A recapitulation on electric vehicle DC charging stations employing photovoltaic sources

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Abstract. In the following couple of years, Electrified automobiles are destined to come to be the critical aspect of the transport field. So, there is direct relation & critical dependency exists with the charging infrastructure. In parallel charging infrastructure has to be designed in such a way that to meet the huge growing demand for on Electrified automobiles to fuel them whenever and wherever necessary. Among this substructure, Charging stations photovoltaic-assisted are attracting a substantial interest due to increased environmental awareness, cost reduction and rise in efficiency of the PV modules. The intention of this paper is to review the technological status of Photovoltaic–Electric vehicle (PV-EV) charging stations during the last decade. The PV-EV charging station is divided into two categories, which are PV-grid and PV standalone charging systems. From a practical point view, the distinction between the two architectures is the bidirectional inverter, which is added to link the station to the smart grid. The technological infrastructure includes the common hardware components of every station, namely: PV array, dc-dc converter provided with MPPT control, energy storage unit, bidirectional dc charger and inverter. We investigate, compare and evaluate many valuable researches that contain the design and control of PV-EV charging system. Additionally, this concise overview reports the studies that include charging standards, the power converters topologies that focus on the adoption of Vehicle-to grid technology and the control for both PV–grid and PV standalone DC charging systems. Keywords. PV-grid charging station, Electric vehicle charging, smart grid, Vehicle to grid, Bidirectional DC converter, Energy storage unit.

1. Introduction

For economic development of any nation, the population depends strongly on fossil fuels, particularly for transportation and electricity generation. Since the number of Vehicles increases every day, the air quality become a serious problem in urban area due to the big amount of the burning of fossil fuels that are greatly responsible for global warming. In the last few years there has been considerable interest in Electric Vehicles (EVs) and Plug-in Hybrid Electric Vehicles (PHEV), which could play an important role in reducing greenhouse gas (GHG) emissions from the transport sector, and have potential as a future alternative to internal combustion (IC) vehicles. However, meaningful GHG emissions reductions with EVs are conditional on low-carbon on their source of electric energy. According to reference [1], the life cycle GHG emissions from PHEVs is assessed and find that they reduce GHG emissions by 32% compared to conventional vehicles.

In this paper, the term of "electric vehicle" refers to all kind of transportation that contains rechargeable batteries; namely Cars, buses, velocipedes motorcycles and trucks.

The augmentation in EV numbers brings a new issue that is the high electricity demand from the grid. One efficient solution to overcome the impact is to decentralize the power generation such as integrating renewable energy local sources into charging infrastructure. To address this challenge, Liu et al. [2] report the interaction between renewable energy and EVs charging problem in the presence of smart grid technologies.

PV power technology is expected to go through a substantial development in future, due to increased environmental awareness, the cost reduction and rise in efficiency of the PV modules. P. J. Tulpule et.

al.[3] have cited several economic and environmental profits of the PV powered charging station in workplace parking. Furthermore, the charging operation is made during the daytime, which means the power generation is in its maximum point. Therefore a considerable cost saving is guaranteed. The installed PV modules on working parking garage’s roof gives also free shelters in bad weather conditions[4]. Because of these advantages, the PV-grid based system is more preferred than other renewable energy based systems.

All electrically power assisted vehicles need to be recharged via charging systems, and the stations that use photovoltaic module as a source of electric energy for the battery recharging are called photovoltaic-charging stations (PVCS).

The PVCS is divided into two mandatory types, which are PV-grid charging system and PV standalone charging systems. In this paper, we will investigate this topic by comparing the features of the two architectures and giving the actual technological status of charging system. For this reason, we present every part of the PV charging infrastructure to give an updated literature to engineers and researchers.

This paper is organized as follows: The second section gives an overview of the chargers standards. The third section analyses the general architecture of the PVCS. In the fourth section, every component of the station is investigated

2. Electric Vehicle charging Standards

From a standardization point of view, there is three main organizations that work to standardize electrical characteristics of EV charging stations in the world: the Society of Automotive Engineering (SAE), CHAdeMO association and International Electro technical Commission (IEC). Besides these bodies, the worldwide leader of the electric carmakers, Tesla motors develops its own standards for its model S, Model X and Roadster electric cars.

