Charging Infrastructures for EV: Overview of Technologies and Issues

O. Veneri**, L. Ferraro*, C. Capasso**, D. Iannuzzi*
*Electrical Engineering Department University Federico II of Naples, Via Claudio 21, 80125 Naples, (*Italy*)
**Istituto Motori - CNR National Research Council, Via Marconi 8, 80125 Naples, (*Italy*)

***Abstract* - This paper presents an overview of issues and technologies related to the proper design of charging infrastructures for road electric vehicles. The analysis is carried out taking into account that the recharging stations of electric vehicles might be integrated in smart grids, which interconnect the main grid with distributed power plants, different kinds of renewable energy sources, stationary electrical storage systems and electric loads. The study is introduced by an analysis of the main characteristics concerning different kinds of storage systems to be used for stationary and on-board applications. Then, different charging devices, modes and architectures are presented and described showing their characteristics and potentialities. DC and AC configurations of charging stations are compared in terms of the issues related to their impact on the main grid and the design of their main components. Specific attention was devoted also to the ultra-fast DC architecture, which appears a possible solution to positively affect a wide spread of plug-in hybrid and full electric road vehicles.**

***Index of terms:* Energy Storage, Recharging Stations, Electric Vehicles, Hybrid Vehicles, Vehicle to Grid.**

I. Nomenclature

EVs	Electric Vehicles,
RESs	Renewable Energy Sources,
V2G	Vehicle to Grid,
DSO	Distribution System Operator
EVSE	Electric Vehicle Supply Equipment

II. Introduction

Nowadays, EVs represent an interesting solution for the growing dependence from fossil fuels, since they allow a considerable reduction of air pollution. However, the diffusion of EVs is still affected by many issues, which are mainly due to interaction and integration of these types of vehicles with the existing power grid. Moreover, in order to have a wide diffusion on the market of no polluting vehicles, they have to present the characteristics of travel ranges and recharging times comparable to the traditional oil-based fuel vehicles. For these reasons EVs require battery packs characterized by high values of both energy storage capacity and charging rates. From this point of view lithium based batteries represent a very interesting solution, as they are showing a great potential, in recent years, to supply electric vehicles having good performance in terms of acceleration and driving range. Nowadays, new technologies of lithium compounds are available, which permit reaching an specific energy up to 180 *Wh/kg* and a maximum charging rate of 6 C reducing the charging times up to 10 minutes [1].

Typical charging modes at low power are suitable for the refilling of battery packs during the night in 7÷8 hours, ensuring low power requirements for the grid. In fact, recent studies demonstrate that the daily travel range is less than 50 *km* in 80% of the cases. For this reason such slow recharging would be acceptable for most users ensuring a travel range from 100 to 150 *km* during the daylight [2].

Longer traveling distances would require frequent electric service stations along the way, able to satisfy the requirements of a significant amount of power, supplied to the battery packs, on order to obtain filling times similar to oil-based fuel cars. In this case, the battery pack could be charged in a few minutes, although a power range from 20 *kW* (in case of small city EVs) to 250 *kW* (in case of heavy vehicles) would be required [3]. The existing electric infrastructures may not be specifically designed to satisfy this great increase in power demand. For this reason, a large deployment of EVs involve the evaluation of the impacts that the charging of vehicles may have on the national power-grid and identification of the best charging strategies to be adopted. These strategies should take into account the number of vehicles to be recharged, both during the night and daylight, the proper integration with RESs and the characteristic of EVs to feed electric energy back to the grid, becoming in this case an active load (V2G concept) and providing several ancillary services, such as peak power and back up [4]. Moreover, the evaluation of charging strategies needs to take in to account the electric energy price and the habits of the EVs owners. On this regard the EV *aggregation agent* (also called aggregator as abbreviated term) plays an important role in between the EV owners and electricity market, DSO and transmission system operator, mainly based on the control of the EV charging/discharging rates. This role of an EV aggregation agent is justified by the fact that each EV owner is unable to manage energy transactions between their vehicle and electric power grid, essentially because of their low electric power capacity (generally few *kW*). Furthermore, an aggregation agent technically makes simpler a smart charging of vehicles [5]. On the other hand, different charging scenarios are possible from the point of view of the EV owners [6]:

