Electromechanical Energy Conversion Systems (EECS),
Niroo Research Institute.
Vol. 1, Issue. 2. Spring 2021

Topological and structural review of EV fast chargers

Ali Asghar Sarabadani, Reza Latifi, Alireza Rezazadeh *

Faculty of Electrical and Computer Engineering, Shahid Beheshti University, Evin, Tehran, Iran

Corresponding author, Email: a-rezazade@sbu.ac.ir

Abstract

The increasing growth of the technology and industry of electric propulsion, and consequently the growth of the industry of electric energy storage systems, including batteries, have raised challenges such as optimizing the charging process and storage of electric energy. One of the important factors in optimizing the charging process is reducing the time interval. Hence, today, topologies such as fast charging and stations equipped with this topologies are expanding. Quick charging topologies reduce the length of the charging process by optimizing the electric charge circuit and optimizing the design of switching elements and its control system. This paper first examines the electric vehicle charging system in terms of the standards that classify the input voltage level as well as the technologies that increase the flexibility and efficiency of the electric vehicle charging system. Technologies such as unidirectional and bi-directional charging system, inductive and conductive charging system, integrated and non-integrated systems are presented and discussed in this article. In the second step, these systems are transformed into switching components and features such as the possibility of development with renewable energy production systems, the possibility of injecting power from the electric vehicle energy storage system into the power grid to provide part of the power required at peak demand and also The complexity and multiplicity of key elements have been examined and compared.

Keywords: Fast Charge, Storage Systems, Charging Process, Fast Charge Stations**.**

1. Introduction

Contrary to popular belief, electric vehicles are not a new and emerging technology. This technology was introduced and produced in the 19th century, but soon replaced with internal combustion engines. One of the underlying causes was the greater amount of energy stored in domestic combustion vehicles, and the other was the high cost of purchasing electric vehicles [1]. Today, the reason for the return of the electric vehicle debate and the growth of this industry is because issues such as greenhouse gas emissions, increasing environmental pollution and reducing reserves fossil fuel have been seriously discussed in worldwide scale [2]. On the other hand, electric vehicles have valuable advantages, one of these advantages is the high efficiency of electric vehicles compared to internal combustion vehicles. The second advantage is the lower number of mechanical parts and, consequently, the lower complexity of the electric vehicle system, which reduces the cost of vehicle maintenance and boost up the speed of assembly and production. And as third advantage, replacing internal combustion vehicles with electric vehicle can reduce environmental pollution in downtowns [3], [4]. However, there are currently problems and limitations for people using electric vehicles, such as long charging time and the poor infrastructure required to provide the charging process [5]. Another major issue with electric vehicles and their charging stations is the negative effects of the charging process on the power grid. Even if the charging station is not equipped with a fast charging process, if the number of vehicles connected to the charging station were high, these effects will be negligible. These negative effects include overload, voltage swing and overvoltage deviation [6], [7]. The following Items are some of expected capabilities features of electric vehicle charging stations to reduce the negative effects and increase the efficiency of the charging stations:

a. The use of renewable energy generation systems to produce part of the station required power or offset part of the power required at peak times.

b. Using energy storage systems such as the battery bank, to store energy and use it at peak demand times.

c. Use systems to inject reactive power into the grid where necessary to prevent power grid voltage drop and voltage swing [3].

Figure 1 shows overview scheme of micro grid and connections between different power generators such as wind power generator and photovoltaic panels, and fast charge stations as load and interconnection with main power grid.

