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A Comprehensive Review on Photovoltaic Charging Station for Electric Vehicles

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Abstract- All over the world there is huge demand for electric vehicles with increase in vehicles we need have an efficient charging station to charge electric vehicles. Usually the conventional charging stations utilize the electric grid to charge the electric vehicles which increases the stress on the grid. To overcome this problem, we need to use renewable energies like solar photovoltaic systems. In this paper we reviewed the various solar based charging stations which utilizes the solar energy to charge the electric vehicles. This paper covers the storage systems, battery and controller, converters, battery exchange stations. This paper gives information to readers about a review of photovoltaic charging station for electric vehicles and solution to various problems faced by the charging station.

Keywords: Renewable Energy; Solar; Electric Vehicle; Charging Station

I. INTRODUCTION

The remarkable increase in the use of electric vehicles (EVs) has resulted in a massive rise in demand for electric energy across the globe. The global electric vehicle market has grown significantly. The number of EVs on the road in 2010 was a few hundred; this number rose to approximately three million in 2017 and approximately six million in early 2019 [1].

According to the rapid increase of EV demand and EV charging, many research centres, and energy supplying companies began thinking seriously about reducing the pressure on local electricity networks because of the increasing number of electric vehicles charging points. Photovoltaic sources are some of the most effective solutions to bridge this deficit faced by local electricity networks, potentially supporting the EV charging infrastructure [2].

The traditional charging stations affect the grid's stability with issues such as harmonics, fluctuations, and voltage outages [3]. By contrast, the RCI has several advantages, such as high efficiency, low system cost, and simple arrangement[4]. Besides, it requires less power conversion levels than those in alternating current (AC)-based facilities [5].

II. ENERGY STORAGE AND FAST CHARGING SYSTEMS

It was reported in that unregulated charging would contribute to the overloading allocation of transformers and feeders and, eventually, the power supply. Hence, most of the literature has suggested stationary energy storage and fast charging systems to overcome this challenging problem. Energy storage limits the charging infrastructure and runs costs by serving electric vehicles during the system's uttermost load intervals [6]. Energy storage can also improve electric vehicles' stability by supplying necessary and sufficient energy to reach

charging stations in the case of emergencies [7]. Many studies were carried out on the benefits of stationary energy storage with fast charging systems. However, to obtain such benefits, an optimum size of the energy storage system is required, taking into account the energy tariffs, expected degree of penetration, and load profiles of EVs [8].

Fast charging stations (FCSs) can solve the charging time issue, which is a crucial element in adopting and deploying EVs [9]. The fast charging works on recharging the EVs quickly, similarly to the conventional vehicles at gasoline stations. Fast-charging plays a vital role in increasing EVs' travelling distance by having FCS along the way. The off-board fast charging module is the important to fast-charging stations whose output is 35 kW. The current and voltage values are 20–200 A and 45–450 V, respectively [10]. As they are both so high, such infrastructures have to be deployed in supervised centers or stations.

III. STORAGE BATTERY AND CONTROLLER

Solar-powered batteries can fulfill unreliable grid electricity demands, which are strong charge, discharge, and intermittent full-charging periods. A range of battery types fulfills these specific criteria. The major battery storage subgroups reviewed for solar energy include a lead-acid battery, lithium-ion battery, and flow battery [11]. To save the additional energy produced by photovoltaics, a central controller is required to redirect the generated power to the battery, as illustrated in Figure 1. Many scholars have investigated the sequence of controllers that are used in photovoltaics [12]. They highlighted that it is essential to improve the productivity of solar energy generation through a maximum power point tracker (MPPT) and pulse width modulated (PWM) technologies [13].

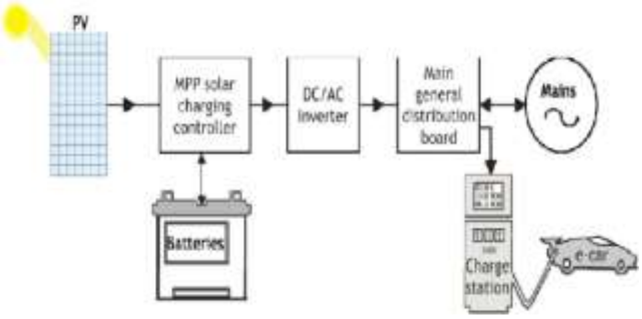

Figure 1. EV Charging Infrastructure with a Solar PV Charger.