- Dumb charging – EV owners are free to charge whenever they want; electric energy cost is constant along the day;

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- Multiple tariff – EV owners are free to charge whenever they want; electric energy cost changes along the day;
- Smart charging – is based on two hierarchical control structures. The first one managed by the aggregator and the other one by the DSO, which controls the EV charging, according to the rules imposed by the aggregators and to the grid power availability;
- V2G – the aggregator and the DSO control EV discharging towards the grid and also the EV smart charging.

Some of these scenarios are strictly related to a successful deployment of smart-grids with digital meters and bidirectional communication systems. For different charging scenarios, even in peak hours, it was estimated that the required network upgrade might reach a cost up to 19% of total network costs. The required investment is higher in the urban areas with high load density. However, the implementation of EVs smart charging strategies with a proper management of V2G makes possible to save up to 60÷70% of the required upgrade cost [7] .

The following sections firstly describe the main characteristics of different kinds of storage systems to be used for stationary and on-board applications; secondly different charging modes and DC/AC configurations of charging stations are compared. Finally, specific attention is devoted to the ultra-fast DC architectures.

III. Main Battery Technologies

Storage systems represent a key component for the energy management related to the charging infrastructures in a smart grid scenario. The main reason is based on the fact that stationary storage systems are required to support both the peak power requirements by the users of the charging station and the natural floating of the renewable power sources. On the other hand, the on-board storage systems need to guarantee a proper travel range required by the vehicle mission, but also to have a charging rate compatible with the available power.

Nowadays, different storage systems for both stationary and on board application are available to these purposes. The main storage systems are based on lead, sodium and lithium battery technologies.

Lead batteries have been largely used for traction applications since the end of the 19th century [8]. Different types of lead-acid batteries have been developed and the main categories are classified as 'flooded' and 'valve regulated' lead acid batteries (*VRLA*). The latter mentioned batteries were developed as an alternative to the first ones, in order to maintain the levels of distilled water and avoid the drying of the cells. This characteristic makes this kind of batteries particularly suitable for road electric vehicle applications. The VRLA batteries are also called 'no maintenance batteries', because they require a minimal attention and maintenance operations by the user. They are characterized by values of energy density in the range of 35÷50 *Wh/kg* and specific power of 150 *W/kg*. As a matter of fact, these kinds of battery are not used anymore for the road electric vehicles, mainly because they present the disadvantage of a very low energy density, low performance at high discharging currents, low charging rate, plus the need by the designer of taking into account the material recyclability for the environmental impact. Anyway, they still present some advantages, such as that the temperature does not affect their performance, they are considered particularly secure, their cost is considerably cheap. For these reasons lead acid batteries are still used for many stationary applications, where restrictive constraints in terms of volume, weight and charging rate are not required.

The sodium batteries are characterized by high working temperatures, required for the sodium to be in the molten state, in fact for these batteries the best performance is in the operative range of 520÷620 *K*. The sodium/sulphur batteries represent a low cost and environment friendly solution to be used particularly for stationary applications, since they are characterized by slight low values of energy density and reduced safety issues related to the combination between sulphur and sodium.

The sodium-nickel chloride, better known as Zebra batteries (Zeolite Battery Research Africa), is a branch of the sodium batteries and represents a breakthrough in the sodium storage system technology, since they are much safer and present higher energy density than sodium/sulphur batteries. For this reason, Zebra batteries are mainly used to power road electric vehicles, in particular urban transportation means, due to the temperature issues to manage. Although the nickel extraction cost is higher than sulphur, Zebra batteries are still environmental friendly. Moreover, their characteristics of high energy density and low power density make them suitable when combined with super-capacitors to realize hybrid configurations [9,10].

