Solar Mobility

Subjects: Energy & Fuels
Contributor: Pei HUANG

As proposed by CEA-INES (namely the French National Institute for Solar Energy) [1], the concept of solar mobility seeks a synergy between the following three systems: EVs, PV systems and the electricity network. The basic idea is to combine a standard grid-connected PV system with standard EVs, also connected to the grid [2].

In the extended solar mobility scope, the energy prosumers are equipped with their own renewable energy systems, electrical storage, EVs and other electrical appliances. The buildings are connected into a renewable energy sharing microgrid, in which the surplus renewable production can be delivered from one building to another. Such energy sharing network provides a platform for the buildings in a micro grid to share their surplus renewable energy generations with other buildings, thus helping enhance the overall cluster-level performances. The energy sharing micro grid is also connected to the power grid, in case there is surplus/insufficient cluster-level renewable generations and electricity exchanges with the power grid is needed. The power exchange of the building cluster with the power grid will be metered by advanced metering facilities.

Keywords: Solar mobility ; Energy sharing ; Peer-to-Peer trading

1. Introduction

As proposed by CEA-INES (namely the French National Institute for Solar Energy) [1], the concept of solar mobility seeks a synergy between the following three systems: EVs, PV systems and the electricity network. The basic idea is to combine a standard grid-connected PV system with standard EVs, also connected to the grid [2]. In order to ensure the solar charging of the vehicles and minimize the grid impact, a local Energy Management System decides on the energy flows. This process is called solar-to-vehicles (S2V) in some studies [3], representing charging EVs directly using electricity from PVs. Vehicles can be charged at home using residential charging stations or at public charging stations in private business or public car parks. They consider such a process reasonable since the average car is parked 95% of the time and charging can take a long time based on current usage models. In their proposed concept, the electricity produced by the residential PV panels is firstly used to supply the home electrical equipment (e.g., household appliances, multimedia devices, etc.), and then to charge the EV battery, as shown in Figure 1. If there is any surplus generation, such an amount is fed into the power grid. The smart grid will collect data on the grid loads and power needs and redistribute the surplus generation to meet these loads/needs. In such a context, buildings, equipped with PV systems and energy storage systems, are becoming energy production sites where EVs can be charged. This convergence between buildings and transport will enable EV batteries to be used as a means of storage and supply of low-carbon electricity to meet fluctuations in production and consumption. Note that the EV battery is also allowed to discharge electricity back to the building/power grid in such a model. This is advantageous for grid management and especially for peak smoothing. This concept has been extensively studied from a technological viewpoint in [4][5][6][7][8][9].

Figure 1. Concept of solar mobility with self-consumption [31].

2. Values, Problems and Challenges to the Solar Mobility

Values: With the increasing deployment of PVs, EVs and energy storage systems, it is important to smartly integrate them to maximize the energy efficiency and cost benefits and, meanwhile, minimize the impact on the power grid. Under such a context, solar mobility can help improve three values: autonomy, sustainability, and affordability. Specifically, autonomy indicates reducing the dependence and impacts on the public power grid. Ideally, within a building community/microgrid, by acting as an electricity prosumer and considering the EV demand, buildings can be largely covered by their own PV system. Sustainability indicates increasing the self-consumption of locally produced PV power, and thus the need for power from the public grid, which largely depends on fossil energy in many countries. Affordability indicates increasing the economic benefits of the whole system.

Problems: Although the importance of PVs, EVs, and energy storage has been well recognized globally, how to integrate and manage them in a holistic way, simultaneously taking into consideration building loads and occupants' living requirements, needs to be addressed. Problems such as large power penetration in the power grid, low energy efficiency and low economic performance urgently need to be solved. Moreover, with the development of the energy sharing concept and associated advanced controls, the conventional solar mobility concept and context are becoming less compatible and limited. For instance, energy sharing within a building cluster enables buildings to share their surplus generation with other buildings (including their EV demands) with insufficient supply, thereby helping improve the overall renewable energy utilization and reducing grid power dependence. However, such energy sharing networks, including the system architecture and associated advanced controls, are not considered in the conventional solar mobility models. This will limit the potential for performance improvements that can be otherwise be articulated and demonstrated by the newly developed concepts and methods. Another example is the lack of energy storage integration in the existing solar mobility model (note that, in this study, EVs are considered to have a separate role from energy storage).