Every organization cited above, offers a range of charger norms that work on both AC and another dedicated to DC voltage. In this paper we investigate only the data belong to DC range. For instance, the SAE has been working on standard J1772, which organizes EV chargers into 3 main categories [5]: Level 1, Level 2 and Level 3. i) Level 1: the charger is on- board and provides DC voltage with maximum current of 80 A, and maximum power of 40 kW. ii) Level 2: the charger provides DC voltage with maximum current of 200 A, maximum power of 90 kW. iii) Level 3: charger is off- board. The charging station provides DC voltage directly to the battery via a DC connector, with a maximum power of 240 kW. All chargers from level 3 are considered as fast chargers. CHAdeMO and IEC proposed some power and current specifications concerning DC fast charging. For more information, a concise summary of power and current level evaluation for electric vehicle DC charging standards are listed in table 1

Table 1. DC charging standards for EV

Level	Max current rating (A)	Max power rating (KW)
SAE standard		
DC level 1	80	40
DC level 2	200	90
DC level 3	400	240
CHAdeMO		
DC fast charging	120	62,5
IEC Standard		
DC fast charging	400	100-200
Tesla Motor		
DC super-charger	340	136

3. Photovoltaic Charging station topologies

The PV-EV charging stations are divided into two categories, which are PV-grid charging system and PV-standalone charging systems. This section reviews the two architectures and gives a technical comparison between them.

3.1.PV-grid charging system

The literature on photovoltaic energy for EV charging is knowing an advanced and exponential development. This is due to the cost, sustainability and flexibility in integrating with the existing grid of the electricity supplied from PV modules.

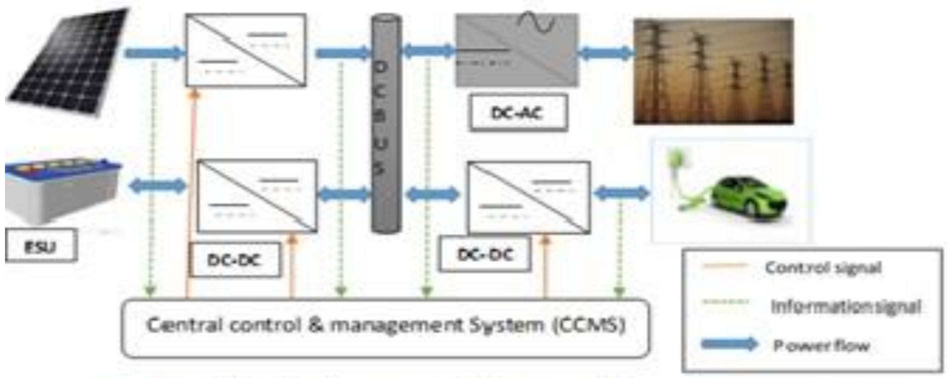

Figure1. A block diagram of PV grid charging system

The showed charging architecture in figure 1, which is studied from different points of view in various published paper[6], [7], is characterized by two conversion stages obtained through AC/DC and DC/DC converters. Furthermore, the dc bus has a high importance, because it is proposed to interface the PV array, the ESU and the EV battery pack combining other dc powered electronics. In this architecture, the batteries or energy storage unit (ESU) could be optional since the station is directly connected to the grid. Nevertheless, it would be a substantial part in case of willing reduce the dependence to the grid. In [8] the authors investigate the convivial topologies for integrated PV-grid charger.

3.2. Standalone PV charging system

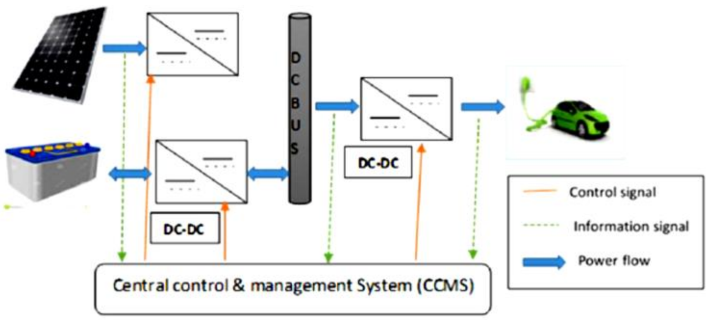

Figure 2. Standalone PVCS

In contrast with PV-EV charging station connected to grid, the standalone or off-grid station could provide energy to EV's batteries without any connection to the power grid. To this end, the charging system is necessarily equipped with an Energy storage unit (ESU) in order to be able to deliver continuously the power to the EV battery during night or when the PV modules cannot produce the sufficient energy[9]. For instance, In [10] authors proposed a standalone photovoltaic vehicle charge using second life lithium batteries as ESU.

