TRENDS ON INTEGRATING THE ELECTRIC VEHICLES IN DISTRIBUTION NETWORKS

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This paper will provide the state-of-the-art of the electric vehicle technology, the integration of electric vehicles in the distribution grids and energy storage so as to provide flexibility , accessibility, economy and security of supply in electricity networks. It is considered that, in cities, the pollution problem can be solved by replacing conventional vehicles with plug-in hybrid electric vehicles (PHEVs) and electric vehicles (EVs). Because of their increasing number and lack of infrastructure to recharge the batteries (public charging stations), charging will be accomplished, in first phase, in residential environment, which will bring additional power consumption in medium voltage and low voltage electric grids.

Keywords: Electric Vehicles, Vehicle to Grid (V2G), Charging Levels

1. Introduction

In the big cities, the transportation sector represents an important factor of pollutant emissions, that is way in recent years electric vehicles (EVs) and plug-in electric hybrid vehicles (PHEVs) market has experienced rapid growth. It is believed that replacing conventional cars with EVs and PHEVs is the solution of the problem of pollution. Other factors that have led to the development of EVs market are represented by the rapid increase in fuel prices, and increasing the share of electricity from renewable sources such as solar and wind power plants, which would translate into a lower cost (much less) for electricity used by electric vehicles [1]. Because the actual conditions are favorable for development of electric cars, more and more automobiles manufacturing companies included in their palette of products at least one EV or PHEV model. So large global organizations have focused on evaluating the number of electric vehicles on the market. One such study was conducted by International Energy Agency (IEA) in 2010 and estimates the share of EVs and PHEVs in total number of automobiles in 2050 and their evolution in the coming years (Fig. 1 and Table 1) [2].

As their number increases, energy researchers have begun to focus on the integration of these vehicles in the power system and the impact that these will have on electric grids, especially medium and low voltage networks.

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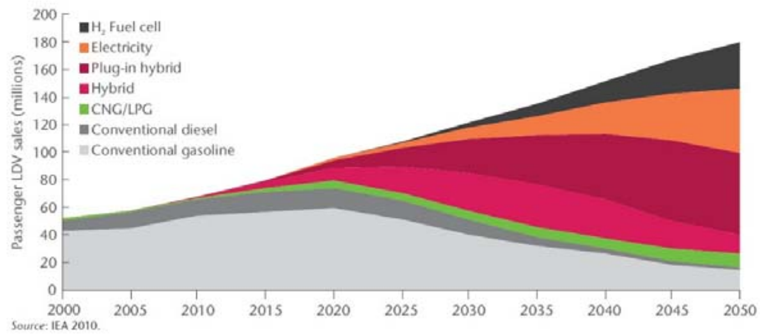

Fig. 1:Evolution of EVs and PHEVs fleet in 2050 [2]

Table 1

Global EV and PHEV sales in BLUE Map, 2010–2050 (millions per year) [2].

	2010	2015	2020	2025	2030	2035	2040	2045	2050
PHEV	0	0.7	4.9	13.1	24.6	35.6	47.7	56.3	59.7
EV	0	0.3	2.0	4.5	8.7	13.9	23.2	33.9	46.6
TOTAL	0	1.1	6.9	17.7	33.3	49.5	70.9	90.2	106.4

Impact on electric grids and studies conducted to minimize these effects is the main subject of this paper structured as follows: in section II it is presented a short description of the main components of EVs mass-produced and in section III there are presented the charging modes regulated by International Electrotechnical Comission (IEC). The fourth section describes the impact of EVs and PHEVs over the electric grids and the solutions proposed for the minimization of the effects using a Smart Management of charging electric vehicles in presence or absence of the renewable sources. The paper ends with conclusions and future work.

2. Electric Vehicles

Electric vehicles have a long history and they were very popular in the early 1900s, but then their popularity decreased due to the development of vehicles with internal combustion engines that have conquered and dominated the automobiles market until recently because of the low price of the petroleum based fuels and simple filling. But in recent years, the countries have become increasingly aware of environmental problems, especially after the Kyoto Protocol has been adopted and more and more studies estimated that petroleum reserves are getting close to being depleted so it was necessary to find alternative solutions for transportation [3]. So the attention of researchers has focused on the development of electric vehicles, which offers some important advantages: zero CO2 emissions and pollutant gases, torque and better response, low noise and lower operating costs [4]. The most important components of an EV are: the electric engine, the battery and the charger. Their selection criteria depend on a multitude of factors: maximize the performance, reliability, ease of control, recharging numbers or minimizing mass, the time required to recharge the battery and energy consumption [5].