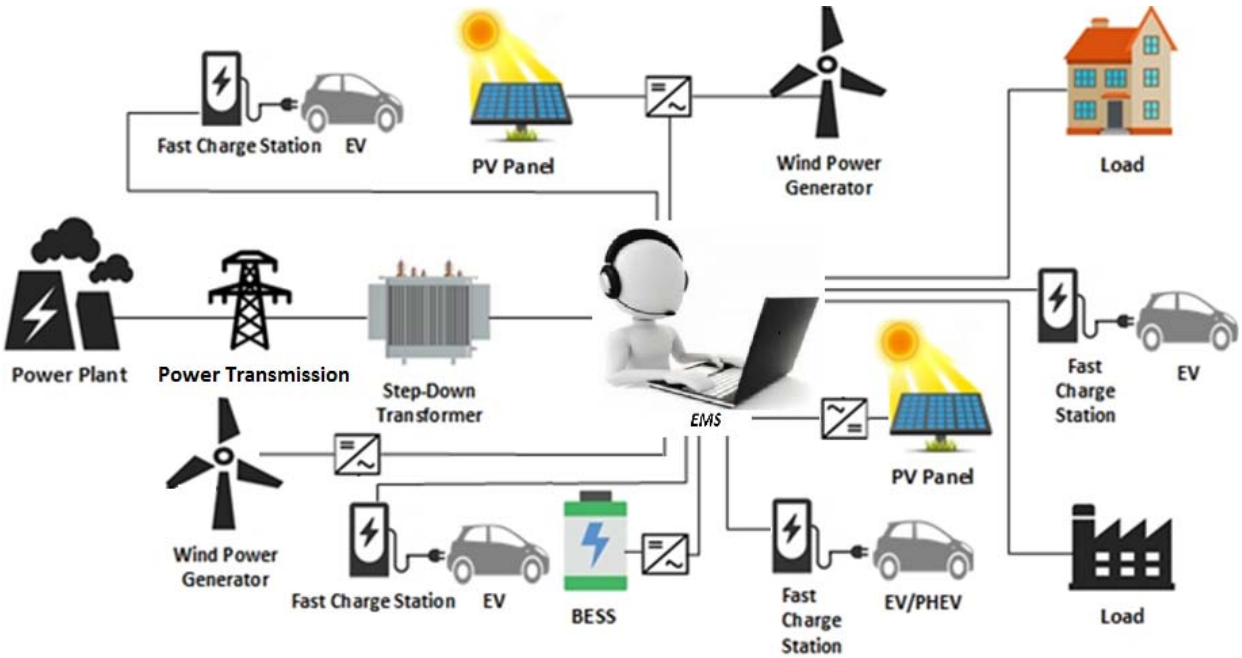

Fig.1 Micro grid equipped to fast charge stations.

2. Electric Vehicle Charging System

The electric vehicle charging system consists of components that initially filter the input power through elements such as inductors and capacitors and resistors from voltage and current harmonics. Secondly, if needed, the form switches the input electricity from alternating to direct. In the third stage, the voltage and current level is converted to the required level by another converter and eventually enters the electrical energy storage system by special contactors. Therefore, the technology of electric vehicle charging systems can be examined in several ways.

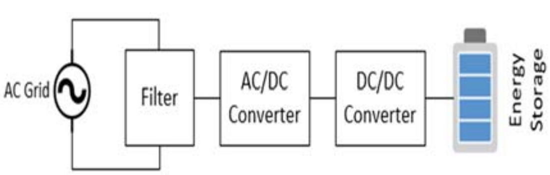

Fig.2 EV charging system diagram.

2.1. Power direction

Today's electric vehicles charging system is designed and manufactured from the perspective of power flow in two ways. The first is known as the "Unidirectional" charging system, is a system which electrical power flows only in one direction, from power grid to the energy storage system. The second charging system, called "Bidirectional" charging system, in addition to being able to flow power from the grid to the energy storage system, it can also act in the opposite direction and inject electricity into the power grid from electric vehicle's energy storage system. Generally the purpose of this system is to provide part of the power demand during peak power consumption which is called V2G or "Vehicle to Grid" system [8].

