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A survey on electric vehicle transportation within smart grid system

N. Shaukat[a], B. Khan[a,*], S.M. Ali[a], C.A. Mehmood[a], J. Khan[a], U. Farid[a], M. Majid[b], S.M. Anwar[c], M. Jawad[d], Z. Ullah[a]

[a] Department of Electrical Engineering, COMSATS Institute of Information Technology, Abbottabad, Pakistan
[b] Department of Computer Engineering, University of Engineering and Technology, Taxila, Pakistan
[c] Department of Software Engineering, University of Engineering and Technology, Taxila, Pakistan
[d] Department of Electrical Engineering, COMSATS Institute of Information Technology, Lahore, Pakistan

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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

* Corresponding author.
E-mail addresses: neelofar169@gmail.com (N. Shaukat), bilalkhan@ciit.net.pk (B. Khan), hallianali@ciit.net.pk (S.M. Ali), chaudhry@ciit.net.pk (C.A. Mehmood), drjabran@ciit.net.pk (J. Khan), umarfarid@ciit.net.pk (U. Farid), m.majid@uettaxila.edu.pk (M. Majid), s.anwar@uettaxila.edu.pk (S.M. Anwar), mjawad@ciitlahore.edu.pk (M. Jawad), engrzahidullah92@gmail.com (Z. Ullah).

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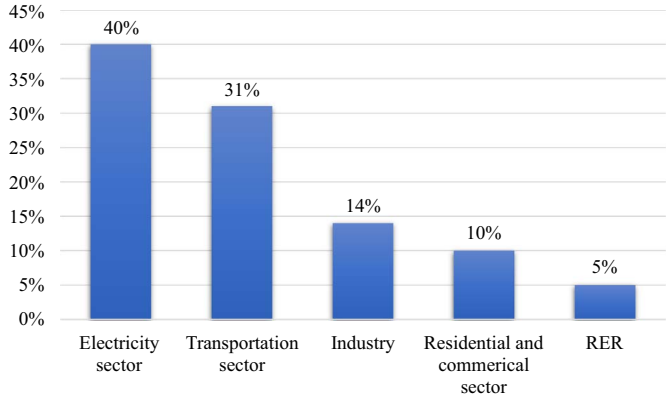

Fig. 1. Various sector wise emission of GHG [9,10].

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

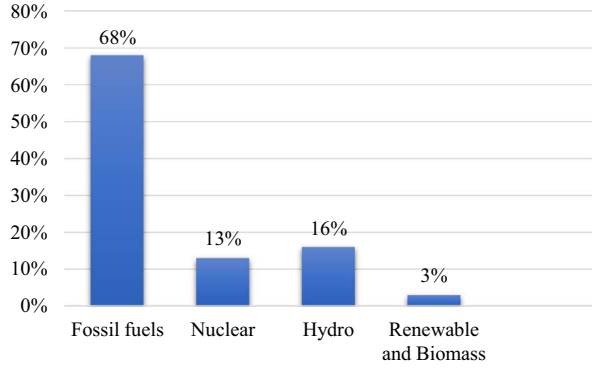

Fig. 2. World's energy dependency for electricity generation [10].

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