IV. CONVERTERS

When it comes to a solar converter, the PV arrays are integrated to a DC/DC converter that allows for full power point tracking control. The AC/DC converter is in charge of converting DC/AC power in a bidirectional fashion [14]. The power used from the grid is primarily AC. It must be converted into DC to charge the electric vehicles. The conversion of power occurs before the charging begins or relays the power from the grid to electricity networks. Therefore, the converters have unique roles in photovoltaic systems based on balanced energy conversion [15]. Different forms and requirements have been examined in detail, for example, string inverters, in which panels are installed in combination with a microinverter, and central inverters, where panels are installed with separate inverters and micro-inverter power optimizers that require further monitoring. These power optimizers are used to track photovoltaic panel arrays' overall performance to constantly alter and change the attached load that keeps the system at maximum operational capability [16].

V. BATTERY EXCHANGE STATION

battery exchange station (BES) is a system that EV drivers can replace their discharged battery with a fully charged battery at BES. The implementation of BES can provide several benefits, such as its very fast exchanging time. For example, Tesla, a well-known electric vehicle maker, swap EV batteries in 90s. One more critical issue about BES benefits is avoiding charging during peak demand [17]. Other benefits of BES are minimal cost management, long battery lives, and low consumption. However, there are few drawbacks of the BES, such as the cost of investment, which is very high. BES construction requires ample space, and the battery management system cannot ensure battery safety.

VI. OPTIMAL PLANNING

The EVs' charging requirement is complicated; therefore, it is not easy to accurately estimate or precisely obtain it. As presented in Table 1, the literature consists of research papers related to the charging scheduling issue. Some of these studies describe the integration of renewable sources with V2G technology during the charging station's planning. The other set of these research papers are focused on the BES.

Charging station planning is a challenging task. It includes considering the availability of renewable sources, uncertainties in traffic demands, the complex nature of location design, and other factors affecting hourly power management such as renewable source, grid peak hours, and V2G. Thus, in a charging station, there is a need to link long-term planning decisions (e.g., location, size, and operation hours) with short-term operation decisions (e.g., grid power usage, energy storage, V2G, and renewables) to form a planning framework. Besides, the availability of the data allows designers of fast-charging stations to have access to the EVs' data over transportation networks, including historical data and real-time charging demand. The collected data encourage an innovative data-driven pattern. Table 1 describes some studies that applied a data-driven approach. Moreover, in the built environment applications, the energy system planning models should have data standardization, interpretability, scalability, flexibility/adaptability, and reconfigurability [18].

Table 1. Charging station planning

Study	Modelling Technique	Source	Station Type
[19]	Stochastic programming	Grid, Solar	Charging Station
[20]	Mixed-integer linear programming (MILP)	Grid, Wind, vehicle to grid (V2G)	Charging Station
[21]	Two-stage stochastic MILP	Grid, Solar	Battery Exchange Station & Charging Station
[22]	Two-stage stochastic MILP	Grid, wind, V2G	Charging Station
[23]	Stochastic Optimization	Grid, Wind	Charging Station
[24]	Probabilistic Model	Grid, Wind, Solar	Charging Station
[25]	Two-stage stochastic MILP	Grid, Solar	Battery Exchange Station
[26]	MILP	Grid, Wind	Charging Station

VII. OPTIMAL SIZING

In recent years, the transportation sector has witnessed a rapid penetration of electric vehicles (EVs). The aim is to enable the sustainability of the system. It was driven by modern innovations in battery technology and in the electric drivetrain. However, as electric vehicles' penetration spreads, the EVs' demand increases, thus introducing additional load to the power systems [27]. There is a need to upgrade and increase the capacities of the electricity distribution systems to contain the overloading challenge and integrate renewable energy sources (RESs) into the charging station. In addition, meeting the ever-increasing EV demands through optimum sizing and operation of the EV charging stations is the most challenging task. Several studies have been reported with regard to addressing the aforementioned challenges and are presented as follows. In, an EV charging station was designed with solar–wind hybrid power sources. The Hybrid Optimization Model for Electric Renewables (HOMER) software was employed for sizing the renewable energy source and for power-sharing to the loads. With one 200 kW capacity WT unit and PV panels, a total power of 250 kW, a total annual energy generation of 843,150 kWh was realized. The charging station has the capacity of charging 5 EVs in 1 h. Likewise, in the MATLAB environment was used to develop a mathematical model of optimal sizing and capacity allocation using the differential evolution (DE) algorithm for a wind energy system that is integrated with an EV battery exchange station [28].

A 200 kW wind generator and 10 kW charge and discharge machine were used to provide energy to both EVs for traveling demand and the entire system's energy balance. The analysis based on the condition of the components regarding power change at different periods reveals that the optimum solution is logical, and through the hybrid system concept, the EVs' energy demand can be achieved. In the same vein, a multi-objective optimization problem based on the DE algorithm was developed by to obtain optimal sizing of EV charging stations and renewable energy sources. The efficiency of the various methods are evaluated in MATLAB for various grids. The results show the optimal sizing of charging station for electric vehicles with improved voltage profile. Similarly, a hybrid improved optimization algorithm based on Genetic Algorithm-Particle Swarm Optimization (GA-PSO) was used by for the optimal sizing of renewable energy sources (RES) and EVs' charging demand.

