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Review on Renewable Energy Based EV Charging System with Grid Support Functionality

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***Abstract*— This paper presents a comprehensive review on renewable energy based Electric Vehicle (EV) charging techniques, energy storage system with grid support functionality. The classification of Electric Vehicles (EVs) / Hybrid Electric Vehicles (HEVs) charging based on standards, and charging techniques have been reviewed. Based on efficiency, feasibility and reliability, renewable energy systems for Electric Vehicle (EV) charging are addressed. To enhance the overall performance of the Electric Vehicles (EVs) / Hybrid Electric Vehicles (HEVs) for service longevity, the energy storage system needs to be properly operated and safely maintained. A qualitative analysis of power electronics topologies along with its advantages and disadvantages are also discussed. Furthermore, a comprehensive analysis of Vehicle-Grid-Integration (VGI) infrastructure its capability, benefits/potential, challenges such as technological, environmental, economic etc. have also been highlighted. A comparative overview of power electronics topologies suitable for VGI infrastructure is also exhibited.**

Keywords*— *Electric Vehicle (EV), Energy Storage System (ESS), Renewable Energy, Vehicle-Grid-Integration (VGI).

I. INTRODUCTION

In recent years, the electricity network is experiencing a significant change, motivated by the growing penetration of renewable energy sources and by the introduction of modern transport infrastructure. Globally, the Electric Vehicles (EVs) and Hybrid Electric Vehicles (HEVs) infrastructure are considered as the most environmental friendly for modern transportation system [1]. The introduction of EVs and HEVs in the modern transport infrastructure is mainly due to the ever-increasing environmental degradation and greenhouse gas generation. Apart from greenhouse gases, the emissions from conventional transport vehicles contain pollutants such as particulate matter, carbon monoxide, and oxides of nitrogen and Sulphur. The conventional vehicle emits hazardous gases and contribute a significant percentage in air pollution which causes several life-threatening illness for human. There is an urgent need to preserve the ecosystem and to conserve energy at the same time is becoming a very important issue for the future. To cater all this, we need better utility grid stability, increased operational efficiencies as well as better customer services while dealing with crumbling and ageing electrical infrastructure.

The Smart Grid (SG), which is considered as a next generation power grid, uses bidirectional power flow and strong communication network to create a globally distributed and integrated energy distribution network [2]. The smart grid network will meet the environmental targets and it will also support all kind of EVs/HEVs as well as distributed energy generation with storage capabilities. The increased EV penetration can have serious impact on the stability of electric distribution network. The EVs/HEVs based transportation network will also provide new opportunity to reduce oil consumption by drawing on electricity from the utility grid and renewable energy sources such solar PV, wind energy, solar thermal, fuel cell etc. The EVs/HEVs can also be used as energy storage system and supply required energy to the utility grid at the time of peak demand. With advancement in storage technology for EVs and HEVs, the concept of Vehicle-to-Grid (V2G), Vehicle-to Home (V2H), Vehicle-to-Vehicle (V2V) and Vehicle-to-Load (V2L) infrastructure have also emerged to support the Smart Grid (SG) environment [3], [4]. The power flow of EVs and HEVs can be bi-directional if it has Vehicle-to-Grid (V2G) capability, which can either be versatile loads (charging mode) or sources of storage (discharging mode). When the EVs and HEVs power are fed into the utility/electrical grid, it is called Vehicle-Grid-Integration (VGI) infrastructure. The concept of VGI and its implementation have been studied for more than a decade and is becoming increasingly popular as the percentage of energy storage system based EVs and HEVs penetration into the market is increasing day-by-day [5], [6]. Integration of renewable energy sources such as solar PV with EVs/HEVs can provide maximum benefits of VGI. Such a development, however, has several technological, environmental, and economic barriers. Meeting all these challenges are very important and crucial for the future of renewable energy based EV charging system with VGI infrastructure [7], [8].

