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A survey on electric vehicle transportation within smart grid system

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ABSTRACT

The electrification of hybrid electric vehicle reduces the reliance of transportation on fossil fuels and reduces Green House Gas emissions. The economic and environmental benefits of the hybrid electric vehicles are greatly reshaping the modern transportation sector. The transportation electrification (TE) brings various challenges to the Smart Grid (SG), such as power quality, reliability, and control. Thus, there is a need to explore and reveal the key enabling technologies for TE. Moreover, the intermittent nature of Renewable Energy Resources (RER) based generation demands for efficient, reliable, flexible, dynamic, and distributed energy storage technologies. The Electrical Vehicles (EVs) storage battery is the promising solution in accommodating RER based generation within SG. The most efficient feature of transportation sector is Vehicle to Grid (V2G) concept that will help in storing the surplus energy and feeding back this energy to the main grid during period of high demands. The storage technology is an integral part of the SG that helps in attaining the proper utilization of RER. In this paper, our goal is to explore the TE sector and its impact on economy, reliability and eco-friendly system. We reviewed the V2G technology and their implementation challenges. We further reviewed various energy storage technologies deployed in EVs within SG, considering attention to their influence on the environment. Moreover, this paper presented a detailed overview of the on board and off board charging infrastructure and communication necessities for EV. The paper also investigated the current issues and challenges of energy storage technologies in EVs. The technical and economic benefits of storage technologies are also considered. Our analysis reviews the role of EVs in decarbonizing the atmosphere. Lastly, the survey explains the current regulation, Standard, and interfacing issues within SG.

1. Introduction

The world's energy generation is mainly dependent on fossil fuel resources. The conventional fossil fuel resources are not only depleting but also have a major concern regarding Carbon Dioxide (CO_2) gas emission, geo-political stability and Green House Gas (GHG) emission. The conventional electric grid reliability has a question mark due to non-renewable and depleting nature of fossil fuel resources [1–7]. The world's energy demand is expected to increase by 50% till year 2030, thus revolutionary changes in the present centralized and unidirectional electric grid is the foremost requirement of the time. The Smart Grid (SG) owing to its bi-directional-power flow and two way commu-

Abbreviations: AMI, Advanced Metering Infrastructure; AMR, Automated Meter Reading; BEV, Battery Electric Vehicle; CAES, Compressed Air Energy Storage; CO_2, Carbon dioxide; DG, Distributed Generation; DER, Distributed Energy Resources; ECES, Electro-Chemical Energy Storage; EDLC, Electric Double Layer Capacitor; ESS, Energy Storage System; EREV, Extended Range Electric Vehicle; EV, Electric Vehicle; FAN, Field Area Network; FC, Fuel Cell; FES, Flywheel Energy Storage; G2V, Grid to Vehicle; GHG, Green House Gas; HAN, Home Area Network; HEV, Hybrid Electric Vehicle; ICT, Information and Communication Technology; IEC, International Electrotechnical Commission; IEEE, Institute of Electrical and Electronics Engineers; LVRT, Low Voltage Ride Through; MG, Micro Grid; MAN, Metropolitan Area Network; M2M, Machine to Machine; MSS, Mechanical Storage System; NIST, National Institute of Standards and Technology; NREL, National Renewable Energy Laboratory; OFC, Optical Fiber Communication; PCC, Point Of Common Coupling; PEV, Plug-In Electrical Vehicles; PHES, Pumped Hydro Energy Storage; PLC, Power Line Communication; PHEVs, Plug In Hybrid Electric Vehicles; PMU, Phasor Measurement Unit; PV, Photovoltaic; R and D, Research and Development; RERs, Renewable Energy Resources; RFB, Redox Flow Battery; SAE, Society of Automation Engineers; SMES, Super Conducting Magnetic Energy Storage; SCADA, Supervisory Control and Data Acquisition; SG, Smart Grid; SOC, State of Charge; TE, Transportation Electrification; TES, Thermal Energy Storage; V2G, Vehicle to Grid; VPP, Virtual Power Plant; WAN, Wide Area Network; WRAN, Wireless Regional Area Network; WSN, Wireless Sensor Network

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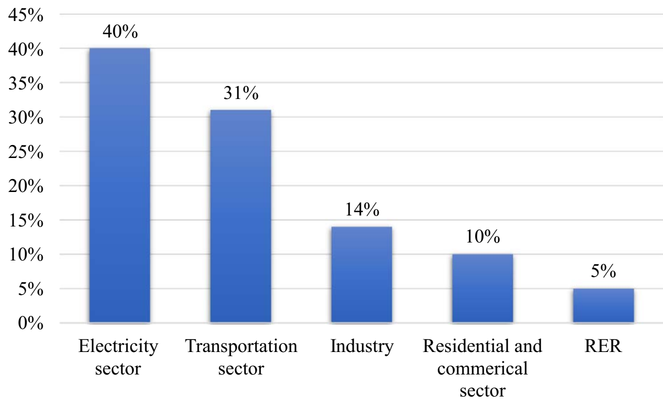

Fig. 1. Various sector wise emission of GHG [9,10].

nication-flow is the most suitable choice for the reliable and sustainable power supply. For the sustainable and reliable electric energy supply, the SG must be capable of providing power from multiple distributed generation, RER, and EV. The intermittent nature of RER demands for efficient and flexible storage technologies to achieve sustainable power supply. The advance and sophisticated control algorithms greatly assist in the improvement of power quality and reliability within SG [8].

CO_2 gas is a major trapping factor in heating (global warming) [11]. The concentration of CO_2 shows a marked increase during past two centuries and resulted in temperature rise of the planet earth. The report in [9] demonstrates that during year 2009, CO_2 emission from fossil fuel combustion, such as oil and coal approached to 10.6GT and 12.3GT, respectively. Fig. 1 illustrates the sector wise GHG emission during year 2009. The electric power generation sector contributes 40% towards the GHG emission, while second major contributing factor in global warming is transportation sector and the GHG emission from RER is only about 5%, as illustrated in Fig. 1.

The conventional electric power is primarily dependent on fossil fuel combustion and contributes towards the emission of GHG. Therefore, the utilization of RER based generation systems in the electricity sector will directly reduce the CO_2 emission. The dependency of world's energy generation on fossil fuel is widely conceded as a cause of increased level of CO_2. Fig. 2 presents the world's energy dependency on fossil fuel, nuclear resources, and RER. The global cumulative contribution of fossil fuels in electric power generation is 68%, while RER have only 3% contribution in power generation mix, as shown in Fig. 2. The huge penetration of fossil fuels in energy generation is also a primary source of other harmful pollutants, such as Nitrogen Oxides (NO_x), Sulfur Oxides (SO_x), and other fine particulate (PM_{25}). The emission of GHG and other harmful pollutants need to reduced until year 2050, to save the environment. Thus, an urgent need is to reduce the dependency of power and transportation sector on fossil fuels.

The “Renewable Electricity” policy makers predict that RER in the

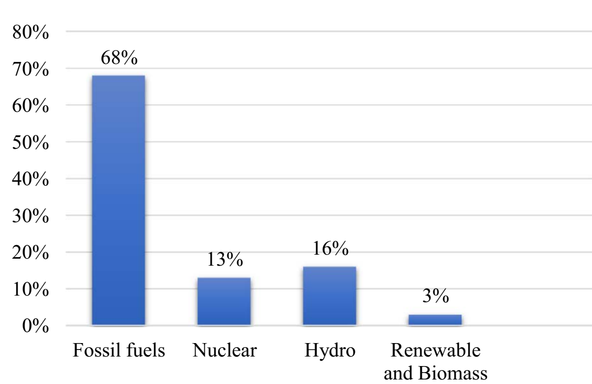

Fig. 2. World's energy dependency for electricity generation [10].

electricity sector will decrease the GHG by 80% till year 2050 in United States (US) [164]. The European Union (EU) commission proposed that 20% energy need must be fulfilled by utilizing RER sector till year 2020. The EU commission further proposed that transportation sector should utilize 10% RER as electrified vehicle in order to address the climate change. The other advantage of aforesaid electrified EVs with help in simple and economic integration of intermitted RER, by acting as distributed storage units. The technical report by NREL shows that PHEV significantly reduces the CO_2 emission [13]. The study in [12] presented a target of 50.7240 MMg CO_2 e/year by utilizing RER for generating 325 GW power and 90% EV penetration. Fig. 3 presents the aforementioned set target of CO_2 emission by EO-S-21-09 for year 2050 GHG emission. Fig. 3 also demonstrates that by utilizing RER in power and transportation sector will considerably reduce the CO_2 emission. In SG systems, by utilizing the RER and EV together will play a vital role in attaining a green and clean future electric grid. The electrification of transport vehicle, will act as an alternative technology towards a low carbon paradigm. For decarbonizing, the alternative technologies, such as (PHEV and EV must rely on RER [12]).

The full de-carbonization of the power and transportation sector is possible with RER penetration. The SG with its intelligent and smart coordinated system assists in achieving the reduced GHG target by flexibly allowing the huge penetration of the RER generation mix, EV, and V2G concept utilization [14]. Although the aforementioned surveys presented a complete overview of the SG, but they lack in aggregating the SG features from TE, environmental impact, and storage technologies in one study.

Many state-of-the-art surveys and reviews on the SG features exist within in the literature. Selected surveys are summarized in the Table 1. In Table 1, “*Y*” justifies the presence of features, while “N” represents that the feature is absent in the referred study.

In the light of above stated issues, the main contributions of our survey are:

- ***Objective 1:*** This survey provides qualitative analysis of key enabling technologies for TE in the SG scenario. The V2G implementation in SG is incorporated that offers better control of current and future environmental and economic problems in TE. Further, the EV technologies, such as: **(a)** BEV, **(b)** HEV, **(c)** PHEV, and **(d)** EREV are also briefly discussed. This survey explains on board and off board charging infrastructure of EV.
- ***Objective 2:*** The impacts of TE on SG, such as: **(a)** impact on SG load capacity, **(b)** impact on power quality, **(c)** impact on economy, and **(d)** impact on environment are thoroughly described in this survey. The V2G concept is elaborated that ensure the most efficient and attractive feature of transportation sector in the SG. Moreover, the challenges and issues in V2G technology are thoroughly discussed. The communication requirements of EV, namely: **(a)** WAN, **(b)** FAN, and **(c)** HAN are investigated.
- ***Objective 3:*** This survey illustrates the concept of energy storage technologies of EV in SG. Taxonomy on ESSs used in EVs powering applications is presented. Further, a detail study is included on all ESSs that are employed in EVs. Furthermore, the challenges and issues in these storage technologies are elaborated. The technical and economic benefits of energy storage technologies employed in SG are also presented.
- ***Objective 4:*** The current regulations, standards, and interfaces issues within SG are critically discussed referring to latest technical study. The SG standard recommended by IEEE, NIST, and ISO are highlighted. Finally, this survey presents the SG interface issues, such as: **(a)** communication interfacing issues, **(b)** power system interfacing issues, **(c)** DG issues, and **(d)** Micro Grid interfacing issues.

The rest of paper is structured as follows: Section 2 illustrates the transportation electrification, while charging infrastructure of the EVs

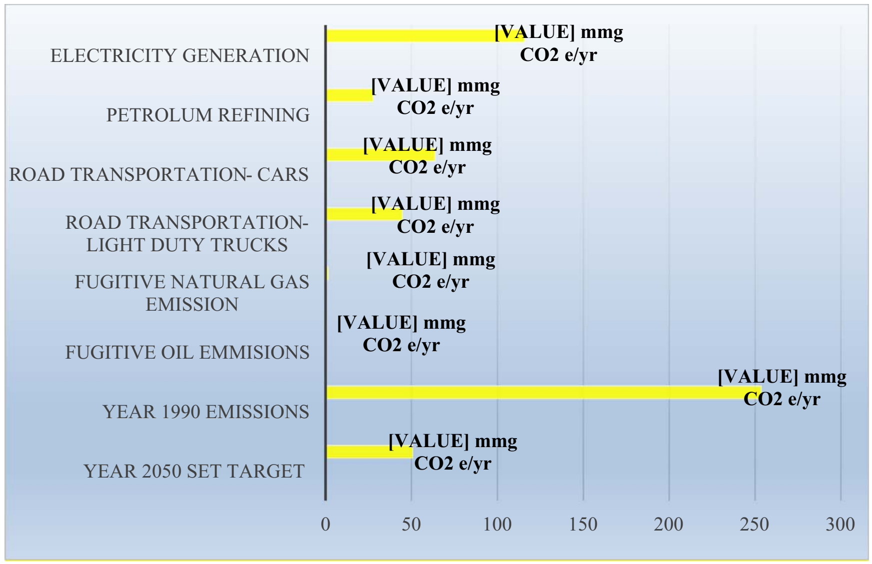

Fig. 3. Goal set by EO-S-21-09 for 2050 GHG emission.

is discussed in Section 3. Section 4 investigates the impact of EVs on the main grid, Vehicle- to- Grid (V2G), and communication requirements of EVs. Section 5 presents energy storage technologies deployed in EVs within SG. Current regulations, standards, and interfaces issues within SG are elaborated in Section 6. Section 7 concludes the paper with brief summary and proposal for future work.

