Integration of road electric vehicles into the Smart Grid system

*Giampiero Brusaglino**
*ATA (Associazione Tecnica dell'Automobile),
Strada Torino 32/A, 10043 Orbassano (TO), Italy
Email: giampiero.brusaglino@ata.it

***Abstract*— The introduction in the mobility system of the externally chargeable electric and hybrid vehicles requires an appropriate specific supporting service and a dedicated infrastructure network. On the other hand they offer the opportunity of an effective integration in the smart grid system, as electric energy users featuring an on board rechargeable energy storage. The infrastructure system should be considered bi-directional in terms of recharging or receiving energy from the vehicles. An E-Mobility management provider should interface energy supply stations with the vehicle drivers through an ICT system to coordinate the charging request or the energy supply opportunity with the grid status, as power availability or demand. The energy exchange interface should be safe, interoperable and user friendly, according to the international Standards presently under definition and appropriate to the various categories of vehicles and environmental situations. The different possible solutions are discussed.**

***Index Terms* — Externally chargeable hybrid vehicles, Electric Vehicles, Smart Grid, Wireless charging**

I. INTRODUCTION

The diffusion of electric vehicles, whose technology is adequately mature, is expected to bring a positive impact on the environmental quality and on the rational use of the primary energy sources.
The externally chargeable electric vehicles require an appropriate system structure to give to needed support along their long life operation.
A basic need is a technical assistance service appropriate with the new technology of the vehicles.
To cope with this issue, the European Project TECMEHV is under development, dedicated to a professional competence formation of operators acting in the field of maintenance of electric and hybrid vehicles [1].
A direct operational need is an energy supply infrastructure, which should be adequately diffused, safe and user friendly, with interoperability feature.
The connection of the vehicles with the electrical network offers, un the other hand, the opportunity of operating an appropriate energy management in view of the optimization of the global energy use. This approach can include the double way energy exchange grid to vehicle and vehicle to grid. In this way the electric and plug-in hybrid vehicles becomes part of the smart grid.
This issue is discussed in the following sections.

II. IMPACT TO ENERGY AND MOBILITY

Fig. 1 summarizes the impact of the electric vehicles on the energy, environment and mobility systems and their contribution to their key objectives

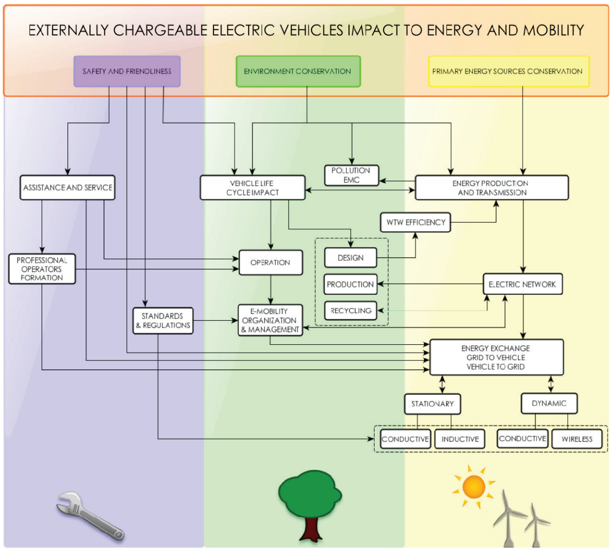


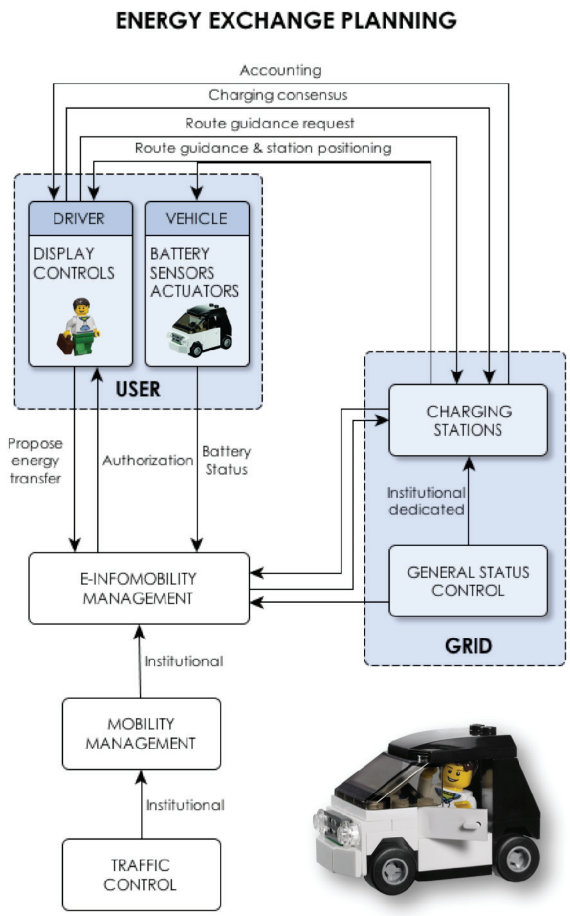
Fig. 1 Externally chargeable electric vehicles impact to energy and mobility