The batteries for EVs and HEVs are valuable resources that contain electricity and can be used not only to drive the car, but also to restore energy for the utility grid, minimize utility bills and power the buildings or homes. The battery chargers play an essential role in the production of EVs and HEVs. The charging time and life of the battery are related to its charger's characteristics. The battery charger must be reliable and efficient, with high power capacity, low cost, low volume and weight. The efficiency of battery modules depends on its modules construction as well as its discharged and charged cycle. The battery chargers play a crucial role in the overall evaluation and growth of the EVs/HEVs technology [9]. The coordination of supply demand is an effective way of achieving high energy efficiency at the system level while meeting the grid stability and trip requirement of EVs/HEVs. The overall efficiency of VGI can be improved by proper coordination between supply available and demand required from customer [10]. The efficiency, reliability and stability of the utility grid can be improved by the use of VGI infrastructure. The VGI operated EVs/HEVs will also provide reactive power control, active power management, it also enables ancillary services such as spinning reserve, voltage and frequency control. The VGI infrastructure also create some issues such as battery degradation and communication problems between EVs/HEVs and the utility grid [11]–[13].

II. EV Charging Classification

Electric Vehicle (EV) charger is an indispensable component of Electric Vehicles (EVs) and Hybrid Electric Vehicles (HEVs) infrastructure that deliver electric current for charging/recharging the EV's batteries. The EV charging system is broadly classified as AC based charging system DC based charging system. The AC charging system and DC charging system are further sub-divided as per its operation and working power levels [14]–[16].

A. AC Charging System

The AC charging system is also called on-board charger; the charger is built inside the EVs/HEVs. The input AC supply based on requirements is directly given to the EVs/HEVs. Further, AC charging system is divided based on following output power levels [15]:

1) AC Level 1 Charging System: This type of chargers can be connected to the existing AC outlets in household or offices (120 V AC, single phase) with output power level of 1.44kW.

2) AC Level 2 Charging System: This type of chargers is specially designed for EV charging with permanently connected to the Electric Vehicle Supply Equipment (EVSE). The nominal supply voltage is 208-240 V AC single phase with maximum output power of 14.4kW.

3) AC Level 1 Charging System: This type of EV chargers have wide range of charging capabilities. The output power level can be more than 14.4kW and it can use single as well as three phase AC supply as input.

B. DC Charging System

The DC charging system is also called off-board chargers and placed at some fixed locations. The AC input supply is converted into DC current inside the charging system before it is supplied to the EVs/HEVs. Based on SAE standard, the DC chargers are classified according to its output power level delivery capabilities to the EV's battery [15]:

1) DC Level 1 Charging System: The DC level 1 charging system can deliver maximum output power up to 36kW. It can supply DC voltages in the range of 200-450 V DC and maximum output current up to 80A DC.

2) DC Level 2 Charging System: The DC level 2 charging system can deliver maximum output power up to 90kW. It can supply DC voltages in the range of 200-450 V DC and maximum output current up to 200A DC.

3) DC Level 3 Charging System: The DC level 3 charging system corresponds to power level between 90kW to 240kW. It can supply DC voltages in the range of 200-600 V DC and maximum output current up to 400A DC.

III. Solar PV Based EV Charging

The concept of solar PV has been used successfully for decades due to its emergence as sustainable and long-term solution, curbing carbon footprint, reducing reliance on fossil fuels and low-maintenance energy solutions [17]. To combat the global warming, rising energy costs and moving towards sustainable development, the solar PV based systems have shown promising results [18], [19]. The environmental and economic benefits of EVs/HEVs can only be realized when they are charged through renewable energy sources such as solar PV based charging systems [20], [21]. The renewable energy based EVs/HEVs charging system can play significant role in mitigating carbon footprint and moving towards sustainable development goals [22]–[24]. Typical architecture of solar PV based EVs/HEVs charging system with grid integration is depicted in figure 1.