2. Transportation Electrification (TE)

TE is gaining high popularity and attention during recent years promising with economic and environmental benefits. The transportation sector is mainly dependent on fossil fuel, such as oil. The crude oil consumption will increase about 54% in the transportation sector till year 2035. The IEA warns that oil price will face a substantial increase in coming decades [58]. Ultimately, there is a pressing need to transfer the transportation from crude oil to electricity [59]. TE appears a promising solution for the various challenges, such as geopolitical concern, fuel economy, energy security, and climate change. By the utilization of (V2G concept, TE is ready to deliver stored energy (in batteries)) to the electric grid [60].

Classifications of EV are: (a) Battery Electric Vehicles (BEV), (b) Hybrid Electric Vehicles (HEV), (c) Plug-In-Hybrid Electric Vehicle (PHEV), and (d) Extended Range-Electric Vehicle (EREV) [61]. Four types of EV are illustrated in Fig. 4. HEV is a combination of battery and traditional combustion engine. The battery is used to provide power for electric motor below speed of 40 miles per hour with zero emissions. The combustion engine will drive the car at higher speeds. PHEV is similar to HEV with additional feature of re-charging by plugging into an electric outlet. Increased fuel efficiency and increased environment friendly impact are distant features of PHEV, in comparison to HEV. BEV are fully operated by electricity. The combination of battery and features of re-charging by electric outlet makes BEV zero emission vehicles. Drivers must beware of BEV range, as its refueling is not as simple as approaching a nearest fuel station. EREV is a combination of BEV and PHEV with more improved fuel efficiency and reduced emissions.

TE also provides the ancillary services to the SG, such as regulation of voltage, frequency, and peak shifting [62]. The huge requirement for the energy storage system arises with the large penetration of RER owing to their intermitted nature [63]. TE in the context of V2G is the most suitable candidate for dynamic energy storage. Under the concept of VPP, TE can be controlled and aggregated [64]. TE on the other side poses many challenges to the power grid, such as in control, planning, and operation [65]. The large number of PHEVs and PEVs integration with the grid also pose a major challenge of power system stability and quality [66]. Advance control schemes and information and communication infrastructure will play a critical role in the complete establishment of TE [21].

3. Charging infrastructure of EVs

The most critical component for the EV is charging infrastructure. According to the report by MIT, the biggest challenge is to develop a nationwide charging infrastructure for EV rather than producing batteries at affordable cost [67]. The standards defined by SAE for EV, is shown in Fig. 5.

The standard associated charges and cords are categorized in three levels for EV. The three levels for EV charging are defined based on power and voltage values. The defined charging level are not universal, but varies according to locations [17], for example, the standard defined for Europe is by International Electrotechnical Commission IEC 61851, while SAEJ1772 is the American standard for EV. The aforementioned two standards cover the electrical, general physical, communication protocol, and performance requirements for EV charging. The standard SAEJ1772 defines that electrical vehicle supply equipment has three functions, such as rectification, voltage regulation, and coupler (physical coupling media for charging the vehicle). The standard SAEJ1772 also ensure several levels of shock protection even in wet conditions. The standard SAEJ2293 entrenched the EV requirements and the off-board charging supply equipment utilized for transferring the electrical energy from electric grid to EV. The standard SAEJ2836 covers the communication requirements for integrating the PEV with the electric grid for energy transfer, energy storage, and other applications. The communication requirement of PEV and DC-Off board charger is covered by standard SAEJ2847, while both On-Board and Off-board charging practices are covered by SAEJ2894 standard. Table 2 presents the characteristics defined by the standard SAE 1772 for AC/DC level [21].

Level 1 and Level 2 convert the AC power into the DC power through vehicle on-board charging. Level 3 is referred as “fast charging”, and provides DC power through Off-board charging. The charging time for PHEV/PEV varies between 3–20 h. Level 1 consumes relatively large time. It is suitable to use Level 1 for overnight charging, for residential charging purpose. Level 2 facilitates both private and public charging of PHEV/PEV. Level 3 is a fast charging, thus suitable for commercial and public charging. The power, voltage, current

Table 1
Summary of some generic state-of-the art surveys.

Ref	EV	EI	SS	V2G	On-BC	Off-BC	FC	TBSS	EBSS	CREVs	OTEVs	CIEVs	IG
[15]	N	Y	N	N	N	N	N	N	N	N	N	N	N
[16]	N	N	N	N	N	N	N	N	N	N	N	N	N
[17]	Y	Y	N	Y	N	N	N	N	N	Y	Y	Y	N
[18]	N	N	N	N	N	N	N	N	N	N	N	N	N
[19]	N	Y	Y	N	N	N	N	N	N	N	N	N	N
[20]	Y	N	Y	N	N	N	N	N	N	N	N	N	N
[21]	Y	Y	N	Y	N	N	N	N	N	Y	Y	Y	Y
[22]	N	N	Y	N	N	N	N	N	N	N	N	N	N
[23]	N	Y	N	N	N	N	N	N	N	N	N	N	N
[24]	N	N	N	N	N	N	N	N	N	N	N	N	N
[25]	N	N	N	N	N	N	N	N	N	N	N	N	N
[26]	Y	Y	N	N	N	N	N	N	N	N	N	N	N
[27]	Y	N	N	N	N	N	N	N	N	N	N	N	N
[28]	N	Y	N	N	N	N	N	N	N	N	N	N	N
[29]	N	N	N	N	N	N	N	N	N	N	N	N	N
[30]	N	N	N	N	N	N	N	N	N	N	N	N	N
[31]	N	N	N	N	N	N	N	N	N	N	N	N	N
[32]	N	N	N	N	N	N	N	N	N	N	N	N	N
[33]	N	N	N	N	N	N	N	N	N	N	N	N	N
[34]	N	N	N	N	N	N	N	N	N	N	N	N	N
[35]	N	N	N	N	N	N	N	N	N	N	N	N	N
[36]	Y	N	N	N	N	N	N	N	N	N	N	N	N
[37]	N	Y	N	N	N	N	N	N	N	N	N	N	N
[38]	Y	Y	N	N	N	N	N	N	N	N	N	N	N
[39]	N	N	Y	N	N	N	N	N	N	N	N	N	N
[40]	N	N	N	N	N	N	N	N	N	N	N	N	N
[41]	Y	Y	N	N	N	N	N	N	N	N	N	N	N
[42]	Y	N	Y	N	N	N	N	N	N	N	N	N	N
[43]	N	N	N	N	N	N	N	N	N	N	N	N	N
[44]	Y	N	N	N	N	N	N	N	N	N	N	N	N
[45]	N	N	Y	N	N	N	N	N	N	N	N	N	N
[46]	N	Y	N	N	N	N	N	N	N	N	N	N	N
[47]	Y	N	N	N	N	N	N	N	N	N	N	N	N
[48]	N	N	N	N	N	N	N	N	N	N	N	N	N
[49]	N	Y	N	N	N	N	N	N	N	N	N	N	N
[50]	N	N	Y	N	N	N	N	N	N	N	N	N	N
[51]	N	N	N	N	N	N	N	N	N	N	N	N	N
[52]	N	N	N	N	N	N	N	N	N	N	N	N	N
[53]	Y	N	Y	Y	Y	Y	N	N	N	N	N	N	N
[54]	N	Y	N	N	N	N	N	N	N	N	N	N	N
[55]	N	N	N	N	N	N	N	N	N	N	N	N	N
[56]	N	N	N	N	N	N	N	N	N	N	N	N	N
[57]	N	N	N	N	N	N	N	N	N	N	N	N	N
OS	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Abbreviations: EV: Electrical Vehicles; EI: Environmental Impact; SS: Storage System; V2G: Vehicle to Grid; Fuel Cell: FC; On-BC: On Board Charging; Off-BC: Off Board Charging; OS: Our Survey; TBSS: Technical Benefits of Storage Systems; EBSS: Economic Benefits of Storage Systems; CREVs: Communication Requirement of EVs; CIEVs: Charging Infrastructure of EVs; IG: Impact on Grid; OTEVs: Optimization Techniques in EVs.

ratings, and phase requirements are demonstrated in Fig. 6. The standard IEC 61815 is derived from SAEJ177 adopted to Asian and European line voltage levels. The IEC 61815 possesses three modes of operation corresponding to three level of SAEJ1772. The Mode 1 of IEC 61815 relates to residential charging with unique grounding requirements, as the current is slightly higher in this standard, compared to SAEJ1772. The Mode utilizes the same voltage levels as Mode 1 with 32 A of current, while Mode 3 allows current up to 250 A (fast charging).

The EV charging infrastructure uses two basic coupling methods, such as conductive coupling and inductive coupling. In conductive coupling, vehicles are plugged into an appropriate electric outlet for charging (traditional coupling). The inductive coupling, however, utilizes magnetic coupling concept rather than direct-wired connections. Two separate windings (coils) are used in inductive coupling of EVs. The one coil is in paddle that fits into the socket, while the other coil is mounted inside the EV. The chargers for EV may be located on-board (inside the vehicle) or off-board (outside the vehicle). The on-board charging infrastructure has limitations in output power ratings, a consequence of size and weight restrictions. The EV with on-board charging infrastructure can be easily charged with an electric outlet anywhere. The associated limitations with the off-board charging are the fixed charging locations. Fig. 7 and Fig. 8 presents the On-board and Off-board charging, respectively.

4. Transportation electrification impact on Smart Grid

This section presents the TE impacts on SG. The V2G technology and communication requirements of EVs are also elaborated in this section. TE is considered to be pertinent feature of future SG. The ‘6’ pertinent perspective of intelligent TE in SG are presented, such as: **(a)** vehicles, **(b)** travelers, **(c)** communications, **(d)** systems, operation, and political, **(e)** infrastructure, and **(f)** social, economics, and political [168]. The transition from typical transportation to TE has posed the management issue to control the interaction of more number of EVs. To manage the large number of EVs, there is a pressing need to introduce aggregator as a middleman between SG and EVs. Further the aggregator provides ancillary service as it is a large source of generation. The EVs interactions within SG provide additional services, such as: **(a)** voltage control, **(b)** frequency regulation, **(c)** spinning reserve, and **(d)** non-spinning reserves [68]. The replacement of PEVs on typical ground transportation will require 8% additional generation

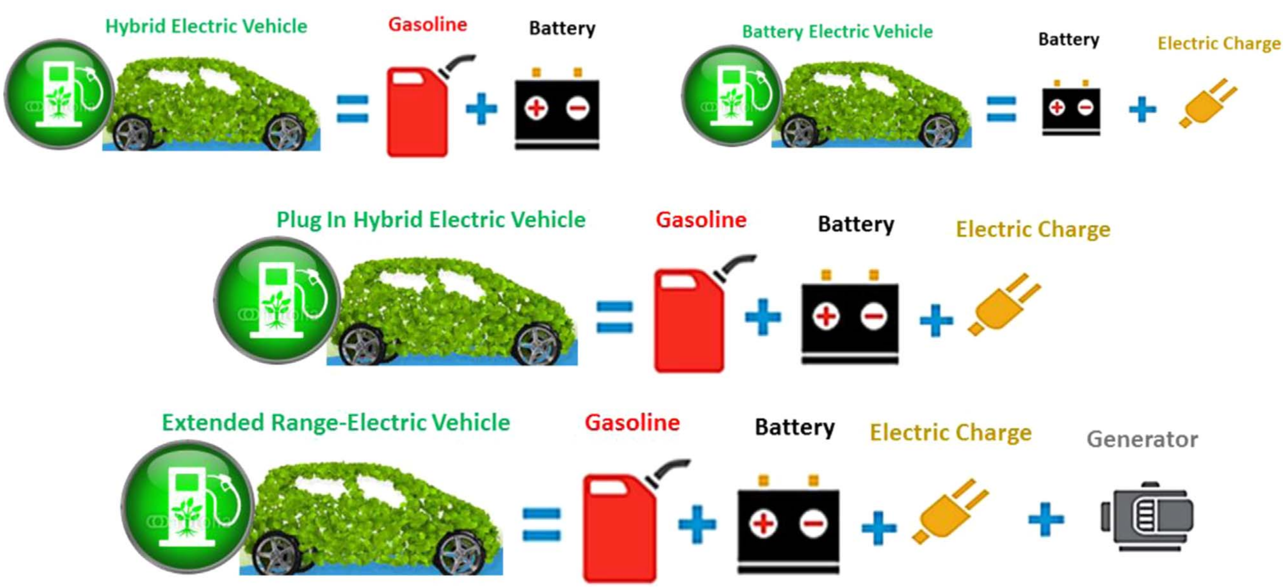

Fig. 4. Types of EV [61].

