PV-Powered Electric Vehicle Charging Stations: Preliminary Requirements and Feasibility Conditions

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Executive Summary

The advent of electromobility is widely seen as an opportunity to reduce the harmful impacts of the transport sector on the environment and public health. A substantial reduction in CO_2 emissions from EV usage can be achieved by the development of solutions based on photovoltaic (PV) systems as a primary energy source. IEA PVPS Task 17 is aiming to clarify the potential of the utilization of PV in transport and to propose how to proceed towards realizing the concepts. Task 17's scope includes PV-powered vehicles as well as PV charging infrastructures.

This report focuses on PV-powered charging stations (PVCS), which can operate for slow charging as well as for fast charging and with / without less dependency on the electricity grid. PVCS can also provide additional services *via* vehicle-to-grid (V2G) and vehicle-to-home (V2H). These may increase the effective use of locally produced solar power. This is the first technical report of subtask 2 of the Task 17. As an interim report, it presents the recent trends in PVCS for passenger cars including system architectures, preliminary requirements and feasibility conditions to increase benefits of PVCS, social acceptance, and proposes steps for realizing PVCS.

Key recommendations

- Main requirements and feasibility conditions for increasing PV benefits are:
  - On user behavior/ flexibility:
    - Prefer daily charging over weekly charging;
    - Accept long and slow charging when possible;
    - Limit charging to the number of kWh required for the daily trip, or charge more when PV power is available;
  - On technical aspects:
    - Limit charging power and stationary storage power to about 7 kW;
    - Choose an optimal size for stationary storage;
    - Give priority to charging stationary batteries by PV over charging from the grid.
- Charge / discharge controlling, optimization, PV production forecasting, and communication between the operators and the end-users are necessary to increase PV benefits;
- Technical and economic optimization of PVCS under local meta-conditions (site, weather conditions, user profile, etc.) and over the lifespan are strongly recommended to make full direct use of the PV energy;
- Well-conceived power management strategies with integrated V2G / V2H may reduce the peak pressure on the public grid while meeting the needs of users, and provide an environmental benefit;
- Societal impact and social acceptance, as well as aesthetic design aspects, of PVCS and new services associated have to be considered and undertaken as preliminary studies;
- Design methodologies and tools will be helpful for optimally sizing PVCS.

A. Recent trends in PV-powered infrastructures for EVs charging for passenger cars

As PV electricity generation is strongly influenced by the weather, back-up sources (i.e. stationary storage and/or public grid connection) are necessary. PVCS may operate in standalone mode and/or in grid-connected mode. According to an overview of existing projects, most of the small size PV infrastructures are generally equipped with slow charging terminals. An interesting example is the standalone charging station EV ARC™ (4,3 kWp), in San Diego (USA). Considering that this infrastructure is placed in Northern France, in summer, during the best solar irradiation conditions, this installation can provide approximately 23,5 kWh/day. Thus, for a consumption of 15 kWh/100 km, the PV daily production can supply an EV for a trip up to 157 km. Moreover, with the consideration of the stationary storage, the EV ARC™ charging infrastructure can supply an EV for a trip up to 400 km. However, daily charging of 400 km, even for the best solar irradiation conditions, is not possible due to the need, i.e. time duration, of the stationary storage recharging. In contrast, EV charging by ultra-fast charging mode requires a power grid connection. This is the case of the Tesla V3 Supercharger, in Las Vegas (USA), equipped with ultra-fast charger of 250 kW. This charger significantly reduces the charging time thanks to the 210 kWh stationary batteries storage, which provides a part of the required power. However, the power grid will often complement the available solar power during the charging sessions and will also charge the battery storage system.

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To be able to host slow charging and fast charging terminals at a PVCS, the PVCS could be a system based on a microgrid (MG), incorporating stationary storage that is charged exclusively from PV sources, with / without public grid connection, using intelligent power control, optimization system, user application interface, and communication system. Thus, in this context, MG is investigated to become a solution to EV charging allowing the use of the PV energy when, where, and how it is generated, charge controlling, and increasing PV benefits.

B. Requirements for expected benefits of PV-powered charging stations for passenger cars

For charging EVs, the MG power flow control is based on the following priority order: PV sources, stationary storage, and lastly public grid connection. It is assumed that the daily average urban/peri-urban road trip for an EV is 20–40 km, and that a normal drive mode will require 3–6 kWh daily energy consumption. To identify the minimum of the PV energy involved in the EV charging several scenarios are simulated under the worst solar irradiation conditions in Northern France, i.e. 45,5 kWh/m² during December for fixed-angle. In addition, it is assumed that the user may inform the PVCS with the following data: arrival time, state of charge (SOC_{EV}) at arrival, desired SOC_{EV} at departure, and park time estimation.
The results presented in these studies show that the preliminary requirements and feasibility conditions to increase PV benefits for PVCS, are:

- In the slow charging mode at 7 kW, the required power can be obtained mainly from PV energy, but the user must then accept that charging is long and slow;
- In the fast charging mode at 22 kW, the charging depends mainly on public grid energy;
- Stationary storage power should be limited at 7 kW for the fast charging mode.

