Cost-effective, Smart Charging Infrastructure for Electric Cars

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Abstract

Some scenarios for electric mobility foresee that by 2050 nearly all cars will be equipped with an electrical plug. In Switzerland, this requires that by then more than 5 million parking lots be equipped with a connection to the electrical grid. Due to this high number of required access points to the grid – there will be more sockets than cars! - the cost per such a grid connection needs to be as low as possible.

If all these cars with electrical plugs would start to charge at the same time, the electrical grid would be overloaded. Therefore the car's charging processes will have to be coordinated, that is, controlled, in order to prevent power failures. Traditionally, it is assumed that a smart grid enables the controlled charging of electrical cars. However, a smart grid does not exist in Switzerland, but the electrical cars are coming now!

In order to find a solution to the problem of the non-existing smart grid, EKZ, the electric utility of the Kanton of Zürich in Switzerland is studying mobile phone communication to remotely control the charging process. By using functions already in an e-car, the charging infrastructure could potentially be kept simple and thus low-cost.

In a joint demo project with IBM Research Zürich and the University of Applied Research Zürich in Winterthur, ZHAW, remote control of the charging process from a simple electrical wall socket was demonstrated. On a smart phone, an e-car driver can set boundary conditions for the charging process, e.g. can wish immediate or later charging. Or, the car owner can delegate the responsibility for the charging to the utility. A virtual power plant application enables optimal charging of the battery, taking sometimes conflicting conditions, like user driving schedules and energy availability, into consideration.

The paper describes the basic concepts and some reasons why a utility like EKZ is interested in eventually using car technology to control the charging process of a customer's e-car battery rather than investing into a traditional smart grid and correspondingly expensive charging infrastructure.

Introduction

By 2050 95% percent of all passenger cars could be equipped with an electrical plug, according to a scenario in a strategy by the City of Zürich (Ref. 1). According to extrapolated data by Swiss Statistics, this would correspond to 5 Mio. plug-in passenger cars. On a national scale, there are more than one parking lot per car, on average up to maybe two.

Propfe and Schmid showed that the availability of charging infrastructure at any destination point of a passenger vehicle is more important for the feasibility of electrical driving than the range of the battery (Ref. 2). Based on the statistics cited above and on the conclusions by Propfe and Schmid one can say that by 2050, 5 to 10 Mio. parking lots in Switzerland should ideally be equipped with electrical sockets. Under such conditions, only rarely would a driver of an electrical car not find a socket when parking. The electrical cars could always be connected to the electric grid, yielding ample time for charging. Availability of lots of time for charging due to the availability of plugs at virtually all parking lots would mean that low current resp. low power charging would be sufficient to deliver close to 100% of all the electrical energy to the car fleet needed for electrical driving. Low power charging also postpones the need to strengthen the electrical grid in that peak loads by concidential high current charges are much less likely.

A few fast charging stations could complement the normal charging stations essentially like an insurance for the few cases when you need intra trip charging.

If millions of parking lots have to be equipped with access points to the electrical grid, the question of affordability arises. In order to assess the order of magnitude of the costs, let us consider two scenarios:

> *Scenario a)* Parking lots are equipped with wallboxes resp. home charge devices (HCDs) as known today.
>
> *Scenario b)* A parking lot is equipped with a simple socket and some low-cost electronics for communcation e.g. with the electrical vehicle.

It is assumed that every year the same number of parking lots will be equipped with infrastructure so that in year 2050 7.5 mio parking lots with sockets will be available. It is further assumed that the electrical installation for both types of installations, wallboxes and simple sockets, costs 500 CHF per parking lot without the HCD or simple socket costs. The price of a wallbox decreases from 1500 CHF in year 2010 to 400 CHF in year 2050, while the simple socket with the low-cost electronics costs 100 CHF a piece.
By 2050, the cumulated costs for the wallbox/HCD-scenario add up to 11.3 billion CHF, whereas the scenario with simple sockets will cost 4.7 billion CHF. See figure 1. The potential saving of 6.6 billion CHF by choosing scenario b) shows that the choice of a solution for charging infrastructure can have major consequences.
Since home charge devices potentially allow higher ampacities than simple sockets/plugs, this characteristic of home charge devices will increase the pressure to reinforce the electrical grid, whereas the simple socket scenario would probably only require selective reinforcement of the grid. In fact, the difference in cost of the two scenarios a) and b) would probably be much bigger than 6.6 billion CHF, if the cost of grid-reinforcements would be taken into account.
If the funds available for the realisation of both scenarios, a) and b), would be the same, choosing home charge devices would allow to only equip about 1/3 as many parking lots compared to the simple socket solution. The availability of parking lots for vehicles with plugs would be much lower, potentially even leading to something as absurd as search traffic for electrical sockets rather than just search traffic for unoccupied parking lots!