For the election of *electric motors*, the following requirements must be taken into account: high instantaneous power and high power density, high torque at low speeds, the time needed for startup and uphill trails, wide range of speeds, including torque and constant power, quick response to commands, high efficiency regenerative braking system, high reliability for the different modes of operation, reasonable price and availability on the market and to enable use of regenerative breaking [5]. Over time there were used several types of electric motors: DC motor with series excitation, DC motor with separate excitation or asynchronous motors. But in recent years, models of mass-produced electric cars were equipped with permanent magnet motor (PM Brushless Motor), which seems to meet most of the conditions listed above, but their main disadvantage is the high price.

Another important component of an EV is its *battery* and currently, EVs evolution is dependent on the development of technologies for storage systems. An EV battery has to provide a high power during strong/ sudden acceleration, large capacity for high autonomy and long life to reduce costs and extend the longevity of the car, but they still have the disadvantage of a high price and some large sizes and weights [6]. The most promising model of battery for electric vehicles is the Li-Ion battery with the anode consisting of LiFePO4, because it has a good energy density (100 Wh / kg), it is not harmful to the environment and it has a long life duration (at least 10 years or 7,000 charge / discharge cycles). Because they have a high cost per unit of energy (500-1000 euro / kWh) [7], batteries are the most expensive part of electric vehicles, depending on their capacity that can be up to 50% of the final price of the automobile.

Not only the battery's characteristics influence the necessary time for charging, but the charger's. The main characteristics of a charger are: to be effective and reliable, provide high power density, low cost and have a reduced volume and weight. A charger must ensure the power flow between electric grid and EV battery with a minimum of distortion and can transfer full power from the charging socket [8].

3. Charging levels

Many discussions and studies regarding electric car focused on their autonomy and the time required to recharge the battery, in relation to autonomy and the easy and fast high power conventional cars. If the power of electric vehicles is synonymous with recharging the battery, during the operation it will be influenced by two major factors: the power charged (for example, voltage / current which will be charged and the number of phases - single-phase or three-phase) and the characteristics of the batteries.

IEC has developed a standard that defines four modes of charging for batteries of EVs and PHEVs (Table 2) [9].

Table 2

Charging levels defines by IEC [9].

Charging Modes	**Main connexion**	**Power**	**Current**	**Recharge range/hour[3]**	**Time**
		[KW]	**[A]**	**[km]**	
Mode 1	AC single-phase connexion	≤ 3.7 kW	10-16	< 20	6-8 hours
Mode 2	AC single-phase and three-phase connexion	3,7 – 22 kW	16-32	20-110	– 3-4 hours (single-phase) – 1-2 hours (three-phase)
Mode 3	AC three-phase connexion	> 22 kW	> 32	> 110	20-30 minutes
Mode 4	DC connexion	> 22 kW	> 32	>110	20-30 minutes

Mode 1: normal socket and connection cable (Fig. 2, a) [10]. The vehicle is connected to the grid through standard socket residential environment. To charge the battery, domestic installation must meet safety regulations, earthing system and a switch to protect the battery against overload. The plug must be fitted with a system to prevent accidental contact with live parts.

Mode 2: Power cable with integrated standard (Fig. 2, b) [10]. The car is connected via a dedicated mains socket residents. Charging is done either single-phase connection; either through phase connection and connection cable has incorporated protection. This is the main mode of charging electric cars at standard outlets, both in the residential as well as public parks, office buildings or shopping centers as integrated protection increases security presence charging. A disadvantage is the high price of the power cord. The total investment for the system load is about 500 euro [8].

Mode 3: Plug and electric vehicle charging dedicated circuit (Fig. 2, c) [10]. In this case the car is connected to the mains through an outlet and a dedicated battery charging circuit. Also, it is present in the circuit of protection and control functions. This mode is specifically charging public stations installed on public roads and ensures battery in just ten minutes. The investment cost for the charging infrastructure is about 1600 euro.