4. Hardware infrastructure in PVCS: State of the art

4.1. PV system with MPPT control

To harvest electric energy from the sun light, PV modules are required to make the conversion. Numerous PV modules technologies exist in the market, namely polycrystalline and monocrystalline modules, thin film, heterogeneous intrinsic thin film[11], [12].The PV power nature is intermittent which depends strongly on weather conditions. Thus, the fluctuation in both solar irradiance and temperature results in nonlinear I–V and P–V characteristic curves, which makes the position of the Maximum Power Point (MPP) variable over time and difficult to be located and tracked. Because of this intermittent dynamic, the Maximum Power Point Tracker is crucial to harvest the maximum power through a dc-dc converter[13]–[15]. The basic principle of any MPPT command can be illustrated by Figure 3.We compare a power (P2) measured at time (t) with a power (P1) measured at time (t-1) : If the derivative is positive (P1 P2), it means that we have exceeded the MPP. According to the actual condition, we increase or we decrease the duty cycle of the PWM control to match the optimal point.

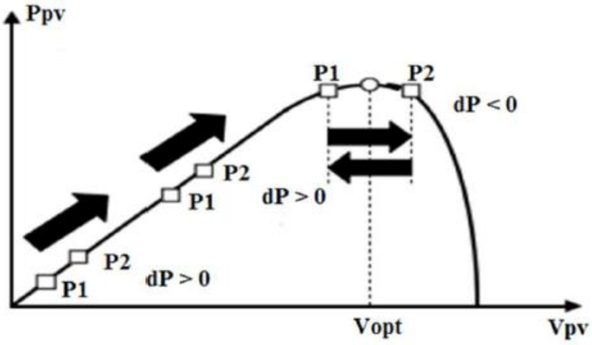

Figure 3. The basic operating principle of MPPT algorithm

In literature, various MPPT approaches have been developed which could devised to intelligent and classical strategies. In the first category we find: Fuzzy Logic, Neural Network, Extremum seeking control, Particle swarm optimization…[15]–[18] However, in the second category we find: Incremental Conductance Perturbation , Fractional Open-Circuit Voltage, and the most widely used technique is Perturb and Observe (P&O) algorithms due to its simplicity and fast response [13], [14], [19]. In addition, a comparison between conventional and intelligent MPPT techniques are investigated in [20], [21]. For more investigation, some interesting papers review nearly all known MPPT techniques and give a comparative between their advantages and disadvantages are in [22]–[24] 4.2.Bidirectional DC Charger The mandatory function of a dc charger in PVCS is to allow an effective control during the charging process by interfacing the dc bus voltage to the EV battery. In literature, charger systems for electric vehicles are classified into off-board and on-board types with unidirectional or bi-directional power flow[25]. This latter type adopts the Vehicle to grid (V2G) concept, since it has not only the capability to charge the EV in one effective way from the grid or the ESU, but also it supports also the power flow in the other direction back to the grid[26]–[28]. Hence, it gives the grid the opportunity to benefit from the energy stored in the EV battery during shortage energy time. Beside this, V2G technology require advanced communication components to guarantee a safe operation and a smart grid to accept the power injection[2], [29].The impact of the V2G on the EV battery pack is evaluated and discussed more deeply in[28], [30]. Concerning the power converter configuration used, we find essentially two structures, namely a non isolated and isolated converters. This latter type ensures the galvanic isolation, by contrast, it presents some drawbacks such as high cost realization due to adding transformers. In the other side, the non isolated bidirectional dc chargers are considered the most appropriate to serve as DC chargers because of their compactness and higher reliability[31]. In [33] authors reviewed the topologies of non-isolated bidirectional DC-DC chargers and proposed application of a rapid charging station at municipal parking decks. In [34] an on-board bidirectional soft-switched battery charger is proposed. Serving the same purpose, The Interleaved design of Bidirectional converter and a half bridge topology are studied in [35], [36] with the aim to minimize the inductor size and increase the efficiency using soft-switching control. On-board chargers are usually used to increase the charge availability for all kind of rechargeable vehicles. However, some constraints must be taken in consideration such as weight, size and power rate since this type is usually used for slow charging during nights or embedded on the vehicle. Therefore there will be an outlook for PV charging stations to move from slow onboard chargers to high-power off-board fast chargers in the future. The dissimilarities between the On-board and OFFboard Dc charger are summarized in the Table 2