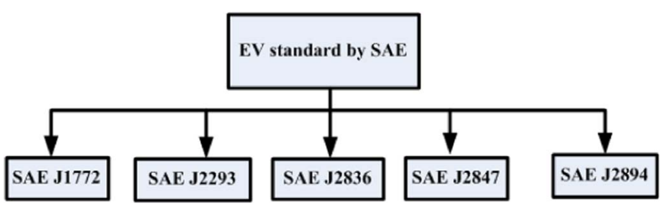

Fig. 5. Standards defined by the Society of Automation Engineers (SAE) for EV [17].

capacity but despite the small increase in power generation, the uncontrolled charging behavior of PEVs will overload the SG. The impacts of TE specifically PEVs on SG are surveyed in [170].

The EVs interaction and RERs integration into SG assist in reduction of CO_2 emission from TE sector and generation sector [92]. The frequency regulation by aggregating the V2G concept is proposed. The optimal charging control of EVs is computed using dynamic programming based on advance optimization problem [69]. The implementation of V2G technology improved the adoption rate of TE. The employment of smart charging algorithm for EVs regulation by changing EVs charging rate around a preferred operating point is proposed [70]. The authors in [71] analyzed the economic and environment friendly integration of PHEVs into TE sector. The PHEVs possess storage capability that assist in useful integration of wind energy into SG [72]. The TE incorporates some serious impacts on SG, such as economy impact, energy system impact, environment impact, and EVs charging impact [92,165]. Further, the TE poses some issues, namely: **(a)** battery lifetime, **(b)** safety, **(c)** optimal sizing, **(d)** charging infrastructure, and **(e)** business models [165].

4.1. EVs charging impacts on SG

The EVs charging impacts on SG are classified as: **(a)** Impact on SG load capacity, **(b)** Impact on power quality, **(c)** Impact on economy and **(d)** Impact on environment. Further, these impacts are discussed in following sub-sections.

4.1.1. Impact on SG load capacity

The impacts of TE especially PHEVs (the next big thing considered in TE market) on distribution network are analyzed. Considering the aspects of PHEVs, such as: **(a)** charging time, **(b)** PHEVs integration, **(c)** driving patterns, and **(d)** charging characteristics; the impacts of PHEVs on distribution network are determined [73]. The EVs possess pertinent capacity of accommodating RERs having reduced cost of backup generation capacity and reduced balancing cost. These benefits of EVs interaction within SG are possible through advanced stochastic analytical framework. The major problem created by EVs is "disorder charging" that may increase the peak load demand [73]. The impacts of '1' million EVs slightly affect the regular electricity demand almost by 1% [74]. The study predicted that 42 million EVs will pose a great challenge, demanding 92% more electric supply. The aforementioned challenge is not only associated with disorder charging but even encountered during "orderly charging". The orderly charging strategy

Table 2
Characteristics defined by standard SAE 1772 for AC/DC level.

Ratings	AC			DC		
	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3
Voltage	120 V	240 V	–	200–500 V	200–500 V	200–600 V
Current	12 A 16 A	80 A	–	< 80 A	< 200 A	< 400 A
Power	1.4 kW 1.9 kW	19.2 kW	> 20 kW	40 kW	100 kW	240 kW
Charging Time	PHEV 7 h BEV 17 h	PHEV 3 h BEV 7 h	Under development	PHEV 22 min BEV 1.2 h	PHEV 10 min BEV 20 min	Underdevelopment
Phase	Single Phase	Both single phase and three phase	Under development	Three Phase	Three phase	Underdevelopment

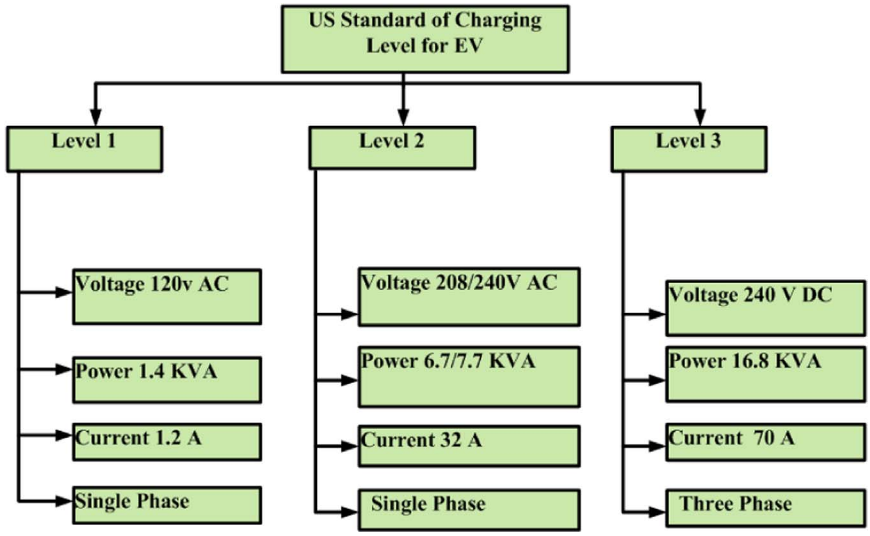

Fig. 6. US standard of EV charging level [17].

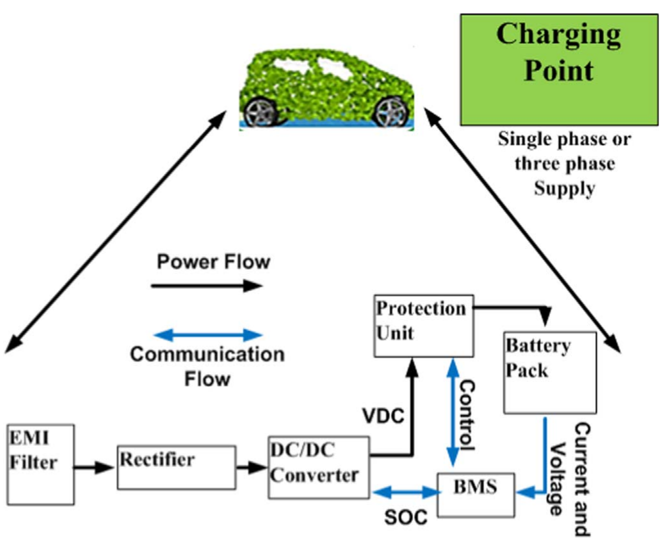

Fig. 7. On-Board Charging of EVs [21].

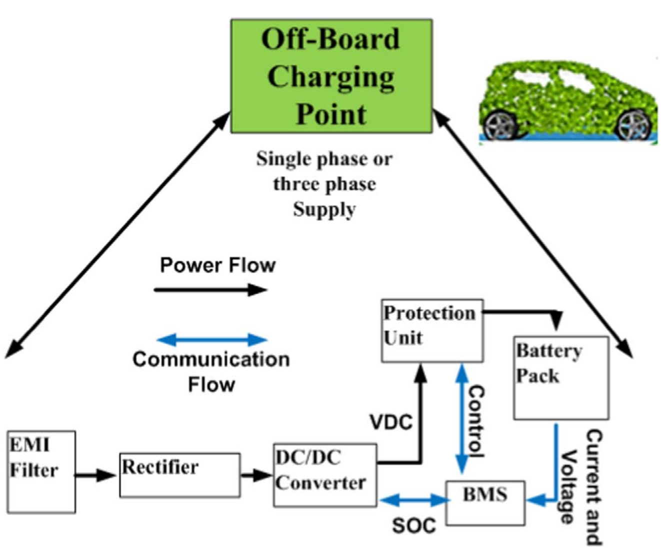

Fig. 8. Off -Board Charging of EV [21].

will have a positive impact in case of RER based integrated energy recourses, offsetting their intermitted nature up to some extent. The flexible charging requirements and network energy balancing in EVs ensure DSM for reliable operation of SG [75]. The Impact of PEVs on SG distribution network and SG losses are investigated using various levels of PEVs penetration in SG [76]. The unconstrained EVs charging degrade the performance, required capacity, and efficiency of SG, while the smart charging plan of EVs assist in leveling of load capacity and avoid installation of extra capacity. The noticeable impacts of EVs on SG include: **(a)** increased power quality issues, **(b)** increased wear on transformers, and **(c)** transmission bottlenecks [92].

4.1.2. Impact on power quality

The EVs charging greatly affects the power quality of the SG. The harmonics effects, distribution transformers effects, fault current effects, and line losses effects may incorporate due to EVs charging [76–82]. The V2G technology driven improves power quality by providing: **(a)** active power regulation, **(b)** reactive power support, **(c)** tracking of intermittent RERs, **(d)** current harmonic filtering, and **(e)** load balancing [78]. The over voltages, transformer overloading, and increased line losses problems are smartly controlled by utilizing the intelligent control schemes for effective monitoring of EVs charging and EVs discharging [83]. The authors in [84] illustrated the disorder charging of EVs. The result of this study showed that the disorder EV charging disturbed the node voltage and damaged the network lines. The EVs interaction in SG resulted in degrade power quality and SG losses [85]. Further, the harmonics effects due to EVs interaction in SG were investigated and discovered that total current harmonic distortion of 20–45% resulted due to charging of EVs. Thus, a need for harmonic control of EV charging is a critical requirement of the EV charging infrastructure. The EVs charging impacts on SG power quality are probabilistically evaluated using Monte Carlo. The Monte Carlo results revealed that battery EV causes more overload on SG distribution transformer, compared with PHEVs [171].

4.1.3. Impact on economy

The economic impacts of EVs in SG are evaluated by involving the EV owner and SG system. The advancement in battery storage technology will improve the EVs economic lifecycle. Economic analysis of various vehicles various EVs are comparatively analyzed by incorporating battery storage technology and enhanced efficiency of electric motors. The TE sector economy will drastically improve by implementation of V2G technology. Moreover, the employment of smart charging infrastructure of EVs has improved the economy of TE sector by saving considerable amount of energy within SG [92]. The massive interaction of EVs possesses capability to reduce CO_2 emissions and fossil fuel consumption. The V2G technology offer useful utilization of RERs in TE sector. But the charging of million EVs overloads SG and results in economic impacts. Further, to visualize the impacts of EV on economy, a comparatively analysis of controlled charging strategy versus uncontrolled charging strategy is performed [172]. The EVs charging impact on economy is discussed in [73]. The focus on the minimization of SG transmission losses towards optimal investment is one of the core research issues [73,86–88]. In [86], the authors described that increasing the number of EVs for charging increases the transformer losses. The increase in EVs will lead towards shorter life span of the transformer. For example, in Los-Angeles and Vermont, 15 kVA and 25 kVA transformers got burn due to EV charging behavior. Therefore, the charging infrastructure of EV needs special consideration.