Lithium batteries are characterized by high power and energy density, which means high performance in terms of acceleration and driving range when used to power electric vehicles [11]. The utilization of lithium batteries implies some concerns to be taken into account related to safety issues, mainly due to the high reactivity of the lithium metal. For this reason, lithium “host” compounds are used in lithium-ion batteries for both positive and negative electrodes, without a significant structural change to the host.

Recent developments of lithium batteries have been obtained by taking advantage of new anode and cathode materials to obtain high energy and power densities. The material most commonly used for cathode in lithium ion batteries is either $LiCoO_2$ or Li-Co-Mn mixed oxides. Both these lithium based batteries present interesting performance in terms of high capacity and high voltage per cell. The main disadvantage of these types of cathode materials is due to the cost of cobalt and limited stability during the recharging phases [12]. Recently, other lower-cost materials for cathode have been tested and proposed, and in particular the $LiFePO_4$ batteries appear to be suitable for road vehicles applications [13]. Their main advantages are based on their characteristics of low cost and abundance of Fe, high thermal stability, safety and durability in terms of life cycle [14]. The energy density of $LiFePO_4$ is slightly lower than $LiCoO_2$ cathode, but the main limitation is represented by a low electrical conductivity [12].

A lithium–titanate battery ($Li_4Ti_5O_{12}$, which is known in the battery industry as *LTO*) is a modified lithium-ion battery that uses lithium-titanate nanocrystals on the surface of its anode instead of carbon graphite. Lithium titanate is a promising anode material for specific applications that require high rate capability and long cycle life. LTO is interesting as it offers advantages in terms of power and chemical stability, although LTO based batteries have a rated voltage of 2.4 *V/cell*, which is lower than $LiCoO_2$ and LFP. On the other hand, the lower operating voltage is balanced by significant advantages in terms of safety. Further, these batteries have fast charging rate, in fact they can be safely charged at rates even higher than 10C, which means charging times lower than 10 minutes for this kind of batteries. The LTO based batteries have also the characteristic of an operating temperature range wider than other lithium battery technologies, in particular they have excellent low-temperature discharge characteristics with an actual capacity of 80% at 243 *K*. Moreover, their life span and power density are not lower than other lithium batteries, and the recharge efficiency can be even higher than 98%. On the other hand, the energy density of 65 *Wh/kg* for the LTO based batteries is higher than lead acid and NiCad batteries, but it is still lower than other lithium ion batteries. There are many stationary applications where diesel-generators work in conjunction with lead acid and NiCad batteries, which could be easily replaced by LTO based batteries. In fact, the applications characterized by a low reliability of the main grid could take advantage of the better cycle life and higher rate capability of LTO based batteries. This means that when the main grid power is available, the batteries can be charged quickly and then discharged slowly when required. This has an effect on energy saving and cost reductions, in terms of diesel consumption and VRLA batteries replacements.

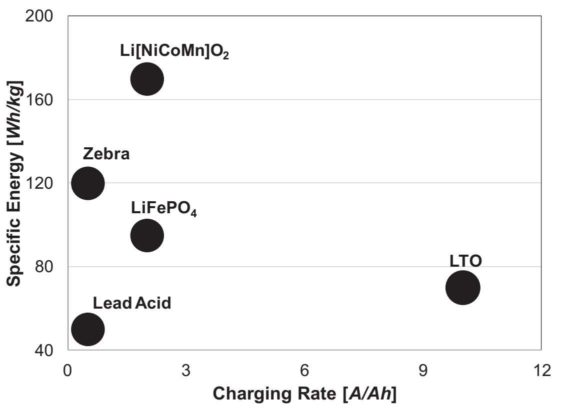

Fig. 1. Comparison between different battery technologies in terms of specific energy vs charging rate.

As a matter of fact, utilities often have peak problems associated with demand and production, because the produced power is not enough to meet the peak demand, while it can be much more than what is needed during off peak hours. However, in this application high energy density batteries are not required, therefore LTO based lithium batteries could be a suitable technology for this kind of applications. On the other hand, when used to supply electric vehicles, the fast charging rate characteristic makes possible an improvement on the recharge times, compared to other battery chemistry, e.g. 10 minutes for LTO based batteries versus to 8 hours for other chemistries. However, many efforts are being made to improve the specific energy and cost [15-17].

