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The use of parking lots to solar-charge electric vehicles

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ABSTRACT

The concept of solar parking lots aims at coupling the development of clean solar electricity and electric mobility. Solar panels provide shade and generate electricity to charge parked electric vehicles. In a vehicle-to-grid approach, the vehicles may also feed the grid and support it with ancillary services.

In this paper, we explore the potential of this solution, starting with a concise overview discussing the technical, environmental and financial issues constraining the development of solar parking lots. A comprehensive review of the literature follows, and finally open issues and prospects for future work are identified. It is intended that this paper may serve as a standalone summary of the most important work on this topic to date.

Contents

1. Introduction

World energy consumption is shifting to electricity – its share in final energy consumption grew from less than a tenth in 1973 to

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nearly a fifth at present [1], being expected to reach about a quarter by 2040 [2]. Alongside, concern over the sources of electricity production is rising: electricity continues to be mainly fossil fuel based (68%) [3], making the electricity sector liable for growing emissions of greenhouse gases (GHG).[1] It is of utter importance to contain these emissions, and so they have been a very relevant topic for the international bodies that are establishing goals to hold climate change (e.g., the European Union determined an 80–95% reduction in GHG by 2050 [4]).

Renewable energy is seen as the solution for coping with both increasing electricity demand and environmental sustainability. The large amount of solar power hitting the earth surface (121,800 TW [5], which in one hour is about the same as all the energy spent in human activities in one year [6]) and the decreasing cost of the solar photovoltaic (PV) is promoting the role of this technology as part of the solution to decarbonize the electricity sector [7].

One other sector must also be decarbonized: the transport sector, responsible for about a third of total final energy consumption, nearly all petroleum based [3], and a quarter of emissions [8]. The most promising way of doing this is to replace the traditional vehicles, with their internal combustion engines (ICE), with electric vehicles (EVs).[2] In fact, EVs are much more on-board energy efficient and clean, as long as they charge using renewable electricity. Models show that a decarbonized grid combined with an EV fleet could lead by 2050 to reductions in GHG emissions of 48–70% in the combined electricity and transportation sectors, relative to 2015 [9].[3]

For this to happen, EVs need to be widely adopted in the future. Although they still only have a small market share, they are making significant headway. This is being achieved by overcoming their traditional bottlenecks, which are the short driving range, the high price (these two are mostly battery related) and the lack of a charging infrastructure, particularly of the fast type.

With regard to driving range, the energy density of the batteries is steadily growing [10], allowing the vehicles to travel a greater distance per charging. As an example, Nissan has recently upgraded its bestselling Leaf model with a battery rated for 250 km of range, 26% more than the previous version [11].

As for the price, Li-ion battery packs have shown an annual price reduction of 14%/year from $1000 per kW h of storage in 2007 to $300–400 at present. Albeit the value seen as necessary to make EVs cost-competitive with traditional vehicles is $150 per kW h, the market is more than doubling annually, and so the prospects are that economies of scale will allow most of this gap to be closed in the near future [12].

As for the charging infrastructure, it is a critical challenge since its public deployment still lacks financial viability, and so the public sector needs to take the lead in installing it [13]. Currently there are several national programs of this kind, such as those in Denmark, the Netherlands, Germany, the UK and the United States; details of these and of others programs are provided in [14].

Since PV represents non-dispatchable and time-floating energy supply whereas EVs could represent controllable loads and energy storage, it clearly makes sense to couple the two [15]. On the one hand, EVs can help the power grid maintain the supply-demand balance, thus allowing a larger penetration of renewable energy. There are several works on this theme, such as [16–18], and an extensive review of it by Richardson [19]. On the other hand, PV production could also enable a larger penetration of EVs, since they do not cause a significant net-load increase if charging from PV [20].

Compared to wind, the EV-PV coupling makes more sense since wind has larger spatial and temporal variation [21] and a grid infrastructure is needed to bring electricity from centralized wind power plants to the EVs charging stations; this is something that does not happen with PV given its distributed model, which also means that much lower electricity transport losses occur. Though, the use of local small wind turbines, in the kW range, as a complement to the solar modules, could be interesting to extend EV charging to times when there is no sunshine available, e.g. night parking [22,33].

However, integrating EVs and PV with the grid, either individually or together, has to be done with due care, otherwise it might instead compromise the grid reliability. For the grid operator, the main concern over PV generation is its uncertainty [24,25]. As for the EVs, they might trigger a surge in demand, causing grid overload. Both situations could lead to power quality degradation and stability issues [17,23]. And so, as Romo and Micheloud [26] point out in their review of these issues, the integration of EVs and PV must be carefully planned, using, for example, scheduled charging or by taking advantage of the smart grid capabilities. If this was done, more PV and EV could enter the power grid [27].[4]

In this context, decentralized on-grid PV power plants and EVs charging directly from them are of less concern to the grid; this is because the grid would not have to integrate a large PV capacity and would not need a big reinforcement to satisfy the increasing EV demand. Moreover, this solution does not imply GHG emissions and the charging infrastructure promotes the EV adoption. It could be implemented via solar arrays installed as shade structures over parking lots to charge EVs during the day [28], i.e., EV solar parking lots. This is the subject under review in this paper. Section 2 introduces the concept and its framework, serving to define and delimit the problem.

Even though there is a considerable amount of literature on EV solar parking lots, it has not yet been reviewed and classified, something we do in Section 3; it is intended that this may serve as a standalone summary of the most important work existing so far on this topic. A general review about EVs charging from PV from the technological standpoint was previously very well prepared by Bhatti et al. [29]. Here we focus on EV solar parking and its infrastructure. Finally, Section 4 identifies the open issues in the literature and gives suggestions for future research. Summing up, the contribution of this work is to gather under one document: (1) a comprehensive overview of EV solar parking lots; (2) a review of their state-of-the-art; (3) a synopsis of what are the challenges and opportunities to develop and implement the concept.

2. Overview

Electric vehicles solar parking lots (EVSPLs) may be public or private held and may be installed practically anywhere: at workplaces, shopping centers, restaurants, supermarkets, hotels, hospitals, city entrances, train stations, airports, universities,

[1] The greenhouse gases associated with electricity generation are essentially CO_2. The growing penetration of renewable energy in the electricity mix is lowering the CO_2 intensity of electricity, usually given in gCO2/kWhe; however, electricity generation is increasing at a faster pace, and so absolute emissions are also increasing [2].

[2] In this paper, EV stands for electric vehicles that connect to the grid, comprising pure electric vehicles (PEVs) and plug-in hybrid electric vehicles (PHEVs, with both types of engines) operating in electric mode.

[3] For an overview of EV technologies and their efficiencies and GHG emissions, see Poullikkas [17].

[4] For a review of EVs interaction with the smart grid and EV smart charging technologies, see Mwasilu et al. [92].