Table 2. Comparison between on/off board dc chargers

	On-board DC charger	Off Board DC charger
Size	small	medium or big
Wight	light	heavy
Charging time	long	short
Power range	< 40 KW	< 240 KW
Power flow	Bidirectional	Mono / Bidirectional

4.3.Bidirectional inverter

The bidirectional inverter for EV charging system play a dual role depending on the current flow direction. It functions as DC-AC converter (inverter mode) when the grid requires the power from the dc bus. In contrast, it operates as an AC-DC converter (rectifier mode), when the DC link need to be supplied from the grid.

Among different configurations of bidirectional inverters, there is two famous categories namely, isolated and non-isolated converters. For PV charging stations connected to grid, the isolated configuration is the favorite one as it operates in high voltage levels and could provide a galvanic isolation between Alternative current part and direct current part of the system .[37], [38]. The key constrained point of the inverter design is the frequency stabilization. Hence, a good converter must have the capability to converter voltage signal nature with suitable synchronization frequency with the power grid and conserve the grid power quality.

4.4.Energy storage system

Due to the intermittent nature of the generated photovoltaic power, the energy storage system (ESS) is indispensable in the charging station, especially for the isolated ones. The role of this ESS is to compensate or absorb the difference between the generated photovoltaic power and the required load power[4] in reduce power requirements from main grid during charging operations [39] For this reason, it is considered as the key element of the energy management in any renewable sources based system [40]. A comprehensive analysis of the ESS concerning different power storage techniques, their efficiencies and economic evaluation is reported in [40].

In general, lead-acid batteries are the most popular storage technology used due to their reduced cost and long lifespan. However, their energy density is small and to offer the sufficient power amount, the lead pack takes a huge volume. With the inauguration of new huge factories deduced to manufacture only lithium ion batteries, the cost becomes cheaper as well as the lead technology. Furthermore, in order to alleviate the impact of dynamic power interactions on battery's lifetime, hybrid energy storage unit (HESS) is proposed. This hybrid ESU may contains, in addition to batteries, supercapacitors, flywheels[41], [42].

4.5.Energy management system

There are many papers that investigate the power management in EV charging system, In the study [45] authors proposed an intelligent energy management system with wireless ZigBee communication. An energy management strategy (EMS) using an artificial neural network is described in[46] in order to shave the domestic peak grid load by the coordinated response of distributed energy resource. Additionally, an offline particle swarm optimization (PSO) is performed besides a dynamic programming (DP) as an online reactive management layer in the study research [47], with the aim to continuously minimize the power flow operation cost. Additionally, a consistent communication is required between the charging management system and the battery management system is usually maintained via the CAN in order to ensure the security and the integrity.

5. Conclusion

This paper briefly reviews works recently conducted in the area of photovoltaic DC charging stations for EVs. A discussion and a comparative study between different components of the charging stations is done. To summarize, the benefits of PV-EV chargers that adopt V2G technology will receive an increased attention and more investments from grid operators and carmakers in the future. As conclusion, The Photovoltaic charging structure is becoming more complex with several functions integrated into the system, which require intelligent controls in each block and real time management for the whole station.

References

[1] C. Samaras and K. Meisterling, 'Life Cycle Assessment of Greenhouse Gas Emissions from Plug-in Hybrid Vehicles: Implications for Policy', Environ. Sci. Technol., vol. 42, no. 9, pp. 3170–3176, May 2008.