In Fig.1 a comparison of the above battery technologies in terms of specific energy and charging rate is reported.

IV. Charging Infrastructures for EVs

EV charging devices are mainly composed by electronic components, which can be on board or off board, to provide energy for the vehicle storage system with the existing power supply infrastructures.

Typical on-board chargers reduce the charging power because of their weight, space and cost constraints and they are generally used to charge battery packs taking a long period of time. Whereas, off-board battery chargers are less affected by size and weight constraints. This means that EVs with off-board battery chargers can take advantage of fast and frequent high power charging phases, in order to extend the effective driving range and reduce the recharging times, until they are comparable with the refilling times of traditional oil based vehicles. On the other hand, the disadvantages of these charging systems include an extra cost for the increased power of the power electronic and a more complex communication system with the recharging vehicle. These devices can be characterized by unidirectional or bidirectional power flows. The former case presents limited hardware requirements and simplifies the interconnection issues. The latter case allows the battery to be charged by the grid and to feed back power into the grid, and allows a power stabilization for the grid by means of a proper power conversion unit [18].

A. *Charging Modes*

Different recharging modes are classified as mode 1÷4 in the international standard IEC 61851-1 [19].

Mode 1 charging refers to the connection of an EV to the AC supply network through a single phase AC line not exceeding 250 *V* AC or a three phase AC line not exceeding 480 *V* AC. at 50-60 *Hz*, using national plug and socket system not exceeding 16 *A* with protective earth conductors, depending on the country and standardization. This low power vehicle charging mode is the slowest mode and can refills a battery during the night reaching the full capacity before the morning. This type of overnight recharge ensures a low electric load for the grid and the car is recharged economically using a low cost night rate power. This recharging mode is mainly used at home and office, since no additional infrastructures are required. [3, 18]

Mode 2 charging refers to the connection of an EV to the a.c. supply network with the same voltage limits as for the Mode 1, using standard wall sockets and plugs not exceeding 32 *A* with protective earth conductors. The difference with the Mode 1 consists on the fact that the vehicle inlet and connector present a control pin. The supply network side of the cable does not require a control pin as the control function is provided by an integrated control box with the further function of in-cable protection device. This recharging mode is primarily used for dedicated private facilities.

Mode 3 charging refers to the connection of the EV to the AC supply network using an electric vehicle supply equipment (*EVSE*), not exceeding 63 *A*, where the control pilot function is extended, as for the mode 2, to a control equipment permanently connected to the AC supply. In this case, connectors with a group of control and signal pins are required for both sides of the cable. This recharging mode is typical of public charging stations and is generally supplied from three-phase AC mains at 50/60 *Hz*. It is also called 'semi-fast' charging solution since it is possible to charge a battery in few hours when the driver is at work or during every day activitiy [3,19].

Mode 4 has been implemented by the CHAdeMO consortium and is characterized by the use of off-board chargers where the control pilot function is extended also to the equipment permanently connected to the AC supply. The supply AC power is converted in the charging station to DC and the plug ensures that only a matching electric vehicle can be connected. Typical charging times of the mode 4 are in a range from 20 to 30 minutes. In this case the charging time is limited by the allowable current of 125 *A* and voltage of 500 *V* of the CHAdeMO standard connector [2]. Combining high power converters with the latest battery technologies this charging mode could allow a recharge from 0 to 80% of battery SOC in less then 5 minutes (ultra-fast charging) [11]. In Fig.2 a simplified scheme of the 4 charging modes is reported.

