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Smart charging solutions for electric mobility

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Abstract Transport electrification is an accelerating reality which should be complemented by the respective charging technologies and services for its successful deployment. While the electric vehicle (EV) market is now fully developed, users still have concerns about key areas of the electric vehicle charging infrastructure. The transition from conventional vehicles to electric ones dictates the design and development of user-centric charging solutions aiming to facilitate the accessibility to as well as the usability of the charging network and improve the user's charging experience. This paper aims to highlight the critical issues of the electric mobility sector and analyse smart charging approaches supporting the large-scale implementation of electric cars.

Keywords: Smart Charging, Electromobility, Smart Mobility

1. Introduction

In recent years, the increased environmental concern and the strategic need for limiting the dependency of the European Union (EU) on energy imports dictate the exploitation of environmental-friendly alternatives in the transport sector which is the second largest pollutant factor following the electricity/heating sector. In this regard, the electrification of the transport sector combined with an increased renewable generation share in the energy mix poses great opportunities towards green and sustainable transportation. Currently, the sales of electric vehicles (EVs) are increasing but their drivers still have concerns about the adequacy and the accessibility to the charging network. EV users are just as satisfied with their driving experience as internal combustion engine vehicle users but the charging experience is still below user's expectations. This is one of the main barriers hindering the wide market adoption of EVs [1] and several challenges must be addressed to improve users' charging experience and support this transition. Ease of usability and accessibility to the charging network is the key challenge towards promoting e-mobility concept in urban environment. Additionally, the interfacing between the two major e-mobility actors, i.e., the Charging Point Operator (CPO) and e-Mobility Service Provider (eMSP) aiming to facilitate the deployment and realization of advanced e-mobility services towards improving user's charging experience and satisfaction poses complexity to the implementation of an interoperable e-mobility ecosystem. Another concern of users is the lack of clear information on what the payment for charging consists of [2] for different eMSP/CPOs. This differs significantly from refueling a conventional vehicle, where users are aware of exactly what they will have to pay and how much the fuel costs per liter. The lack of reliable and real-time information on the availability of the charging network is also a concern [3], as charging infrastructures are frequently blocked by parked cars, conventionally or electric ones.

The increased charging electricity needs to serve EV mobility, especially via the “plug-n-charge” approach at home and high-power charging, can lead to potential increase in the network peak demand [4],[5]. Thus, network operators must be prepared to respond promptly to this sudden increase in the energy demand, otherwise, network operational problems might arise such as congestions and voltage excursions [8]. The future electricity networks should be planned and operated not only based on the worst-case principle (i.e. networks are upgraded based on the maximum loading) but also consider the flexibility that can be provided be managing the charging process of EVs [9], [10], [11] and [12]. Long charging times are due to both the battery charging process and both for the lack of infrastructure, such as fast-charging stations. In this respect, innovative technologies and services need to be designed and developed to mitigate the negative impacts of EV deployment in the electricity grids, such as user-centric smart charging strategies and innovative micro grid system approaches for high-power charging stations [6]. Such innovative charging solutions aim to serve EV user’s charging needs and expectations and support electricity suppliers/grid operators to serve the increased energy charging needs in the most cost efficient way.

According to the estimates, in 2019 the number of electric vehicles circulating on the road, worldwide, is approximately 5.6 million units. In the coming years, this number is destined to increase, in fact, it is expected that in 2050 the number of circulating units could be equal to 1166 million [7]. Moreover, also the European regulations aims to increase the number of charging stations to be installed in the cities. The deployment of charging infrastructures is still uneven between regions and it does not correspond to the actual charging needs, making EVs unattractive to many drivers. The successful transition to transport electrification implies the development of an adequate public charging network which can be easily accessed by EV users in the most convenient way. Sometimes, the development of such a network is constrained by space limitations in urban environments. In light of this, alternative charging solutions, besides stationary charging stations, should be offered that can be easily deployed in urban cities. Depending on the area and the needs of the local users, different mixture of charging options will be preferable. Thus, there is need for tools that will enable the efficient and sustainable planning of the charging network considering diverse charging technologies, the region characteristics, local society needs and the local network capacity.

The goal of the paper is to expose the critical issues of the electric mobility sector and analyse smart charging services aimed at supporting the large-scale implementation of electric cars.