4.1.4. Impact on environment

The employment of EVs will transform the transportation sector to environment friendly atmosphere by reducing the CO_2 emission up to considerable level. The authors in [89] demonstrated that EVs will reduce the emission of CO_2 by 1–6% by the end of year 2025 and 3–28% by the end of year 2030. The CO_2 emissions are greatly reduced by incorporating EVs interactions within SG. Further, the massive interaction of EVs in V2G mode assists in provision of clean and safe energy. The EVs also provide clean environment by eliminating the dependency on fossil fuel that release high CO_2 emissions into atmosphere [89]. The study in [90] discussed the EVs impact on the environment and described 85% emission reduction of CO_2 gas. The EVs interactions are advantageous over RERs integration into SG due to provision of voltage regulation services. The V2G technology in TE sector offer clean energy to SG that incorporates less environmental impacts on SG [91]. CO_2 emissions are of great concern while evaluating the environmental impacts of EVs interaction within SG system. Compared with internal combustion engine, the efficient electric motor in EVs assist in reduction of CO_2 emissions and introduce less impact on environment. The EVs impact on environment in various countries is evaluated in [92].

4.2. Vehicle-to-Grid (V2G) technology

The increased energy crisis and environmental concerns paved the way for adoption of EVs over typical transportation that is based on internal combustion engine. The V2G concept in TE assures bidirectional power flow between EVs and SG. The V2G technology provides numerous services to SG, such as: **(a)** reactive power compensation, **(b)** peak load shaving, **(c)** spinning reserve, **(d)** SG regulation, and **(e)** load leveling. Moreover, the benefits, challenges, and framework of V2G technology are reviewed in [166,167]. In TE sector, V2G is the promising solution for feeding the surplus energy back to the SG during high peak demand period. The V2G technology is proposed by Amory Lovins in 1995 and further research is carried out by Professor William Kempton [91,92]. The V2G technology that is technical aspect of EVs interaction within SG has advanced according to latest technical and literature reports [93]. The V2G EV capability is employed in distributed EV coordination mechanism to minimize variation in SG load [98].

Electric cars in V2G technology act as distributed storage units. The power transfer between vehicle and SG requires an efficient exchange of information, such as statistical information, technical data, and state-of-charge (SOC) of batteries [17]. The EVs integration with bidirectional power flow assists in control integration of RER with the SG [93]. The SG in normal condition will send power back to the EV during the period of increased power generation by solar, wind, and other RERs. The EV will behave as distributed storage unit that helps to reduce the effects of RERs intermittency. The efficient and cost effective operation of the EV is made possible by effectively utilizing the control schemes for optimal charging and discharging. To get a maximum profit from EVs, there is an emergent need to intelligently schedule the charging of EV. The charging optimization without V2G and with V2G is comparatively analyzed using computer software. The optimized charging control with V2G achieved better performance results by reducing the peak demand, compared to optimized charging control without V2G [101]. Due to rapid deployment of V2G technology in EVs, the V2G aggregator is introduced that provide additional frequency regulation services. Further, the EVs owners demand is met by incorporating optimal dispatching strategy of V2G aggregators [173].

The '3' consistent scenarios namely: **(a)** fossil, **(b)** average, and **(c)** green for V2G development and analysis are incorporated for future SG balancing and stability [169]. The technique of cross impact analysis is incorporated for future prediction of V2G technology implementation [169]. The reactive power compensation capability of V2G driven EVs is attractive feature in TE, because this property enable the full battery charging and avoid the exchange of active power, thus resulting in decreased overload on SG [174]. The integration of RERs into SG causes voltage fluctuations, these fluctuations are then controlled by the battery charging of V2G. Moreover, the battery life of V2G driven EVs can be enhanced using smart energy management system [175]. To ensure energy transfer in V2G and vehicle to vehicle, an optimal EV charging scheduling technique is incorporated. These scheduling techniques in SG ensure consumer satisfaction and better energy utilization, compared with existing power grid [178].

The optimal scheduling of charging and discharging of the EVs require proper utilization of optimization techniques, such as Binary Particle Swarm Optimization (BPSO), Discrete PSO (DPSO), linear programming, dynamic programming, and Q-learning algorithms. The augmented optimal power flow and charging of EVs model is built in IEEE 14 bus system. The result for this joint model maximizes the performance of the system, thus maximizing the cost of charging and generation, using a non-convex dynamic optimization problem. The aforementioned joint model can be employed for more complicated charging problems, incorporating additional constraints. The AMI and VPP assist in smart interactions of EVs within SG. The multi-layer framework is also developed for the realization of the V2G concept. The optimal battery charging operation plays a critical role in the PHEVs battery life. Fig. 9 illustrates the smart and optimum charging infrastructure for EVs in SG under V2G paradigm.

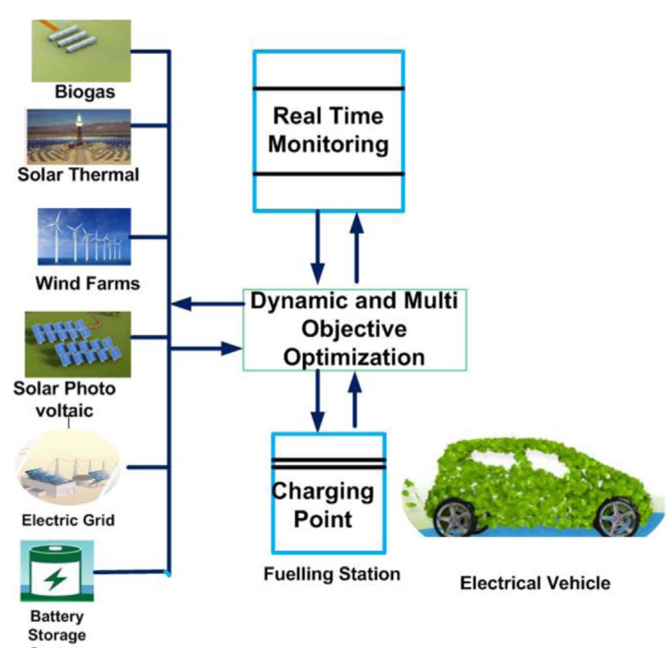

Fig. 9. The smart and optimum charging infrastructure for EVs in the SG under V2G concept [17].

Table 3
Charging techniques for PHEVs with associated research problems.

Ref.	Operational mode	Problem	Suggested Techniques
[94–96]	Unidirectional	Synchronized charging of PHEVs	Techniques used such as ● RT-SLM, ● Optimization based structure ● Optimized algorithms for charging
[97]	Unidirectional	Function of EV charging supplier	Optimization Technique
[98]	V2G	Scheduling time for charging discharging of PHEVs V2G effects on grid	Optimization Technique such as, ● Binary Particle Swam Optimization (BPSO)
[70], [99–109]	V2G	Charging and Discharging control of PHEVs in V2G for peak voltage reduction. Improved Cost and charging time	Techniques such as, ● Q-learning algorithm, ● Fuzzy based control structure, ● Linear approximation model ● Quadratic approximation model, ● BPSO, ● Discrete and continuous PSO, ● Dynamic programming, ● Optimal algorithm, ● Markov chain
[110]	V2G	Exploitation of PHEVs parking lot	● Real time current controlled structure for parking lot.
[111]	V2G	Impact of various battery charging rates of PHEVs on power quality	● MATLAB Based techniques ● Decoupled harmonic power flow techniques
[112]	Charging control	Charging schedule for PHEVs	● Combined charging-OPF optimization based technique
[113]	Charging control	Tradeoff during implementation of different Load control techniques of EVs	● Technique such as, TCOPF
[114]	Charging control	Exploitation of surplus distribution capacity	Techniques such as, ● Queuing theory, and ● Statistical analysis
[115]	Charging control	Recharging Allocation for EVs	Techniques such as, ● Voronoi and ● priority order circular
[116]	Charging control	Integrated structure of EVS through AMI and VPP	Method utilized such as, ● AMI architecture
[117]	Charging control	V2G concept Implementation	Techniques such as, ● PSO and ● Multilayer framework
[118–121]	Online mechanism Models, such as Game theoretic	PHEVs charging schedule matching	Methods such as, ● Online mechanism, ● Decentralized smart charging structure ● MAT sim, ● Nash certainty
[122,123]	Optimized battery charging	Reduced battery de-gradation of PHEVs	Techniques such as, ● BPSO and ● NSGA-II,
[124]	Optimized battery charging	Improved Cost of energy Improved battery aging cost for PHEVs	Optimization technique such as, ● Genetic algorithm

The charging trajectory of PHEVs should follow the optimum charge trajectory to achieve a longer battery life. Table 3 presents various charging techniques for PHEVs with associated research problems [93].

The participation of V2G within SG provides compensation for intermittent nature of RER and SG economy. The V2G lacks effective implementation in real-time because of communication bottlenecks and unproven economical and business models for EVs. The other issue in the delayed implementation of V2G is the high cost of batteries. The biggest difficulty in developing batteries is poor understanding of battery technology, for example, change in one part of the battery introduces many new unforeseen problems, thus requires more research and testing. The battery technology is also incapable of frequent switching between charging state and discharging state. The largest capacity battery is produced by Tesla with 85KWh. Various companies for EVs and battery capacities are presented in Fig. 10.

4.2.1. Challenges and Issues in V2G Technology

The V2G technology has improved the role of TE in SG by providing additional services. However, the interactions of million V2G driven EVs posed some serious challenges and issues that must be addressed and evaluated afore the implementation of V2G technology in TE sector. These issues and challenges are discussed in this sub-section based on latest technical study and literature surveys. The ‘2’ prominent issues persist in V2G EVs, such as: **(a)** charging and discharging strategy and **(b)** bidirectional charging. These issues are caused due to harmonic pollution and load fluctuation [176]. The V2G driven EVs act

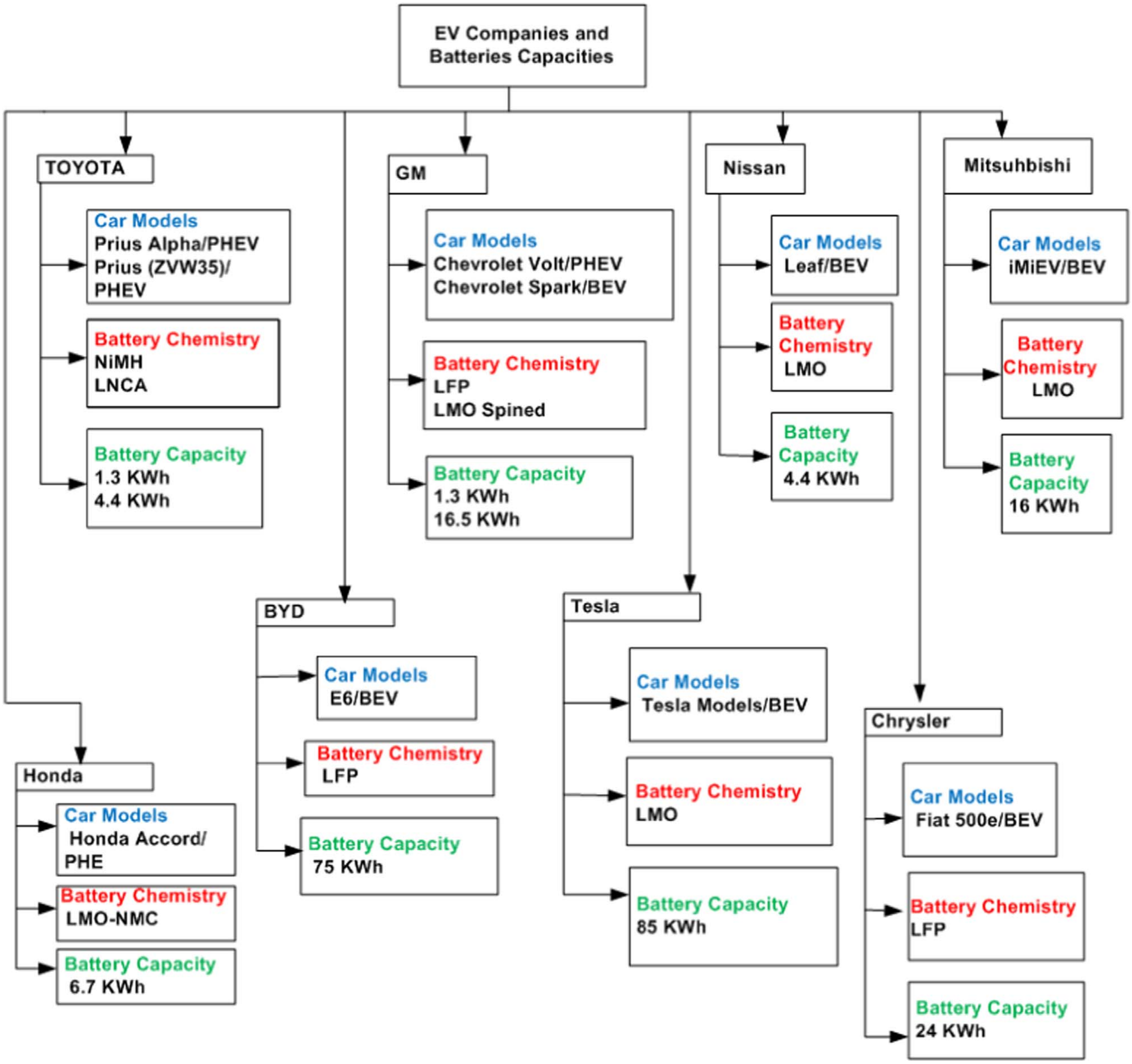

Fig. 10. Companies for EVs with produced battery capacities [21].

as distributed energy source during peak load demand. The bidirectional communication and power flow in SG support the interaction of V2G driven EVs, and also provide easy access to cyber attackers. Therefor the privacy preservation problem in V2G network is analyzed using various approaches and techniques. These privacy preservation techniques address various privacy preservation problems in V2G EVs [177]. The energy resource scheduling in distribution networks is vital problem in SG integrated TE sector. The V2G concept in TE provides optimal scheduling for distributed energy resources [107].