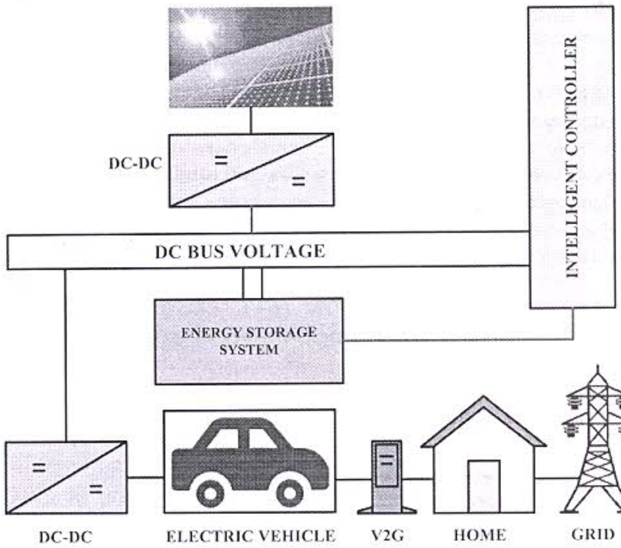

Fig. 1. Solar PV based EV charging with grid integration

According to the recent study conducted by Nation Renewable Energy Laboratory (NREL), the maximum EVs/HEVs charging take place in early morning, late afternoon and evenings, which coincide with the grid's peak load demand profile. Consequently, if the EVs/HEVs charging takes place (or occur) during grid's peak hours, the EV owner may be compelled to pay a higher amount for charging services. Considering renewable energy sources are intermittent in nature, the Energy Storage Systems (ESS) or auxiliary energy storage such as battery, flywheel energy storage, hybrid capacitor, fuel cell etc. are needed for renewable energy based EVs/HEVs charging system to provide stable, reliable and consistent charging throughout the day. The detailed analysis of ESS for renewable energy based EV charging applications is presented in the subsequent section.

A typical functional architecture of solar PV based system consisting solar PV, non-isolated unidirectional DC-DC converter and Maximum Power Point Tracker (MPPT) algorithm is shown in figure 2. In order to achieve high DC bus voltage and high power level for EVs/HEVs charging application, the solar PV modules are arranged in series-parallel configuration. The function of unidirectional DC-DC converter and MPPT control algorithm are to extract the maximum power from solar PV and to regulate the output voltage at the common DC bus voltage. Extensive research work on solar PV based EVs/HEVs charging and its control algorithm design are presented [25]–[28].

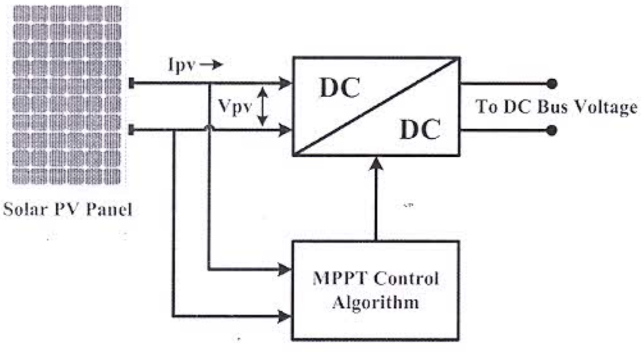

Fig. 2. Functional architecture of solar PV system

IV. Topology For EV Charging System

The topology for EV chargers can be classified depending upon the location of chargers (on-board/ off board), power flow direction (unidirectional/ bidirectional) and other features such as vehicle integration type of renewable energy used in systems [29], [30].

A. Unidirectional and Bidirectional Converters

The EV chargers can be broadly classified on power flow direction as unidirectional charger and bidirectional charger. While unidirectional topologies are commonly used, bidirectional topologies are gaining importance due to its necessity for Vehicle to Grid Integration functionality. A typical block diagram of unidirectional-bidirectional converter representing power flow direction is depicted in figure 3.

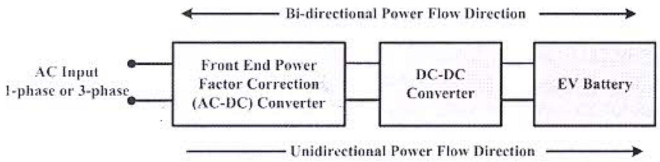

Fig. 3. Unidirectional-bidirectional converter power flow

In unidirectional chargers, the power flow is from the utility interface to the electric vehicle battery. These topologies have advantages of simplicity and robustness as compared to bidirectional topologies. In [31], a 3.3kW on board charger consisting of front end PFC and a series resonant DC-DC converter was proposed for on-board EV charger. The system used high switching frequency along with soft switching to achieve both high power density and high efficiency. The DCDC converter side topologies include those based on zero voltage switching and LLC resonant topologies [32]. An EV charger consisting of interleaved PFC and ZVS full bridge converter was proposed in [33]. The system had an overall efficiency of 93.6% at 3.3kW output power. DC-fast charging systems are unidirectional converters as they are off-board chargers and benefit of using bidirectional converters is not significant [29].

