GREEN EMOTION - ADAPTION OF E-MOBILITY INFRASTRUCTURE TO MASS-MARKET REQUIREMENTS

Heike BARLAG
Siemens AG – Germany
Heike.Barlag@siemens.com

Christine SCHWAEGERL
Siemens AG – Germany
Christine.Schwaegerl@siemens.com

Will CROOKES
Alstom Grid – UK
will.crookes@alstom.com

Fainan HASSAN
Astom Grid – UK
fainan.hassan@alstom.com

Sebastian MATHAR
fka – Germany
mathar@fka.de

ABSTRACT

In the project Green eMotion important players from industry, the energy sector, municipalities as well as universities and research institutions have joined forces in order to develop and demonstrate a framework and marketplace for electric vehicles in Europe. The project lays a special focus on the interoperability of the electro-mobility technology and on a smooth functioning of the EU single market. Therefore special focus lays on standardization as a main basis for interoperability of hardware and software systems as part of the European electro-mobility marketplace.

Two examples for that are the needs in the field of fast charging and inductive charging. Green eMotion will evaluate different solutions for the integration of fast chargers into the grid and also demonstrate fast charging in Spain and Ireland.

The basic feasibility of contactless battery charging systems has already been demonstrated more than 100 years ago. Prototype systems which satisfy the safety and functional requirements for series applications in the automotive field are already available in the 10 kW power class. In order to gain consumer acceptance, it is necessary that the environmental issues mentioned above are handled carefully and transparently to show that a contactless battery charging system does in no way harm the environment. That will also be evaluated and demonstrated in the Green eMotion project.

We expect a major contribution from these results to the standardization in Europe. Here Green eMotion will actively promote its solutions and recommendations in the relevant European standardization committees.

INTRODUCTION

The European FP7 project Green eMotion aims with a 50 million € budget and 42 different partners from industry, utilities, vehicle manufacturers, cities and universities to demonstrate an integrated European solution on electro-mobility. It will start from March 2011.

Currently a significant number of isolated demonstration projects for electro- mobility are carried out in Europe without sufficient exchange and connection between the important players which is necessary to reach sustainable results and facilitate the required interoperability and consumer convenience needed for a mass market rollout. By merely extending and combining these projects no real impact will be achieved because consumer acceptance can only be created at a large scale if a holistic user-friendly framework is created.

The concept of the project Green eMotion is based on the conviction that electro-mobility in Europe has to be approached in a systematic and holistic way making use of innovative ICT solutions and involving regional stakeholders at the same time. Technical solutions must be interoperable, scalable and standardized to enable a mass market rollout.

Therefore in several work packages Green eMotion is dealing with the evaluation of interoperable technical solutions and standards, i.e. covering ICT solutions, network impact or vehicles technologies. This paper describes the activities in the field of charging infrastructure with a special focus on the most promising future technologies fast charging and wireless charging.

CHARGING INFRASTRUCTURE SCENARIOS

EV battery charger power level

Electric vehicle (EV) battery charging systems are mainly classified into three levels regarding their power ratings. These levels were defined by the Electric Power Research Institute and codified in National Electric Code (NEC), along with corresponding functionality requirements and safety systems. Ideally, any car should be able to connect to any of these levels; namely Level 1, Level 2 or Level 3, charging points [1].

Level 1 chargers typically refer to the present day plug-in sockets. In most of Europe, this is single-phase 230V, and up to 16A (or 13A in the UK). Since the power from the socket is limited to 3.7 kW Level 1 chargers require long charging time (hours) and are therefore normally associated with overnight charging.

Level 2 charging points refer to higher power than Level 1, typically around 5-10kW. Level 2 is typically described as the “primary” and “preferred” method for a battery electric vehicle charger for both private and public facilities (car park). Due to higher power provided by that Level 2 charging point the charging time is reduced to around 1-2 hours. The installation in public areas calls for standardized communication channels between the battery inside the car and the public charging point to achieve essential monitoring and billing functions. These additional functions require not only advanced communication technology, but also an intelligent and user-friendly interface.

Level 3 car chargers or fast chargers provide the highest power, typically in the range of 50kW up to 150kW [1], compared to Levels 1 and 2. So charging the battery requires minutes rather than hours.