The transition to RERs and TE in SG has brought new challenges to accommodate massive penetration of V2G driven EVs in SG. The required communication system and infrastructure are major challenges that need high attention while dealing with V2G technology implementation [179]. The macroscopic interaction related challenges in V2G driven EVs, such as: **(a)** V2G communication security and reliability, **(b)** V2G modeling objectives, **(c)** architecture, and **(d)** integration software were discussed. Further, the technical aspect challenges in V2G driven EVs including: **(a)** physical layer, **(b)** MAC layer, **(c)** V2G communication requirement, **(d)** security threats and authentication protocol, **(e)** routing protocols, and **(f)** wireless charging were evaluated. Moreover, various open research issues in V2G driven EVs were elaborated in [180].

4.3. Communication requirements of EV

The massive penetration of EVs into SG has posed serious challenges that include: **(a)** SG infrastructure, **(b)** communication architecture, and **(c)** control system [21]. In this sub-section, the communication requirements for EVs interaction are discussed based on latest technical reports and surveys. The advanced communication architecture and smart metering system are reviewed for efficient and reliable integration of EVs in SG [21]. The key enabling technologies for real time implementation of EV and V2G are efficient bi-directional power flow, two-way communication, and information exchange between SG and EVs. The communication requirements of EVs are classified into three categories as: **(a)** Wide Area Network (WAN), **(b)** Field Area Network (FAN), and **(c)** Home Area Network (HAN). The utilization of these communication networks depends on the charging location of EVs. The FAN and HAN possess application for a residential and public parking charging statics. The possible communication protocols for EVs include: **(a)** AMI, **(b)** SCADA, **(c)** cellular communications, and **(d)** other wireless communication technologies. The communication and computation requirements are adopted by EVs aggregators. Further, the various charging scenarios of controlled EVs are evaluated in [181].

The state-of-the-art communication technology namely Wireless Access in Vehicular Environment (WAVE) is evaluated for V2G applications in SG. The challenges associated with EVs are also incorporated [182].

The mobility of huge number of EVs within SG can be controlled through scalable and robust communication system infrastructure to support bidirectional power flow and duplex communication between SG and EVs. Further, the incurrence of communication delays in EVs aggregation system and load frequency control loop during EVs interaction within SG will degrade the stability and dynamics of SG. To control the aforementioned uncertainties, various schemes for load frequency control are deployed [183]. The charging communication between charging infrastructure and PHEVs based on ISO 15118 Standard is proposed in [184]. The V2G driven EVs are capable to supply surplus energy to SG and require duplex communication and bidirectional power flow control within SG. The innovative energy management schemes assist EVs in controlling the abovementioned requirements [185].

The utilization of wireless communication technologies for EVs demands for special consideration towards security issues. The user privacy must be kept confidential. The communication system infrastructure for EVs must immune towards unauthorized access. The security challenges become more complicated in a public charging environment. The privacy preservation in TE is achieved using various privacy preservation strategies [177]. The current security protocols used in EVs are cryptography and AES 128-bit length block cipher developed by NIST in 2002. The 3 G cellular network uses A5/3 block cipher KASUMI. The GSM network uses Rijndael-based Algorithm for EVs. Fig. 11 presents some wireless communication technologies for V2G concept realization.

5. Energy storage technologies within Smart Grid

This section presents energy storage technologies deployed for EVs interaction and RERs penetration within SG. The challenges and technical Issues in energy storage technologies are analyzed. Finally, the technical and economic benefits of EVs energy storage technologies are presented.

The electric energy shows a marked increase in consumer demand exceeding by **20 × 10³ TW/h** per year. The world's energy generation is mainly dependent on fossil fuels with considerable environmental impact, increasing at the rate of 3% per year [125,126]. Associated environmental concerns and depleting nature of fossil fuels appeal for gradual replacement of conventional resources with RERs. Currently, RERs contributes only 4% in electricity production from the wind and solar, excluding hydropower. The contribution from RERs is estimated to increase by 25% till year 2030 [127].

The interaction of the RERs with the SG requires special attention in control, monitoring, management, and design of SG [128]. The RERs are highly uncertain and dependent on weather condition and pose a major challenge of SG stability and SG reliability. The aforementioned challenges, however, can be prevented by utilizing compensating measures, such as energy storage technologies [129,130]. The massive penetration of RERs and EVs demands for energy storage systems (ESSs) that provide flexibility and back-up generation within SG. Further, ESSs assisted in controlling the intermittency of RERs up to considerable extent and improved the overall efficiency of SG. The ESSs present critical link between energy demand and supply. The implementation of ESSs motivates RERs penetrations into SG [135]. ESSs are the key technologies that are employed for reliable and efficient operation of RERs and EVs penetration within SG [130]. The SG interfaced ESSs is best solution to **(a)** control the intermittency of RERs, **(b)** improve SG power quality, and **(c)** energy management within SG. In SG, the electrochemical storage systems are of great concern due to the remarkable features, such as: **(a)** efficiency, **(b)** flexibility, and **(c)** scalability [134].

The energy storage technologies store the surplus energy from RER during the period of higher production. The surplus stored energy is sent back to the SG or consumers during peak demand period [131,133]. The utilization of various types of energy storage technologies within SG and integration method of ESSs are elaborated in [132]. The energy storage technologies provide an economical way to store and use energy rather than upgrading power plants. In particular, the storage technologies for a remotely located island power system need special attention. The storage technologies must be able to withstand the large charging/discharging cycle. The long-life span is also a critical requirement of the storage technologies [134].

ESSs plays pivotal role in RERs and EVs interactions within SG and is hot research topic nowadays. Various smart techniques and algorithms are employed in ESSs to facilitate the RERs and EVs integration within SG. In this regard, various comprehensive techniques and methodologies are presented to control operation of electrochemical batteries for useful integration of RERs within SG [187]. The intermittency and instability of RERs is controlled using hybrid energy storage system based on smart energy management algorithm. The simulation results of aforementioned system were verified and tested.

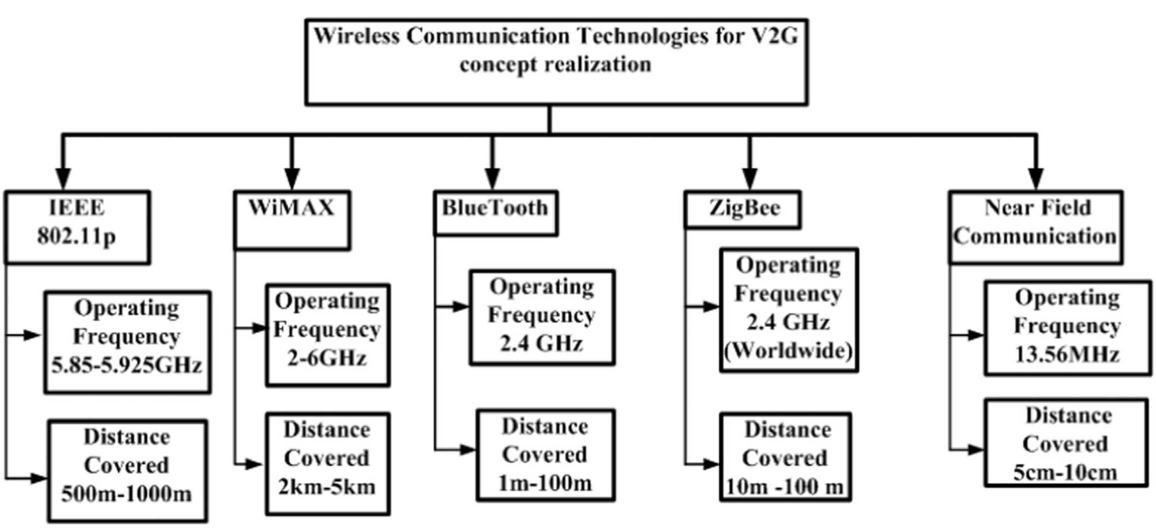

Fig. 11. Wireless Communication Technologies for V2G concept realization [21].

Table 4
Typical features of storage system.

Features				**ECES**								
	PHES	**SMES**	**EDLC**	**Advance Lead Acid**	**Sodium Sulfur**	**Sodium-Nickel-Chlorine**	**Lithium ion**	**Fuel Cells**	**Redox Batteries**	**FES**	**TES**	**CAES**
Power MW	3000	400	100	10–40	34	1	16	1	2–100	20	20	3000
Energy MWh	10^4	10	10^2	10^0 – 10^1	10^1	6	20	> 10	6–120	5	10	10^3
Energy Density Wh/kg	0.3	1.2	10–30	25–50	150–120	95–120	100–200	800–1300	10–50	11–30	70	10–30
Discharging Time	10 h	Seconds	Seconds	10^0 h	10^0 h	10^0 h	10^0 h	> 10^0 h	10^0–10^1 h	Minute	Hours	10^0–10^1 h
Response Time	Minute	Milli seconds	Milli seconds	Milli seconds	Second	Seconds	Milli seconds	Milli seconds	Milli seconds	Milli seco-nds	Minute	Minute
Round Trip Efficiency	70–85%	Data not available	95%	75–85%	85–90%	85%	95%	35–45%	85%	85%	Data not available	60–75%
Life Cycle *10^3	20	Data not available	500	3	4.3–6	4–8	4–8	50	> > 13	10^1 – 10^2	10	30
Capital Cost [$/KWh]	10–350	Data not available	4600	130	550	600	600	> 10000	900	2400	5000	130–550

The use of smart energy management algorithm for hybrid energy system assisted in reducing the intermittence and instability of RERs [186]. Table 4 represents the typical features of ESSs [134].

5.1. Taxonomy of energy storage systems in EVs

The classification of ESSs in EVs include: **(a)** electrical, **(b)** electrochemical, **(c)** mechanical, **(d)** thermal, **(e)** chemical, and **(f)** hybrid. Based on composition and formation of materials, ESSs in EVs are categorized into different types. The taxonomy of ESSs employed in EVs is illustrated in Fig. 12 [188].

The common ESSs employed in EVs powering application incorporate: **(a)** secondary electrochemical batteries, **(b)** fuel cells, **(c)** Ultracapacitors, **(d)** flywheel, **(e)** superconducting magnetic coils, and **(f)** hybrid [188]. The detail study on ESSs in EVs is conducted in following sub-section.

5.2. Energy storage technologies associated with EVs interactions within SG

Electrical energy storing capability is major obstacle in development of EVs interaction within SG. To properly manage the EVs interaction within SG, various techniques for ESS development in EVs are incorporated [133]. The V2G driven EVs possess the property to feed surplus energy back to SG. Therefore, there is a pressing need to introduce ESSs to store surplus energy and feed that extra energy to SG during high peak demand period. Further, the ESSs incorporation in EVs reduces the voltage fluctuation caused by intermittent RERs integration in SG. The EVs storage systems store the RERs output power and in return provide smooth and reliable energy to SG. The introduction of useful and efficient penetration of EVs within SG requires advanced ESSs. The ESS deployment in TE and SG applications is presented [130]. The ESS driven EVs are the emergent technologies that substitute fossil fuels. To encourage the EVs participation in SG, high performance energy storage technologies are needed. The high discharge time of ESSs assist in useful interaction of EVs within SG [188].