The bidirectional converters can charge battery from the electricity grid as well as can fed battery power into the grid thereby supporting VGI functionality. Due to cost constraints, bidirectional converters are typically intended to be used at level 2 AC power levels. Dual active bridge converter has been proposed for use in case of isolated bidirectional converters [34]. Non-isolated bidirectional topologies include two quadrant buck-boost converter. However, non-isolated topologies are not typically used due to safety concerns. Other bidirectional topologies include the use of Matrix converters. These converters, however, has complex control requirements.

B. Integrated Converter

For optimum utilization of limited space in EVs, the use of integrated EV chargers have been proposed. The charger filter inductor windings and motor windings are shared in order to reduce the overall weight and volume of the system. Implementation of control algorithm and additional hardware are the challenge [9], [29]. Schematic diagram of integrated converter based charger is shown in figure 4.

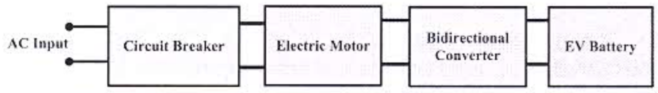

Fig. 4. Schematic diagram of integrated charger

C. EV Charging Algorithm

A typical functional architecture of EV charging consisting Energy Storage System (ESS), DC-DC converter with control algorithm and electric vehicle to be charged is depicted in figure 5. In view of the intermittent nature of renewable energy sources, the energy storage system is used to store the energy and act as the input to DC-DC converter unit. The DC-DC converter uses buck-boost, buck or boost converter and its function is to provide regulated output voltage. The converter topology can be isolated or non-isolated type.

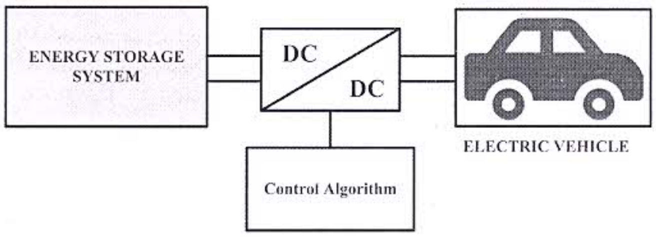

Fig. 5. Block diagram of EV charging

The various charging techniques are available in the literature for EV charging applications [35], [36]. These are given as:

- Constant Current (CC) charging
- Constant Voltage (CV) charging
- Constant Power (CP) charging
- Trickle Current (TC) charging
- Pulse charging
- Negative Pulse (NP) charging
- Pulse Frequency Current Control (PFCC) charging
- Taper and Float (T&F) charging

The CC-CV based EV charging is the most popular techniques for fast charging and generally employed in most of the commercially available EV chargers.

V. Energy Storage System (ESS)

Energy Storage System (ESS) is indispensable part of EVs/HEVs infrastructure. The energy storage industry has continued to grow, adapt and innovate over the past decades in order to meet the rising energy requirements. The ESS transforms electrical energy into some sort of energy that can be stored and released according to the needs. The ESS guarantees energy supply stability and boost system efficiency as well as reliability. Its size and scalability depends on the form of energy stored. The selection of energy storage for any particular applications depends on the required power and energy ratings. There are several approach for classifications of ESS, however, the most widely adopted approach is based on the form of energy stored. Energy can be stored in the form of thermal energy, chemical energy, electrochemical energy, mechanical energy, electrical energy etc. [37].

Battery is the most widely adopted energy storage system for EVs/HEVs infrastructure. There are several features one should consider when choosing the most appropriate battery for EVs/HEVs applications. The important criteria for the selection of battery include energy density, reliability, life cycle, availability, longer life, cost, power density and compactness [38]. The other important selection parameter of battery includes State of Charge (SoC), State of Health (SoH) and State of Power (SoP) [38]. The detailed characteristics and performances of Energy Storage Systems (ESS) suitable for EV charging applications are presented in Table I [39]–[41].