Tables 1 demonstrates charging times required for the three levels depending on the battery capacity of the EV. Assuming an average consumption of 17 kWh/100 km with a 5 min charging at 150 kW the “charged” driving distance is in the range of 60km (40 miles), which roughly corresponds to the average travel distance in Europe. Also in case of higher battery capacities allowing higher travel distances (i.e. of 300 km with 50 kWh) the charging time remains within acceptable limits.

For all levels the charging efficiency is assumed as 80%. The application of Level 3 charger depends upon the development of the battery technology to allow rapid charging.

Table 1. Example of charging times for different levels of chargers assuming 80% charging efficiency

Type of charger	Battery capacity used	Charging time
Level 1, 3 kW	10 kWh	4.2 hrs
Level 2, 10 kW	10 kWh	1.3 hrs
Level 3, 150 kW	10 kWh	5 min
Level 3, 150 kW	50 kWh	25 min

Since Level 3 is for commercial and public applications and is intended to perform similar to a commercial gasoline service station, the car charger should be available at anytime. The billing function and the intelligent systems are also needed since Level 3 car charger is open to public. The advanced communication needed for public chargers (level 2 and 3) leads to the necessity for standards so that the vehicles can connect to the whole network of available chargers.

Infrastructure requirements for Level 3 chargers

The power system infrastructure supplying these chargers has not yet been properly addressed. There are many standardization efforts focusing on the connectors and communication protocols for all charging levels (e.g. SAE J-1772 and IEC 61851). It seems that Level 3 is the most demanding regarding system infrastructure requirements, and also most demanded from the customer point of view. Different schemes are possible; two examples for Level 3 chargers are shown in Figure 1 and Figure 2 to illustrate different issues that may arise when designing a system for supplying a charging station and which may impact the standardization efforts.

LVDC distribution for fast chargers

The layout of a Low Voltage DC (LVDC) distribution for fast charging is shown in Figure 1. The AC medium voltage (11kV) from the grid is converted to low voltage (400V) through a transformer at first and then an active rectifier is connected after the transformer to generate the DC voltage from the output of the transformer.

The advantages of the LVDC distribution are: i) protection is easy; ii) a single active rectifier is employed and it can also be used to realize VAR compensation or other functions. The disadvantages of the LVDC distribution are: i) the distribution current will be very high due to the low voltage conversion; and hence ii) all components and cable diameters are relatively large.

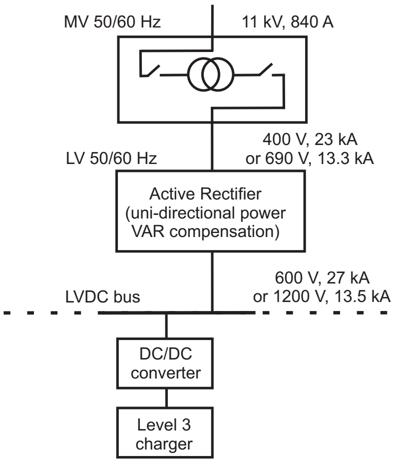

Figure 1. LVDC system for fast chargers

MVDC distribution for fast chargers

The layout of the Medium Voltage DC (MVDC) distribution for fast charging is shown in Figure. 2. The AC voltage (11kV) from the grid is converted to the DC voltage (18kV) with an active rectifier. With a DC/DC converter, the medium DC voltage is converted to a low DC voltage (600V or 1kV), which is the input to the fast charger.

The advantages of the MVDC distribution are: i) similar to the LVDC distribution, the main active rectifier can be used to realize VAR compensation or even other functions; ii) smaller transformer and DC/DC converter can be used because of the lower currents.

The disadvantages of the MVDC distribution are: i) protection will be difficult due to the DC medium voltage generated at the output of the active rectifier; ii) a medium voltage connection is not always available.

The two scenarios show that there are a lot of options depending on the specific needs. In any case a careful evaluation and standardization is needed to avoid potential negative impacts of electric vehicles on distribution networks.