2.2. on-board & off-board systems

In "on-board" systems, all equipment, including high power converters, rectifiers and filters, is fitted to the vehicle and it does not require a special stand to charge the vehicle. The main advantage of this system is that it does not require charging station, but on the other hand it has some disadvantages such as weight gain, increase vehicle volume, increase vehicle prices and limit the power level of the vehicle charger system. In "off-board" systems, all major equipment is designed and operated outside the vehicle as a charger station and panel. The main advantage of this type of system is the lack of power level limitation and the possibility of utilizing fast charging systems as well as reducing the weight, volume and cost of the vehicle [9].

2.3. Integrated systems

In integrated charging systems, the charger plug connects directly to the electric vehicle's traction motor and uses the traction motor as an input current filter, the rotor and stator as an insulator transformer, and the traction inverter as a switch converter. The main advantage of this system is to reduce costs and the complexity of the charging circuit [10], [11].

2.4. Induction and non-induction systems

The inductive charging systems are designed like a transformer, with the primary side outside the vehicle and the secondary side inside the vehicle. Magnetic induction and charging are then performed by placing the specified part of the vehicle in position. One of the advantages of this system is the need for no contactor for charging, but the low efficiency and high losses of this charging system is one of its disadvantages [12]. In non-inductive systems, the input terminal of the charging converter is connected directly to the network by conductors and contactors.

2.5. Charger voltage levels

International Electrical Research Institute “EPRI” and Society of Automotive Engineers “SAE” have set standards for voltage levels for electric vehicle charging systems. These standards are Level 1 AC, Level 2 AC and Level 3 "Fast Charging" [13]. It should be noted that, in the new standards, its fast charging system is classified into two levels of level 1 and level 2 direct current charging [14]. In the Level 1 AC standard, the used voltage is 120V single phase with a current of about 15 to 20A. In this standard, the transmission power is about 1.4 to 1.9 kW [15]. The time required to fully charge an electric vehicle using this type of charger is approximately 8 to 16 hours depending on the size and type of battery and is generally used in the parking of homes and residential complexes for overnight charging.

The AC level 2 standard is used in both personal and public station. The voltage level of this standard for personal station is single-phase 240V with current of 40A and for generic stations is 400V three-phase current with 80A current [13]. The system is capable of delivering power of 7.7 to 25.6 kW and takes about 4-8 hours to fully charge the vehicle.

Level 3 standards have been introduced for use in public places. In this standard, the voltage level is about 208 to 600 volts with current up to 200 amps. Charging time for up to 80% of battery storage capacity with this standard is about 10 to 15 minutes. The reason for studying this system in the range of 0 to 80% is the long charging process time in the remaining 20% [16], [17].

Table 1. Voltage and power levels and charging time of different electric vehicle charger standards

Level	*Voltage & Current*	*Phase*	*Charging Duration*	*Power*	*Station Type*
Level 1 - AC	120V-15A 120V-20A	Single Phase	10-13 hr	1.44-1.92 kW	Home panel
Level 2 - AC	240V-40A 400V-80A	Single Phase / 3Phase	1-3 hr	7.7-25.6	Home panel / Public
Level 1 -DC	208V-80A 600V-80A	3Phase	0.5-1.44 hr	13.3-38.4	Public Station
Level 2 - DC	208V-200A 600V-200A	3Phase	0.2-0.58 hr	33.3-96	Public Station

3. Charging station topologies

The collection of electric vehicle charging stations can be classified into several categories from the basic elements used in them.

3.1. stations with AC / DC / DC back-to-back converter

At these stations, an AC to DC converter is supplied directly from a distribution transformer and also connected to a harmonic filter.
Next, DC to DC converters are used to supply different voltage levels and also to stabilize the voltage. The existence of a direct power feeder gives the whole system flexibility and can be used to expand station with energy storage systems such as battery banks or renewable energy systems such as solar panels. On the other hand, using this feeder and two-way converters, the energy available in the electric vehicle storage system can be used to inject power into the grid during peak load [3].

3.2. stations with multi-input slots with common AC feeder

At these stations, each of the electric vehicle chargers is fed from a low voltage power grid by a low frequency transformer used as an isolator. A three-phase AC power converter converts 50 Hz to medium-voltage direct current, then converts it to a second high-frequency "25kHz" alternator, and finally high-frequency AC power converts to direct current.