VI. Vehicle-Grid-Integration

Vehicle-Grid-Integration (VGI) infrastructure provides exciting possibilities to move towards EVs/HEVs in transport sector due to its unique characteristics of feeding electricity back to the utility grid. A typical functional diagram of VGI consisting electric vehicle, DC-DC and DC-AC converter with control algorithm and utility grid is depicted in figure 6. It supports renewable energy integration, improves overall performances of utility grid, offers reactive power compensation, load balancing, regulation of active power, filtering of harmonic components, voltage and frequency compensation etc. [42], [43]. Three key elements are needed for proper operation of VGI infrastructure [44], [45]; 1) Power connection for energy transfer, 2) Logical connection to assess availability of electrical capacity in the EVs/HEVs and 3) Recording/auditing the services provided to utility grid.

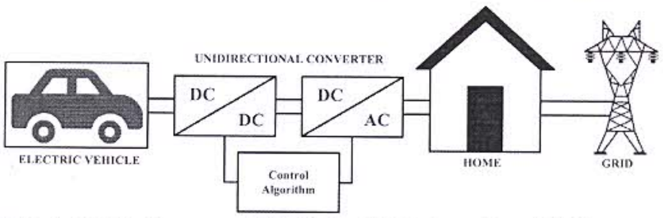

Fig. 6. Block diagram of Vehicle-Grid-Integration (VGI)

The electrical capacity of VGI diverges with time based on type of battery, State-of-Charge (SoC) and State-of-Health (SoH). For optimal and efficient utilization of VGI electrical capacity, a real time monitoring of VGI is very essential [4]. For interactive coordination between EV and utility grid, optimization models such as searching valley scheduling, variable threshold optimization, variable charging and discharging rate optimization algorithms are given [46].

VII. Conclusion

The extensive details of renewable energy based Electric Vehicle (EV) charging techniques along with energy storage system and grid integration is reviewed in this work. Based on SAE standard, the AC and DC EV charging system are categorized. EV chargers are classified as on-board and off-board types with having unidirectional and bidirectional capabilities. Generally, on-board chargers are low-power and low-cost chargers. Off-board DC chargers with high power capabilities are used in fast charging applications. Out of numerous charging techniques, Constant Current and Constant Voltage (CC-CV) based charging techniques is suitable for rapid EV charging. With advancement in rechargeable battery technology, the Lithium-ion battery is suitable for EV charging due to its highest energy density, high life cycle, high power density, safe operation, low self-discharge rate, highest energy efficiency. It is noted that the true benefits of EV charging infrastructure can be achieved only when it is powered by renewable energy sources such as solar PV. The innovations and development in intelligent charging techniques can give impetus for further deployment of renewable energy sources EV charging stations. Further, it can curb the global greenhouse gas emissions caused by the use of conventional transportation vehicles. Various charging topologies such as unidirectional, bidirectional, integrated chargers and wireless charging topologies were covered. The bidirectional EV charging topology allow the injection of battery power into the utility grid. Galvanic isolation provides overall safety in electric vehicle infrastructure. The maximum benefits of renewable energy based EV charging with vehicle-grid-integration can be achieved by establishing optimum and interactive communication between electric vehicles and power market. The vehicle-grid-integration improves overall performance of the electricity grid. The overall success of electric vehicle charging with grid integration infrastructure depends on efficient integration of renewable energy sources, advancement in storage technology and intelligent and reliable control and communication between EV-grid.