The increased requirement of EVs applications are met by employment of efficient ESSs. Therefore, understanding the concept and performance of ESSs is essential. The review of various ESSs and their application in EVs are presented [189]. The promising key technology of efficient ESS for EVs include '3' aspects: **(a)** power electronics, **(b)** power source, and **(c)** power flow control strategy [189]. The state of the art energy management control strategies, supervision control

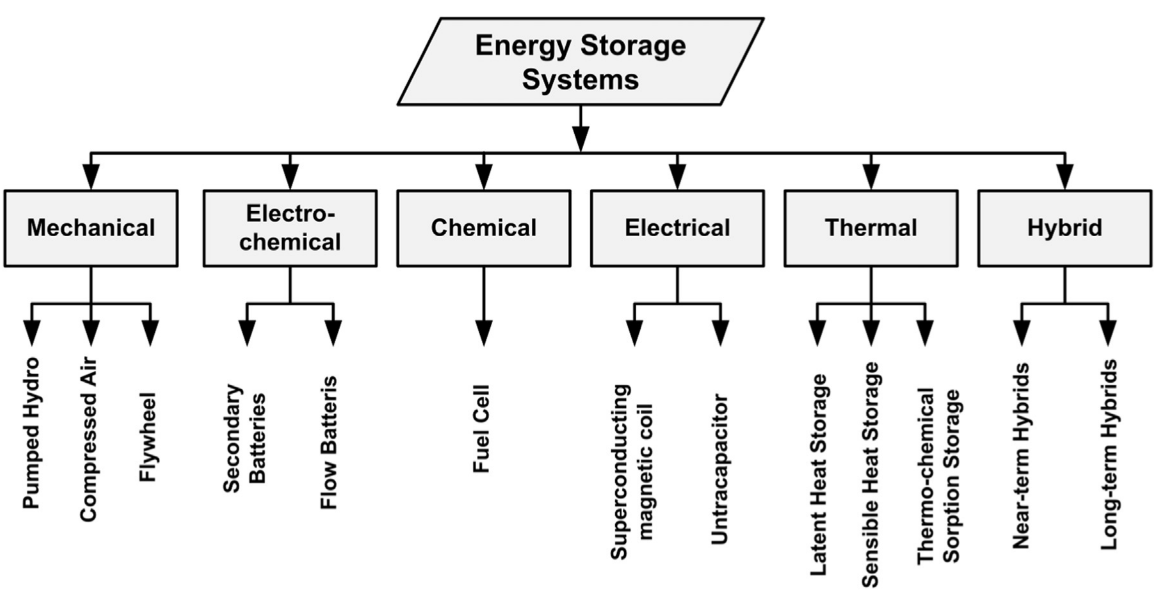

Fig. 12. Taxonomy of ESS in EVs [188].

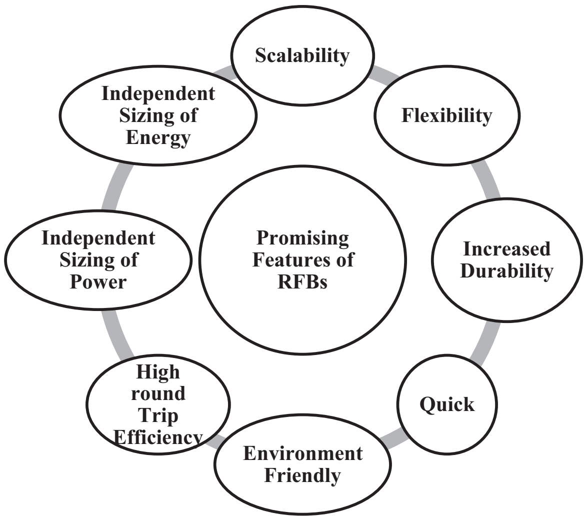

Fig. 13. Promising features of RFBS [156].

strategies, energy sources, and storage devices employed in EVs are surveyed in [191]. The characteristics, types, component system, and control of hybrid EVs are overviewed in [192]. The battery life prediction, battery performance, and battery health are of major concern that must be determined to ensure efficient and reliable operation of batteries. Moreover, various approaches and strategies are developed to check and monitor battery status and performance [193]. In the following sub-sections, the ESSs employed in EVs will be briefly explained.

5.2.1. Mechanical storage system (MSS)

The MSSs are commonly employed ESS worldwide. The MSS include '3' storage technologies, namely: **(a)** pumped hydro ES, **(b)** flywheel ES and **(c)** compressed air ES [188]. The EVs application opts for FES technology, compared to other MSSs.

(a) **Pumped Hydro Energy Storage (PHES)**

PHES are most popular form of MSS that works on the principal of pumping reserved water of high head to power turbine generator for electricity generation. The PHES stores 3% energy capacity of global energy generation [188]. The world's most exploited storage technology with storage capacity of 127 GW from the total 128 GW worldwide capacity is PHES [136]. The PHES storage technology works efficiently in range of 20–50 MW. Currently, the 3 GW PHES is installed in US-VA. The main application of PHES is energy management [137,138]. The PHES is only suitable for areas with potential difference in water level, mainly mountainous regions. The associated environmental and long-term reservoirs filling concerns are two major drawbacks of PHES. The aforementioned drawbacks are the demanding challenges for the implementation of PHES in some countries [139].

(b) **Compressed Air Energy Storage (CAES)**

The compressed air mixed with natural gas is expanded and converted to modified gas that feeds gas turbine generator for electricity production [188]. In [140], the authors discussed the CAES in Germany (1978). The rated capacity for CAES in Germany is 290–900 MW with 66 bar applied pressure. The application area of CAES technology is energy management, large capacity production [188], and Research and Development (R and D) related activities.

(c) **Fly Wheel Energy Storage (FES)**

Among MSS, the FES systems are deployed in EVs applications due to employment of advanced power electronics in their structure. FES systems incorporate the efficiency between 90–95% [188]. The FES technology possesses very fast response but is still in its development phase. The gyroscopic effect of the earth's rotation has high impact on the FES. The round-trip efficiency of FES is immensely dependent on discharging time for frictional effects of electromagnetic bearings [145]. The FES with a rated value of 400 MW/1 MW h is installed in England for R and D activities at joint European tours. Another FES technology is installed in Japan at a Fusion Institute of Japan Atomic Energy Agency with storage capacity of 2.2 MW h [143]. The FES with higher energy ratings and lower rated power are used for grid storage applications, such as FES with rated values of 20 MW/5 MW h [144]. The application area of FES includes frequency regulation. Further, the structure and characteristics of FES system are elaborated in [188].

5.2.2. Electro-Chemical Energy Storage (ECES)

The ECES incorporates all typical rechargeable batteries. In ECES, the electrical energy is transformed to chemical energy. Further, this chemical energy is transformed back into electrical form with reduced physical changes [188]. The ECES technology has site versatility, wide scalability, and static structure with simple mechanism. The best alternative with short to long-term storage capabilities assisting RER generation is ECES [151,152]. The ECES will act as a distributed storage system and its growth will increase to 150 GW [153]. The chemical based energy storage technology helps in compact system design, providing both power conversion and storage application. The ECES is expected for wide implementation across the globe in coming years. The flow batteries and rechargeable batteries (secondary) are commonly used form of ECES that are deployed for EVs interaction within SG [188].

(a) **Flow batteries**

The flow batteries are rechargeable and store energy in electroactive form [188]. The suitable choice for stationary energy storage is Redox Flow Battery (RFB) [154,155]. RFBs possess high efficiency, high life cycle, power flexibility that makes RFBs attractive in standalone SG systems [188]. The most promising features of RFBs are presented in Fig. 13.

The main operating principle of RFBs is based on the reduction and oxidation reactions occurring in two electrolytic solutions [157]. R and D of RFB technology requires special attention to achieve full commercial potential [158]. Table 5 presents the state of the art worldwide installed RFBs plants [134].

(b) **Secondary rechargeable batteries**

Secondary rechargeable batteries are electrochemical energy storage system and are used in portable energy storage devices for EVs [188]. The EVs include various secondary rechargeable batteries, such as: **(a)** nickel-based, **(b)** lead acid, **(c)** metal-air based, **(d)** high temperature lithium, and **(e)** other batteries types. These batteries types are deeply investigated in [188].

5.2.3. Chemical Storage System (CSS)

The CSS are based on chemical reaction of compounds that allow the storing and releasing of energy in the system. Fuel Cells (FCs) are the conventional CSS that continuously converts fuel chemical energy into electrical energy. Further analysis about CSS including FC is provided in [188].

(a) **FCs storage technology**

The FC is capable to produce electricity, based on supply of active materials. The energy generation from FC can reduce CO_2 emissions and use of fossil fuel [188]. The FC storage technologies are used to store energy for short timescales, such as hours and days. The other satisfactory solution for longer time span storing energy is FC [159]. The excess energy is used in electrolysis of water that is decomposed into its constituents; Hydrogen and Oxygen. The hydrogen is finally stored and used to produce electricity as an alternative solution [160]. The application area of FCs in SG includes: **(a)** TE, **(b)**

Table 5
State-of-the art worldwide installed RFBs plants.

Year	Location	Capacity	Application	Project by
1996	Electric-power, Kashima-Kita. Japan	200 kW, 800 KW h	Peak/Load Leveling	Mitsubishi chemicals
1996	Kansai-Electric, Tasumi. Japan	450 kW/900 kW h	Load/Peak Shaving	Sumitomo electric industries
2000	Japan-(Kansai Electric.)	200 kW/1.6 MW h	Load/Peak Shaving	Sumitomo electric industries
2001	Wind farm, Japan	170 kW/1 MW	Stabilization of power from Wind turbine.	Sumitomo electric industries
2001	Tottori Sanyo, Japan	1.5 MW/1.5 MW h	Peak Shaving and emergency backup power	Sumitomo electric industries
2001	ESKOM-power, South Africa	250 kW/500 kW h	Load/peak shaving Backup.	VRB power
2001	GG-University, Japan	500 kW/5 MW h	Load/peak shaving	Sumitomo electric industries
2001	Italy (CESI)	45 kW/90 kW h	Distribution power systems Research and development.	Sumitomo electric industries
2003	Japan (High Tech Factory)	500 kW/2 MW h	For wind energy storage As a replacement to diesel fuel	Sumitomo electric industries
2003	King-island, Windfarm	250 kW/1 MW h	As a replacement to diesel fuel. Wind energy.	Pinnacle VRB for hydro Tasmania
2004	Us-UT, Moab. Castle valley.	250 kW/2 MW h	Feeder augmentation. For the support of voltage.	Pacific Crop by VRB power
2005	Japan, (Tomamae)	4 MW/6 MW h	Stabilization of wind energy.	SEI for electric power development Co, Ltd.
2010	Vierakker,,the Netherlands	100 kW h/18 kW	No data available	Cell storm GmbH, Austria.