3.3. Transformer less charging stations

This topology has been proposed to increase the power density at charging stations by eliminating the low frequency transformer. However, for this model of stations, there are two solutions. The first solution is to use a low voltage grid to feed the stand and the other is to use a medium voltage grid and increase the flow range at the charging station. The disadvantage of the first solution is to significantly increase the ohmic losses due to the high amplitude of the current [3]. Table 2 shows the above stations systems and different converter topologies which used in these stations more accurately.

Table 2. Different converter topologies

Topology	*Reference*	*Expandable with energy storage system*	*Bidirectional*	*Expandable with renewable energy systems*	*Topology complexity and multiplicity of components*
Bidirectional AC / DC / DC converter	[18] – [19] – [20] – [21] – [22] – [23]	✓	✓	✓	Low
Unidirectional AC / DC / DC back-to-back converter	[24] – [25]	✓	×	×	Low
Multi-input converter with common AC feeder	[26]	×	✓	×	Low
Transformer-free converter with direct current feeder	[27] – [28] – [29]– [30]	✓	✓	✓	High
Transformer-free converter without direct current feeder	[31] – [32]	✓	✓	✓	High

Continue of table 2. Different converter topologies

Topology	***Reference***	***Expandable with energy storage system***	***Bidirectional***	***Expandable with renewable energy systems***	***Topology complexity and multiplicity of components***
Matrix converter	[33]	✓	✓	✓	High
Unidirectional Boost converter	[34]	✓	×	✓	Low
Vienna rectifier converter	[35]	✓	✓	✓	Low
Buck/Boost Converter with reduced switch	[36]	✓	✓	✓	Low
Traction motor based converter with 9-pulse inverter	[37]	✓	×	✓	Low
PFC-based integrated converter	[38]	✓	✓	✓	High
Parallel dual inverter based converter with traction motor	[39]	✓	×	✓	High
Dual Inverter-based Backward Converter	[40]	✓	✓	✓	High
SCR based full bridge controlled rectifier	[41]	✓	×	✓	High
Twelve pulse diode bridge rectifier followed by full bridge DC – DC converter	[42]	✓	✓	✓	High
Twelve pulse diode bridge rectifier followed by midpoint clamped three level buck converter	[43]	✓	✓	✓	High

4. The effects of charging stations on the power grid

EV charging stations for electric vehicles have negative effects on the power grid because of the high power consumption and the high number of electronic power elements. These effects include unstable network voltage, overload, low power quality “increasing harmonics, etc.” Charging stations for electric vehicles have negative effects on the power grid because of the high power consumption and the high number of electronic power elements. These effects include unstable network voltage, overload, low power “harmonic input to the network, etc.” One of the main reasons for the unstable voltage as well as overload in the power grid is the large-scale power demand coming into the grid by electric vehicle charging stations, especially in times of increasing number of connected vehicles, which can eventually lead to blackout and negatively affect the reliability of the power grid.

One of the main reasons for the decline in power grid quality is the presence of switching elements in electric vehicle charging stations. Switching elements cause harmonics to be injected into the grid. Harmonic injection into the grid increases the THD of the grid calculated by the following formula, and ultimately reduces grid power quality [44].

$$THD_V = \frac{\sqrt{\sum_h^H V_h^2}}{V} \quad (1)$$

$$THD_I = \frac{\sqrt{\sum_h^H I_h^2}}{I} \quad (2)$$

Table 3 shows the negative impacts of electric vehicle charging stations on the power grid and solutions to reduce the negative impacts [17].