The first part of the field relates to the attention that the mobility system has to dedicate to the persons as its user in terms of safety, convenience and friendliness. An answer to this issue is the technical assistance that professional operators, duly trained, should give to the electric and hybrid vehicle park to assure a safe and effective operation. This assistance should also apply to infrastructure and vehicle to grid safe and user friendly interfacing.
The second part relates to the issue of the environmental protection, which is a wide boundary constraint that the mobility system should consider as a commitment for the natural resources and human health safeguarding.
This issue involves the vehicle life cycle of the vehicle, in all phases of deployment process, from the design concept, to production, up to recycling, and finally to the operation.
The third part relates specifically to the energy and its ultimate objective is the primary energy sources conservation, which is directly interacting with the environment safeguarding.
The externally chargeable electric and hybrid vehicles can have a significant role in the energy "well to wheel" energy chain, as electricity user having an board rechargeable energy storage.

III. VEHICLE – GRID INTERACTION

The infrastructure system should be considered and work as bi-directional energy exchange "grid-to vehicle" and "vehicle to grid", in order to get the maximum benefit in in the management of the global energy in terms of

availability and time opportunities, addressing the use optimization of the primary energy sources.
The electric power network should be complemented by an IC (information and communication) network vehicle-infrastructure, to supply the user with all the indications concerning the approach to charging station and implement the energy exchange.
For the near – medium term the interaction driver/vehicle - grid could be envisaged with respect to the electric vehicle charging or, more generally, energy exchange with the infrastructure in rationally organized way.
The following figure outlines the operation flow to plan and implement the energy exchange grid to vehicle and vehicle to grid



IV. AN INTERACTIVE SYSTEM USER – GRID

An Electric Infomobility Management (EIM) Center should be envisageable in connection with already existing Information and Communication system regarding the traffic control and management.
On the basis of the state of charge of the battery and in consideration of the mission plan requirement, the driver can propose to the EIM a battery charging ,or battery to grid energy restitution.
Based on grid power situation a cost based energy exchange can be planned and authorized.
The driver is advised about the nearest available charging station and a route guidance is given to approach the charging station.
An automatic vehicle positioning can be envisaged based on the technology available techniques for the opportune user friendly procedure to implement the energy exchange
The automatic vehicle guidance to the charging positioning is even more convenient in the case of wireless energy exchange.
Energy exchange procedure starts after driver consensus and relevant accounting is implemented.

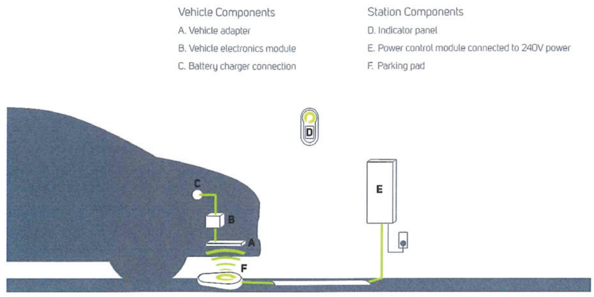


Fig. 3 Wireless energy transfer scheme.

The energy transfer by induction concept was initiated in the past and deeply studied, addressing the intention of make available a more user friendly charging procedure. Experiments were performed at the Vrije Universiteit Brussel for charging electric vehicles by making use of frontal transmitters to which the vehicles should approach (example shown in fig. 4)