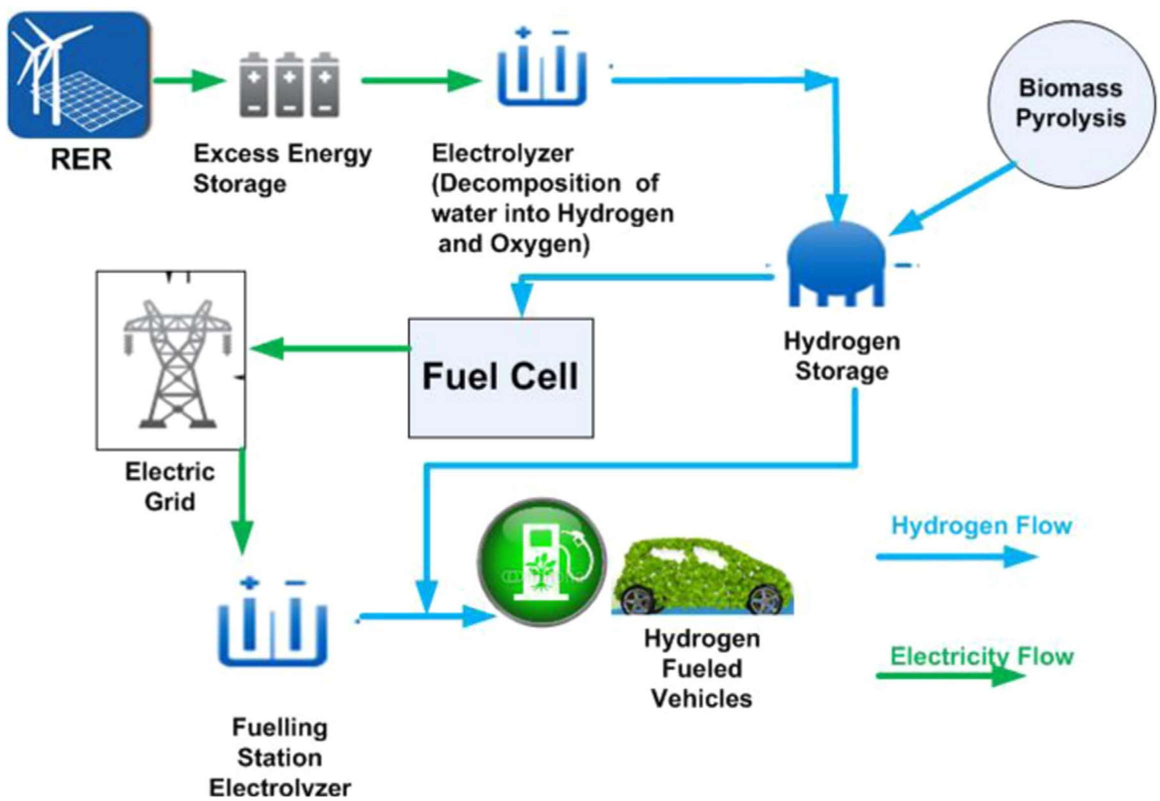

Fig. 14. Fuel Cell [162].

DG, **(c)** RER, and **(d)** telecommunications industry [161]. The pure hydrogen operated FCs does not emit CO2 gas and other harmful pollutants. The zero emission (Fuel Cell) technology greatly assists DG power systems. In addition, FCs are more reliable and exhibits lower maintenance costs [161]. Fig. 14 presents the hybrid structure of RER, FC, Electric Grid, Hydrogen Fueled Vehicles, and Electrolyzes.

FC is an efficient alternative of batteries for backup power and more predictable than other storage technologies. The batter storage capacity diminishes with time, while FC has ten years' life expectancy with undiminished power quality. FC require little on-site maintenance and are cleaner and quieter, compared to generators [161,163]. The advantages of FCs when operating as a backup power supply are: **(a)** 60% efficiency, **(b)** high scalability, **(c)** flexible for parallel operation, **(d)** wider temperature range (40°F to 122°F), and **(e)** no moving parts (Longer Life). The detail study on FC technology is provided using tabular and graphical presentation [188].

5.2.4. Electrical Storage System (EeSS)

The storing technologies of EeSS are different from ESS. The energy is directly stored in electrical form in EeSS and avoid the process of conversion. The EeSS are Ultracapacitors (UCs) and superconducting magnetic energy storage (SMES) [188].

(a) **Ultracapacitors**

The structure and function of UC is similar to that of common capacitor. However, UC possesses high energy capacity up to kilo farads and is referred as 'super capacitor'. UC is the most acceptable ESS employed in EVs due to its remarkable feature like: **(a)** longest operation lifetime, **(b)** no maintenance, and **(c)** temperature insensitivity. The UCs classes include EDLC, hybrid capacitor, and pseudo capacitors. The electric double layer capacitor (EDLC) is discussed in following text. Further investigation of UC is provided in [188].

- **Electric Double Layer Capacitor (EDLC)**

The EDLC possesses higher power density, compared with other capacitors. But EDLC also possesses some drawbacks, such as high cost, high self-discharge, and low specific energy [188]. The EDLC is also termed as Super Capacitor. The EDLC storage technology is used in assistance with power supplies in PHES to cope with surge power requirements. The round trip efficiency of EDLC is highly dependent on discharge-time due to internal losses (capacitor discharge). The grid applications of EDLC include sag compensation [149,150]. The EDLC is a very expensive technology but requires less maintenance [147]. The structure and others details about EDLC is provided in [188].

(a) **Superconducting Magnetic Energy Storage (SMES)**

SMES store energy in magnetic field. The pertinent features of SMES technology are: **(a)** capable of full energy discharge, **(b)** long life cycle, **(c)** quick response time, and **(d)** high energy storage efficiency [188]. The SMES has application in power quality service due to its fast-operational response [146,147]. The improved power quality and sag compensation are the two main applications of SMES for EVs application within SG. The SMES with a power range of 10 MW–1000 MW will be available till year 2030–2040 [148]. The authors in [188] presented the structure and detail study on SMES technology.

5.2.5. Thermal Energy Storage (TES)

TES system store heat energy in an isolated reservoir from solar and electric heater. Later, the stored energy in TES is utilized in SG generation plants. The TES is achieved in different ways, namely: **(a)** thermo-chemical storage system, **(b)** sensible heat storage, and **(c)** latent heat storage [188]. These ways of TES are briefly discussed in [188]. The automatic thermoelectric generation system that converts waste heat into electricity is employed in EVs for optimizing fuel cost and overall efficiency [188]. The TES is used in SG for time shifting of solar photovoltaic power towers and energy management services. The high power and improved energy capacity are two main advantages of TES. The time shifting by TES is possible by delaying the energy dispatch [142].

5.2.6. Hybrid storage system (HSS)

Single ESS is insufficient to meet the requirements of EVs interaction within SG. The prominent features of ESSs include: **(a)** cost, **(b)** life cycle, **(c)** power density, **(d)** energy density, and **(e)** discharge rate. No ESS possesses all these features. Therefore, a combination of two ESS is needed that will optimize the aforementioned features for balanced energy storage. As a result, HSS were developed that electronically combined the output power of '2' or more ESSs with complementary properties. The different combinations of ESS with complementary features make HSS. HSSs are classified into: **(a)** CAES and UC hybrids, **(b)** battery and flywheel hybrids, **(c)** CAES and battery hybrids, **(d)** FC and flywheel hybrids, **(e)** battery and FC hybrids, **(f)** battery and battery hybrids, **(g)** UC and battery hybrids, **(h)** SMES and battery hybrids, and **(i)** FC and UC hybrids. Further, the HSS are comparatively analyzed in [188].

5.3. Challenges and Issue in EVs energy storage technologies

The employment of ESSs improves the EVs interactions within SG up to considerable extent, however, these ESSs poses some issue and challenges for their adoption in EVs interaction within SG operation. The pertinent challenges that are incurred due to ESSs implementation include: **(a)** long life span of EVs and **(b)** long charging/discharging cycles of ESSs. The battery cost of EVs is one third of EVs Overall cost and is big challenge faced by EVs interactions within SG [191]. The authors in [192] pointed current challenges in hybrid EVs including: (a) drawback in energy density for EVs application, (b) high EV cost, (c) refueling stations infrastructure, and (d) slow recharging time. The issues and challenges in FC-hybrid EVs, such as: (a) battery lifetime, (b) power lifetime, (c) power electronics interface, (d) energy management system, (e) hydrogen violability are elaborated in [190].

The vital issues associated with EVs storage system are: **(a)** cost of ESSs and **(b)** aging of ESSs [133]. The research issues encountered due to EVs storage system are incorporated, namely: **(a)** SG development, **(b)** fuel cell EVs, and **(c)** inadequate consideration of price arbitrage incentive regulation [135]. The ESSs performance is affected with various application improvement and technological changes. The issues in current ESSs include: **(a)** materials composition and proper disposal, **(b)** power electronics interface, **(c)** energy management, **(d)** sizing, **(f)** safety measures, and **(e)** cost. These issues adversely affect the development of ESSs in EVs. These prominent issues with recommendation are presented [188]. The key challenges, such as: ESSs optimization for efficiency improvement and advance control strategies are of great concern and need more research and investigation while dealing with EVs storage system [189]. Moreover, the key issues in EVs, such as energy storage, power management system, system configuration, power electronics, and motor generation must be properly addressed while accounting for EVs interaction with SG [192]. The massive interaction of EVs within SG having un-coordinating charging poses negative impacts on SG. Therefore, the employment of aggregation agents that provides charging strategies for EVs, assist in handling EVs peak demand and other issues. The EVs fast charging stations with ESSs are investigated in detail. The ESSs plays vital role in SG operation and provides basics for fast charging stations of EVs with shorter charge time [194].

5.4. Technical and economic benefits of the storages technologies

The technical and economic benefits of the storage technologies include: **(a)** flexible and reliable integration of RERs into the SG, **(b)** used as a distributed energy supply, **(c)** attain an optional operating point by providing the variable output, **(d)** superior per load efficiency, **(e)** used for regulation application, **(f)** achieve real time congestion relief in transmission, **(g)** enhanced grid reliability, **(h)** allows distribution and transmission upgrade deferrals, **(i)** can serve as a standby power-source, **(j)** facilitate transportation and heat generation, **(k)** reducing the cost, **(l)** improved grid sustainability, **(m)** peak shifting, **(n)** avoids an additional cost for generators, **(o)** allows more efficient use of RERs, **(p)** reducing the cost of investment by cutting off the need of upgrading transmission and distribution network, **(q)** environment friendly, and **(r)** inexpensive on average as compared to other power-related installations [135]. Based on latest literature survey, the efficiency of ESSs for EVs application can be improved using advance optimization technique for ESSs alloys, materials and chemical solution. The optimized ESSs will change upgrade energy density, capacity, durability, environmental and economic impact, and recharge and discharge rate profiles [188]. Table 6 highlights features of the main energy storage system [134].

Table 6
Features of the main energy storage system.

Features				ECES								
	PHES	SMES	EDLC	Advance Lead Acid	Sodium Sulfur	Sodium-Nickel-Chlorine	Lithium ion	Fuel Cells	Redox Batteries	FES	TES	CAES
Scalability	Improved	Improved	Small	Improved	Improved	Improved	High	High	High	High	Small	Small
Flexibility	Small	Small	Small	Improved	Improved	Improved	Improved	High	High	Improved	Small	Small
Environmental Impact	High	Minor	Minor	Minor	Small	Minor	Minor	Minor	Minor	Low	Low	High
Safety Issues	High	Small	Moderate	Small	Moderate	Moderate	Low	Moderate	Low	Moderate	Moderate	High

6. Current regulations, standards, and interfaces issues within SG

This section presents the current regulations, standards, and interfaces issues within SG reported in latest technical and literature studies. The transition from conventional power grid needs regulations and standards to govern SG sustainable operation and control. The current regulations required for SG operation are briefly overviewed. The SG standards covering communications system technologies and power system technologies according to **(a)** IEEE, **(b)** NIST, and **(c)** IEC are defined based on latest technical study. Finally, the interface issues within SG like **(a)** communication interfaces issues and **(b)** power system interfaces issues are elaborated in following sub-sections.

6.1. SG regulations

The conventional regulatory scheme that was designed long years ago is followed in power system networks [198]. The current regulations in SG need effective policies that offer incentives for generation operators and investors [203]. In future SG, there should be a shift from classical regulatory model to new regulatory model, to keep reliable, cost efficient, and sustainable power flow operations. To acquire new environmental goals, the SG infrastructure managers are facing demands for reinvestments in new resources for on grid and off grid tasks. Due to reinvestment, the current actors will clear the picture of vertical interfacing between regulated and unregulated tasks. The reinvestment policy effects of new resources on network action, resources, and costs are compared with the assumptions of current network regulations [195].

The regulation between generator and distribution system operator is presented using investment provision model. The network regulation based on investment provision showed better results. The current regulations added the words ‘cost efficiency’ and ‘economically’ to the future SG concept. Fuel choices are imposed with appropriate pricing methods while considering CO_2 emissions. The conventional and current network regulations on SG investments and operations are elaborated. In Europe, the modern incentive based regulation is implemented using various regulatory models [195].