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TABLE I: ENERGY STORAGE SYSTEM (ESS) [39]–[41]

Energy storage type	Energy density (Wh/kg)	Specific power (W/kg)	Life cycles	Energy efficiency (%)
Lead Acid (Pb-Acid)	30-50	180	200-2000	70-80
Nickel-cadmium (Ni-Cd)	50-80	200	2000	75
Nickel-iron (NiFe)	50-60	100-150	2000	75
Nickel-metal hydride (Ni-MH)	70-95	200-300	<3000	70
Sodium-nickel chloride ($NaNiCl_2$)	90-120	155	1200+	80
Lithium-ion (Li-Ion)	118-250	200-430	2000	>95
Lithium-titanate ($Li_2T\ iO_3$)	80-100	4000	18000	--
Zinc-air	460	80-140	200	60
Hybrid Capacitor	10-15	1-2M	40 years	>95
Flywheel Energy Storage	10-150	2-40K	15 years	80

REFERENCES

[1] S. Alshahrani, M. Khalid, and M. Almuhaini, "Electric Vehicles Beyond Energy Storage and Modern Power Networks: Challenges and Applications," *IEEE Access*, vol. 7, pp. 99031–99064, 2019.

[2] P. Y. Kong and G. K. Karagiannidis, "Charging Schemes for Plug-In Hybrid Electric Vehicles in Smart Grid: A Survey," *IEEE Access*, vol. PP, no. 99, 2016.

[3] H. Turker and S. Bacha, "Optimal Minimization of Plug-In Electric Vehicle Charging Cost with Vehicle-to-Home and Vehicle-to-Grid Concepts," *IEEE Trans. Veh. Technol.*, vol. 67, no. 11, pp. 10281–10292, 2018.

[4] B. C. Liu, K. T. Chau, D. Wu, and S. Gao, "Opportunities and Challenges of Vehicle-to-Home , Vehicle-to-Grid Technologies," vol. 101, no. 11, pp. 2409–2427, 2013.

[5] B. W. Zhou, T. Littler, and H. F. Wang, "The impact of vehicle-to-grid on electric power systems: A review," *IET Conf. Publ.*, vol. 2013, no. 623 CP, pp. 2–5, 2013.

[6] B. Koushki, A. Safaee, P. Jain, and A. Bakhshai, "Review and comparison of bi-directional AC-DC converters with V2G capability for on-board ev and HEV," *2014 IEEE Transp. Electrif. Conf. Expo Components, Syst. Power Electron. - From Technol. to Bus. Public Policy, ITEC 2014*, 2014.

[7] X. Mou, Y. Zhang, J. Jiang, and H. Sun, "Achieving Low Carbon Emission for Dynamically Charging Electric Vehicles through Renewable Energy Integration," *IEEE Access*, vol. 7, pp. 118876–118888, 2019.

[8] S. Esther, S. K. Singh, A. K. Goswami, and N. Sinha, "Recent Challenges in Vehicle to Grid Integrated Renewable Energy System: A Review," *Proc. 2nd Int. Conf. Intell. Comput. Control Syst. ICICCS 2018*, no. Iciccs, pp. 427–435, 2019.

[9] S. Haghbin, S. Lundmark, M. Alakula, and O. Carlson, "Grid-connected integrated battery chargers in vehicle applications: Review and new solution," *IEEE Trans. Ind. Electron.*, vol. 60, no. 2, pp. 459–473, 2013.

[10] Q. S. Jia, "On supply demand coordination in vehicle-to-grid - A brief literature review," *Proc. - 2018 33rd Youth Acad. Annu. Conf. Chinese Assoc. Autom. YAC 2018*, pp. 1083–1088, 2018.

[11] M. Yilmaz and P. T. Krein, "Review of benefits and challenges of vehicle-to-grid technology," *2012 IEEE Energy Convers. Congr. Expo. ECCE 2012*, pp. 3082–3089, 2012.

[12] S. Habib and M. Kamran, "A novel vehicle-to-grid technology with constraint analysis-a review," *Proc. - 2014 Int. Conf. Emerg. Technol. ICET 2014*, pp. 69–74, 2014.

[13] S. Mkhize and D. G. Dorrell, "Practical limitations of vehicle to grid (v2g) infrastructure," *Proc. IEEE Int. Conf. Ind. Technol.*, vol. 2019-Febru, pp. 1616–1621, 2019.

[14] J. Sears, D. Roberts, and K. Glitman, "A Comparison of Electric Vehicle Level 1 and Level 2 Charging Efficiency," *2014 IEEE Conf. Technol. Sustain.*, pp. 255–258, 2014.