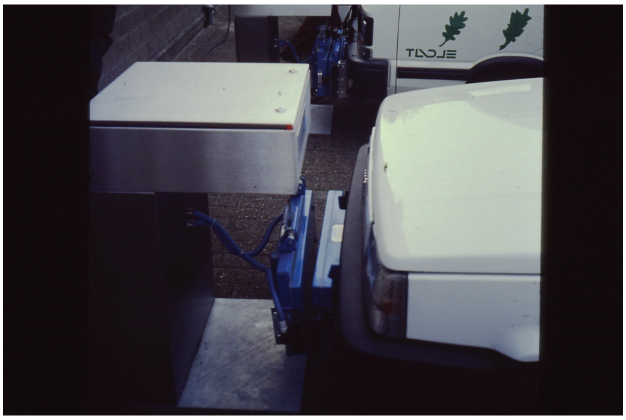


Fig. 4 Inductive charging of electric cars at the Vrije Universiteit Brussel

Experiments were performed at the VUB (Brussel) to analyse the impact of electrical and mechanical parameters of the system, as current frequency, air gap, efficiency, EMF aspects.
Experimental application and demonstration of this kind of approach were done with the system Praxitel and Tulip in France.
Inductive charging systems are presently in use, for example in the GTT electric bus in regular service in Torino, which perform battery recharge within some 10

min stop, as range extension with respect to the basic charge in the depot overnight.
More recently, a new technique of energy transfer by magnetic flux has been developed, via magnetic flux through resonant primary and secondary circuits. This technique allows the energy transfer with larger air gap and a larger flexibility for miss alignment of transmitter and receiver, while keeping a good energy efficiency and magnetic flux radiation in the normative limits.
Fig. 5 shows the coupling parts on board and on ground of a resonant circuit energy transducer system for electric car.
Charging electric vehicles basic procedure, for energy rational utilization, should be at home, overnight, at the most opportune off-peak period for the energy production, and consequently, more economic.
Also in this circumstance the user is advised about the most recommendable time slot, according to grid situation.
The described system based on recharge or energy transfer through charging stations should be considered for the range extension exigencies. For the interoperability of energy exchange situation, the vehicles should be provided by charging connection conductive and plugless.

Fig. 5 Energy transducer parts on board and on ground of a wireless charging system for an electric car.

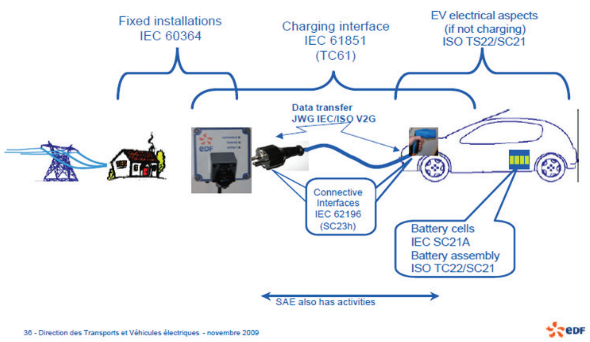


Fig. 6 Conductive charging system with related standards

V. Dynamic Charging

The wireless charging concept with resonant circuits can give more hint to the target of electrifying routes, based on inductive transfer of energy with moving vehicles.

The idea, originated in the U.S.A. in years ‘80s, by initiative of the Department of Energy and the Department of Transportation, was to address the electrification of the motorways, with electric vehicles running in platoons, capable of getting out of the electric road with their on board batteries. Researches were performed at Lawrence Livermore Laboratory in the years ‘80s and experimental application was done with an electric bus in Santa Barbara to verify the feasibility and the EMF radiation.
With the new technology, more flexible in terms for alignment and operating with higher air gap in the transducers, a larger freedom could be reached in driving and managing the vehicle.
The idea was to make available the system for all types of vehicles, including trucks and cars.

Fig.7 and 8 show the section of the inductive energy transmitter system with the road infrastructure and the pick up on board of the vehicle, with reference to Santa Barbara trial.

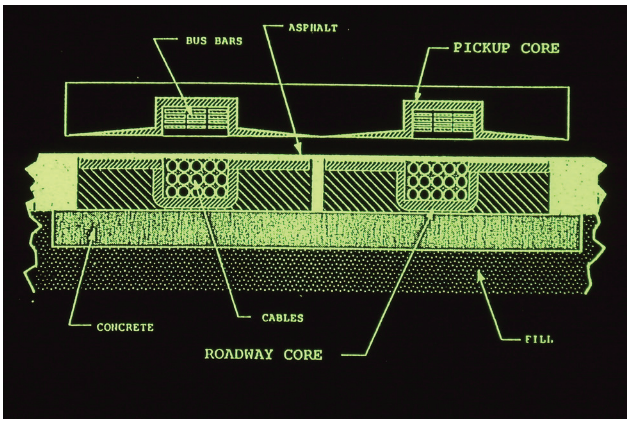


Fig. 7 Cross section of the inductive energy transmitter system for vehicle in motion

