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Electric vehicles and smart grid interaction: A review on vehicle to grid and renewable energy sources integration

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ABSTRACT

This paper presents a comprehensive review and assessment of the latest research and advancement of electric vehicles (EVs) interaction with smart grid portraying the future electric power system model. The concept goal of the smart grid along with the future deployment of the EVs puts forward various challenges in terms of electric grid infrastructure, communication and control. Following an intensive review on advanced smart metering and communication infrastructures, the strategy for integrating the EVs into the electric grid is presented. Various EV smart charging technologies are also extensively examined with the perspective of their potential, impacts and limitations under the vehicle-to-grid (V2G) phenomenon. Moreover, the high penetration of renewable energy sources (wind and photovoltaic solar) is soaring up into the power system. However, their intermittent power output poses different challenges on the planning, operation and control of the power system networks. On the other hand, the deployment of EVs in the energy market can compensate for the fluctuations of the electric grid. In this context, a literature review on the integration of the renewable energy and the latest feasible solution using EVs with the insight of the promising research gap to be covered up are investigated. Furthermore, the feasibility of the smart V2G system is thoroughly discussed. In this paper, the EVs interactions with the smart grid as the future energy system model are extensively discussed and research gap is revealed for the possible solutions.

Contents

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1. Introduction

In the world today fossil fuels are the dominant energy sources for both transportation sector and power generation industry. Depletion of fossil fuel reserves gives a wakeup call for finding the alternative energy sources for these sectors. In fact, the future of oil economy which is considered to be highly dependable by vehicle fleets in the world is not only unsustainable but also very limited. Besides, burning fossil fuels produces greenhouse gases (GHGs) which highly influence the world climate change. According to the report [1], the oil consumption in transport sector will raise by 54% until the year 2035. Also the projection by Energy Information Agency (EIA) reveals that the oil prices will substantially rise in the next two decades. In this context, various efforts related to reducing oil consumption have emerged. In the transportation sector, electric vehicles (EVs) are the promising solution and they are taking a remarkable pace in the vehicle market. In the future, the economic studies predict a replacement of the internal combustion engine vehicles (ICEVs) with the EVs. The Australian Energy Market Commission (AEMC) projection shows up that by the year 2020 the growth in the EV's share of new vehicle sales will increasingly account for less than 10%, and it will further account for 15% to 40% increase of the new light vehicle sales after the year 2020 [2]. Much effort has to be devoted to reach the future EV market projections as they feature high initial cost compared to the ICEVs.

On the other hand, the electrification of transportation sector appears to be one of the feasible solutions to the challenges such as global climate change, energy security and geopolitical concerns on the availability of fossil fuels. The EVs are potential on serving the electric grid as independent distributed energy source. It has been revealed by some studies that most vehicles are parked almost 95% of their time. In this case, they can remain connected to grid and be ready to deliver the energy stored in their batteries under the concept of vehicle to grid (V2G) introduced earlier by Kempton [3].

To this end, the EV technology can provide the grid support by delivering the ancillary services such as peak power shaving, spinning reserve, voltage and frequency regulations [4] whenever needed. Besides, the integration of large renewable energy sources (RES) like wind and photovoltaic (PV) solar energies into the power system has grown up recently. These RES are intermittent in nature and their forecast is quite unpredictable. The penetration of the RES into the power market is enormously increased to meet the stringent energy policies and energy security issues.

China for the year 2020 has set a goal to install 150–180 GW of wind power and 20 GW of PV solar power. This huge penetration of the RES into power system will require large energy storage systems (ESS) to smoothly support electric grids so that the electrical power demand and operating standards are met at all the times [5]. In this case, the EV fleets are the possible candidate to play a major role as the dynamic energy storage systems using the V2G context. To this point, the EVs can be aggregated and controlled under the virtual power plant (VPP) concept model [6]. While the EVs are providing these opportunities through charging and discharging of their battery packs, a number of challenges are imposed to the power system grid. These challenges compel the changes on the planning, operation and control of the electric grid [7]. To the utility, the EVs are both the dynamic loads which are difficult to schedule but also a potential back up for the electric grid. Similarly, the vehicle owners have some notion that possessing an EV will substantially increase an extra operating cost when compared to owning an ICEV. Hence, an attractive scenario is needed to merge them so that a sharing of load can be realized between the two parties.

However, as the majority of the people witness and become aware of the contemporary penetration of the EVs, they would require knowing how much it costs for recharging their vehicles and find a way to minimize charging costs similar to their usual ICEV refueling practice. On the other hand, a cost for selling power to the grid should instantaneously be known by the vehicle owners or EVs fleet operator/aggregator in the case of providing V2G services. Furthermore, the aggregator has to know in real-time the characteristic parameters (i.e. driving patterns, state of charge, total capacity, etc.) of the aggregated EVs for the network management response such as demand side management issues, frequency regulation and other ancillary services [8]. Definitely, this demonstrates how the EVs would change the way we daily understand and interact with the electric grid. The cost of electricity will be sensitive and determinant factor for the EV owners or energy market players to interact with the grid while the load profile will dictate on the grid operator (GO) side.

With the deregulated power market, the real-time-pricing scenario is quite intuitive but it requires advanced metering, information and communication control systems. This is shifting the existing grid to the future electric grid network mostly referred to as smart grid where the EVs as dynamic loads and potential energy buffer (i.e. dynamic ESS) can be accommodated. In the smart grid infrastructure, the real-time pricing and communication are conceivable through smart metering and advanced information and communication technology (ICT) [9]. Intelligent scheduling of the EV charging is also attainable to relieve the stresses on the power distribution system facility. These mutual relationships between the EVs and smart grid make a perfect match for a modern power system model.

To further identify and potentially utilize these aforementioned opportunities a clear understanding of an integrated framework of the EV niche market, distributed RES and electric power grid is vital and indispensable. This paper extensively reviews and assesses the EVs interactions with the smart grid infrastructure as the future energy system model. A research gap is discussed to unveil possible solutions and the EV-V2G future research trends are uncovered. The integration of the renewable energy sources especially wind and PV solar using the EVs is evaluated in the light of the latest research works. We also examine the feasibilities of the V2G transactions under the recent pilot projects and demonstrations. For the purpose of this study, the battery electric vehicle (BEV) and plug-in hybrid electric vehicle (PHEV) can be referred to as electric vehicles (EVs).

The paper is organized as follows: the integration of the EVs into the power system under the V2G concept and its realization within the VPP phenomenon are reviewed and discussed in Section 2. On the other hand, Section 3 extensively assesses the interaction of the EVs and smart grid with the focus on the smart charging and advanced metering and communication infrastructures. An intensive review on the integration of the RES using EVs is presented in Section 4. Moreover, Section 5 evaluates the feasibility of the EV integration in the smart grid infrastructure with an insight of the relevant current and future projects. Also the general EV and V2G future trends are unveiled in this section. At last, the conclusion is drawn in Section 6.

2. EVs integration into electric grid

Integration of a large number of EVs into the electric power system is a major challenge which requires an intensive assessment and observation in terms of economic impacts, operation and control benefits at optimal conditions. Many existing literatures analyzed the impact of the EVs on the distribution power system [10] while others dig-down the different application