The paper is structured as follows: in this second section, the general information on electric vehicles and charging infrastructures are analysed, highlighting the advantages and disadvantages of electric mobility and the main problems of the sector. In the third section, the Smart charging concept is described as solution to improve the performance and costs of the charging operation. Furthermore, three algorithms that allow the implementation of smart charging are analysed and compared. In the fourth section introduces the eCharge4Drivers concept, a real case study for the future implementation of the smart charging solutions. Finally, the conclusions and possible future developments in the sector are reported.

2. Introduction to EV and charging technologies

Three types of EVs are available on the market: i) Hybrid vehicles, ii) Plug-in Hybrid Vehicles, iii) Battery Electric Vehicles.

The hybrid vehicles use both an internal combustion engine and an electric motor for propulsion. Hybrid vehicles use different technologies to improve efficiency and reduce emissions:

- the regenerative braking;
- an internal combustion engine to generate electricity and recharge the batteries or to power the electric motor;
- the electric motor as a propeller for most of the driving time, reserving the internal combustion engine only for when it is necessary.

Hybrid vehicles can operate autonomously without the need to recharge the battery using the electrical distribution network.

The Plug-in Hybrid Vehicles use the same technology as traditional hybrid vehicles, also implementing a high-capacity battery that can be recharged by connecting to the electricity grid, as happens for electric vehicles. There are two possible configurations for this type of vehicle:

- Series Plug-in Hybrid Vehicles or Wide Range Electric Vehicles, where only the electric motor provides traction to the wheels, while the internal combustion engine is only used to generate electricity. The vehicle uses the electricity stored in the battery until it is discharged, at which point the internal combustion engine intervenes which generates enough electricity to power the electric motor. For short-term journeys, these vehicles may not use any type of fuel, other than electricity supplied by the battery;
- Parallel or Mixed Plug-in Hybrid Vehicles, where both motors are mechanically coupled to the wheels, and both propel the vehicle under most driving conditions. The purely electric power supply usually occurs at low speeds.

Compared with battery electric vehicles, the plug-in hybrid vehicles have a longer driving range and a shorter charging time. The Battery Electric Vehicles use high-capacity rechargeable batteries (usually lithium ion) to store electrical energy and electric motors (which can be DC motors or synchronous or asynchronous AC motors) for propulsion. Recharging the battery requires connectivity between the electric vehicle and the electrical distribution network. Depending on the battery capacity, the maximum driving range is ranging from 100 to 400 km. As for the recharging times, they strictly depend on the type of battery installed on the vehicle and the type of recharge being used [9]. About the charging methods, three levels are available [13]:

- Level 1, supported on all types of electric vehicles and uses a domestic power socket connected to the distribution network as a power source. It does not require particular types of installation, but it requires long charging times.
- Level 2, makes use of special charging equipment designed to speed up charging times and therefore requires the installation of some dedicated electrical devices and circuits.

- Level 3, DC Fast Charging, further minimizes charging times, but requires systems suitable for charging management and requires the greatest number of auxiliary installations. It is also not supported by all vehicle types available on the market [14].

The following table summarizes the technical data of the various types of recharge.

Table 1. Comparison between the charging levels Errore. L'origine riferimento non è stata trovata.

	Level 1	Level 2	Fast Charging
Voltage	120 V	208 o 240 V	from 200 to 450 V
Connection type	AC	AC	DC
Nominal power	1.4 kW	7.2 kW	50 kW
Maximum power	1.9 kW	19.2 kW	>150 kW
Recharge time (up to 80% charging level for a battery of 16kWh, totally discharged)	>12 hr	>3 hr	>20 min

3. The Smart charging concept

Smart charging or intelligent charging refers to a system where an electric vehicle and a charging device share a data connection, and the charging device shares a data connection with a charging operator. Smart charging allows the charging station owner to monitor, manage, and restrict the use of their devices remotely to optimize energy consumption. There are various possible techniques for implementing intelligent charging. Currently, five methods allow for intelligent charging of electric vehicles:

- Time-of-use pricing (TOU pricing) without automated control;
- ON/OFF control;
- Unidirectional vehicle control (V1G);
- Bidirectional vehicle-network control (V2G, vehicle-to-grid);
- Dynamic pricing with automated control.