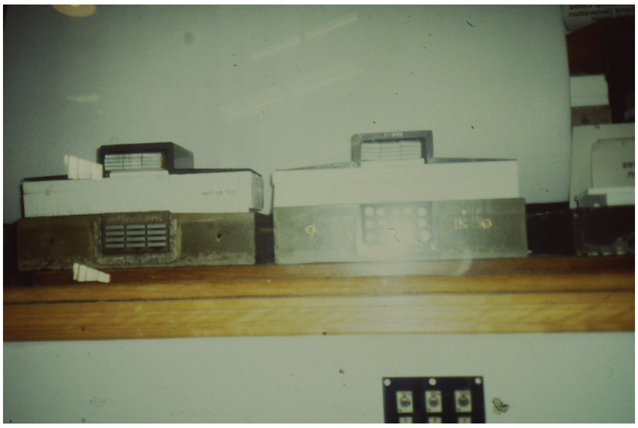


Fig. 8 Study brass board for study of wiring structure and air gap of the inductive dynamic charging system.

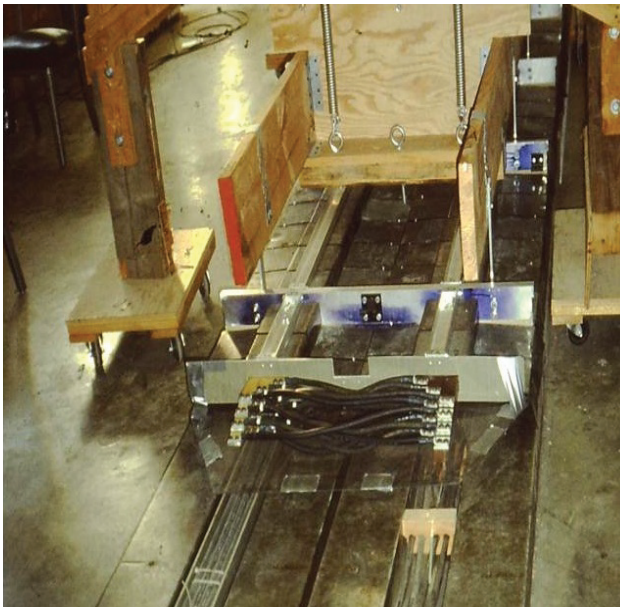


Fig. 9 Bench test for parameter analysis of dynamic inductive charging system at Lawrence Livermore Laboratory (Cal.)

Fig. 10 Electric bus for the experimental testing of dynamic charging in Santa Barbara.

Various experimental applications have been done around the world, producing a wide range of information about the parameters of the system of inductive charging static or dynamic on the operational response. and applicability.

The new technology based on resonant circuits (transmitter and receiver vibrating at the same frequency), which allows higher air gap and larger application flexibility, with good transfer efficiency, opens now the way for a wider perspective of use.
Fig. 11 shows the concept of transferring energy by activating segments of inductive infrastructure in correspondence with the transit of the vehicle.

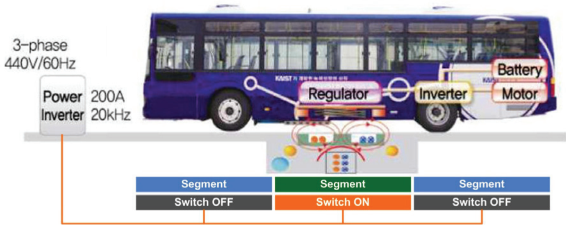


Fig. 11 Sequential activation of inductive infrastructure (source: OLEV –Online Electric Vehicle project)

The hybrid grid–battery system with dynamic on line energy charge, offers the benefit of load leveling of the electrical line. Actually, the power picks during acceleration are shaved by the contribution of the battery, which gets energy back from the recovery during braking or slopes. This is an inherent contribution to the energy saving in the grid.
The technology of the wireless charging system can offer also the possibility of considering, at the design level, the alternative of charging the battery at fixed point on the line, during vehicle stops.
The trade-off, to be considered in terms of energy and cost, is put between the two solutions:
- vehicle system with large battery pack, requiring lighter, localized infrastructure, and
- vehicle system with lower battery quantity, requiring heavier infrastructure, along the line, but allowing the load leveling of the electric supply line.
The wireless dynamic charging system can typically be used for public means of transport in line service, at least as a firs application, due to the easily identification to the infrastructure layout and the supply network configuration with respect to the service to be fulfilled by the vehicle.
However, the wireless energy supply with moving vehicles can be conceived also for smaller electric vehicles, like delivery trucks or passenger cars.
In this case the Information and Communication Technology (ICT) should be of fundamental support for the information to the driver about the location and the availability of the infrastructure to host the vehicle for a wireless charging and to synchronize the entrance of the new vehicle with the existing platoon.

