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Electric vehicles charging using photovoltaic: Status and technological review

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ABSTRACT

The integration of solar photovoltaic (PV) into the electric vehicle (EV) charging system has been on the rise due to several factors, namely continuous reduction in the price of PV modules, rapid growth in EV and concerns over the effects of greenhouse gases. Despite the numerous review articles published on EV charging using the utility (grid) electrical supply, so far, none has given sufficient emphasis on the PV charger. With the growing interest in this subject, this review paper summarizes and update all the related aspects on PV–EV charging, which include the power converter topologies, charging mechanisms and control for both PV–grid and PV-standalone/hybrid systems. In addition, the future outlook and the challenges that face this technology are highlighted. It is envisaged that the information gathered in this paper will be a valuable one-stop source of information for researchers working in this topic.

Contents

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1. Introduction

The concern over the environment due to the greenhouse gases emitted by the conventional internal combustion engines (ICE) is seen as a major factor that will accelerate and sustain the growth of the electric vehicle (EV) usages. With the recent technological advancement in the battery technology, power electronics converters, control and microelectronics, EV is expected to make serious inroads in the motor industry. Moreover, these prospects have initiated the integration of electrical power and transportation systems in a way that has not been conceivable before [1]. The main link between the two sectors is the charging of the batteries, which is the source of power for the traction, control, lighting and air-conditioning. However, charging by grid imposes an extra burden on the electrical supply, particularly during the peak demand duration [2]. One viable solution to reduce the negative impact is to promote charging using alternative sources.

With the continuous downward trend on the price of photovoltaic (PV) modules, solar power is recognized as the competitive source for this purpose [3]. Furthermore, PV system is almost maintenance free, both in terms of fuel and labor [4]. The application of PV is further enhanced by the advancement in conversion technologies, battery management as well as the improved installation practices [5]. During daytime, the EV is parked idly in the parking area under the exposure of the full sun. If the car-park is roofed by PV, the availability of PV power allows for an opportunity for "charging while parking" [6]. This is an economical and convenient solution to charge EV at workplaces and parking areas [4]. An example of a structural diagram of PV parking is shown in Fig. 1 [7]. Structural-wise, the roofed parking provides free shelters from sun and rain, which is a favorable feature in hot climate countries [8]. Since the charging is done during the peak demand (daytime), the savings from the electricity tariff is substantial [9].

Over the years, a number of charging methods using PV have been proposed. The most prominent is the combination of PV and the grid, which is referred in this paper as the PV–grid charging. It uses the PV power whenever possible, but switches to the grid when the PV power is insufficient or unavailable. Another approach is to utilize the PV minus the grid, which is known as the PV-standalone charger [10]. There are several variations for this approach, with the inclusion of other power sources such fuel cell and auxiliary storage. In addition, efforts have also been made to integrate the PV modules/cells onto the body of the EV itself.

Fig. 1. An example of PV based parking lots for EV charging [7].

Numerous works have been published on EV charging using grid, including several excellent review papers, for example [11,12]. However, so far there is no effort has been done to compile and update the works related to charging using solar energy despite the growing interest in this topic. From the survey, it is found that the number of papers on this issue has risen significantly over the last decade, hence the impetus for this review. The discussion begins with a brief summary of the electric vehicles, batteries and the structure of charger that includes PV. This is followed by the evaluation on the actual charging hardware which comprises of MPPT dc–dc converter, bi-directional dc charger and bi-directional inverter. Next, the charging modes for the PV–grid approach is detailed out. In addition, a table on recent work is provided to summarize the research conducted for the PV–grid charging. In the subsequent section, the PV-standalone charging that includes several hybrid configurations is described. Finally, a discussion on the future outlook and the challenges—which focus on the energy management system is given. To probe further, a list of 117 related papers is provided in the reference.

2. Brief overview of EV and PV technologies

2.1. EV and battery

The EV is widely referred to an electrically powered vehicle which uses one or more motors for its propulsion. The terminology includes electric car, train, lorry/bus, motorcycles, scooters etc. In this paper, the definition of EV is limited to the hybrid electric (HEV), plug-in hybrid electric (PHEV) and purely battery electric (BEV) vehicles. In charging context, the main difference between the PHEV/pure EV is that it provides plugs that allow for external charging, while the HEV does not. The HEV charges its battery internally by the kinetics of its combustion engine. [13]. The evolution of the EV propulsion battery begins with the lead-acid, progressing to nickel and currently to lithium [14]. Modern EV is no longer using the lead-acid due to its low specific energy, chemical leakage and poor temperature characteristics. They have since by replaced by nickel and now, almost exclusively lithium [15]. Lithium battery is the preferable choice due to its higher energy efficiency, power density, compact and lighter weight [16]. Moreover, it provides fast charging capability, wide operating temperature range, no memory effect, long cycle life and low self-discharge rate. Currently, lithium-based battery includes a wide diversity of chemical substances; for instance, the lithium ferro phosphate ($LiFePO_4$) provides ease in term of handling due to its superior thermal stability in the fully charged condition. In addition it has a low risk of explosion when accidentally over charged or short circuited. Lithium–titanate (LTO) is the latest type, which