the future. In the project these tariffs are used for a direct control of flexible generation plants or loads which are equipped with a remote terminal unit. For all consumers without a bidirectional connection to the VPP the traffic light tariffs are used as price incentives to recommend whether it is advisable to shift the energy demand to other times or not. At present the operated algorithm in the VPP is based on hourly time intervals with a day-ahead forecast for the next 24 hours (shorter time intervals up to an almost real-time control can also be realised). Green time intervals signal a regional excess of feed-in of the generation plants. In the red time intervals the energy demand should be reduced because of a high utilisation of the networks or only low generation of DERs (fig. 2).

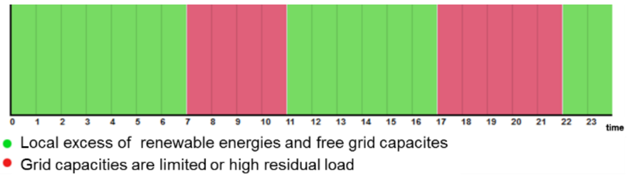

Figure 2: Exemplary traffic light tariff in 'Well2Wheel' [2]

The ability to retrieve flexibilities allows the organisation of small self-balancing network cells. These are able to compensate imbalances in neighbouring balancing groups and can provide ancillary services (e.g. reserve power) to the overlay network as well. The target is a reciprocal compensation of neighbouring cells (schedule adherence) and not the operation of totally autonomous network cells [3]. To demonstrate this regional compensation and the transition of EVs from the supply area of one to another DSO in the research project, the supply area of the HSE AG is divided into five regional grid zones (fig. 1).

INTEGRATION OF ELECTRIC VEHICLES

The power system simulations in real network topologies have shown that even a small number of simultaneous charging processes of EVs in a local network area can cause problems of voltage violations (steady-state voltage deviations violating EN 50160 [4]) or thermal overload, because of the high charging powers. The standard load profiles which are used at present for households will completely change if they own an EV [2]. The utilisation of network capacities especially in residential areas with a high penetration rate of EVs will change as well. The prediction of the future utilisation is done in the project by the use of real vehicle data. Therefore, communication boxes are installed in 17 EVs which transmit all relevant driving data to the VPP as input data for the calculation algorithms, e.g. charging times, state of charge or amount of recharged energy. Depending on the user behaviour of the drivers (private or commercial use) the demands on a charging strategy vary.

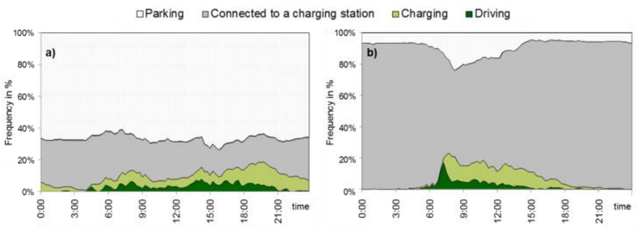

Figure 3: Driving data of EVs a) private b) commercial use

In figure 3 the driving data of two different EVs of the project over a period of eleven month is shown. It can be seen that the main charging interval of a privately used EV is in the evening hours between 18:00 and 21:00 after arriving at home from work if it is charged uncontrolled (fig. 3a). This is particularly critical in residential areas since it correlates exactly with present peak load hours of private households in the winter months.

The EVs of companies have a completely different using behaviour. Figure 3b shows the charging times of an EV which is primarily driven by a public authority. This profile might also be representative for offices. Most of the official trips are done before noon. The demand for charging power is smoothly distributed throughout the day until finishing time which is the peak interval in network areas with office complexes. Since company cars are connected to a charging station almost the whole day, there exists a huge potential for demand side management if a control of the charging processes is possible.

To avoid congestion or voltage band violations, charging processes have to be shifted to times of low load or high generation of DERs. Furthermore, multiple simultaneous charging processes have to be avoided. For a direct charge control, the charging stations in 'Well2Wheel' were modified to 'smart' charging stations. Therefore, different types of charging stations were equipped with bidirectional communication devices and charge control units (fig. 4).