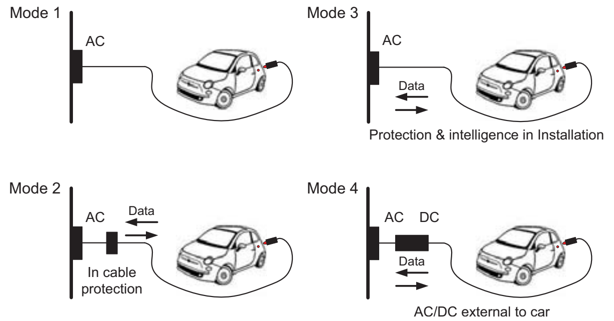

Fig. 2. IEC 61851-1 Charging Modes.

Table 1 synthesizes the main characteristics of the charging modes, according to IEC 61851-1 [19].

TABLE I. IEC 61851-1 CHARGING MODES

Charging Mode	Max Current per phase	Charging Time	Vehicle Battery Charger
Mode 1	16 *A*	4÷8 *h*	On Board
Mode 2	32 *A*	2÷4 *h*	On Board
Mode 3	63 *A*	1÷2 *h*	On Board
Mode 4	400 *A DC*	5÷30 *min*	Off Board

Actually, the market situation still presents a discrepancy with reference to the above mentioned modes since EVs manufactures usually prefer to equip their vehicles with a Mode 1 one-phase on board charger. In this case the standard 16 *A* sockets can be used, de-rated to a constant load of 10÷12 *A*, limiting the recharging power in a range from 2.3 to 2.8 *kW* [20]. Nevertheless the future market trend is to present the possibility to recharge the battery pack both in mode 1÷2 and in mode 4 by means of the installation of two different sockets on the car for the two different types of plug, as already done for the Nissan Leaf and the Mitsubishi i-Miev [21,22]. For this reason there is a growing interest in studying different charging architectures for the mode 4.

B. AC and DC Charging Architectures

Two different charging architectures are proposed with AC or DC bus [23]. Nowadays the electric energy production and transmission infrastructures are designed to work in AC and most of the electric loads, such as lights, electric motors, domestic appliances, are supplied in AC. In particular a charging AC architecture for EVs would be based on an AC bus to enable and at the same time to manage the energy sharing among battery chargers, RESs, and the electric grid. A block scheme of this architecture is proposed in Fig. 3, where the electric energy can be shared through bidirectional power converters. This architecture would be suitable to realize a smart charging scenario presenting different strategies of V2G energy management, obtained with a proper EV aggregation agent.

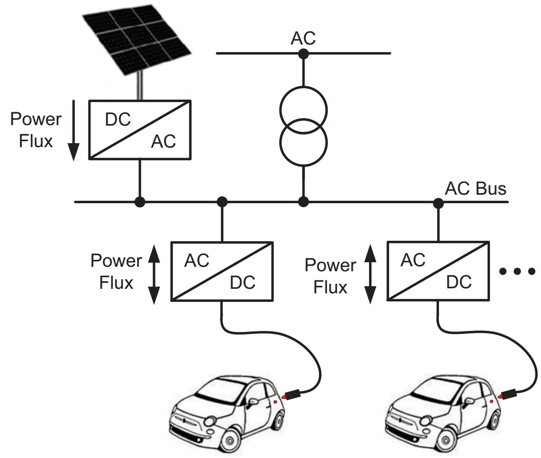

Fig. 3. EV Charging Architecture with AC Bus.

The growing interest towards distributed power plants, RESs, EVs, DC electronic equipment brings to reconsider a new energy management strategy. As matter of fact, the EV storage systems need to be recharged in DC, generally requiring the connection to the AC bus by means of low efficiency AC-DC converters. Moreover, distributed electric generation with RESs is mainly realised in DC, in this case the electric energy needs to be converted in AC, for the interconnection with either the electric grid or the AC bus, and then converted again in DC to supply the great part of the electric loads and to recharge the battery packs of EVs. These energy conversions AC-DC (in particular DC-AC-DC, in case of PV power plants) present the disadvantages of high losses. A proposed solution for these kinds of issues consists in a DC bus based architecture, which requires fewer AC-DC power conversion stages and thus reduces losses and hardware costs. As shown in Fig. 4, the proposed architecture utilizes just one high efficiency AC-DC converter, also called Grid Tie Converter, to realize a DC bus, connecting the charging EVs through bidirectional DC-DC converters instead of equivalent AC-DC converters required by the AC bus architecture, with great advantages in terms of energy efficiency and costs [23]. Moreover, the DC bus makes possible RESs generation systems to be connected directly through a simple DC-DC converter, avoiding the double conversion losses (DC-AC-DC). It was estimated that this architecture presents conversion losses reduced from about 32% to less than 10% [24].