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[3] Assuming an average consumption of 20 kWh/100km

Mode 4: Fast charging station (Fig. 2, d) [10]. Electric car is connected to the main grid through an external charger. DC charging station is equipped with protection functions and control. This charging mode is not addressed to residential areas, but charging points are located near highways, high traffic roads or cities. The voltage is 480 V or higher and requires a special charger to convert AC to DC.

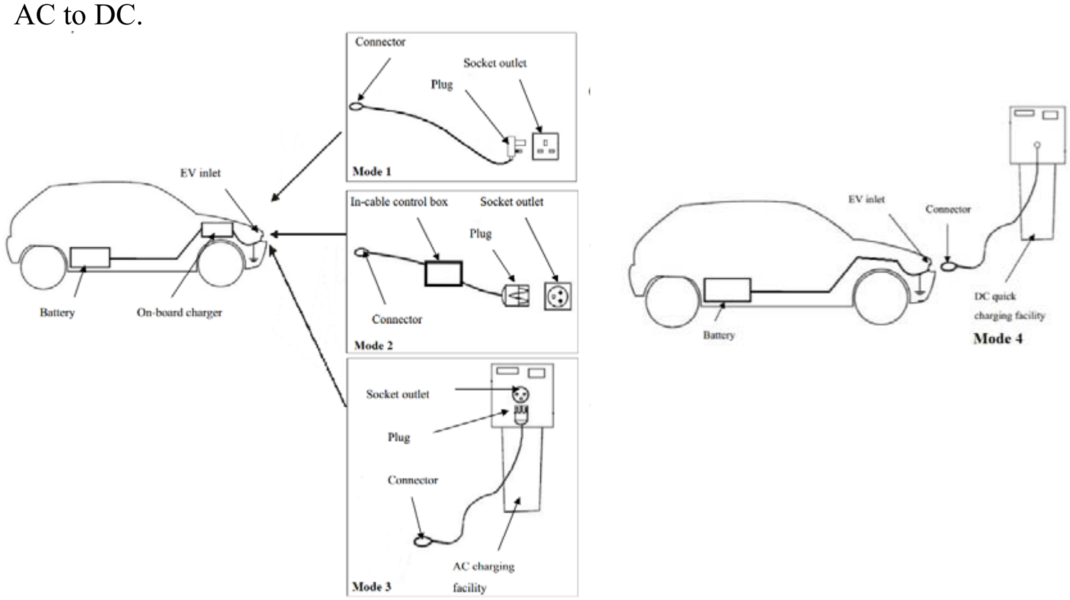


Fig. 2. Main charging connexions [10]

4. Impact of EVs and PHEVs on the electric grid

The increasing number of electric vehicles will lead to additional consumption of electricity, especially in low and medium voltage grids since, at the beginning, the batteries charging will be done in the residential area because of the lack of the necessary infrastructure for charging at public stations. So the distribution network operator will have to manage the additional consumption in order to avoid the congestions in the electric grids, which would have a negative effect on voltage control, power quality (harmonics and subharmonics), supply and demand balance, relay protection. An important issue is the unpredictable behavior of users of EVS and their desire to recharge their EV when they want (uncontrolled charging) [11].

Several studies [12], [13], [14], [15] have dealt with finding optimal solutions for unidirectional charging so that the impact on the load curve to be minimal. Another approach is based on unidirectional charging and different pricing levels depending on schedules, so it removes the prohibition to charge the car at certain times. The differential pricing will encourage charging cars in periods when demand for power is low and practice the high tariffs during peak periods so that if a user needs to charge EVs battery during peak he has this option, only that he will pay a much higher price [16]. But increasing the number of electric vehicles will have not only negative effects on the electric grids, but it will offer several advantages: the possibility of storage electricity in batteries of the EVs at the consumers, implementing the concept of Vehicle to Grid (V2G), providing ancillary services.

a. *Vehicle to Grid (V2G)* is the concept that allows to an electric vehicle to communicate with the electrical grid so that during high power demand periods, their batteries can provide the peak power and inject it in the electric grid in order to improve the sustainability and resilience of electric power infrastructure [11]. A large number of studies were conducted to evaluate the advantages of the V2G concept, but it is difficult to implement it because the sense of power flow becomes bidirectional and the actual protections of the electric grids cannot permit this. So it is necessary to make investments in new protections, smart metering devices and intelligent control systems for real-time communication, which will permit the system operator to see the charging-discharging capacity and the state of charge of the battery [17].

b. Integrating EVs in electric grids with renewable sources

A significant number of studies have been done regarding the integration of EVs in networks that produce electricity from renewable sources such as onshore and offshore wind turbines and photovoltaic plants.

