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Grid integration issues for EVs / PHEVs: the DERlab approach

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The DERlab network

DERlab is the European Network of Excellence of independent laboratories dealing with the sustainable integration of distributed energy resources (DER) into the electricity grids. The mission of DERlab is to perform tests, pre-competitive and pre-normative research, as well as training activities, supporting the transition towards more decentralised power generation.

Furthermore, DERlab was recently established as an Association, ensuring the continuity of the consortium actions in this field.

Present results of the Network of Excellence include, for example, the preparation of an international white book defining research and standardisation needs for the grid integration of inverters, titled: "International White Book on the Grid Integration of Static Converters". The draft concept is available on the internet under www.der-lab.net. A similar document dealing with grid-tied stationary and mobile storage will be produced. For this purpose, DERlab is currently preparing a dedicated workshop series.

Towards smart grids: the case of storage

For an efficient integration of a considerable amount of distributed generation, and especially variable renewable energies sources (DG/RES) at the distribution level, a transition to the so-called “active networks” is becoming a necessity [1]. In this context, aggregators, e.g. storage components, being intermediates between RES and the grid, are an attractive solution to better manage these upcoming active networks. When selected and sized properly, storage devices such as batteries, flywheels, super-capacitors, Electric Vehicles (EV) as storage etc., are suitable for different functions having the crucial impact of increasing the controllability of the system.

The simulations carried out in several studies [2, 3] indicate that storage combined with DG power supply feeding energy into the grid, provide local power balancing and contribute in power quality. Furthermore, the technical benefits in islanding operation protect a micro-grid from possible grid interruptions, providing reliability to the consumers. Power quality along with reliability become major issues as technology develops, and could soon become tradable quantities as ancillary services. For example, in the USA, American Electric Power is planning to place storage equipment in residential areas to store electricity for a few hours to serve four or six houses. Together, those storage units could provide back-up power to neighborhoods during outages and other applications if aggregation is applied. AEP’s goal is to deploy 1000 MW of energy storage by 2020.

Moreover, the capability of balancing the divergence of the actual demand from the demand forecast can be proven beneficial. If daily RES production profiles are similar to the load curves of consumers, storage should be able to smooth power or energy mismatching because of weather or demand fluctuations. A clear example of this can be the Irish case where balancing the grid has become an issue due to the large wind power penetration after 2000: 25% of the total power with typical availabilities of 30%, and just a small interconnection between the island and Scotland.

Additionally, other possible functions of storage could influence the RES integration. Surplus energy from RES could be stored and reused at peak demand periods, when energy and power pricing increases substantially.

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EVs and PHEVs: a specific case of grid-connected storage

EVs and PHEVs also need to be considered under this approach, as being specific cases of grid-connected storage. These small-scale storage devices need to be connected to the grid for charging, and thus increase the network load. Without a suitable management strategy, operational problems may appear, increasing congestion in already heavily loaded grids. The influence on the grid can be considerable if they are introduced in large numbers, but such distributed storage devices could be turned from a burden into an asset.

As an example, a study has been performed at Arsenal Research in order to investigate the impact on the network of different load strategies for the daily charging cycle: Immediate End of Travel Day, Delay to 10pm, Optimized to Off-Peak, Opportunity Charging (Multiple charging events per day)

Figure 1 (a) shows the load profile for the optimum off-peak strategy. Besides the economical benefit of the operation of the power plants on a constant level, this avoids the costly network upgrading. On the contrary, the 'delay-to-10' strategy (besides the 'immediate end of travel day' at peak times) would have the most impact on the grid.

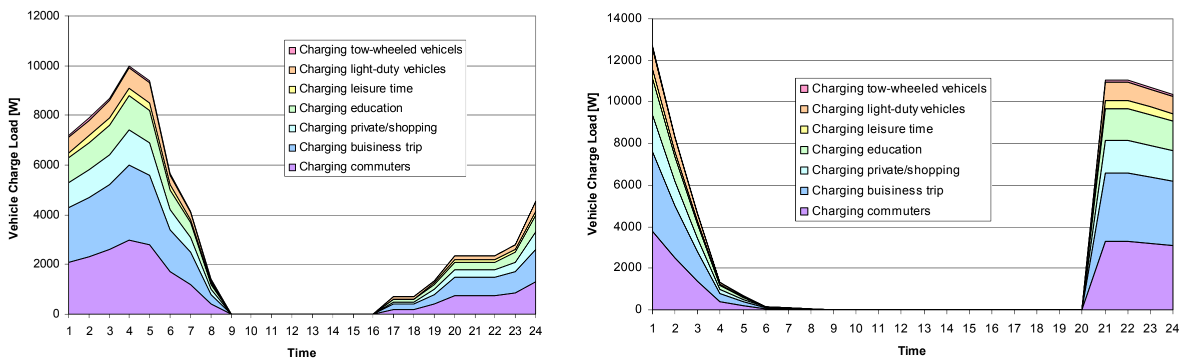

Figure 1: Total load curve over one day (24 hours) – **(a)** Optimized to Off-Peak for Austria, **(b)** Delay-to-10 (20% coverage) [4]

On the other hand, this distributed storage could also be used to provide grid services. If appropriate management techniques are introduced in the EV control, then this bidirectional device can be exploited in the best possible way taking into account its charge and discharge capabilities. For instance, charging may be avoided in peak load hours, when EV may inject power in the grid reinforcing the lines, and charge again when the system load is low. Strategies may be explored under several criteria such as the most technically effective solution, as well as the most economically beneficial. Several partners of the DERlab consortium have ongoing studies on these issues, in the frame of national or international projects, developing especially management strategies for the different grid services.