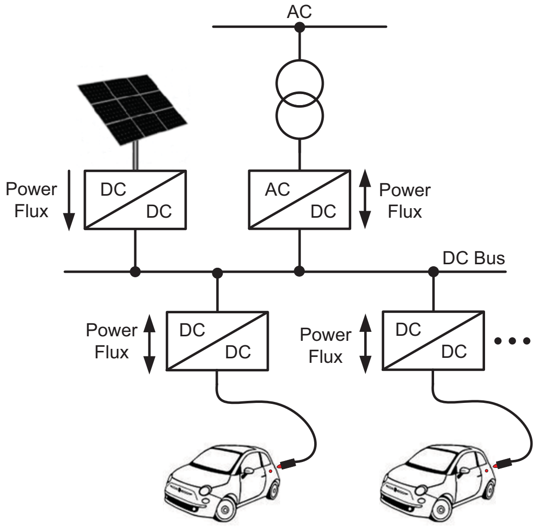

Fig. 4. EV Charging Architecture with DC Bus.

V. ULTRA FAST CHARGING ARCHITECTURE

The main objective of the ultra fast charging is the reduction of charging times up to less than 5 minutes. In order to satisfy this objective the electricity distribution system is required to supply power peaks, and therefore that system needs an over-dimensioning of cables, power transformers, devices, etc. The working conditions become more and more critical when many different vehicles are charged simultaneously. Starting from the architecture shown in Fig. 4, a first possibility of reducing the above impact of the ultra-fast charging on the grid is based on decoupling the load from the AC supply network, by means of stationary energy storage systems. In this case the energy storage system works as a power buffer interposed between the grid and the charging vehicles. This configuration could also allow reducing the sizing, of the grid tie converter, in terms of power [2,20].

As shown in Fig. 5, the charging architecture is characterized by two-stage conversion with an AC/DC and DC/DC converters [3].

The typical scheme of a buffered EV charging architecture can be seen as a three-ports DC bus architecture, connecting the main network, the electric vehicle and the energy storage buffer. The charging power coming from the grid tie converter depends on the power available from the battery buffer, and on the efficiency of the DC/DC converters.

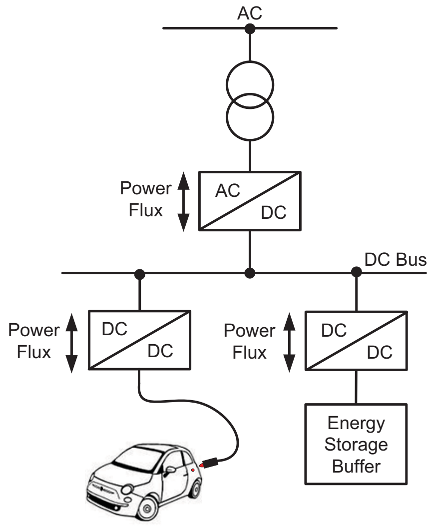

Fig. 5. EV Charging Architecture with Buffer.

Two different energy management strategies for the just described ultra fast charging architecture can be evaluated, which affect the design of the AC/DC converter and of battery buffer: load levelling and load shifting strategy. For the first case, the average charging power is supplied by the main grid whereas the power peaks are supplied by the battery buffer. For the load shifting strategy, the battery buffer stores energy during the night, when the grid overall load is minimal, and it releases energy for the EV charging during the day, when the grid is heavily loaded [20]. This way, the AC/DC converter can be downsized, taking into account that its function can be limited to the low power charging operations, during the buffering phase, and to support the discharge power from the battery buffer, during the high power charging of the vehicle.