Challenges: Intermittency is one of the major shortfalls of solar power, which has a direct influence on the voltage stability and the overall power system security, while, for EVs, their charging loads are difficult to predict as they are highly affected by driving patterns and driving distances. Both PV power production and EV power demand are highly uncertain. For instance, an EV can be used for commuting purposes during the day where access to charging facilities is not available. This means that charging could only happen in an EV owner's premises during the nighttime when no electricity can be generated by PV. Such time mismatches will limit the deployment of solar energy in the mobility sector. Thus, it is challenging to bridge the temporal and spatial supply–demand mismatch to facilitate solar mobility. When buildings and energy storage are integrated into the solar mobility context, another challenge is the proper management of different types of systems with various response characteristics and operating constraints. This review paper will aim to propose some useful solutions from existing studies to address these challenges.

3. Extended solar mobility scope

Figure 2 defines the extended scope of solar mobility (as compared with Figure 1) and highlights the location of reviews for each sub-system. In the extended solar mobility scope, the energy prosumers are equipped with their own renewable energy systems, electrical storage, EVs and other electrical appliances. The buildings are connected into a renewable energy sharing microgrid, in which the surplus renewable production can be delivered from one building to another. Such energy sharing network provides a platform for the buildings in a micro grid to share their surplus renewable energy generations with other buildings, thus helping enhance the overall cluster-level performances. The energy sharing micro grid is also connected to the power grid, in case there is surplus/insufficient cluster-level renewable generations and electricity exchanges with the power grid is needed. The power exchange of the building cluster with the power grid will be metered by advanced metering facilities.

Figure 2. Scope of solar mobility and the major sub-systems.

3. Future research directions

Advanced building coordinated controls with EV regulating considered: Existing studies have developed a number of controls for both the electrical/thermal energy storage and the EVs. These controls can be divided into individual controls (i.e. focusing on single-level performance) and coordinated controls (i.e. focusing on multiple-level performance). However, with the concern of complexity, the existing controls rarely integrate the EV operating controls in the whole building energy system management. The flexible charging/ discharging capability of EV batteries are not fully exploited, which restrains the cluster-level performance in renewable energy utilization. Future work is needed to develop more comprehensive and advanced controls, which can fully deploy both the electrical/thermal energy storage and the EVs.

Alternating current (AC) power or direct current (DC) power: In the recent decades, the modern solutions have raised a number of DC loads (e.g. pumps, compressors, servers, EVs, etc.), and most of the renewable based distributed generation units directly produce DC output power. Considering the increased energy efficiency, the improved system reliability and reduced complexity in DC microgrid, researchers have reconsidered the DC power grid for application, instead of AC power. Most of the existing energy sharing networks are based on DC power. However, not all these redesigning procedures of DC power grid are accomplished until now. More researches are needed to make such advanced systems a reality in a large scale. In addition to the technical development of DC microgrid and related controls, great efforts are also needed in legislation to promote the real implementation of the energy sharing DC microgrid, since the legislation on DC power microgrid and the energy sharing among different buildings are still unclear in many countries.

Proper plan of energy sharing building clusters: The benefits brought by renewable energy sharing among different buildings, e.g. increased renewable energy self-utilization and reduced energy storage capacity required, are greatly affected by the type of buildings in the cluster [10]. For instance, there can be more renewable energy sharing between a residential building an office building, compared with the sharing between two residential buildings. Therefore, the building cluster, in which energy sharing is enabled, should be well planned to maximize the benefits brought by renewable energy sharing. Besides the energy characteristics, geographical locations of the buildings should also be considered to avoid large energy loss due to the long-distance power transmission. Future work is needed to develop such building cluster plan methods.