Table 3. Negative impacts of electric vehicle charging stations on the power grid and solutions

negative impact	***Reference***	***proposed solution***
power quality	[45] – [46] – [47] – [48]	*Install harmonic filter *Install smart filter bank *Apply smart grid with load management strategies
Increased network power losses	[49] – [50] – [51] – [52]	* Distributed charging uniformly * Apply coordinated charging strategies
Increasing power demand at peak power consumption	[53] – [54]	* Using smart charging systems * Using controlled charging strategies
Voltage Swing	[55] – [56]	* Apply voltage control methods * Coordinate voltage using auto tap-changer transformers
Transformers Overload	[57]	*Using smart charge management techniques

5. Conclusion

This paper introduces the electric vehicle charging systems in terms of voltage level, unidirectional and bi-directional power flow, on-board and off-board systems, integrated or non-integrated, inductive or non-inductive charging systems. According to the standards of the International Electrical Research Institute, charging level is divided into three levels: level 1 AC, level 2 AC and level 3 DC. Level 1 standard is suitable for home panels for electric car charging at night and level two and three standards for commercial complex charging stations as well as dedicated electric car charging stations. Bi-directional charging technology has been introduced for injecting power from the electric car storage system into the power grid to compensate part of the grid's power demand, but the disadvantages of this technology include reducing the life of the electric car energy storage system and increasing the complexity of the charging system. In integrated systems, all major components of the car charging system are incorporated inside of vehicle and eliminates the need for a dedicated electric car charging station, but increase weight, volume, cost, and limits the amount of power input to the car's energy storage system. In integrated systems, the winding of the vehicle's traction motor plus the electric motor drive is considered as a filter and switch of the charging system and the charge is passed through these components. Including the benefits of this technology to reduce the number of components in the charging system and consequently it reduces system complexity and reduces costs. In inductive charging systems, the input portion of the converter is designed as a transformer and the primary and secondary components are designed outside and inside the vehicle respectively and by placing the vehicle in a designated location at the charging station, the electrical induction causes the current to flow into the vehicle's charging system. At the end of this article, we introduce the important and practical topologies of the electric vehicle charging system in terms of capability to develop and expand with renewable energy systems, capability to develop with energy storage systems such as battery banks, unidirectional power flow or bidirectional and finally comparing the complexity and multiplicity of components are studied and compared and finally the negative effects of these chargers and stations are investigated.

6. Reference

[1] Rajashekara K. (1994) “History of electric vehicles in general motors.” IEEE Trans Ind Appl; 30(4):p897–904.

[2] Jia YingYong, Vigna K.Ramachandaramurthy, Kang MiaoTan etal. (2015). “Bi-directional electric vehicle fast charging station with novel reactive power compensation for voltage regulation.” Elsevier-International Journal of Electrical Power & Energy Systems Volume 64, January 2015, P 300-310

[3] Mohsen Ahmadi, N. Mithulananthan and Rahul Sharma. (2016). “A Review on Topologies for Fast Charging Stations for Electric Vehicles” .IEEE International Conference on Power System Technology (POWERCON): 10.1109/ POWERCON. 2016.7753886

[4] Sovacool, Benjamin K. (2010). “A transition to plug-in hybrid electric vehicles (PHEVs): why public health professionals must care.” Journal of epidemiology and community health 64.3: p185-187.

[5] M. Nicholas, G. Tal, and J. Woodjack. (2013). “California statewide charging survey: What drivers want?” 92nd Annual Meeting of the Transportation Research Board, January, 2013.

[6] C. H. Dharmakeerthi, N. Mithulananthan, and T. K. Saha. (2011). “Overview of the impacts of plug-in electric vehicles on the power grid.” in Innovative Smart Grid Technologies Asia (ISGT), 2011 IEEE PES, 2011, pp. 1-8.

[7] R. C. Green, W. Lingfeng, and M. Alam. (2010). “The impact of plug-in hybrid electric vehicles on distribution networks: a review and outlook” in Power and Energy Society General Meeting, 2010 IEEE, 2010, pp. 1-8.