Figure 4: Modified charging stations in 'Well2Wheel'

The charge control unit allows an automatic shift of the charging process corresponding to the traffic light tariff. In a red tariff interval the charging process is completely interrupted or the available charging power is reduced. Of course in case of urgent need for charging, the users have the option of an immediate charging. The charging stations receive the traffic light tariffs via GPRS/UMTS. They can also send back measurement values of their points of common coupling (voltage, power factor) to the VPP, which can use these values for the calculation of the following traffic light intervals.

AUTOMATED ENERGY MANAGEMENT

In combination with a home automated control system, self-generation and energy storage, the potential of load shifting can be further increased. At the same time, the operating comfort for the user rises. The management of domestic appliances and the charging of the EV can be controlled via the same user interface. With the help of preconfigured user strategies private households owning EVs can turn into active consumers with grid convenient consumption profiles. The energy demand is automated shifted by an energy management in accordance with the requirements of the local network.

To demonstrate the autonomous energy management in private households owning an EV, one of the modified ‘smart’ charging stations is integrated into the existing home automated control system of the low-energy house ‘SurPLUShome’ at the TU Darmstadt. The conceptual design and the first practical implementation was realised as an experimental setup in a laboratory (fig. 5).

Figure 5: Laboratory setup of the energy management

In the laboratory, beside the charging station, a washing machine and a tumble dryer are integrated in the energy management. They are representative for the controllable domestic appliances of a household. A small lead-acid storage acts as a buffer to increase the potential for load shifting. Switchable work lights represent the base load. The feed-in of a PV-system is simulated with the help of data about the solar irradiation at this location. The main challenge for the realisation of the energy management was the integration of different communication systems (KNX-fieldbus, Modbus, Powerline) of the appliances. The merging of the different interfaces to a local control network is done in the software ‘Eisbaer SCADA’. This software is also used for the visualisation of the whole energy management and serves as graphical user interface (GUI) of the home automated control system. Most of the control interfaces are connected via KNX-fieldbus. KNX is a 24 V DC fieldbus which is used for the power supply of KNX-devices and the transmission of communication protocols. The programming and configuration of KNX-devices is done in the software ETS [5].

After realisation of the communication infrastructure and data exchange, three different strategies for the energy management have been developed: optimisation of self-consumption, grid convenience and a combination setup.

Strategies of the energy management

The strategy of an optimised self-consumption uses the difference between the feed-in of the own PV-system and the current consumption of all loads of the household (residual load). Flexible domestic appliances, charging processes of the EVs and the charging/discharging of the energy storage are shifted in accordance with the surplus generation of the PV-system. The control system is able to adapt the charging power of the charging station in three power levels. The power exchange of the battery is precisely controllable equivalent to the amount of surplus. This strategy decreases the total electricity demand from the public power supply system and saves purchase cost for electricity of the household.

For a grid convenient control of all appliances the energy management system in ‘Well2Wheel’ regularly retrieves the current traffic light tariff of the regional grid zone from an ftp-server of the network control centre. In the green time intervals the flexible domestic appliances are switched on and the EV and energy storage is recharged. In a red time interval the residual load of the household is minimised, e.g. by discharging the storage. This helps the DSO to reduce peak loads in the local network or to use a temporary excess of renewable energies in the region.

Under present framework in Germany, the optimisation of self-consumption is the most economical option of a household to use self-generated energy. The provision of flexibilities to a DSO by a private consumer is currently not financially compensated, but time-variable electricity tariffs will probably be available in the future. Therefore, the third implemented strategy in the energy management is combination of both strategies presented before (fig. 6). Priority is given to the optimisation of self-consumption, but if free flexibilities are left, these are additionally used to improve the profile of electricity consumption towards the DSO. If e.g. the entire surplus is covered by the shift of domestic appliances and the traffic light tariff signals a green time interval, the available capacities of an EV or of the storage are used to support the local distribution network.