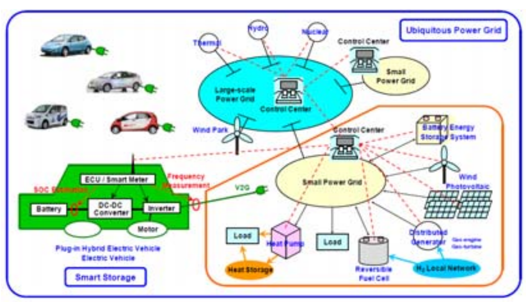
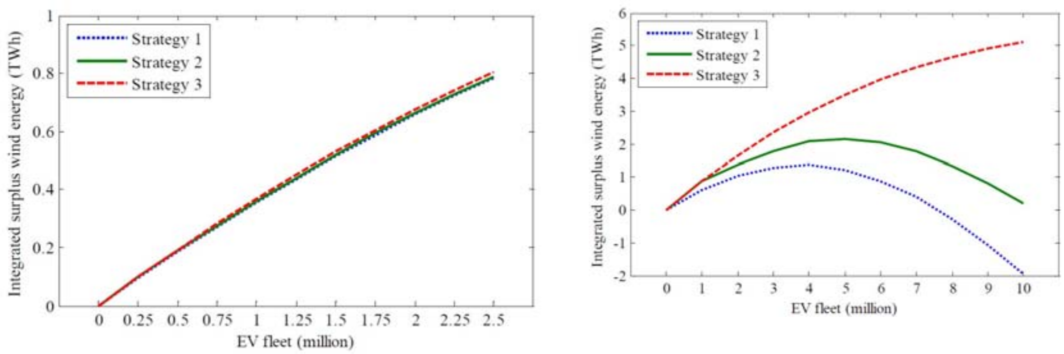


Fig. 3: Energy Management System (EMS) [19]

The most promising option is the creation of a local dispatch center to manage both the production of electricity from renewable sources and the fleet of EVs and their storage capacity at a moment (Fig. 3) [18].

One such study was conducted in Germany, where it is considered that the production of electricity from wind power will reach 74.2 TWh in 2020 and 122.8 TWh in 2030. In the study it is also considered that EVs fleet will reach 1 million cars in 2020 and 6 million cars in 2030. Given these assumptions and the electricity consumption for those periods were proposed three strategies of charging: in the first case electric vehicles are charged only during the night (interval 0:00 to 6:00), in the second case the system operator can decide that no EV is to be charged if the production of electricity from wind is decreased and the third strategy proposes (that) an optimum number of EVs to be charged so as to follow the curve of production of wind power plants. The results of this study are shown in Figs. 4 *a* and *b*.



(*a.*) (*b.*)

Fig. 4: Proposed strategies for recharging EVs [20]

As it can be seen, the differences between the three strategies appear only in case of charging a large number of electric cars, which gives the system operator a better manage of a surplus electricity that can be stored in their batteries. An important factor of this study was to avoid the occurrence of congestion on transmission lines due to overload [20].

5. Conclusions and future work

This paper shows the effects of market development of electric vehicles and problems due to their integration in medium and low voltage networks. It also presents the advantages of implementation of V2G concept and the new challenges.

Future works include development of optimal algorithms for charging the electric vehicles so as the power losses and the impact on the equipment of distribution grids to be minimized.

R E F E R E N C E S

[1]. *C. Jin, J. Tang and P. Ghosh,* "Optimizing Electric Vehicle Charging: A Customer's Perspective", IEEE Transactions on Vehicular Technology, **vol. 62**, no. 7, Sept. 2013.

[2]. "Technology Roadmap: Electric and plug-in hybrid electric vehicles", IEA, 2011.

[3]. *L. Situ*, "Electric Vehicle Development: The Past, Present & Future", 3rd International Conference on Power Electronics Systems and Applications, 2009.