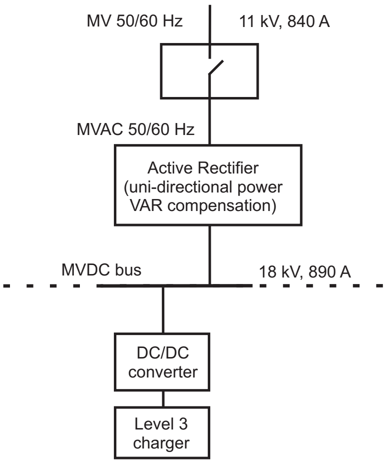

Figure 2. MVDC system for fast chargers

WIRELESS BATTERY CHARGING FOR EV

Introduction

Today, every electric vehicle in series production is equipped with a conductive (i.e. cable-bound) battery charging system. A basic challenge here is to optimize the connection technology to the charging station. Any plugging and unplugging of an electric vehicle after parking is tedious and vulnerable to weather conditions like snow, frost, rain etc.

A contactless battery charging system (Fig. 3) does not require any manual plugging/unplugging of the connector by the consumer. Instead, the energy transfer takes place in a contactless, fully automated manner based on a transfer module mounted on the underside of the vehicle.

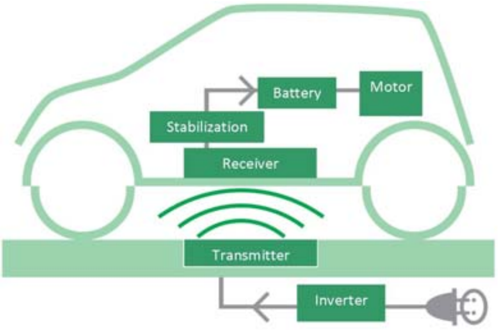

Figure 3. Basic layout of a contactless battery charging system

The physical plausibility of such systems was already proved more than 100 years ago by Nikola Tesla [2]. Although there is no new ground breaking technology involved, there are still numerous challenges to be overcome in making the system series ready and compliant with current industry standards for electric vehicles.

Present state of the technology

Figure 4 shows the block diagram of a typical inductive battery charging system. Three functional blocks can be identified which make up the contactless energy transfer system:

- Transmitter module (rectifier and converter)
- Inductive transfer device (pair of coils)
- Receiver module (rectifier and stabilization circuitry).

The function of the transmitter module, fixed invisibly in a position a few centimeters beneath the road surface, is to rectify the three phase voltage from the mains electrical network. The rectified DC voltage is then converted to a high frequency AC voltage by the converter. This AC voltage is fed to the primary side of the coil pair. The energy is transferred from the primary coil to the secondary coil, mounted on the underside of the vehicle. The stabilized DC voltage is then provided to the battery management system (BMS) of the high voltage battery in the vehicle.

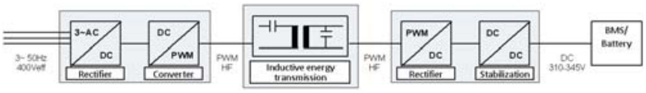

Figure 4. Schematic of the energy transfer system

EMC and environmental issues

While it is easily possible to detect an energy transfer in a conventional charging system, no such indicators are available for contactless charging. Certain animals possess sensory organs to detect magnetic fields. Migratory birds for example use their abilities to orient themselves along the magnetic field of the earth. Human beings on the other hand posses no sensory organs to detect the presence of magnetic and electric fields. Indirect effects like standing hairs can only hint towards the presence of strong electric fields. It is absolutely necessary that no high-strength magnetic fields are generated during the contactless energy transfer in order to prevent any interference of nearby systems and components and assure the security of people and animals.

In order to quantify exposure to magnetic fields, the ICNIRP (International Commission On Non-Ionizing Radiation Protection) published a study in 1998 [3] with frequency dependant reference values presented in Figure 5 that represent until today the accepted state of the art.

In the frequency range typically used by contactless energy transfer systems (20-100 kHz), an upper limit of 6.25 µT has been specified for a complete body exposure for civilians. It is hence necessary to ensure that the magnetic field strength in the area around and inside the vehicle does not exceed the 6.25 µT limit. The most efficient way to maintain the field strength limits is different in every individual case and depends on the coil and vehicle geometry. Technically, two basic approaches are possible:

- Guiding the magnetic field through highly permeable material (ferrites)
- Shielding through conducting material (e.g. copper or aluminum).