Furthermore, the PV benefits are greatest when EV charging is operated daily rather than weekly, when the slow charging mode is used, and where parking time is known in advance in order to optimize the EV charging during the estimated parking time. A user interface is required to facilitate the interaction between the EV users and the charging station and to take into consideration the EV users' preferences. The public grid can provide energy where required, and / or surplus PV production can be fed into the grid.

C. Technical and economic feasibility analysis of PV-powered charging stations for passenger cars

The PVCS has been analyzed from a technical, economic, and environmental point of view. A three-step methodology, leading to a quantitative evaluation of the PV benefits obtained for PVCS, was designed. A tool has been proposed to adjust the investment cost of the PVCS using four parameters: the type of PV panels, number of PV panels, number of terminals, and the capacity of the stationary storage. The tool can be used to optimally size the PVCS and then, to obtain by simulation the operating modes aiming at increasing the use of PV energy for EV charging.
An economic and environmental evaluation of a PVCS with stationary storage over a period of 10 years and four different locations and scenarios shows that:

- The highest net present value (NPV) is obtained with grid-only charging, which is likely due to the high investment costs of the storage system;
- The emissions per km travelled for each scenario show that:
  - For 100% PV scenario emissions can be as low as 12 to 13 g CO_2-eq per km travelled;
  - In all locations the grid-only scenario has the highest CO_2 emissions with grid-charged EVs;
  - Scenarios with PV and stationary storage show emissions reductions compared with a gasoline-fueled vehicle.

The results presented in these studies show that with the right combination of the stationary storage and PV array sizes, the use of PVCS can be a feasible EV charging solution from a technical, financial and environmental perspective in comparison not only with a gasoline-fueled vehicle, but with a grid-charged EV as well.

D. New services associated with PV-powered charging stations

EV batteries can be used as an energy storage system, and deliver energy through V2G and V2H, when there is an opportunity. State of the art research shows that V2G systems are not yet ready for industrial-scale use. However, multiple projects are testing V2G applications. For example, the city of Utrecht in the Netherlands is experimenting at large scale with a smart PV charging bidirectional EV sharing system. PVCS can provide an environmental benefit in the operation of V2G / V2H services.

A successful implementation of V2G / V2H also depends on the development of a management algorithm able to satisfy the charging / discharging demand. To provide ancillary services to the public grid during peak periods, with EV batteries having a dual “load-source” role, a peak and valley searching algorithm (SPVA) able to deal with the intermittency of PV generation, EV charging demand, and V2G has been designed. SPVA defines the optimal charging/discharging start times of EVs, their arrival time, departure time, initial state of charge, and the minimum or maximum state of charge at the time of departure, to achieve peak shaving and valley filling while reducing the costs of energy from the public grid, which is beneficial to the public grid and EV users.

E. Societal impact and social acceptability of PV-powered charging stations and new services (V2G, V2H)

Studies have been conducted and show that the aesthetic aspects, user experience, and user acceptance of new forms of EV charging are key to the success of PVCS.

A case study in France shows that a large majority socially accepts the PVCS while some imperatives have to be considered. The general trend seems to be favorable to the charging of EVs using PV energy and to the discharge through the V2G/V2H strategies. However, the investment costs to develop, build, install, and maintain, as well as the PVCS’s design and aesthetic aspect are the most important limits.

A survey carried out in The Netherlands showed the specific impact of PV ownership on respondents’ EV experience and their likelihood to adopt (purchase/lease/use) the solar mobility applications. A significant difference in EV ownership was found between respondents with residential PV and respondents without it, indicating a positive relationship between the use of solar energy at home and an interest in electric transport.

An aesthetic design of the PV infrastructure may help user acceptance. One of the main design limitations is the small area available for installing PV systems, particularly for designs for which PV cells are integrated on vehicles. Solar charging infrastructure typically has more space available. Designs for PV-powered charging infrastructure, also show how PV systems can be used for powering a wide range of modes of transportation beyond electric passenger cars. Finally, an important aspect of designing these applications is the use of their visual appearance for communicating to users their function and their focus on sustainability.

F. Main issues and the way forward to effective implementation and use of PV-powered charging stations

Main issues for effectively implementation and use of PV-powered charging stations

- Need for improved understanding of:
  - Pro and cons of slow charging versus fast charging from the stakeholders’ perspectives;
  - Influence of bidirectional charging (V2G / V2H) on the life of EV battery and power electronics;
- Lack of:
  - Proven models for the user experience to make optimal decisions in selecting charging points;
  - Business models and business process implementation and optimization tools to increase PV benefits;
  - Optimal charging strategies in various scenarios, e.g. on-road and covered public parking, residential and office buildings private, in cities public parking, for light and heavy-duty vehicles.

The way forward

PVCS may offer significant benefits to drivers and an important contribution to the energy transition. Their massive implementation will require technical and sizing optimization of the system, including stationary storage and grid connection, but also change of the vehicle use and driver behavior. Long parking time for EVs, short driving distance (around 45 km), and slow charging mode allow to maximize the PV benefits of PVCS.

The next steps for the subtask 2 will focus on global cost and carbon impact assessment methodology, human-system interfaces, charging control and power management with demand response, real time power management including optimization algorithm, experimental validation and analyze of experimental results, PV benefits assessment for V2G / V2H, new survey on the social acceptance of PVCS and new services and the analysis compared to the first survey.

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