TOU pricing is the simplest smart charging technique. Based on the current state and available energy of the network, charging prices rise or fall, giving incentives to recharge vehicles at network valley hours, for example at night. The goal of TOU pricing is to avoid overloading the network during peak hours, allowing all users to have a stable and secure service. This technique does not provide direct control on the vehicle charging, so it is not necessary to integrate the vehicle into the smart grid. It informs the user of the current price of the recharging service, and he/she will decide, according to his/her needs, whether or not to recharge the electric vehicle (implicit demand response) [15].

On/off control involves the integration of the vehicle into the smart grid. The user can carry out the recharging operation at any time. On the basis of the energy demand and the number of loads connected to the network, the recharging service can be temporarily paused or stand-by (on/off) [14].

The unidirectional control (V1G) is a direct evolution of the on/off control. In this case, the charging profile can be dynamically adjusted in real time at any value between the maximum and minimum charging rate considering the network load conditions. Therefore, there is no complete shutdown of the service, but the amount of electricity supplied to the charging station and to the vehicle is limited. The bidirectional vehicle-network control (V2G) incorporates the same technologies used in the V1G approach, but it allows bidirectional power flow between the EVs and the grid (charging/discharging) [15]. Dynamic pricing with automated control optimizes the charging experience, meeting both the needs of the user and those of the smart grid. Obviously, due to the complexity of both hardware and software architectures, the capex and opex of the systems are increased [15]. To be able to implement smart charging, the integration of electric vehicles into the smart grid and a control system are required. This supervisor aims to monitor the status of the network in real time, the energy demand and the available network capacity for charging.

In [16], smart charging is implemented aiming to minimise the charging cost taking into account the temperature and "health" of the car battery during the charging operation. Especially in V2G charging with bi-directional energy flow, the battery is stressed, since it is used for non-mobility purposes, and this has significant impact on the battery ageing. In [17] an algorithm is described for the management of a recharging station for fast charging in direct current, in which photovoltaic cells are installed.

Three different approaches are discussed in the next subsections for the implementation of smart charging in a smart grid, highlighting the peculiarities and the different methodologies that have been adopted in the related literature.

3.1 Reinforcement Learning implementation

Reinforcement learning is a machine learning technique that aims to create autonomous agents able to choose actions to be taken to achieve certain objectives through interaction with the environment. The reinforcement learning is applied to solve the problem of managing the charging of electric vehicles. In [18] reinforcement learning is implemented to carry out a real-time scheduling of the charging/discharging cycles of electric vehicles. The authors try to find the optimal choices, interacting directly with the system and observing the results obtained based on the decisions of the agent. The agent can thus learn, based on the actions that have produced the best results. Once the electric vehicle is connected to the grid, the agent makes the decision to charge or discharge the vehicle based on the current state of the system. The decisions are made by the agent at hourly intervals depending on the State of Charge (SoC) of the vehicle, the current price of electricity, which depends on the amount of available energy that can be supplied from the electricity grid, and the time of arrival and departure of the car.

3.2 Model Predictive Control implementation

Model predictive control (MPC) is an advanced control technique that allows to control a system while satisfying previously imposed constraints. Predictive model controllers are based on dynamic models of a given process, usually built on the basis of empirical data and statistical methods. The main advantage of the MPC is to be able to optimize the current performance of the system, taking into account the possible future evolutions. The MPC can anticipate future system events and represents a possible approach to the problem of charging electric vehicles. In [19] the MPC is implemented to supervise a charging station integrated in a smart grid.

Users make the reservation of the charging slot via an APP, providing the minimum SoC that they want to reach and the time of arrival and departure of the vehicle. The APP shows the user the available slots that meet their requests and, based on the choice made by the user, the APP provides the aggregator with the charging schedule of the various slots. Finally, the aggregator, based on the current price of electricity, carries out the recharging operation trying to minimize costs.