Moreover, limitation of current SG regulations includes: **(a)** absolute cost infeasibility, **(b)** lower income generation by standard revenue drivers, and **(c)** weak explicit incentives. The features of European high power network regulations modes are highlighted. Further, the requirements for network regulations are investigated [195]. Due to rapid evolution in electric system, current regulation is not providing sufficient incentives to operators and end users. The latest regulatory interventions in the SG domain, smart metering domain, and electromobility domain are discussed. The current regulations are concerned for both new and traditional network users to encourage more dynamic behavior [196]. The current regulations for DG and RERs based generation with penetration issues and grid access are presented in [197].

In US, regulated market price is followed for retail market and provide fixed retail price [199]. The regulatory barriers and regulatory prospects for future SG are critically analyzed. The regulatory authority should ensure the RERs integration in distribution as well as transmission networks regulation for network tariff. The network tariff may incorporate charges, namely: **(a)** capacity charges, **(b)** energy charges, **(c)** reactive power charges, and **(d)** use of system charges [200]. Frequency regulation strategy for EVs is presented. The regulation contract between aggregator and grid operator is made that makes a new corporate model for V2G [201]. The EV battery stations with data center servers will play vital role in SG regulations. Integrated system for EV battery is proposed that optimize regulation capacity and maintain power quality to swapping battery stations [202].

6.2. SG standards

The leading standardization roadmaps in SG are as: **(a)** US: NIST, **(b)** IEEE: P2030, **(c)** IEC SMB: SG 3 Roadmap, **(d)** European Union: Mandate CEN/CENELEC M/441, **(e)** Japan: METI SG Roadmap, **(f)** Korea: SG Roadmap 2030, **(g)** China: SGCC Framework, **(h)** Germany: BMWi E-Energy Program, **(i)** Microsoft: SERA, and **(j)** CIGRE: D2.24 [205]. This survey thoroughly investigates IEEE, NIST, and IEC standards in SG in following subsections.

6.2.1. IEEE standards

IEEE is world largest association focusing on SG standardization based on technological advancement [216]. IEEE has described the standards and guidelines for SG operation using latest technologies in power system, power control, and ICT. IEEE and other international bodies have identified wireless and wired communication technologies. The IEEE standards for communication technology protocols are defined as: **(a)** ZigBee IEEE 802.15.4b, **(b)** Wi-Fi IEEE 802.11 g, **(c)** Bluetooth IEEE 802.15.1a, **(d)** WiMAX IEEE 802.16, and **(e)** 6loWPAN IEEE 802.15.4 [204]. The IEEE 802.22 for WRAN and IEEE 2030-2011 for communication infrastructure are defined. Moreover, the IEEE 1901 for PLC, IEEE 802.3ah for OFC, IEEE 802.16 for WiMAX, and IEEE 802.16 for MAN are described in [207]. IEEE 802.21 defines media independent handover and IEEE 802.3 defines Ethernet [213]. For multi-source plug and play environment in diverse metering devices, the IEEE 1701 and IEEE 1702 are followed [215].

IEEE P2030 standard meets the interoperability requirements of SG. IEEE P2030 emphasizes on system level approach for interoperability devices of power system, communication system, and information technology platforms [205]. Security standards of SG are well defined by IEEE [206]. IEEE has provided the updated standard of PMU as IEEE C37.118.1-2011. In general, the PMU should follow IEEE C37.118. The IEEE Std.1588 and IEEE Std.2030-2011 are employed for precision time control and SG interoperability reference respectively. IEEE Std.1547.4 for MG and IEEE Std.1547.6 for distributed networks are recently initiated [207]. For AMR, the standard IEEE 1377 is followed. IEEE 1451 and IEEE 1451.5 are defined for smart sensor and WSN. For delay requirement and M2M communication, IEEE 1646 and IEEE 802.16 P are followed [209]. IEEE 61499 is defined for distribution control in SG Automation [217].

6.2.2. NIST standards

NIST controls the development of standardization efforts, models, and protocols for providing reliable and secure service for SG [216]. According to NIST, the future SG must ensure **(a)** improved resilience to disruption**, (b)** improved power quality, **(c)** enhanced efficiency of electric power systems, **(d)** Facilitating increased deployment of renewable energy, **(e)** self-healing and predictive maintenance in system disturbances, **(f)** reduced GHG emission by employing TE, **(g)** transition to PHEVs and new storage choices, **(h)** grid security improvement opportunities, **(i)** DERs accommodation, and **(j)** increasing consumers choices. The ZigBee has been defined by NIST as communication standard for installation at consumer premises network. Smart metering implementation has also been defined by NIST [205]. SG is divided into 7 domains by NIST namely: **(a)** bulk generation, **(b)** transmission, **(c)** distribution, **(d)** service providers, **(e)** consumers, **(f)** market, and **(g)** operations. NIST provide security standards to encrypt the data communication in SG [206]. The NISTIR 7628 define guidelines for SG cyber security [210].

6.2.3. IEC standards

IEC is development organization that focuses on general requirements of SG architecture. IEC SG strategic group is created in 2008 to monitor SG efforts in electrical industry [216]. The IEC 61000-4-30 for power quality, IEC 61850 for communication system regulations, and IEC 14908-3 for PLC are defined [207]. The IEC 61850-7-420 extension is used to incorporate MG. IEC 61968-9 is followed by implementation of AMR and AMI technology in SG [209]. IEC has defined standards for SG security and encryption [206]. The IEC 62351 is followed for protection of SG control system and is an extension of IEC 61850 with security measures [211]. The IEC 61970 and IEC 62056 have been defined for communication and metering data exchange respectively [212]. IEC 61968 works for communication in distribution domain [214]. The IEC 15118-2 defines messaging structure and data exchange between communication networks in SG. The overall SG reliability and security are defined by IEC TC57 WG13 [215]. IEC 60870 defines inter-control center protocol and IEC 62056 is used for meter reading, load control, and tariff. IEC 14543 defines home electronic system architecture [216]. The IEC 61400-25 defines the operation of wind power plants [217].

6.3. SG interfaces issues

This sub-section highlights the interfacing issues encountered in SG operation, such as: **(a)** communication interfaces issues and **(b)** power system interfaces issues. The power interfaces issues are classified as: **(a)** DG interfaces issues and **(b)** Micro Grid (MG) interfaces issues. The prominent issues in SG are due to communication technologies, sensing devices, measurement instruments, control schemes, and automation operation [220]. The SG accounts for critical issues and challenges that persist in conventional power system. These issues are classified as: **(a)** demand response, **(b)** reduction in carbon footprint, **(c)** conservation of energy, **(d)** costly assets deployment, and **(e)** generation diversification [227]. The design, deployment, and maintenance are key challenges for smart power system implementation [220]. The energy crisis and carbon emission are two critical issues in power system [229].

6.3.1. Communication interfaces issues

In SG, the communication interfaces issues are: **(a)** interference, **(b)** lower data rates, **(c)** security concerns, and **(d)** product availability limitations. The licensed frequency band issues are also present in communication system [228]. The key issues faced in all SG communication technologies are: **(a)** packet loss, **(b)** packet corruption, **(c)** disconnection, **(d)** jittering, and **(e)** time delay [220]. The open issues occurred in green communication technology and data center are resented in [238]. From communication perspective, the security and reliability issues are vital for SG implementation. The AMI performance is affected by cyber security issues. Cyber security is serious issue for complex and more interconnected SG. Privacy, interoperability, and data integrity are the issues encountered in information technology. Standard implementation for advance sensing, recharge time for EV, and congestion at transmission, are also vital issues reported in communication system interfaces [235].

6.3.2. Power system interfaces issues

The conventional power system issues persist due to some reasons, such as: **(a)** fossil fuel scarcity, **(b)** extensive deployment of advanced DER technology, and **(c)** electric utility deregulation [226]. The most prominent issue that persists in almost all power system is supply and demand mismatch due to load variations, transmission losses, and generator dynamics. The synchronization issue and data distribution issue for SG are discussed in [208]. For V2G interaction within SG, the issues persist namely: **(a)** battery technology, **(b)** lack of SG technology support and duplex communication infrastructure, **(c)** distribution system complexity, and **(d)** security [234]. The harmonics injections, failure diagnosis, conduction and switching losses, and component temperature variations are explicit issues in power electronics interfaces to SG [220]. The power interfaces issues are further explained as DG interfaces issues and MG interfaces issues.

- ***DG Interfaces Issues***

  The large-scale penetration of RERs to SG has posed serious issues and challenges as these RERs possess intermittent and limited predictable nature. The important challenges of RERs based integrations are: **(a)** LVRT and **(b)** inter area oscillations [219]. Solar based DG causes voltage rise at PCC due to reverse power flow and is regarded critical issue for power flow operation in power system [221]. Significant issues that affect the distribution systems due to PV penetration are: **(a)** voltage fluctuations, **(b)** voltage rise, **(c)** voltage balance, and **(d)** harmonics. Further, the islanding issues vital for system stability and system integrity are discussed in [222]. At high wind ratio, the intermittent wind energy results in grid frequency variation and voltage deviation. Power system stability and power quality are also affected by intermittent wind power [224].

  Voltage regulation is the most pertinent technical challenge and leans to limit the penetration rate of RERs based generation into distributed networks. To mitigate voltage regulation, control schemes are employed [223]. The additional technical solutions for increased penetration of RERs are costly and uneconomical [230]. Moreover, the RERs penetration in SG raises some key issues and challenges, such as: **(a)** stability control, **(b)** control coordination, **(c)** protection system, **(d)** power quality, and **(e)** optimal operation [232]. In DG interface to power system, the supply quality is affected by harmonics, dc injection, and voltage flickers. The placement of DG units near to load and load dynamics coupling with power electronics converter are key issues to be addressed for DG based generation [141].

- ***MG Interfaces Issues***

  Isolated MGs face the challenge of keeping the real-time balance of power demand and generation with dynamically varying energy demand. In MG, the real-time distribution control is also complex due to the unsecure connection between sensing devices and controllers [218]. The normal operation of MG is concerned to fluctuation and intermittency resulted from unstable micro sources and nonlinear loads [225]. The power quality issue occurs in MG due to DER based integration [233]. Stability and control issues also exist in MGs. Moreover, the Protection coordination issues in MG are discussed in [226]. The reactive power sharing control is also an issue for MG operation [231]. Complexity control and protection issues are reported in hybrid MG operation [236]. The static and dynamic issues for wind energy integration in MG are elaborated in [237].

7. Conclusion and future work

The TE in SG is the only choice for low carbon energy supply due to reduced emission of GHG and other air pollutants. HEV will dominate the typical ground transportation that is based on fossil fuels. PHEVs began for reduction of transportation cost and carbon emission. The RER based EVs charging and discharging is valuable addition to the power grid. Reduce usage of fossil fuels by improving utilization of RER with better storage capacity using PHEVs is the demanding need in SG. EVs possess a key contribution for implementation of Vehicle to Grid (V2G) and Grid to Vehicle (G2V) technology. The V2G is the most prominent feature of TE in term of energy storage. The era of EV brought many challenges for power grid system, such as: **(a)** power quality**, (b)** economy, **(c)** reliability, **(d)** economy, **(e)** control, and **(f)** grid load capacity. In this regard, the key enabling technologies and intermittent nature of RER should be considered for EVs accommodation in SG.

This survey emphasized on V2G mode in implementation of EV transportation in SG. The implementation and technical challenges were elaborated. The on board and off board charging infrastructures for EVs were presented and onboard charging is recommended due to ease in charging processes. Further, the TE impacts on grid incorporating the V2G were reviewed. The V2G provides an economic benefit but lacks in real implementation due to unproven economic model and communication bottle necks. The communications requirements for EVs implementation in SG were also discussed. The commonly used energy storage technologies in EVs were discussed in detail. The current issues and challenges in ESSs of EVs and the technical and economic benefits of ESSs were thoroughly investigated. The survey concluded with explanation of current regulations, standards and interfaces issues within SG.

The storage capacity of EVs is limited for household power backup due to reduced numbers of EVs. The storage capacity of EVs will enhance in coming few decades when the typical transportation will be replaced by EVs and will provide high power reserve to SG. Research and development of storage devices in EVs will unlock new ways for deregulated energy market players in future. The power conversion and storage applications by chemical based storage technologies will bring new momentum in SG. In near future, we will survey smart grid analysis with respect to Pakistan. We will also explore energy and demand relationship for grid-interfaced system models. In future, we will consider wide area EVs system implementation for improved control and stability analysis of SG.

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