[8] Murat Yilmaz and Philip T. Krein, Fellow. “Review of Battery Charger Topologies, Charging Power Levels, and Infrastructure for Plug-In Electric and Hybrid Vehicles.” IEEE Transactions on Power Electronics: Volume: 28, Issue: 5, May 2013 .doi: 10.1109/TPEL.2012.2212917

[9] L. Solero. (2001). “Nonconventional on-board charger for electric vehicle propulsion batteries.” IEEE Trans. Veh. Technol., vol. 50, no. 1, pp. 144–149, Jan. 2001.

[10] S. Lacroix, E. Laboure, and M. Hilairet. (2010). “An integrated fast battery charger for electric vehicle.” in Proc. IEEE Veh. Power Propulsion Conf., Sep. 2010, pp. 1–6.

[11] L. De-Sousa and B. Bouchez. (2010). “Combined electric device for powering and charging.” Int. Patent WO 2010/057892 A1, 2010.

[12] Nguyen TD, LiS, LiW, MiCC. (2014). “Feasibility study on bipolar pads for efficient wireless power chargers.” In:Proceeding soft hetwenty-ninthannual IEEE applied power electronic

conference and exposition (APEC);2014.p.1676-1682.

[13] “EV charging infrastructure deployment guidelines” BC. Electric Transportation Engineering Corporation; 2009.p.1–51.

[14] “Installation guide for electric vehicle supply equipment.” Massachusetts Di-vision of Energy Resources; 2014.p.1–26.

[15] SAE Electric Vehicle and Plug-in Hybrid Electric Vehicle Conductive Charge Coupler, SAE Standard J1772, Jan. 2010.

[16] Braunl T.EV Charging Standards 2012: p 1–5.

[17] Hussain Shareef a,n, Md.MainulIslam b, AzahMohamed b.(2016). “A review of the stage-of-the-art charging technologies, placement methodologies, and impacts of electric vehicles.” Elsevier, Renewable and Sustainable Energy Reviews64 (2016)403–420.

[18] Arancibia, Arnaldo, and Kai Strunz. (2012). “Modeling of an electric vehicle charging station for fast DC charging.” Electric Vehicle Conference (IEVC), 2012 IEEE International. IEEE, 2012.

[19] Reed, Gregory F., et al. (2012). “Advancements in medium voltage DC architecture development with applications for powering electric vehicle charging stations.” Energytech, 2012 IEEE. IEEE, 2012.

[20] S. Rivera, B. Wu, S. Kouro, V. Yaramasu and J. Wang. (2015). “Electric Vehicle Charging Station Using a Neutral Point Clamped Converter With Bipolar DC Bus.” in IEEE Transactions on Industrial Electronics, vol. 62, no. 4, pp.19992009, April 2015.

[21] Aggeler, Daniel. (2010). “Ultra-fast DC-charge infrastructures for Evmobility and future smart grids.” Innovative Smart Grid Technologies Conference Europe (ISGT Europe), 2010 IEEE PES. IEEE, 2010.

[22] J. Y. Yong, V. K. Ramachandaramurthy, K. M. Tan, and N. Mithulananthan. (2015). “Bi-directional electric vehicle fast charging station with novel reactive power compensation for voltage regulation.” International Journal of Electrical Power & Energy Systems, vol. 64, pp.300- 310, III 2015.

[23] M. Ahmadi, N. Mithulananthan and R. Sharma. (2015). “Dynamic load control at a bidirectional DC fast charging station for PEVs in weak AC grids.” Power and Energy Engineering Conference (APPEEC), 2015 IEEE PES Asia-Pacific, Brisbane, QLD, 2015, pp. 1-5.

[24] S. Bai, Y. Du and S. Lukic. (2010). “Optimum Design of an EV/PHEV Charging Station with DC Bus and Storage System.” in proc. of IEEE Energy Conversion Congress and Exposition (ECCE), Sept. 12-16, 2010, pp. 1178-1184.

[25] Bai, Sanzhong, and Srdjan M. Lukic. (2013). “Unified active filter and energy storage system for an MW electric vehicle charging station.” Power Electronics, IEEE Transactions on 28.12 (2013): 5793-5803.