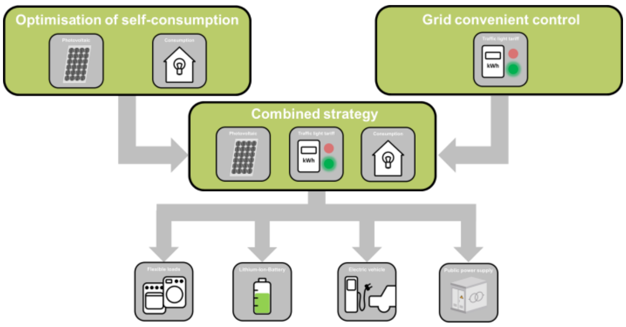

Figure 6: Implemented strategies for energy management

A surplus or deficit, which cannot be absorbed by flexible loads or the batteries, has to be balanced by the public power system for all energy management strategies.

Visualisation of the energy management

On the home screen of the graphical user interface of the energy management the user can see the current traffic light interval and can easily choose between the three different strategies. Figure 7 shows the home screen of the energy management. It is optimised for touch control and allows a direct access to all necessary appliances and functions:

- Detailed settings for the optimised control strategies (e.g. limits for the depth of discharge of the storage, preconfiguration of automatic controlled appliances)
- State of charge of the EV, current charging power and button for immediate charging
- State of charge of the storage and power exchange
- Status of the flexible domestic appliances and manual setting of starting times
- Current feed-in of the PV-system and overview of the forecasted generation
- Diagrams and statistics about energy consumption, load profile, rate of self-consumption, etc.

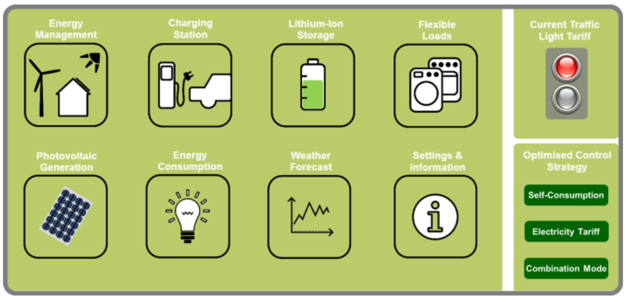

Figure 7: Home screen of GUI of the energy management

Implementation at the 'SurPLUShome'

For a practical analysis of private households, the energy management developed in the laboratory is implemented in the low-energy building 'SurPLUShome' (fig. 8a) in Darmstadt. Figure 8b shows the touchpanel for the control of the energy management which is installed in the living room of the building.

Figure 8: a) SurPLUShome b) Start screen building control

The building is equipped with a home automated control system based on KNX-fieldbus as well. The roof and all facades are covered with PV-panels which have a total installed power of 19 kWp [6]. For heating, cooling and ventilation of the house a 2,1 kW heat pump is installed. The generation of hot water is supported by a geothermal probe. Additionally to the control of the lighting and the domestic appliances, one of the 'smart' charging stations and a lithium-ion battery (S_r=12 kW) are integrated in the energy management. The energy storage has a capacity of 11 kWh and serves as a buffer to increase the flexibility and charge the EV by self-generated electricity in the evening and night hours. To minimise the wear of the battery only the range of a state of charge level between 15 % and 90 % is used. When these levels are violated the storage is not further used for load adjustment until a moderate state of charge is reached again. Besides the demand side management of flexible loads, the developed GUI has also been upgraded by a control menu for the jalousies, windows and outlets. For an improved user convenience the control pages show the ground plan of the rooms (fig. 9).

Figure 9: Menu page for control of the lighting

A presence detector on the ceiling supports the household in saving energy. It detects the absence of the residents and automatically starts preconfigured energy-saving activities depending on the selected strategy and time of absence. When a 1-hour absence is detected all lights, the oven and all outlets with multimedia devices are switched off. Longer times of absence trigger an adaption of the heating and cooling. The inside temperature is adjusted down, windows are closed and jalousies are controlled depending on brightness and the outside temperature. As a reverse function, the lights at the entrance are switched on and the heating/cooling is enabled again when the residents arrive at home.