[2] L. Liu, F. Kong, X. Liu, Y. Peng, and Q. Wang, 'A review on electric vehicles interacting with renewable energy in smart grid', Renew. Sustain. Energy Rev., vol. 51, pp. 648–661, 2015.

[3] P. J. Tulpule, V. Marano, S. Yurkovich, and G. Rizzoni, 'Economic and environmental impacts of a PV powered workplace parking garage charging station', Appl. Energy, vol. 108, pp. 323–332, 2013.

[4] R. H. Ashique, Z. Salam, M. J. B. A. Aziz, and A. R. Bhatti, 'Integrated photovoltaic-grid dc fast charging system for electric vehicle: A review of the architecture and control', Renew. Sustain. Energy Rev., 2016.

[5] L. Dickerman and J. Harrison, 'A New Car, a New Grid', IEEE Power Energy Mag., vol. 8, no. 2, pp. 55–61, Mar. 2010.

[6] H. Hõimoja, A. Rufer, G. Dziechciaruk, and A. Vezzini, 'An ultrafast EV charging station demonstrator', in Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM), 2012 International Symposium on, 2012, pp. 1390–1395.

[7] S. Bai, D. Yu, and S. Lukic, 'Optimum design of an EV/PHEV charging station with DC bus and storage system', in Energy Conversion Congress and Exposition (ECCE), 2010 IEEE, 2010, pp. 1178–1184.