VIII. CONTROL AND ENERGY MANAGEMENT

Connecting the renewable energy-based stations to the grid leads to several challenges. Besides the grid integration and fluctuation issues, the charging operation presents a critical shortage due to the inharmonious charging process concerning power quality and demand specifically for fast-charging stations. Hence, it is crucial to control the charging behaviour to reduce these issues' impacts. For example, an analysis of electricity production conducted by to calculate relevant performance indicators of the electricity supplied by the grid indicated significant variability of the CO2 emissions. It highlights the need for accurate knowledge of operational parameters to support future smart grid management. Therefore, the management of the EV charging behavior would moderate the fluctuation of renewable energy, optimize the grid's peak demand, and make efficient load characteristics of the grid. The literature comprises several studies on impacts of charging loads on the grid. For example, Green et al. studied impacts of EVs on the distribution network, and Amini et al. discussed effects of large-scale charging infrastructure on the system's total loss. In a probabilistic model is used to investigate incremental impacts of EV charging on the distribution network.

IX. CHALLENGES OF RENEWABLE ENERGY-BASED CHARGING INFRASTRUCTURE

Power quality:
It was noticed that generating renewable power could introduce power quality problems. According to the changing nature of wind and solar, generating renewable power is intermittent, with high fluctuations, and non-dispatchable. The RCI features mainly in charge of power quality challenges include the modularity of renewable generators. Power quality seems to be one of the most critical aspects that could affect the reliability and stability of RCI.

Stability:
It refers to the recovery of the power system after blackouts and control of the voltage and frequency. Stability challenges are mostly caused by the excess of power from renewable energy, and battery storage that can cause significant damage to RCI. Controlling the stability can ensure the power system is performing correctly and not approaching instability. Power balance: The power unbalancing occurs in RCI because of the renewable sources' uncertainty and variability.

Charging prices:
The vast implementation of renewables alters the structure of costing to be capital intensive. To ensure that implementation is profitable, the pertinent planning firms need to consider long-term energy prices. Notably, the number of utility programs that offer renewable energy-based EV charging is limited and only concerned about residential customers. There is a need for various approaches to serve heavy-duty vehicles, employee workplace charging, and retail customers at the public charging loads.

Locations:
The literature demonstrates several attempts to evaluate medium- and large-scale wind farms to secure energy demand required by the EV charging infrastructure. It was noticed that urban areas are not suitable for installing the

turbines as the wind energy based system requires broad premises. The large buildings are the major obstacles in wind directions. However, some city authorities do not allow heavy-duty vehicles to enter cities at specific times. Thus, installing charging infrastructure in suburban or rural areas can serve medium- and heavy-duty vehicles. By contrast, the installation of RCI in urban areas could face some problems. For instance, in multi-unit residential buildings, the study stated several problems: parking availability, building limitations, and governance issues. Hence, optimal planning of location and optimal scheduling for charging are critical factors that must be considered in implementing RCIs

X. Conclusions

The integration of renewable energy and EVs draws the future mode of transportation. The more penetration of EVs and RCIs means more reduction of carbon emissions and fossil fuel consumption. However, there are some challenges for the deployment of renewable energy-based infrastructures due to their natural fluctuation. For wind turbines, the location and environmental factors are critical issues for installation. Urban areas have been found to be unsuitable because of their noise and requirement for spacious premises. For solar systems, the focus of electricity production is only on the daytime; this limits its supply in meeting the significant typical electricity demand. Wind and solar energy are considered to be good sources for EV charging infrastructure. However, their integration with EVs, V2G charging facilities, and ESS can form RCI with a microgrid plan for network charging. In optimal planning, it was noticed that active research concerns the charging scheduling issue. Some of them consider the integration of renewable sources with V2G during the planning phase. RCI planning is challenging because of the availability of renewable sources, uncertainties in traffic demands, the complex nature of location design, and other factors affecting the hourly power management such as renewable source, grid peak hours, and V2G. The literature demonstrates the lack of studies in renewables' charging infrastructure in adopting real data to improve control strategies, sizing, and real-time control. In control and management, the excellent interaction among the infrastructure and high-distance range EVs leads to the smart charging and discharging strategy. Charging pricing approaches indicate a limited number of utility programs that support renewable charging, and they are only focused on residential customers. New charging programs must be introduced for heavy-duty vehicles and retail customers at public charging loads.

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