[15] S. S. Williamson, A. K. Rathore, and F. Musavi, "Industrial Electronics for Electric Transportation: Current State-of-the-Art and Future Challenges," *IEEE Trans. Ind. Electron.*, vol. 62, no. 5, pp. 3021–3032, 2015.

[16] G. Carli and S. S. Williamson, "Technical considerations on power conversion for electric and plug-in hybrid electric vehicle battery charging in photovoltaic installations," *IEEE Trans. Power Electron.*, vol. 28, no. 12, pp. 5784–5792, 2013.

[17] R. M. Elavarasan *et al.*, "A Comprehensive Review on Renewable Energy Development, Challenges, and Policies of Leading Indian States with an International Perspective," *IEEE Access*, vol. 8, pp. 74432–74457, 2020.

[18] B. K. Bose, "Global energy scenario and impact of power electronics in 21st century," *IEEE Trans. Ind. Electron.*, vol. 60, no. 7, pp. 2638–2651, 2013.

[19] R. Domínguez, A. J. Conejo, and M. Carrión, "Toward fully renewable electric energy systems," *IEEE Trans.*

Power Syst., vol. 30, no. 1, pp. 316–326, 2015.

[20] G. R. C. Mouli *et al.*, "Economic and CO2 Emission Benefits of a Solar Powered Electric Vehicle Charging Station for Workplaces in the Netherlands," *2016 IEEE Transp. Electrif. Conf. Expo, ITEC 2016*, 2016.

[21] A. Y. Saber and G. K. Venayagamoorthy, "Plug-in vehicles and renewable energy sources for cost and emission reductions," *IEEE Trans. Ind. Electron.*, vol. 58, no. 4, pp. 1229–1238, 2011.

[22] G. R. C. Mouli, P. Bauer, and M. Zeman, "Comparison of system architecture and converter topology for a solar powered electric vehicle charging station," *9th Int. Conf. Power Electron. - ECCE Asia "Green World with Power Electron. ICPE 2015-ECCE Asia*, pp. 1908–1915, 2015.

[23] J. Traube, F. Lu, and D. Maksimovic, "Photovoltaic power system with integrated electric vehicle DC charger and enhanced grid support," *15th Int. Power Electron. Motion Control Conf. Expo. EPE-PEMC 2012 ECCE Eur.*, pp. 1–5, 2012.

[24] A. R. Bhatti, Z. Salam, M. J. B. A. Aziz, K. P. Yee, and R. H. Ashique, "Electric vehicles charging using photovoltaic: Status and technological review," *Renew. Sustain. Energy Rev.*, vol. 54, pp. 34–47, 2016.

[25] B. K. Verma, S. Devassy, S. K. Ram, A. Abhishek, and A. Dhakar, "Control of a Multi-functional Solar PV-Battery System for Operation in a Microgrid Environment," *2019 8th Int. Conf. Power Syst. Transit. Towar. Sustain. Smart Flex. Grids, ICPS 2019*, 2019.

[26] H. Kumar, M. S. Rana, S. Suresh, S. K. Mishra, and A. K. Rathore, "Mixed Energy Source Charging Architecture for Electric Rickshaws," *2020 IEEE Int. Conf. Power Electron. Smart Grid Renew. Energy, PESGRE 2020*, pp. 1–5, 2020.

[27] A. B. De Los Mozos, G. R. C. Mouli, and P. Bauer, "Evaluation of topologies for a solar powered bidirectional electric vehicle charger," *IET Power Electron.*, vol. 12, no. 14, pp. 3675–3687, 2019.

[28] A. Verma, B. Singh, A. Chandra, and K. Al-Haddad, "An Implementation of Solar PV Array Based Multifunctional EV Charger," *2018 IEEE Transp. Electrif. Conf. Expo, ITEC 2018*, pp. 372–379, 2018.

[29] 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, 2013.

[30] Y. Du, X. Zhou, S. Bai, S. Lukic, and A. Huang, "Review of non-isolated bi-directional DC-DC converters for plug-in hybrid electric vehicle charge station application at municipal parking decks," *Conf. Proc. - IEEE Appl. Power Electron. Conf. Expo. - APEC*, no. 1, pp. 1145–1151, 2010.