[4]. *L. M. Goia, V. Vernescu* "Automobilul electric (Electric Vehicle)",Mesagerul energetic, no. 112, Feb 2011, pp.45-48.
[5]. *J. F. Ramos, F. A. Khatir,* "Electric Vehicle Based on Standard Industrial Components", Departamento de Electrónica, Universidad de Málaga, International Conference on Renewable Energies and Power Quality (ICREPQ'10), Granada (Spain), 2010.
[6]. *S. Haghbin, S. Lundmark, M. Alaküla and O Carlson*, „Grid-Connected Integrated Battery Chargers inVehicle Applications: Review and New Solution", IEEE Transactions on Industrial Electronics, **vol. 60**, No. 2, Feb. 2013.
[7]. *C. Cortes, W. Martinez, L. Munoz* , „Sizing of Ultracapacitors and Batteries for a High Performance Electric Vehicle", IEVC 2012, IEEE International Electric Vehicle Conference.
[8]. *M. Yilmaz, and P. T. Krein*, "Review of Charging Power Levels and Infrastructure for Plug-In Electric and Hybrid Vehicles", IEVC 2012, IEEE International Electric Vehicle Conference.
[9]. "European electricity industry views on charging Electric Vehicles", EURELECTRIC position paper, Apr. 2011.
[10]. http://www.emsd.gov.hk/emsd/e_download/pps/pub/Charging_Facilities_Electric_Vehicles.pdf.
[11]. *P. Minghong, L. Lian, J. Chuanwen,* "Review on the economic dispatch and risk management of the large-scale plug-in electric vehicles (PHEVs)-penetrated power systems", Renewable and Sustainable Energy Reviews 16, 2012.
[12]. *G. A. Putrus, P. Suwanapingkarl, D. Johnston, E. C. Bentley, M. Narayana*, "Impact of Electric Vehicles on Power Distribution Networks", Vehicle Power and Propulsion Conference, VPPC '09, IEEE, 2009.
[13]. *W. Jian, W. Kuihua, L. Zhizhen, W. Feng, Z. Yi,* "Impact of Plug-in Hybrid Electric Vehicles on Power Distribution Networks", Power and Energy Society General Meeting, IEEE, 2010.
[14]. *K. Clement-Nyns, E. Haesen, J. Driesen*, "The Impact of Charging Plug-In Hybrid Electric Vehicles on a Residential Distribution Grid", IEEE Transactions on Power Systems, **vol. 25**, No. 1, 2010.
[15]. *C. Farmer, P. Hines, J. Dowds, S. Blumsack*, "Modeling the Impact of Increasing PHEV Loads on the Distribution Infrastructure", Proceedings of the 43rd Hawaii International Conference on System Sciences, 2010.
[16]. *S. Deilami, A. S. Masoum, P. S. Moses, M. A. S. Masoum*, "Real-Time Coordination of Plug-In Electric Vehicle Charging in Smart Grids to Minimize Power Losses and Improve Voltage Profile", IEEE Transactions on Smart Grid, **vol. 2**, No. 3, 2011.
[17]. *W. Zhenwei, T. Liang, K. Shi and M. Baifeng*, "Electric Vehicle Charging Power Technology And Operations Management", 5th International Conference on Electricity Distribution, Shanghai, China, 5-6 Sep. 2012.
[18]. *P. Lombardi, P. Vasquez, Z.A. Styczynski*, "Plug-in Electric Vehicles as storage devices within an Autonomous Power System. Optimization issue", PowerTech, 2009 IEEE Bucharest, 28 Jun. 2009- 2 Jul. 2009.
[19]. *Y. Ota, H. Taniguchi, T. Nakajima, K. M. Liyanage and A. Yokoyama*, "An Autonomous Distributed Vehicle-to-Grid Control of Grid-connected Electric Vehicle", Fourth International Conference on Industrial and Information Systems, ICIIS 2009, Sri Lanka, 28 - 31 Dec. 2009.
[20]. *S. Mischinger, W. Hennings, K. Strunz,* "Integration of Surplus Wind Energy by Controlled Charging of Electric Vehicles", 3rd IEEE PES Innovative Smart Grid Technologies Europe (ISGT Europe), Berlin, 2012.