The first case utilizes the fact that a highly permeable material ($\mu R > 1$) in the immediate vicinity of the coils conducts the magnetic field better than air ($\mu R = 1$) does and hence prevents generating a large amount of interference in the surrounding space. In the second case, stray magnetic fields induce eddy currents in the conducting shield plate. These currents in return generate their own magnetic field which opposes the primary field according to Lenz's law. A suitable combination of ferrites and shield plates can help to reduce the level of exposure to an acceptably low level.

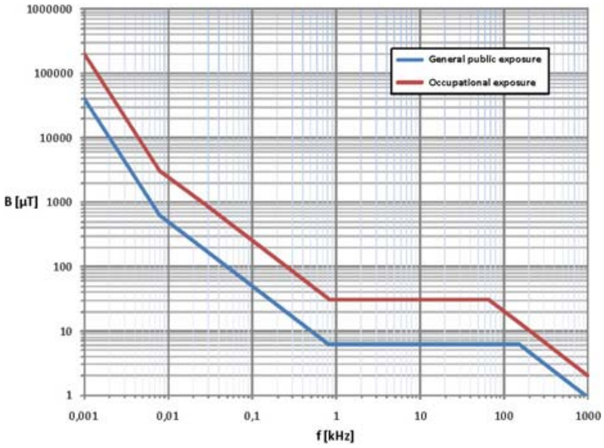

Figure 5. Reference values for exposition to magnetic fields according to ICNIRP [3]

Standardization issues

As mentioned in the previous chapter, a compliance with the ICNIRP limits - which are basically accepted by all experts - can help to protect people against possible negative effects of the magnetic fields in the proximity of an inductive energy transfer system. However, a safe operation is only one necessary part for a successful commercial launch of contactless battery chargers. One major prerequisite for a significant market penetration of such systems is the availability of standardized and interoperable solutions. Some exemplary concrete technical parameters, which need to be defined, are:

- Geometry (e.g. diameter) of the primary and secondary coils
- System operating frequency
- Primary and secondary reactive power compensation topologies

Only when all technical factors fit to each other, every properly equipped EV will eventually be able to charge at any wireless charging station.

The first European standardization committee, which invited all relevant stakeholders in the field of inductive energy transfer for electric vehicles to commonly pool their resources, was the German Engineering Society (VDE). In 2009, its business unit DKE founded the working group AK353.0.1. The mandate of this task force was to elaborate an application guide for contactless EV battery charging units. Meanwhile, also on IEC level, a formerly dormant working group has been reactivated, namely IEC 61980. Based on the outcome of the DKE - a first draft application guide published in January 2011 - the IEC 61980 is currently establishing a task force with the mission to extend the German application guide to an international IEC standard.

One major target of the Green eMotion project is to support this standardization process through the application of concrete technical solutions which show the proper functioning of a given strategy. In the context of inductive charging, a wireless charging station prototype will be designed, developed and finally built up in a real-world scenario. As soon as the operability of this solution has been proven over several months, all major outcomes will be fed back into the IEC and DKE working groups, in order to support the respective standardization processes on national and international level.

CONCLUSION

The described examples for different grid implementation scenarios for level 3 charging infrastructure shows how important a European evaluation of the different options is. The Green eMotion project will develop a future-proof and interoperable fast charging station (Level 3). This will be demonstrated in Spain and Ireland. Secondly, all aspects related to the upstream electrical infrastructure will be part of Green eMotion's standardization oriented work. Also, measures for avoiding potential negative impacts of electric vehicles on distribution networks will be demonstrated in Ireland.

In the case of inductive charging there is a special need for standards to ensure the safety of these systems additional to those already valid. Another essential need of the end customer is interoperability, i.e. the fact that any properly equipped vehicle can be charged at any charging station. Safety as well as interoperability targets can only be reached satisfactorily through common standardization approaches. The Green eMotion project will significantly help European standardization bodies through its pragmatic and practical real-world approach.

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