[31] J. S. Kim, G. Y. Choe, H. M. Jung, B. K. Lee, Y. J. Cho, and K. B. Han, "Design and implementation of a high-efficiency on-board battery charger for electric vehicles with frequency control strategy," *2010 IEEE Veh. Power Propuls. Conf. VPPC 2010*, no. Ccm, 2010.

[32] F. Musavi, M. Edington, W. Eberle, W. G. Dunford, and S. Member, "Evaluation and Efficiency Comparison of Front End AC-DC Plug-in Hybrid Charger Topologies," *IEEE Trans. Smart Grid*, vol. 3, no. 1, pp. 413–421, 2012.

[33] D. S. Gautam, F. Musavi, M. Edington, W. Eberle, and W. G. Dunford, "An automotive onboard 3.3-kW battery charger for PHEV application," *IEEE Trans. Veh. Technol.*, vol. 61, no. 8, pp. 3466–3474, 2012.

[34] D. C. Erb, O. C. Onar, and A. Khaligh, "Bi-directional charging topologies for plug-in hybrid electric vehicles," *Conf. Proc. - IEEE Appl. Power Electron. Conf. Expo. - APEC*, pp. 2066–2072, 2010.

[35] J. Y. Yong, V. K. Ramachandaramurthy, K. M. Tan, and N. Mithulananthan, "A review on the state-of-the-art technologies of electric vehicle, its impacts and prospects," *Renew. Sustain. Energy Rev.*, vol. 49, pp. 365–385, 2015.

[36] S. Habib, M. M. Khan, F. Abbas, L. Sang, M. U. Shahid, and H. Tang, "A Comprehensive Study of Implemented International Standards, Technical Challenges, Impacts and Prospects for Electric Vehicles," *IEEE Access*, vol. 6, pp. 13866–13890, 2018.

[37] F. Nadeem, S. M. S. Hussain, P. K. Tiwari, A. K. Goswami, and T. S. Ustun, "Comparative review of energy storage systems, their roles, and impacts on future power systems," *IEEE Access*, vol. 7, pp. 4555–4585, 2019.

[38] A. Khaligh and Z. Li, "Battery, ultracapacitor, fuel cell, and hybrid energy storage systems for electric, hybrid electric, fuel cell, and plug-in hybrid electric vehicles: State of the art," *IEEE Trans. Veh. Technol.*, vol. 59, no. 6, pp. 2806–2814, 2010.

[39] S. F. Tie and C. W. Tan, "A review of energy sources and energy management system in electric vehicles," *Renew. Sustain. Energy Rev.*, vol. 20, pp. 82–102, 2013.

[40] T. D. Atmaja and Amin, "Energy storage system using battery and ultracapacitor on mobile charging station for electric vehicle," *Energy Procedia*, vol. 68, pp. 429–437, 2015.

[41] S. Vazquez, S. M. Lukic, E. Galvan, L. G. Franquelo, and J. M. Carrasco, "Energy storage systems for transport and grid applications," *IEEE Trans. Ind. Electron.*, vol. 57, no. 12, pp. 3881–3895, 2010.

[42] W. Choi *et al.*, "Reviews on grid-connected inverter, utility-scaled battery energy storage system, and vehicle-to-grid application - Challenges and opportunities," *2017 IEEE Transp. Electrif. Conf. Expo, ITEC 2017*, pp. 203–210, 2017.

[43] 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, 2013.

[44] H. N. T. Nguyen, C. Zhang, and M. A. Mahmud, "Optimal Coordination of G2V and V2G to Support Power Grids with High Penetration of Renewable Energy," *IEEE Trans. Transp. Electrif.*, vol. 1, no. 2, pp. 188–195, 2015.

[45] M. S. A. Khan, K. M. Kadir, K. S. Mahmood, M. I. I. Alam, A. Kamal, and M. M. Al Bashir, "Technical investigation on V2G, S2V, and V2I for next generation smart city planning," *J. Electron. Sci. Technol.*, vol. 17, no. 4, 2019.

[46] T. Zhou and W. Sun, "Research on multi-objective optimisation coordination for large-scale V2G," *IET Renew. Power Gener.*, vol. 14, no. 3, pp. 445–453, 2020.