[26] Joy, T. P., Kannan Thirugnanam, and Pranaw Kumar. (2013). “A multi-point Bidirectional Contactless Charging System in a charging station suitable for EVs and PHEVs applications.” India Conference (INDICON), 2013 Annual IEEE. IEEE, 2013.

[27] Wang, Shuo, Russell Crosier, and Yongbin Chu. (2012). “Investigating the power architectures and circuit topologies for megawatt superfast electric vehicle charging stations with enhanced grid support functionality.” Electric Vehicle Conference (IEVC), 2012 IEEE International. IEEE, 2012.

[28] Crosier, Russell, Shuo Wang, and Mohamed Jamshidi. (2012). “A 4800-V gridconnected electric vehicle charging station that provides STACOM-APF functions with a bi-directional, multi-level, cascaded converter.” Applied Power Electronics Conference and Exposition (APEC), 2012 Twenty-Seventh Annual IEEE. IEEE, 2012.

[29] 2012-Crosier- Crosier, Russell, Shuo Wang, and Yongbin Chu. (2012). “Modeling of a grid-connected, multifunctional electric vehicle charging station in active filter mode with DQ theory.” Energy Conversion Congress and Exposition (ECCE), 2012 IEEE. IEEE, 2012.

[30] Crosier, Russell, and Shuo Wang. (2013). “DQ-frame modeling of an active power filter integrated with a grid-connected, multifunctional electric vehicle charging station.” Power Electronics, IEEE Transactions on28.12 (2013): 5702-5716.

[31] Vasiladiotis, Michail, Alfred Rufer, and Antoine Béguin. (2012). “Modular converter architecture for

medium voltage ultra-fast EV charging stations: Global system considerations." Electric Vehicle Conference (IEVC), 2012 IEEE International. IEEE, 2012.

[32] Vasiladiotis, Michail, and Alfred Rufer. (2015). "A Modular Multiport Power Electronic Transformer with Integrated Split Battery Energy Storage for Versatile Ultrafast EV Charging Stations." Industrial Electronics, IEEE Transactions on 62.5 (2015): 3213-3222.

[33] Waltrich, Gierri, Jorge Duarte, and Marcel AM Hendrix. (2012). "Multiport converter for fast charging of electrical vehicle battery." Industry Applications, IEEE Transactions on 48.6 (2012): 2129-2139.

[34] B. Singh, B. N. Singh, A. Chandra, K. Al-Haddad, A. Pandey, and D. P. Kothari. (2004). "A review of three-phase improved power quality ac–dc converters." IEEE Trans. on Industrial Electronics., vol. 51, no.3, pp. 641-660, June2004.

[35] B. Kedjar, H. Y. Kanaan, and K. Al-Haddad. (2014). "Vienna Rectifier with Power Quality Added Function." IEEE Trans. on Industrial Electronics, vol. 61, no. 8, pp. 3847-3856, Aug.2014.

[36] D. S. Wijeratne and G. Moschopoulos. (2014). "A Novel Three-Phase Buck-Boost AC-DC Converter." IEEE Trans. on Power Electronics, vol.29, no. 3, pp. 1331-1343, March 2014.

[37] I. Subotic, E. Levi,M. Jones, andD.Graovac. (2013). "On-board integrated battery chargers for electric vehicles using nine-phase machines." in Proc. Int. Elect. Mach. Drives Conf., Chicago, IL, USA, 2013, pp. 226–233.

[38] G. Pellegrino, E. Armando, and P. Guglielmi. (2010). "An integral battery charger with power factor correction for electric scooter." IEEE Trans. Power Electron., vol. 25, no. 3, pp.751–759, Mar. 2010.

[39] L. Tang and G. J. Su. (2009). "A low-cost, digitally-controlled charger for plug-in hybrid electric vehicles." in Proc. IEEE Energy Convers. Congr. Expo.,San Jose, CA, USA,2009, pp. 3923–3929.