[8] N. Naghizadeh and S. S. Williamson, ‘A comprehensive review of power electronic converter topologies to integrate photovoltaics (PV), AC grid, and electric vehicles’, in 2013 IEEE Transportation Electrification Conference and Expo (ITEC), 2013, pp. 1–6.
[9] O. Ekren and B. Y. Ekren, ‘Size optimization of a PV/wind hybrid energy conversion system with battery storage using simulated annealing’, Appl. Energy, vol. 87, no. 2, pp. 592–598, 2010.
[10] S. J. Tong, A. Same, M. A. Kootstra, and J. W. Park, ‘Off-grid photovoltaic vehicle charge using second life lithium batteries: An experimental and numerical investigation’, Appl. Energy, vol. 104, no. Supplement C, pp. 740–750, Apr. 2013.
[11] O. Vetterl et al., ‘Intrinsic microcrystalline silicon: A new material for photovoltaics’, Sol. Energy Mater. Sol. Cells, vol. 62, no. 1, pp. 97–108, 2000.
[12] A. H. Fanney, M. W. Davis, and B. P. Dougherty, ‘Short-term characterization of building integrated photovoltaic panels’, in ASME Solar 2002: International Solar Energy Conference, 2002, pp. 211–221.
[13] S. Li, H. Liao, H. Yuan, Q. Ai, and K. Chen, ‘A MPPT strategy with variable weather parameters through analyzing the effect of the DC/DC converter to the MPP of PV system’, Sol. Energy, vol. 144, no. Supplement C, pp. 175–184, Mar. 2017.
[14] J. Ahmed and Z. Salam, ‘An improved perturb and observe (P&O) maximum power point tracking (MPPT) algorithm for higher efficiency’, Appl. Energy, vol. 150, no. Supplement C, pp. 97–108, Jul. 2015.
[15] S. L. Brunton, C. W. Rowley, S. R. Kulkarni, and C. Clarkson, ‘Maximum Power Point Tracking for Photovoltaic Optimization Using Ripple-Based Extremum Seeking Control’, IEEE Trans. Power Electron., vol. 25, no. 10, pp. 2531–2540, Oct. 2010.
[16] P. S. Gavhane, S. Krishnamurthy, R. Dixit, J. P. Ram, and N. Rajasekar, ‘EL-PSO based MPPT for Solar PV under Partial Shaded Condition’, Energy Procedia, vol. 117, no. Supplement C, pp. 1047–1053, Jun. 2017. [17] C. S. Chiu, ‘T-S Fuzzy Maximum Power Point Tracking Control of Solar Power Generation Systems’, IEEE Trans. Energy Convers., vol. 25, no. 4, pp. 1123–1132, Dec. 2010.
[18] M. A. Sahnoun, H. M. R. Ugalde, J.-C. Carmona, and J. Gomand, ‘Maximum Power point Tracking Using P&O Control Optimized by a Neural Network Approach: A Good Compromise between Accuracy and Complexity’, Energy Procedia, vol. 42, no. Supplement C, pp. 650–659, Jan. 2013.
[19] D. Sera, L. Mathe, T. Kerekes, S. V. Spataru, and R. Teodorescu, ‘On the Perturb-andObserve and Incremental Conductance MPPT Methods for PV Systems’, IEEE J. Photovolt., vol. 3, no. 3, pp. 1070–1078, Jul. 2013.
[20] H. Bounechba, A. Bouzid, K. Nabti, and H. Benalla, ‘Comparison of Perturb & Observe and Fuzzy Logic in Maximum Power Point Tracker for PV Systems’, Energy Procedia, vol. 50, no. Supplement C, pp. 677–684, Jan. 2014.
[21] K. Sundareswaran, V. Vignesh kumar, and S. Palani, ‘Application of a combined particle swarm optimization and perturb and observe method for MPPT in PV systems under partial shading conditions’, Renew. Energy, vol. 75, no. Supplement C, pp. 308–317, Mar. 2015.
[22] M. A. Danandeh and S. M. Mousavi G., ‘Comparative and comprehensive review of maximum power point tracking methods for PV cells’, Renew. Sustain. Energy Rev.
[23] F. T. Sawant, P. L. Bhattar, and C. L. Bhattar, ‘Review on maximization of solar system under uniform and non uniform conditions’, in 2017 International Conference on Circuit ,Power and Computing Technologies (ICCPCT), 2017, pp. 1–7.
[24] A. Khare and S. Rangnekar, ‘A review of particle swarm optimization and its applications in Solar Photovoltaic system’, Appl. Soft Comput., vol. 13, no. 5, pp. 2997– 3006, May 2013.
[25] M. Yilmaz and P. T. Krein, ‘Review of Battery Charger Topologies, Charging Power Levels, and Infrastructure for Plug-In Electric and Hybrid Vehicles’, IEEE Trans. Power Electron., vol. 28, no. 5, pp. 2151–2169, May 2013.
[26] G. R. C. Mouli, P. Bauer, and M. Zeman, ‘Comparison of system architecture and converter topology for a solar powered electric vehicle charging station’, in 2015 9th International Conference on Power Electronics and ECCE Asia (ICPE-ECCE Asia), 2015, pp. 1908–1915.
[27] J. Channegowda, V. K. Pathipati, and S. S. Williamson, ‘Comprehensive review and comparison of DC fast charging converter topologies: Improving electric vehicle plug-towheels efficiency’, in 2015 IEEE 24th International Symposium on Industrial Electronics (ISIE), 2015, pp. 263–268.
[28] M. Yilmaz and P. T. Krein, ‘Review of the Impact of Vehicle-to-Grid Technologies on Distribution Systems and Utility Interfaces’, IEEE Trans. Power Electron., vol. 28, no. 12, pp. 5673–5689, Dec. 2013.
[29] M. G. Vayá and G. Andersson, ‘Integrating renewable energy forecast uncertainty in smart-charging approaches for plug-in electric vehicles’, in PowerTech (POWERTECH), 2013 IEEE Grenoble, 2013, pp. 1–6. [30] J. D. Bishop, C. J. Axon, D. Bonilla, M. Tran, D. Banister, and M. D. McCulloch, ‘Evaluating the impact of V2G services on the degradation of batteries in PHEV and EV’, Appl. Energy, vol. 111, pp. 206–218, 2013. [31] S. Chakraborty, T. Senjyu, H. Toyama, A. Y. Saber, and T. Funabashi,