Exemplary use case of the energy management

This chapter describes exemplarily the application of the combined strategy for a 30-minutes time interval which is shown in figure 10. At the beginning the household has an almost constant load (lighting, air condition, etc.) of 1 kW. The PV-system (feed-in ~8 MW) is generating an energy surplus. For the optimisation of self-consumption and because of a red tariff interval the connected EV is only charged with a reduced charging power of 6,9 kW (level 2). The remaining difference is feed in the public grid. When the generation of the PV-system reduces, the energy management automatically adapts the charging power for the EV to level 1 (3,7 kW). After a quarter of an hour the generation decreases so much that it cannot completely supply the demand of the household any more even if the charging process of the EV is interrupted.

During the rest of the illustrated time the energy storage is discharged to compensate the deficit. Grid purchase is avoided because the traffic light tariff is signalling a red time interval. In this case the EV can only be charged by an activation of the 'immediate-charging' mode.

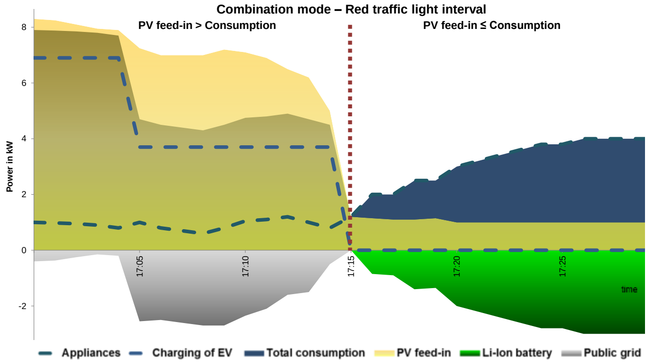

Figure 10: Exemplary power curve of a household by use of the automated energy management (combination mode)

CONCLUSION AND OUTLOOK

It can be expected that an accumulation of fast charging processes of EVs will lead to a new challenge for the distribution networks in the future. The research project 'Well2Wheel' shows in practice that intelligent control strategies for charging processes and time-flexible energy consumption of private households can support operation efficiency and grid stability.

For practical demonstration a 'smart' charging station for EVs was integrated in the home automation system of the low-energy building 'SurPLUShome' and an intelligent energy management for touch control was set up. By the implementation of different autonomous strategies for the energy management, residents are able to optimise self-consumption when owning a PV-system or can shift their energy demand in accordance with the requirements of the local distribution grid. Within the project the network requirements are signalled to the consumers by day-ahead traffic light tariffs which are calculated in a VPP.

In summary, the project 'Well2Wheel' has shown so far that households can act as active consumers with flexible electricity demands when automated energy management systems are implemented in their houses. Thereby, local peak loads occurring because of simultaneous charging processes of EVs could be avoided in order to reduce congestion and grid expansion.

In the further course of the project the performance of the energy management platform will be improved and typical use cases with an inhabited building and real driving cycles of an EV are carried out.

REFERENCES

[1] Bundesverband der Energie- und Wasserwirtschaft: "*Erneuerbare Energien zum ersten Mal wichtigster Energieträger im deutschen Strommix*", BDEW press release, Berlin, 2014.

[2] P. Franz, et al.: "*Integration of electromobility in a distribution grid: results of the beacon project Well2Wheel*", CIRED Workshop, Rome, 2014.

[3] V. Buehner, et al.: "*The economy of Smart Grids requires Smart Markets*", VDE Congress, Stuttgart, 2012.

[4] EN 50160: "*Voltage characteristics of electricity supplied by public distribution networks*", Beuth Verlag, Berlin, 2011.

[5] KNX Association: "*KNX Solutions*", Brussels, 2014. Available: www.knx.org

[6] M. Hegger: "*Sunny Prospects*", Müller + Busmann Verlag, Wuppertal, 2010.