[40] Ruoyun Shi, Sepehr Semsar and Peter W. Lehn. (2018). "Constant Current Fast Charging of Electric Vehicles via a DC Grid Using a Dual-Inverter Drive."

[41] Different fast charging methods and topologies for EV charging - 978-1-5386- ©2018 IEEE.

[42] D. Aggeler, F. Canales, H. Zelaya - De La Parra, A. Coccia, N. Butcher, and O. Apeldoorn. (2010).

[43] Longcheng Tan, Bin Wu, Venkata Yaramasu, Sebastian Rivera and Xiaoqiang Guo. (2016). "Effective Voltage Balance Control for Bipolar-DC-Bus- Fed EV Charging Station with Three-Level DC-DC Fast Charger." IEEE Transactions on Industrial Electronics, Vol. 63, NO. 7, JULY 2016.

[44] KuttL, SaarijärviE, LehtonenM, MolderH, et al. (2013). "A review of the har-monic and unbalance effects in electrical distribution networks due to EV charging." 201312th International Conference on Environment and Electrical Engineering (EEEIC), Wroclaw; 2013.p.556-561.

[45] Boynuegri AR, UzunogluM, ErdincO, GokalpE. (2014). "A new perspective in grid connection of electric vehicles: different operating modes for elimination of energy quality problems." Appl Energy2014; 132:435–51.

[46] Balcells J, GarcíaJ. (2010). "Impact of plug-in electric vehicles on the supply grid." Lille: IEEE Vehicle Power and Propulsion Conference (VPPC); 2010.p.1–4.

[47] Masoum MAS, Deilami S, Islam S. (2010). "Mitigation of harmonics in smart grids with high penetration of plug-in electric vehicles." In: Proceedings of the IEEE Power and Energy Society General Meeting, USA; 2010.p.1-6.

[48] Masoum MAS, Moses PS, Deilami S. (2010). "Load management in smart grids considering harmonic distortion and transformer derating." Gaithersburg, MD: IEEE Innovative Smart Grid Technologies Europe (ISGTEurope); 2010.p.1–7.

[49] Deilami S, Masoum AS, Moses PS, Masoum MAS. (2010). "Voltage profile and THD distortion of residential network with high penetration of Plug-in Electrical Vehicles." IEEE Innovative Smart Grid Technologies Conference Europe (ISGT Europe), Gothenburg; 2010.p.1-6.

[50] Nyns KC, Haesen E, Driesen J. (2010). "The impact of charging plug-in hybrid electric vehicles on a residential distribution grid." IEEE Trans Power Syst 2010; 25(1):371–80.

[51] Deilami S, Masoum AS, Moses PS, et al. (2011). "Real time coordination of plug-in electric vehicle charging in smart grids to minimize power losses and improve voltage profile." IEEETransSmartGrid2011; 2 (3):456–67.

[52] Sortomme E, Hindi EMM, MacPherson SDJ, et al. (2011). "Coordinated charging of plug-in hybrid electric vehicles to minimize distribution system losses." IEEE TransSmartGrid2011; 2(1):198–205.

[53] Kristofferson T, Capion K, MeibomP. (2011). "Optimal charging of electric drive vehicles in a market environment."Appnergy2011; 88:19408.

[54] Denholm P, Short W. (2006). "An evaluation of utility system impacts and benefits of optimally dispatched plug-in hybrid electric vehicles." Golden, CO: National Renewable Energy Laboratory; 2006.

[55] Rajakaruna S, Shahnia F, Ghosh A. (2015). "Plug in electric vehicles in smart grids." 1st ed.Springer Science and Business Media Singapore PteLtd; 2015.

[56] Mitra P, Venayagamoorthy GK. (2010). "Wide area control for improving stability of a power system with plug-in electric vehicles." IET Gener Transm Distrib2010; 4(10):1151–63.

[57] Qian K, Zhou C, Yuan Y. (2015). "Impacts of high penetration level of fully electric vehicles charging loads on the thermalageing of power transformers." IntJ Electr ower Energy Syst2015; 65:102–12.