‘Determination methodology for optimising the energy storage size for power system’, IET Gener. Transm. Distrib., vol. 3, no. 11, pp. 987–999, 2009.
[32] M. Vaidya, E. K. Stefanakos, B. Krakow, H. C. Lamb, T. Arbogast, and T. Smith, ‘Direct DC-DC electric vehicle charging with a grid connected photovoltaic system’, in Conference Record of the Twenty Fifth IEEE Photovoltaic Specialists Conference - 1996, 1996, pp. 1505–1508.
[33] Y. Du, X. Zhou, S. Bai, S. Lukic, and A. Huang, ‘Review of non-isolated bidirectional DC-DC converters for plug-in hybrid electric vehicle charge station application at municipal parking decks’, in Applied Power Electronics Conference and Exposition (APEC), 2010 Twenty-Fifth Annual IEEE, 2010, pp. 1145–1151.
[34] S. Ebrahimi, R. Akbari, F. Tahami, and H. Oraee, ‘An Isolated Bidirectional Integrated Plug-in Hybrid Electric Vehicle Battery Charger with Resonant Converters’, Electr. Power Compon. Syst., vol. 44, no. 12, pp. 1371–1383, Jul. 2016.
[35] A. K. Rathore and U. R. Prasanna, ‘Analysis, design, and experimental results of novel snubberless bidirectional naturally clamped ZCS/ZVS current-fed half-bridge DC/DC converter for fuel cell vehicles’, IEEE Trans. Ind. Electron., vol. 60, no. 10, pp. 4482–4491, 2013.
[36] S. Dusmez, A. Khaligh, and A. Hasanzadeh, ‘A zero-voltage-transition bidirectional dc/dc converter’, IEEE Trans. Ind. Electron., vol. 62, no. 5, pp. 3152–3162, 2015.
[37] Y. Xia, W. Wei, Y. Peng, P. Yang, and M. Yu, ‘Decentralized Coordination Control for Parallel Bidirectional Power Converters in a Grid-Connected DC Microgrid’, IEEE Trans. Smart Grid, vol. PP, no. 99, pp. 1–1, 2017.
[38] S. Kouro, J. I. Leon, D. Vinnikov, and L. G. Franquelo, ‘Grid-Connected Photovoltaic Systems: An Overview of Recent Research and Emerging PV Converter Technology’, IEEE Ind. Electron. Mag., vol. 9, no. 1, pp. 47–61, Mar. 2015.
[39] C. Capasso and O. Veneri, ‘Experimental study of a DC charging station for full electric and plug in hybrid vehicles’, Appl. Energy, vol. 152, pp. 131–142, Aug. 2015.
[40] H. Ibrahim, A. Ilinca, and J. Perron, ‘Energy storage systems—characteristics and comparisons’, Renew. Sustain. Energy Rev., vol. 12, no. 5, pp. 1221–1250, 2008.
[41] G. Joos, M. de Freige, and M. Dubois, ‘Design and simulation of a fast charging station for PHEV/EV batteries’, in 2010 IEEE Electrical Power Energy Conference, 2010, pp. 1–5.
[42] C. Spataru, Y. C. Kok, and M. Barrett, ‘Physical energy storage employed worldwide’, Energy Procedia, vol. 62, pp. 452–461, 2014.
[43] W. Jing, C. H. Lai, S. H. W. Wong, and M. L. D. Wong, ‘Battery-supercapacitor hybrid energy storage system in standalone DC microgrids: areview’, IET Renew. Power Gener., vol. 11, no. 4, pp. 461–469, 2017. [44] M. d R. A. Calado, S. J. P. S. Mariano, J. A. N. Pombo, and R. J. C. Pinto, ‘PV charging station for electric vehicles: Management and interface system’, in 2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC), 2016, pp. 1–5.
[45] P. Kulshrestha, L. Wang, M. Y. Chow, and S. Lukic, ‘Intelligent energy management system simulator for PHEVs at municipal parking deck in a smart grid environment’, in 2009 IEEE Power Energy Society General Meeting, 2009, pp. 1–6.
[46] K. Mahmud, S. Morsalin, M. J. Hossain, and G. E. Town, ‘Domestic peak-load management including vehicle-to-grid and battery storage unit using an artificial neural network’, in 2017 IEEE International Conference on Industrial Technology (ICIT), 2017, pp. 586–591.
[47] M. O. Badawy and Y. Sozer, ‘Power Flow Management of a Grid Tied PV-Battery System for Electric Vehicles Charging’, IEEE Trans. Ind. Appl., vol. 53, no. 2, pp. 1347– 1357, Mar. 2017