[18]

3.3 Fuzzy Logic implementation

The main advantages of fuzzy logic are the flexibility to multiple fields of application, the robustness and therefore the tolerance to the uncertainty that can be present in the input values, and the simplicity of interpreting the control rules and introducing new ones. In [20] fuzzy logic is used to schedule the charging cycles of electric vehicles based on their priority. The authors of the paper propose a possible algorithm capable of allocating certain time intervals to the recharging of electric vehicles, minimizing the costs of the recharging operation and taking into account the state of the electrical network, in order to avoid possible overloads. The aggregator represents the distributed control centre responsible for the collection and processing of information both from the electricity grid and from individual charging stations. Upon arrival of an electric vehicle, the reference charging station updates the aggregator providing the time of arrival of the car, the SoC and the departure time desired by the user. The vehicle's charging priority is determined based on these factors and the time slots (15-minute intervals) dedicated to charging are allocated, taking into account the priority and general status of the network. The system inputs, represented by the SoC (%) and by the total residence time (hours, hr) pass through an interference system together with the fuzzy rules, so as to obtain the charge priority of each vehicle. The algorithm proposed in the paper reduce the high demand peaks by recharging vehicles when power consumption and energy prices are low, effectively optimizing the recharging operation and satisfying both the constraints imposed by the electricity grid and preferences. expressed by users.

3.4 Comparison between the three smart charging methods

The control techniques for charging management minimize operating costs and the constraints imposed by consumers who use the service and by the supplier of the service. Although each algorithm is characterized by different implementation criticalities, the advantages far outweigh the disadvantages.

Table 2. Comparison between the three smart charging methods

	Advantages	Disadvantages
Reinforcement Learning	• It is not necessary to define a rigorous model of the system, it is based on empirical data • Excellent flexibility and adaptability to possible variations	• The agent must be trained to optimize the recharge according to

	of the parameters taken into consideration; • Applicability to multiple operational situations.	different parameters;
Model Predictive Control	• Multiple constraints can be imposed simultaneously on the parameters of the system being analyzed; • The state of the system can be anticipated; • It allows the integration of advanced smart charging techniques.	• A rigorous description of the dynamics of the system is necessary;
Fuzzy Logic	• Excellent "robustness"; • Easy large-scale implementation; • Control laws are easy to understand, so it is easy to introduce new ones.	• Simplified description of the system under analysis; • Difficulty in integrating, simultaneously, multiple constraints on various parameters.

4. Case study: the eCharge4drivers approach

To meet the above challenges and unblock electromobility, the different smart charging techniques and services will be implemented in the eCharge4Drivers project. eCharge4Drivers project aims to improve the EV charging experience within cities and on long trips, making it comparable to the one refuelling an ICE vehicle providing enhanced information to the drivers before, during and after charging. eCharge4Drivers is co-funded by the EU under the H2020 Research and Innovation Programme (grant agreement No 875131). The project will demonstrate alternative user-centric charging options, namely an innovative mobile charging service for users in urban areas where the charging network is inadequate or not developed, charge points at lamp posts for urban areas with space limitations and battery swapping stations for LEVs aiming to reduce the capital cost of LEVs by leasing the battery from a battery network. A Location Planning Tool will be offered to investors and authorities in order to develop a public charging network in the most cost efficient and sustainable way. The project will develop and demonstrate improved easy-to-use charging stations equipped with various direct payment methods, larger displays allowing sophisticated interaction with the users, vehicle detection sensors for the parking bay, liquid cooling of cables for more comfortable handling, and more efficient grid connection. The charging stations and all actors' back-ends will support the ISO 15118 Plug & Charge feature and will enable the standardized and interoperable transfer of enhanced information (like cumulative energy transferred, price, presence of parked car and others). In parallel, eCharge4Drivers will strengthen the interconnections between actors in the ecosystem (CPOs, eMSPs and eRoaming platform). This enhanced interconnection will enable the interoperability of all services and will enable eMSPs to offer more sophisticated, and smart, user-centric services to the users before, during and after the charging process. For example, the user will know before the charging the exact location of the charging station, its technical characteristics, the estimated price, the real-time availability of the parking bay and the RES share.

The user will be able to compare offers according to his/her preferences and select/book the most convenient one. During the charging session, the user will be able to monitor in real time the cumulative energy transferred, the state of charge of the battery and the charging cost and control the charging process. After the charging process, the user will be able to either pay directly at the charging station, or if he/she has a service contract, there will be an automatic billing, i.e. the user will be able to pay ‘passively’ everywhere anytime with only one contract. The user-friendly charging systems and interoperable services of this project will be demonstrated in 10 areas, including metropolitan and nationwide ones along the TEN-T network and cross-border routes. The project concept on how convenient charging can be achieved is schematically depicted in Fig. 1.