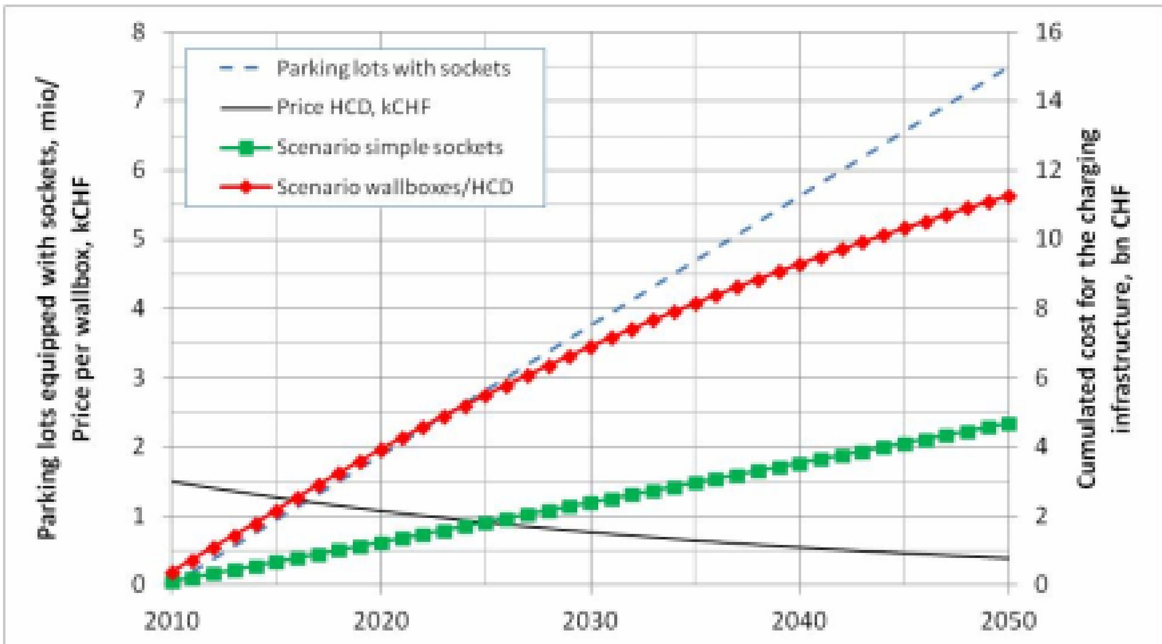

Figure 1 Cumulative costs to equip up to 7.5 mio parking lots in the year 2050 (blue dashed curve) with a) home charge devices (red curve with romboids) and b) simple sockets with low-cost electronics (green curve with rectangles).
The thin line is the price of a home charge device in kCHF assumed for the calculation.

The high cost of home charge devices and the question whether they are necessary at all lead to the study regarding the possibility of low-cost charging infrastructure.
One potentially very elegant way to achieve simplification of the AC charging infrastructure is by using functions already existing on bord of electrical cars, rather than by duplicating those functions off-bord in the charging infrastructure. The power of AC charging is controlled by on-bord chargers, either stand-alone or integrated into the motor inverter anyway. The current is “counted” by at least one entity in the vehicle – if not, state of charge of the battery and residual range could not be indicated to the driver on the dashbord! All these functions on bord of the car could be controlled using the mobile phone network. By doing so, controlled charging of many electrical cars would not depend on the existence of a grid-bound, that is land-based, smart grid e.g. using PLC (power line communication).
From a communication standpoint a mode 3 capable HCD is only a relay station for information. First the information is sent via cable-bound communication to the HCD, from there through the charging cable into the electrical vehicle. Taking the shortcut of directly communicating with the electrical vehicle connected by mobile phone seems to be straightforward, easy, and potentially low cost since connectivity is given anyway.