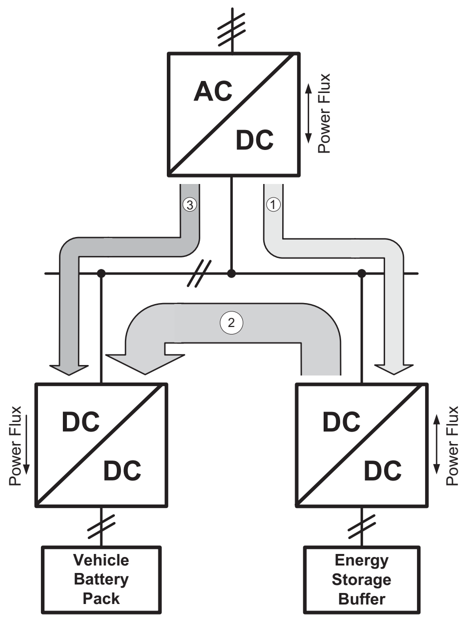

Fig. 6. Main power fluxes in buffer architecture.

The main power fluxes for the ultra fast architecture are shown in Fig.6, in particular:

- the flux (1) represents the charge at low power, when no vehicle is connected to the charging station, from the grid into the energy storage buffer to guarantee the energy availability for the following high power EV charge.
- the flux (2) and the flux (3) are involved in the high power charge for the EV, when most of the power comes from the buffer and the amount of the power supplied by the grid with the flux (3) is the same of the flux (1), based on the rated power of the AC/DC converter.

By means of the proposed architecture, an ultra-fast recharge, from 0 to 80% of SoC, was evaluated as possible in 5 minutes, for an electric vehicle with a 22 *kWh* battery pack (i.e. Mitsubishi i-Miev), using both the buffer and the grid power. In this case a recharging infrastructure, based on a 22 *kW* AC/DC converter and a 210 *kW* DC/DC high power converter, was proposed with an energy buffering time (time taken to recharge the battery buffer) of about 45 minutes for a $LiFePO_4$ stationary battery pack. This kind of battery pack was proposed as energy storage buffer to take advantage of the characteristics for these batteries to be discharged at very high rate, without a remarkable loss of actual capacity with respect to their nominal value [2]. On the other hand, the battery pack of the recharging vehicle could be conveniently chosen using the lithium-titanate technology, taking advantage of its high charging rate capability, as explained in section III.

VI. Conclusions

In this paper an overview of issues and technologies was reported related to the design of charging infrastructures for road electric vehicles. Different charging architectures were compared, showing their advantages and disadvantages in terms of interaction with the main grid, renewable energy sources and stationary and on board storage systems. In particular the DC ultra fast charging architecture appears to present interesting characteristics in terms of recharging times and high efficiency, and it is expected to have a reduced impact on the main grid, when it is part of a smart grid including stationary storage systems. In this contest the battery pack to power electric vehicles play a fundamental role to guarantee long driving range and fast recharging time. On this regards lithium titanate batteries seem to be confirmed as a promising technology for their high charging rate capability, although some issues, in terms of energy density and costs, are still related to this storage system technology.

VII. Acknowledgments

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VIII. References

[1] M. Etezadi-Amoli; K. Choma; J. Stefani, “Rapid-Charge Electric-Vehicle Station,” *IEEE Transactions On Power Delivery, vol. 25 (3), July 2010.*

[2] H. Hoimoja, A. Rufer, G. Dziechciaruk; A. Vezzini, “An Ultrafast EV Charging Station Demonstrator,” *International Symposium on Power Electronics, Electrical Drives, Automation and Motion, pp.1390-1395 June 2012*

[3] D. Aggeler; F. Canales; H. Zelaya; A. Coccia; N. Butcher; O. Apeldoorn, “Ultra-Fast DC-Charge Infrastructures for EV-Mobility and Future Smart Grids. Innovative,” *Smart Grid Technologies Conference Europe (ISGT Europe) IEEE PES, pp. 1-8, 11-13 Oct 2010.*