Proper pricing strategy for promoting solar mobility: The electricity pricing strategy has large impacts on the renewable energy flow, as well as the solar mobility [11]. There are two sets of electricity prices involved in this context: the prices of electricity purchasing from or selling to the power grid, and the prices of electricity purchasing/selling within the energy sharing building neighbourhood. The latter price is proposed due to the developing trend of building cluster and energy sharing concept. A proper pricing strategy should be able to provide incentives for households when they share their surplus solar power generations [12]. Future work is needed to develop such proper pricing strategy.

Communication protocols: The imbalance between power demand and supply may cause lines congestion, overload, reverse power flow, voltage-VAR deviations and excessive phase unbalances. To mitigate such conditions and guarantee system integrity within its technical limits, clear monitoring structure and management protocols need to be defined and implemented. In fact, as EV and DER can belong to different domains and subdomains (i.e. DER, consumption, industrial, commercial and residential), the domain affiliation implies different energy management strategies and communications support. To ensure reliable and safe information exchanges between the facilities and demands in different domains and fields, future work is also needed to develop proper communication protocols.

References

1. Vu, T.; F. B, J.M. Design of a Management and Simulation's Tool for Solar Car Park. In Proceedings of the 23rd European Photovoltaic Solar Energy Conference and Exhibition, Valencia, Spain, 1–5 September 2008; pp. 3443–3446.
2. Taverdet-Popiolek, N.; Thais, F. Multi-criteria analysis of innovation policies in favour of solar mobility in France by 2030. Energy Policy 2016, 97, 202–219, doi:10.1016/j.enpol.2016.07.036.
3. Birnie, D.P. Solar-to-vehicle (S2V) systems for powering commuters of the future. J. Power Sources 2009, 186, 539–542, doi:10.1016/j.jpowsour.2008.09.118.

4. Kempton, W.; Letendre, S.E. Electric vehicles as a new power source for electric utilities. Transp. Res. Part D: Transp. Environ. 1997, 2, 157–175, doi:10.1016/s1361-9209(97)00001-1.
5. Schwan, D.-I.T.; Unger, R.; Bäker, B. Modelling and Optimization of Renewable Energy Supply for Electrified Vehicle Fleet. In Proceedings of the 8th Conference on Sustainable Development of Energy, Water and Environment Systems, Dubrovnik, Croatia, 22–27 September 2013.
6. Zhang, Q.; Tezuka, T.; Ishihara, K.N.; McLellan, B.; Keiichi, I. Integration of PV power into future low-carbon smart electricity systems with EV and HP in Kansai area, Japan. Renew. Energy 2012, 44, 99–108, doi:10.1016/j.renene.2012.01.003.
7. Nunes, P.; Farias, T.L.; Brito, M.C. Day charging electric vehicles with excess solar electricity for a sustainable energy system. Energy 2015, 80, 263–274, doi:10.1016/j.energy.2014.11.069.
8. Codani, P.; Le Portz, P.-L.; Claverie, P.; Petit, M.; Perez, Y. Coupling local renewable energy production with electric vehicle charging: A survey of the French case. Int. J. Automot. Technol. Manag. 2016, 16, 55, doi:10.1504/ijatm.2016.076443.
9. Mesarić, P.; Krajcar, S. Home demand side management integrated with electric vehicles and renewable energy sources. Energy Build. 2015, 108, 1–9, doi:10.1016/j.enbuild.2015.09.001.
10. Huang, P.; Sun, Y. A clustering based grouping method of nearly zero energy buildings for performance improvements. Applied Energy 2019, 235, 43–55.
11. Huang, P.; Xu, T.; Sun, Y. A genetic algorithm based dynamic pricing for improving bi-directional interactions with reduced power imbalance. Energy Build. 2019, 199, 275–286, doi:10.1016/j.enbuild.2019.07.003.
12. Lovati, M.; Zhang, X.; Huang, P.; Olsmats, C.; Maturi, L. Optimal simulation of three peer to peer (P2P) business models for individual PV prosumers in a local electricity market using agent-based modelling. Buildings 2020, 10, 138, doi:10.3390/buildings10080138.