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

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

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

I. Introduction

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

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

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

II. EV Charging Classification

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

A. AC Charging System

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

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

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

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

B. DC Charging System

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

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

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

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

III. Solar PV Based EV Charging

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

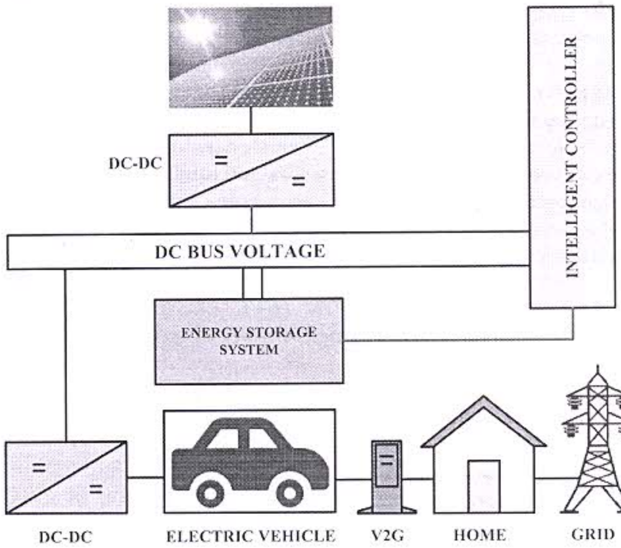

Fig. 1. Solar PV based EV charging with grid integration

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

A typical functional architecture of solar PV based system consisting solar PV, non-isolated unidirectional DC-DC converter and Maximum Power Point Tracker (MPPT) algorithm is shown in figure 2. In order to achieve high DC