The available storage capacity for these grid services is far from being negligible. A current study from the Austrian "Klima- und Energiefonds" [4] estimates the secure available battery capacity is about 82% of the total capacity of the electrical vehicle fleet. The total annual battery capacity includes passenger cars, light duty and two wheeled vehicles, assuming a penetration of 20% EV. Only 11% of the batteries capacities are actually needed for driving or charging during the day times, and additional 7% could be on demand injected into the power grid (mostly during the night time) (Figure 1). This high amount of share on battery capacity could contribute significantly to energy balancing and even black-start capabilities.

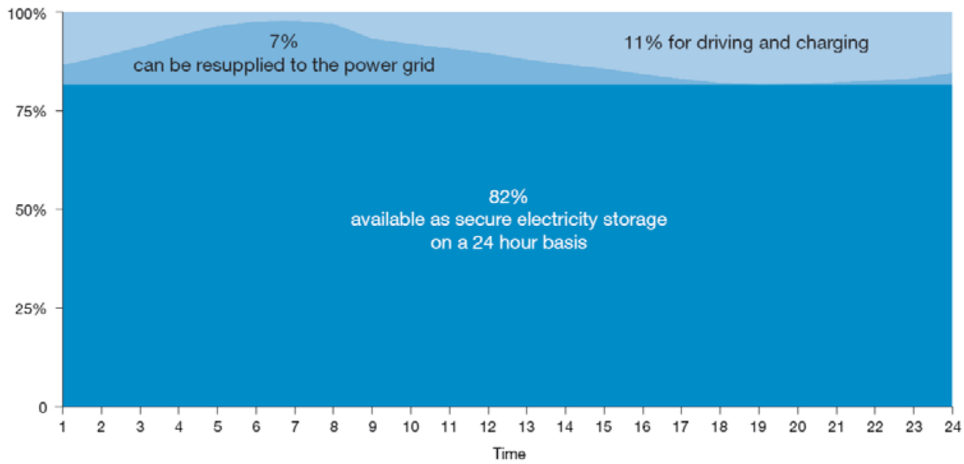

Figure 2: Availability of the total daily battery capacity for different uses according to an average utilisation pattern. [4]

Technical and regulatory issues to be solved

Besides the necessary technology development on the vehicle and storage side, a wide range of technical and regulatory issues related to the grid interconnection of EVs have to be solved prior to creating a mass market for EV. The whole system

from the road through the plug and the household to the distribution network has to be considered and related test procedures must be developed.
Concerning the economical aspects, the cost / benefit optimisation of the control of the power flow between the vehicle’s battery and the grid requires the estimation by the controller of both the benefit and the cost for both parties. The benefit for the power system is related to the value of the services that may be provided. For the vehicle owner, the maximum benefit is obtained when the cost of the electricity for charging the battery is minimised. The cost estimation is related to the energy losses in the AC / DC inverter as well as in the battery, and in the reduction of the battery lifetime.

Without an active integration of EVs into the grid control, it will not be possible to fully exploit the benefits that electromobility could bring for the future Smart Grids. To achieve this active integration, many issues are involved including requirements for charging stations, the physical connection and form-factors of batteries, administrative issues, communication between vehicle and power system and probably several other entities for the management of the storage/charge/discharge.
For this purpose, several DERlab partners are setting up experimental facilities with the suitable capabilities.
For instance, at ISET, an integrated system test bench is in preparation combining the already existing test benches of the vehicle electrical system of the Kassel university, a virtual battery, a household demand side management system and a network simulator through a roller dynamometer. With these modules the whole picture from driving behaviour to network interconnection requirements can be investigated.
At Arsenal Research, a comprehensive and multi-disciplinary development environment is available for electric drives and alternative vehicle concepts. This development environment comprises modelling and simulation on vehicle and component level, design of electric machines and power electronics, development of intelligent control strategies up to prototyping and verification on test beds and an accredited high performance energy storage test bench. For time and cost-efficient

development processes, a hardware-in-the-loop test environment was established allowing a direct coupling of the simulation environment with the test beds.

At INES/CEA, the focus is put on the interaction and complementarities between EV charging and energy available from photovoltaic arrays. A simulation platform has been set up, as well as an experimental approach which includes instrumented electric vehicles and battery test benches. This allows complete vehicle characterization, and validation of the developed control strategies. The next planned step is to work more closely on the vehicle interface, i.e. the charging station.