[4] J. A. P Lopes, F. J. Soares, P. M. R. Almeida, “Integration of Electric Vehicles in the Electric Power System,” *Proceedings of the IEEE, vol. 99 (1), pp. 168-183, Jan. 2011.*

[5] R. J. Bessa; M. A. Matos; F. J. Soares; A. P. Lopes, “Optimized Bidding of a EV Aggregation Agent in the Electricity Market,”. *IEEE Transactions On Smart Grid, vol. 3 (1), March 2012.*

[6] J. A. P. Lopes; F. J. Soares, P. M. R. Almeida, “Identifying Management Procedures to deal with connection of Electric Vehicles in the grid,” *PowerTech, IEEE Bucharest, pp. 1-8, 2009.*

[7] L. P. Fernández; T. Gómez; R. Cossent, C. Domingo; P. Frías,: “Assessment of the impact of plug-in electric vehicles on distribution networks,” *IEEE Transactions Power Syst., vol. 26 (1), pp. 206–213, Feb. 2011.*

[8] J. C. Maxwell, “A Treatise on Electricity and Magnetism,” *3rd ed., vol. 2. Oxford (U.K.) – Clarendon, 1892, pp. 68-73.*

[9] A. van Zyl, “Review of the Zebra battery system development,” *Solid State Ionics, vol. 86-88, pp. 883-889, 1996.*

[10] C.H. Dustmann, “Advances in ZEBRA batteries,” *J Power Sources, vol. 127, pp. 85-92, 2004.*

[11] S. Dhameja,” Electric Vehicle Battery Systems,” *Newnes, Boston, 2002.*

[12] J.W. Fergus,: “Recent developments in cathode materials for lithium ion batteries,” *Journal of Power Sources 195 (2010) pp. 939-954.*

[13] A.K. Padhi, K.S. Nanjundaswamy, J.B. Goodenough, “Phospho-olivines as positive-electrode materials for rechargeable lithium batteries,” *Journal of Electrochemical Society 144(4) (1997) pp. 1188-1194.*

[14] B. Scrosati, J. Garche, “Lithium batteries: status, prospects and future,” *Journal of Power Sources 195 (2010) pp.2419-2430.*

[15] M.S. Whittingham, “Electrical Energy Storage and Intercalation,” *Chemistry Whittingham, M.S., Science11 June 1976: Vol. 192. no. 4244, pp. 1126 –11272.*

[16] K. Hayashi, Y. Nemoto, J. Yamaki, “Mixed solvent electrolyte for high voltage lithium metal secondary cells,” *Electrochimica Acta, Vol.44, Issue 14, 1 March 1999, pp. 2337-2343.*

[17] J. McDowall, “Understanding Lithium-ion technology,” *Batcon Conference Proceedings 2008.*

[18] M. Yilmaz, P.T. Krein, “Review of charging power levels and infrastructure for plug-in electric and hybrid vehicles,” *Electric Vehicle Conference (IEVC), 2012 IEEE International , vol., no., pp.1-8, 4-8 March 2012.*

[19] Electric Vehicle Conductive Charging System - Part 1: General Requirements - IEC 61851-1, 2001.

[20] H. Hoimoja, A. Rufer, “Infrastructure Issues Regarding The Ultrafast Charging Of Electric Vehicles,” *International Advanced Mobility Forum, Geneva, 7-8 March 2012.*

[21] http://www.nissan.co.uk

[22] http://www.mitsubishi-cars.co.uk/imiev/

[23] B. Sanzhong, Y. Du; S. Lukic, “Optimum design of an EV/PHEV charging station with DC bus and storage system,” *Energy Conversion Congress and Exposition IEEE ECCE, Atlanta, GA, USA 12-16 Sept. 2010, pp.1178-1184, ISBN: 978-1-4244-5286-6.*

[24] P. Savage, R. Nordhaus, P. Jamieson, “DC Microgrids: Benefits and Barriers,” *Yale school of forestry & environmental studies (2010).*