To demonstrate the concept of wireless remote control of functions on bord of electrical cars, EKZ, IBM and ZHAW realized working prototypes.

Materials and Methods

Two Twingo cars converted by Kamoo.ch into fully electrical cars were equipped with dataloggers that both send and receive data from a server by mobile phone.. Thus commands can be sent to the electrical car. One command operates a switch in the AC cord between the socket in the car’s body and the on-bord charger. If the switch is open, the on-bord charger does not start to charge, while it does so if the switch is in the closed state (and if the battery is not already fully charged). Since the chargers on bord of the two Twingo cars are only unidirectional ones, the traction batteries in this project are only grid-coupled sinks of electrical energy, not sources.
The datalogger is a new version of the “EV Monitor” box as described in Reference 3, developed by the Zürich University of Applied Sciences in Winterthur, ZHAW. The box is a gateway from the CAN-bus (serial bus for industrial and automotive applications) to GSM/GPRS (mobile phone). Via this gateway many different parameters, but most importantly the “state of charge” and the current of the car’s traction battery can be read and be stored in a database. By visualizing this data, the absence or the presence of a charging process as well as its progress can be monitored remotely. The position of the car is known as long as the GPS of the EV Monitor sees the satellites.

The team of Mr. Dieter Gantenbein from the IBM Research Zürich designed and prototyped services in the cloud that allow to perform operations on the data in the warehouse and to visualize results using web frontends. See Ref’s. 4 and 5.
An application called “IBM EV Manager” allows to both monitor the electrical car remotely and to choose charging modes, using a portable device like a smartphone or a tablet computer.
The DSO-entity of the utility (distribution system operator) can use this same installation, the servers and the communication channels, to control the electrical car as a switchable load, exactly as it does with boilers, freezers and heat pumps. Metering the charged electrical energy would also be be possible, but was not the focus of this demo-project.
If data of renewable energy like solar or wind energy is fed into the data-warehouse, a virtual power plant application can control both energy sources and sinks for demand-response management purposes. E.g. the e-cars can then be charged if electrical energy is available, and charging can be interrupted when there is little energy in the grid.

Results and Discussion

RESULTS

The Twingo electrical cars can be monitored at any time and place. When driving the charge-state of the battery is becoming smaller due to the current drawn by the motor. When recharging the battery the “state of charge” increases thanks to the current running into the traction-battery from the grid. The high temperature Zebra battery in these Twingo cars have some standby-losses. They can be monitored remotely and measures can be taken to avoid deep discharges.
While connected to the electrical grid using a standard domestic (Switzerland, T13, max. 8A continuous current) or industrial plug (CEE type 63, 16A), the charging process can take place. It can be enabled or disabled from a graphical user interface(GUI) on a PC or smart phone. The time it takes for the command to be performed in the car after having been executed on the GUI – referred to as the latency time – is less than one minute. It is being wated until the car contacts the service.

Fig. 2 The main menu. On each button is a summary of the most relevant information. Behind each button there is detailed information. In the anti-clockwise direction, starting on the lower right edge: With the Sub-menu “Vehicle” one can choose an e-car from a list. On top to the right: One can see a map showing the “Position” of the e-car in relation to the closest charging stations (data by www.lemnet.org). On top to the left: The batterystate of charge and an estimation of the remaining range in kilometers is displayed. Bottom, to the left: With the button “Offers” the user can select various charging modes. On the button the user finds an estimation of the time at the end of the charge.

The following three charging modes can be selected:
The first option called “Immediate” does not change the basic behavior of the on-board charger of the electrical car. Once the mode 1 cable is plugged in, the e-car starts to charge.
In the Twingo the current limit is set with a push button on the wiper lever. The default charging current is usually set 8A, sufficient to recharge the energy used for the typical daily distance of 40 km in Switzerland.
Manually, the charging current can also be set to 16A when faster charging is required and the local socket is designed for such current.