In general, the battery charging from the grid at road charging points or by wireless infrastructure, can be considered as range extension means with respect to the basic and recommendable overnight charging procedure.

VI. STANDARDS SUPPORTING INTERACTION VEHICLE – INFRASTRUCTURE

Since some years Standardization Bodies have started important works to establish standards for battery charging in conductive and inductive ways, including

procedures for safe recharging, interoperability interfaces and communication vehicle – infrastructure protocols.
More recently standards are under development regarding wireless inductive charging.
A standard is under development regarding “Electric vehicle Wireless Power Transfer systems”- Part 1:general requirements (IEC 61980-1).
The same document provides a Part 2 (as a New Work Item), regarding “Specific requirements for communication between electric road vehicle and infrastructure with respect to wireless power transfer (WPT) system with an a.c. supply input voltage up to 1000 V”.
Part 3 of the same series of documents contemplates, as New Item, ”specific requirements for magnetic field power transfer”.
These documents are complementing the series of documents regarding the prescriptions for conductive charging and inductive charging already existing, or in preparation for vehicle and infrastructure.
The Standard Bodies CEN and CENELEC, responsible for the European Standards relevant respectively for vehicles and electrical systems, have received a mandate from the EU/EFTA (Mandate 246) to coordinate standards and actions, in support to Electric Authorities for the development of an infrastructural system to assure the safe charging of the electric vehicles in the EU Member States, with the interoperability of plugs and vehicles.
In 2010 an Electric Vehicles Focus Group has been established in Europe, for coordinating the implementation of the EU mandate.
The development of the infrastructures for battery charging is in progress, within the initiatives of Electric Utilities and governmental and regional Authorities.
The standards related to the various areas of the vehicle – infrastructure system are presently available or in the final phase of development.
Some of them are recalled in the fig. 12.

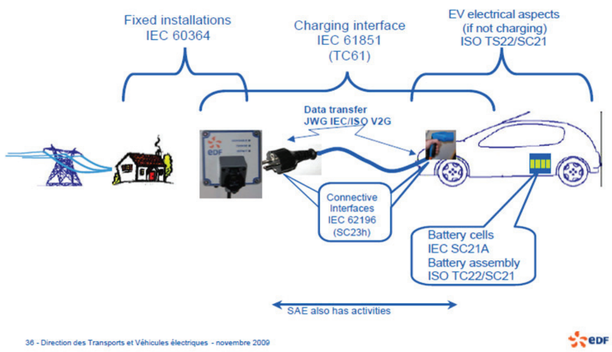
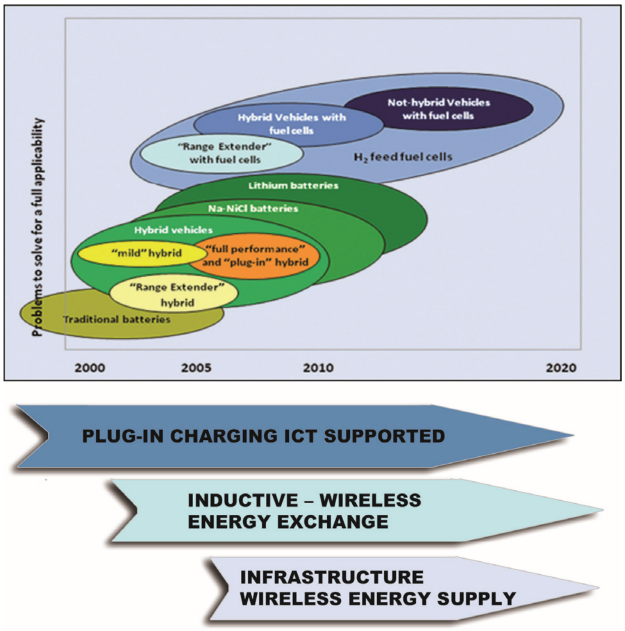


Fig.12 The vehicle – infrastructure system and relevant standards

The integrated Vehicle - Grid - Management - Communication system can be implemented according to the need and opportunity related to the diffusion of the mobility means and technologies.