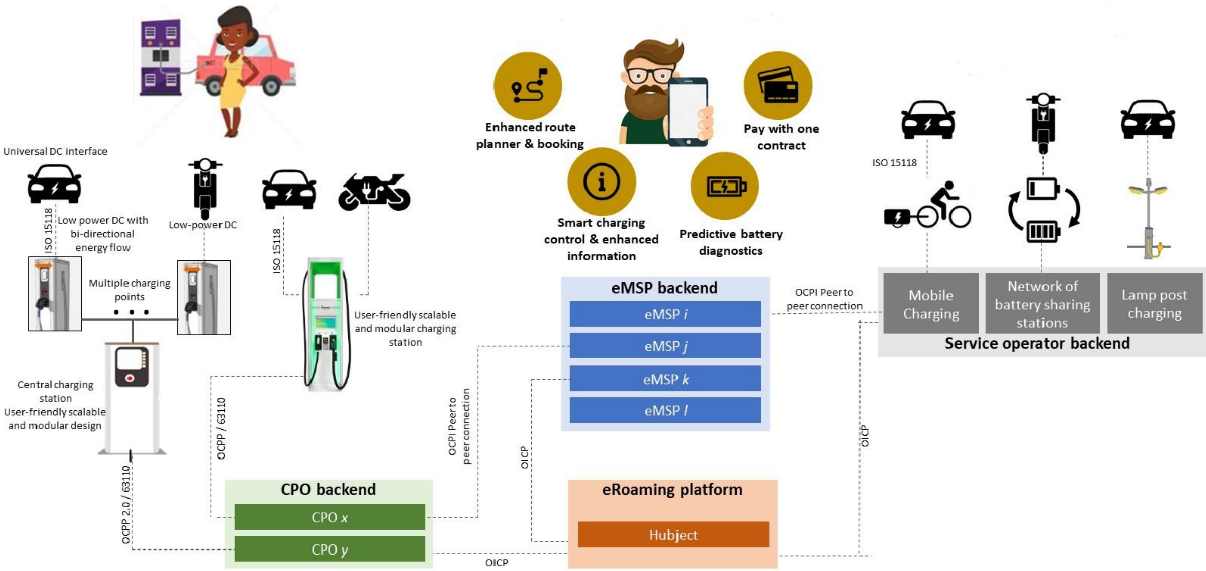

Figure 1. The eCharge4Drivers concept [18]

In order to realise the main vision of the project, the following strategic objectives are addressed:

- Develop and demonstrate user-friendly charging stations and smart charging solutions for passenger vehicles and LEVs
- Enable and demonstrate the interoperability of end-to-end communication (vehicle-to-charging station, charging station-to-back-end and back-end-to-user) by implementing the ISO 15118 Plug & Charge feature and Open Charge
- Open Charging Point Protocol (OCPP) in its charging stations and the back-offices of all in the consortium, additionally enabling the provision of enhanced information to the EV users, before, during and after a charging session
- Maximise benefits (i.e. reduce costs) for the users by designing and demonstrating innovative efficient charging stations and charging components, smart power management modules and smart charging strategies, that will additionally enable the more efficient integration of EVs in the electricity network
- Deploy and demonstrate innovative charging solutions for on-street residential charging for passenger vehicles, including a mobile charging service and charging points on lamp posts,

and standardised battery swapping stations for LEVs

- Understand the user needs so that its charging solutions and services substantially improve the user charging experience
- Accelerate the deployment of charging infrastructure and other charging services in a sustainable and user-centric way.

5. Conclusions

Electric mobility is the future of the transport sector, and in order for this to be correctly integrated in our cities, it is necessary to introduce adequate charging system. Smart grids and smart charging are only a first step towards a new future full of innovation and possibilities. Using the knowledge generated, the eCharge4Drivers project will determine the optimum mix of charging options to cover the user needs, recommendations for legal and regulatory harmonisation and guidelines for investors and authorities for the sustainability of charging infrastructure and services.

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