A second charging option called “Premium” in this demo application shifts the charging period to the night. The main goal is to avoid a contribution to the peak load of the electrical grid during day light hours. See Fig. 3.

Using the third option “Intelligent” (Fig. 4), the user can delegate the responsibility for the charging to the utility. Using a virtual power plant application, a utility can find solutions for demand-response problems, with regards to the vehicle-side based on user driving and charging history. Like this the car can for example always be charged up to 85% at 4:30 pm when the user usually leaves work.
The user needs to change the charging preferences only if his usage of the car changes, e.g. if he leaves for the week-end already Thursday rather than Friday evening.

The GUI (graphical user interface) is convenient both for the driver and the utility. At the touch of a finger or a mouse click charging options can be changed and the charging process initiated or interrupted. Watch video, Ref. 7.

Fig. 3 The blue rectangle during the night represents off-peak load charging of the electrical car. Usually, kWh-prices are lower during the night.

Fig. 4 The virtual power plant application calculates a “charging time table” that takes conflicting requirements into account, such as user preferences and available energy.

Still missing in this initial phase of the demo project are different user profiles. E.g. direct control with minimal time lag may only be given to the utility, while the driver may only choose the charging method in line with the the service level agreement with the utility.

Also, the electricity is not yet metered in the car. If a certified current meter would be used by the EV Monitor, electronic metering would be very simple.

Also missing in this smart phone application is the remote control of the acclimatization and heating system. Furthermore, a combined “route and recharge”-planning screen with publicly available charging spots and reservation features would be desirable.

Under the open sky the position of the car is known, its battery state is known, and charging can be switched on or off. Most importantly, monitoring and remote control is possible without a land-based smart grid installation between the utility' grid control center and the socket to which the car’s charging cable is connected.

DISCUSSION

It could be shown that by using the existing mobile phone system, remote control of an electrical car by a utility is possible without relying on a traditional smart grid intelligence in the charging infrastructure. Mode 3 using cables and connectors with signal lines respectively pins is not any longer a prerequisite for smart charging. The sockets to which the electric Twingo’s with the EV Monitor on board were connected were simple industrial sockets having no communication pins. A further advantage of this approach is that standby electricity consumption is minimized because a simple socket has no such loss.
Potentially, large investments into smart grid-connected charging infrastructure are ultimately not needed since the mobile telephony network is an already existing alternative.
Data bases of cars and wall sockets combined with properly designed interfaces and services will allow a DSO to manage the charging process of all electrical cars within its electric grid.
No home charging devices have to be telematically connected with the DSO’s control unit via grid-bound communcation channels like power line communication PLC. No expensive Mode 3 capable home charge devices are needed to remotely control the on-board charger.

One next step will be to improve the geo-localisation of the electric car. In order to know exactly who delivered the electrical energy to the wall socket, the parking lot needs to be identified precisely. An application containing the information about the association of parking lots and sockets will then allow the retrieval of such information as the name of the electricity retailer and the maximum ampacity of the electrical installation. Also, distribution of charging power to different cars on nearby parking lots becomes possible.

One way to achieve precise geo-localisation can be by putting an electronic device into the wall socket that allows communication of socket and e-car. Also public spaces can be equipped with simple sockets complemented by some low-cost electronics.

Critics will comment that the mobile phone network has a too big latency time and can therefore not be used for managing the charging process. However, the latency issue can be solved by designing on board chargers to stop charging as soon as grid frequency and voltage are beyond normal values. (Ref. 6, swiss2grid-Project, www.s2g.ch).

ICT platforms integrated into the electric cars will be common (see the Nissan Leaf). So no extra on-board units like the EV monitor will be required. This will furthermore reduce the cost of remotely controlling the electrical cars as a switchable load.
The gateway between the mobile phone network and the CAN bus to the charger will also enable fine tuning the charging power within the limits set by the car’s traction battery management system.
Vehicle to grid would become possible as soon as the chargers are able not only to draw current from the grid, but also to feed electricity back into the grid.

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Abbreviations

DSO	Distribution system operator
HCD	Home charge devices
PLC	power line communication).
PWM	Pulse width modulation

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