Standardisation is a pre-requisite

As outlined above, the whole system from the road through the plug and the household to the distribution network has to be considered and related test procedures must be developed. To really finalise this approach, it is necessary to go up to the standardisation step. Standards for the use of EVs as bidirectional storage units are crucial to enable the real deployment of EVs on a large scale.

Up to now, important efforts were put on the development of standards concerning the operation of vehicles themselves. Some of these have produced important results, while others remained incomplete and after several years some points are obsolete. The main difficulty in the standardisation of EVs generally lies in the fact that an EV can be regarded either as electrical equipment or as road vehicle. In order to cope with the difficulty since 1970’s, IEC and ISO have begun a cooperation for the definition of standards including topics like operation, safety etc. [5].

This approach should include the improvement and extension of already existing standards such as IEEE 1547.3, which could be considered as a guide for Monitoring, Information Exchange and Control of Distributed Resources Interconnected with Electric Power Systems. This guide could define the requirements for communication between the storage units (inside the EVs) in order to obtain the best energy management.

However, the IEEE 1547.3 standard focuses on the grid’s point of view, while standards concerning the vehicles’ parts are also necessary. In this direction, IEC TC69, WG2 is currently working on topics which focus on the vehicle charging devices. Some of them have to do with the use of the AC inverter as a charging device in order to obtain fast charging, or for supply network management purposes such as peak shaving. The bidirectional power flow between EV and grid is also under study [5].

More generally, the absence of a harmonised interconnection standard in Europe has been identified as one of the most severe obstacles towards the wide deployment of DER and as a result to the change towards active electricity networks. This statement becomes true in particular if its scope is broadened to mobile devices. The harmonisation needs range from technical issues, like the plug, over economical like the metering, to administrative ones, like grid codes (Figure 3). The work of the DERlab consortium will focus on the development of grid interconnection requirements (grid codes for vehicles) and related testing procedures. The work will be done on a European level taking advantage of the already existing network, considering the experiences of its members from already 11 EU states in collaboration with experts from manufacturers, network operators and universities.

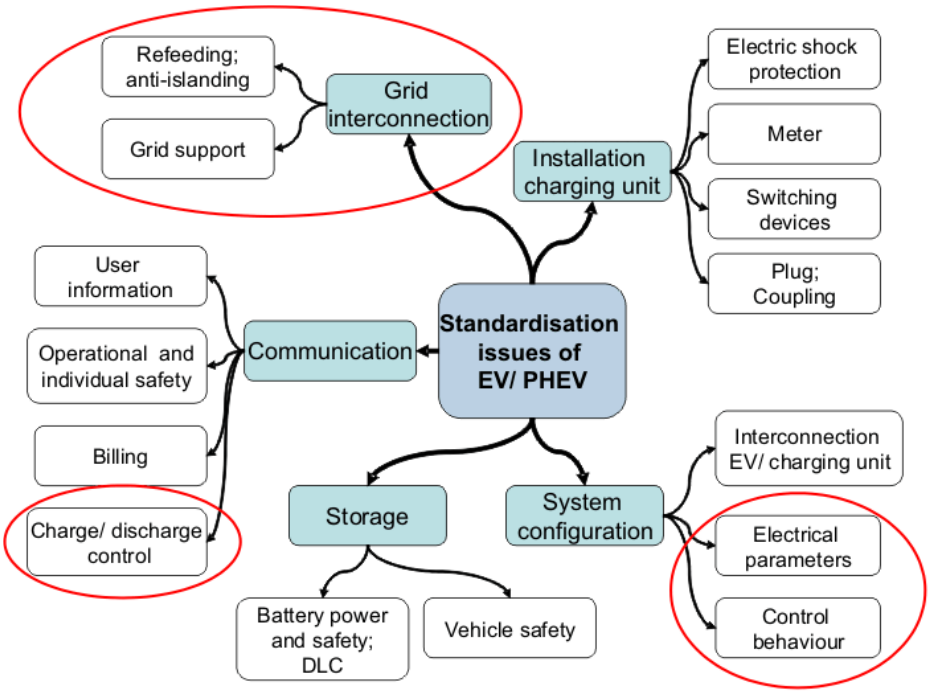

Figure 3: Harmonisation needs for electric vehicles and the focus of DERlab

Conclusion

Besides their evident environmental advantages, EVs also have to be seen as storage devices interacting with the electrical network, with a bidirectional activity in the very near future. These mobile storage devices will clearly increase the network load and thus constraints on the network while recharging. However, bidirectionality also offers a great potential for improving the network management. In this context, coordinated research and pre-standardisation are clearly pre-requisites to the wide deployment of EVs on the market. This anticipation is necessary in order to enable the electrical networks to cope with the additional constraints, and even better, to positively use the EVs charge/discharge characteristics for improving the network management. With its broad experience in DER related expertise and involvement into national and international standardisation, DERlab will widely contribute to this coordinated research and pre-standardisation work, up to the standardisation level.

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