In the following figure a scenario is depicted of the introduction of the various technology means in terms of time frame for the validation of the technologies, which can be further on diffused according to the market request.
The relevant infrastructure should consequently be installed as well as the management system connected with the appropriate information & communication network.



Infrastructure and supportive network

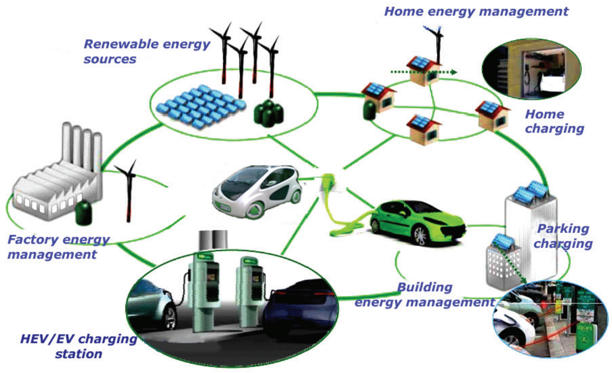
Presently the electric vehicle park, including the “plug-in” hybrid vehicles, should be ready to accept the guidance from the e-mobility management for time and location of battery recharging through the conventional communication system.
Electric vehicles with high energy storage batteries, especially requiring appropriate operating environmental conditioning (e.g. high temperature) can envisage the opportunity of energy exchange with the grid also in terms of energy supply to the grid, for those missions characterized by lower energy involvement with respect to the overnight charge.
This could be the case also for Fuel Cell vehicles in the future, in which the on board energy content, from hydrogen, can exceede the mission requirement.
The vehicle charging in static position can be profitably implemented by inductive energy transfer, for a better user friendliness, especially if supported by automatic positioning of the vehicle at the charging station.
The technical means for the information and communication already exist for general service.
What should be implemented is the dedicate application to the electric vehicle services with respect to the supportive infrastructure for energy exchange and for the technical assistance.

As far as the hardware is concerned, the development of the infrastructures for battery charging is in progress, within the initiatives of Electric Utilities and governmental and regional Authorities.
In some Italian cities, as Milano, Roma and Torino, the installation of charging facilities has been initiated, upon initiative of the electric Utilities ENEL, IREN, A2A and the Municipalities.
In the Emilia Romagna region the establishment of an infrastructure network for battery charging with a maximum 30 – 35 km distance from each other station.
Installation of charging facilities have also been done in Switzerland, by dedicated organizations as Alpiq, Protoscar and Greenmotion.
In France, in particular in Paris, Upon initiative of EDF, various recharging points have been installed at the parking lots.
In UK, charging points have been established in towns and also on motorways: a network of 15 charging points "The Electric Highway" connects London, Bristol, Exeter, Birmingham, Liverpool and the Lake District.
In USA the Car Charging Group, a provider of EV charging service, is planning to install charging facilities in several sites, as Santana Row in San Jose (Cal.) Bethesda Row in Bethesda and Town Square in Rockwille (Maryland), Pentagon Row and The Village at Shirlington in Arlington (Virginia).
Systems are presently under study to give support to the drivers for the identification of the available charging stations and for payment

VII. CONCLUSION

The electric vehicles introduction in the mobility system can offer the opportunity of operating, to an important extent, the leveling the electric load of the grid, by relying on the existence of a rechargeable energy storage on board and with the appropriate management base on the relation vehicle – grid.
The infrastructures are being diffused for plug-in static charging and appropriate relevant standards are under development.
Inductive - wireless static charging facilities can be appropriately provided according to available technologies for easier use by the customer.

Following figure depicts an envisageable scenario in which the electric vehicles are integrated in the Smart Grid System.



The electric vehicles can be a key element of the eco-sustainable energy and transport system.
The Information and Communication technology means, which are existing and in operation for regular services, should be applied to the interaction vehicle-infrastructure, for the benefit of the user, the total energy system and, as a consequence, of the environment.

The TECMEHV program includes for the online competence framework also the professional formation regarding energy management and communication car to car, car to infrastructure, navigation system as well as charging methods with reference to the vehicle on board system and at the infrastructure level.

ACKNOWLEDGMENT

Special acknowledgements are given to Roberta Reggiani and Alessia Cavallaro for the accurate refinement of this paper.

REFERENCES

[1] G. Brusaglino, G. D'Anzieri, Electric vehicles integration within the energy system, SPEEDAM 2012 International Congress IEEE Proceedings, Sorrento.