Applied Energy 168 (2016) 434–443

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

System design for a solar powered electric vehicle charging station for workplaces ☆

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HIGHLIGHTS

- 10 kW solar powered EV charger with V2G for workplaces in Netherlands is analyzed.
- Optimal tilt for PV panels to get maximum yield in Netherlands is 28°.
- PV array can be 30% oversized than converter, resulting in only 3.2% energy loss.
- Gaussian EV charging profile with low peak closely follows PV generation.
- 10 kW h local storage reduced grid energy exchange by 25%.

ARTICLE INFO

Article history:
Received 18 September 2015
Received in revised form 19 January 2016
Accepted 28 January 2016
Available online 11 February 2016

Keywords:
Batteries
Electric vehicles
Energy storage
Photovoltaic systems
Solar energy

ABSTRACT

This paper investigates the possibility of charging battery electric vehicles at workplace in Netherlands using solar energy. Data from the Dutch Meteorological Institute is used to determine the optimal orientation of PV panels for maximum energy yield in the Netherlands. The seasonal and diurnal variation in solar insolation is analyzed to determine the energy availability for EV charging and the necessity for grid connection. Due to relatively low solar insolation in Netherlands, it has been determined that the power rating of the PV array can be oversized by 30% with respect to power rating of the converter. Various dynamic EV charging profiles are compared with an aim to minimize the grid dependency and to maximize the usage of solar power to directly charge the EV. Two scenarios are considered – one where the EVs have to be charged only on weekdays and the second case where EV have to be charged all 7 days/week. A priority mechanism is proposed to facilitate the charging of multiple EV from a single EV–PV charger. The feasibility of integrating a local storage to the EV–PV charger to make it grid independent is evaluated. The optimal storage size that reduces the grid dependency by 25% is evaluated.

1. Introduction

Two major trends in energy usage that are expected for future smart grids are:

1. Large-scale decentralized renewable energy production through photovoltaic (PV) system.
2. Emergence of battery electric vehicles (EV) as the future mode of transport.

Firstly, the use of renewable energy sources such as solar energy is accessible to a wider audience because of the falling cost of PV panels [1]. Industrial sites and office buildings in the Netherlands harbor a great potential for photovoltaic (PV) panels with their large surface on flat roofs. Examples include warehouses, industrial buildings, universities, factories, etc. This potential is largely unexploited today. Secondly, EVs provide a clean, energy efficient and noise-free means for commuting when compared with gasoline vehicles. The current forecast is that in the Netherlands there will be 200,000 EV in 2020 [2].

This paper examines the possibility of creating an electric vehicle charging infrastructure using PV panels as shown in Fig. 1. The system is designed for use in workplaces to charge electric cars of the employees as they are parked during the day. The motive is to maximize the use of PV energy for EV charging with minimal energy exchange with the grid. The advantages of such an EV–PV charger will be:

☆ This work was supported by TKI Switch2SmartGrids Grant, Netherlands.
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http://dx.doi.org/10.1016/j.apenergy.2016.01.110
0306-2619/

Fig. 1. Design of solar powered EV charging station.

1. Reduced energy demand on the grid due to EV charging as the charging power is locally generated in a 'green' manner through solar panels.
2. EV battery doubles up as an energy storage for the PV and reduces negative impact of large scale PV integration in distribution network [3].
3. Long parking time of EV paves way for implementation of Vehicle-to-grid (V2G) technology where the EV acts as a controllable spinning reserve for the smart grid [4–7].

Several earlier works have analyzed the design of an EV charging station based on PV [8–17]. The mutual benefit of charging EV from solar energy has been highlighted in [18,19] where the potential to charge EV from solar allows for higher penetration of both technologies. In [20], the negative effects of excess solar generation from PV on a national level has been shown to be mitigated by using it for charging EVs. This is especially applicable for charging at workplace as shown in [19]. In [21,22], for the case of Columbus and Los Angeles, USA, the economic incentive and CO_2 offsets for PV charging have been shown to be greater than charging the EV from grid.

A major disadvantage of charging EV from PV is the variability in the PV production. Smart charging provides for flexibility of EV charging in order to closely match the PV production. [23] has shown that smart charging combined with V2G has the dual benefit of increasing PV self-consumption and reducing peak demand on grid. In [24], the EV charging profile is varied with time so that maximum PV utilization occurs. In can be seen that the excess PV energy reduces with higher EV penetration [25,26]. Alternately, the total number of vehicles that are charging at a constant power can be dynamically varied so that the net charging power follows the PV generation, as seen in [27]. This type of sequential charging shows great benefit than simultaneous EV charging, which is proved in [28] by considering 9000 different cases. A time shift scheduling is used in [29] to manage the charging of e-scooters so that the net charging power follows the PV profile. This method is further improved with the use of weather forecast data [30].

A second method to overcome the PV variation is to use a local storage in the PV powered EV charging station, like in [26,31–35]. The storage is typically charged when there is excess solar energy and is then used to charge the EV when solar generation is insufficient [26]. In [36], three different algorithms for (dis)charging the local storage are compared and it was shown that a sigmoid function based discharging of the storage and charging during night and solar excess was the best strategy.

Since storage is an expensive component, optimally sizing the storage is vital. This aspect has been neglected by the papers mentioned above. Secondly, research works that analyzed the use of smart charging have not considered the use of local storage and vice versa. The two methods are investigated together in this work for a solar powered EV charging station. Thirdly, in case of workplace charging it is important to distinguish the effects of weekday and weekend EV charging load. This is because rooftop PV installed in workplace will produce energy even in the weekends even though the EVs of the employee are not present on Saturday-Sunday. This paper analyses the PV system design and EV charging in a holistic manner considering the above aspects. The new contributions of the work compared to earlier works are as follows:

1. Determination of the optimal orientation of PV panels for maximizing energy yield in Netherlands and comparing it with the use of tracking systems.
2. Possibility of oversizing the PV array power rating with respect to the power converter size based on metrological conditions of the location.
3. Dynamic charging of EV using Gaussian charging profile and EV prioritization, which is superior to constant power charging.
4. Determination of grid impact of two different types of workplace/commercial charging scenario considering 5 days/week and 7 days/week EV load by running round-the-year simulation.
5. Optimal sizing of local storage considering both meteorological data and smart charging of EV

The paper is divided into five sections. In the second section, a model is developed to estimate the electricity output of a PV system in the Netherlands, taking into account the meteorological conditions. The optimal orientation of PV panels in the Netherlands for maximum yield is determined. In the third section, different dynamic charging strategies for EV are analyzed, such that EV charging can closely follow the PV generation. In the fourth section, the benefits of having local battery storage in the EV–PV charger are investigated and the optimal storage size is determined.

2. EV charging in workplace using PV

EV charging in Europe is defined by the standards in [37,38]. The charging plug type widely used in Europe for AC charging is the Type 2 Mennekes plug. It supports both single and three phase AC charging at Level 2 charging power level [39].

However in the future, DC charging using Chademo and the Combined Charging Standard (CCS) will be most preferred charging standard for charging EV from PV at workplace due to the following reasons:

1. Both EV and PV are inherently DC by nature.
2. Dynamic charging of EV is possible, where the EV charging power can be varied with time.
3. DC charging facilitates vehicle-to-grid (V2G) protocol.

In this paper, a 10 kW EV–PV charger will be considered that provides both charging and discharging of car for up to 10 kW, as shown in Fig. 2. This is in line with the draft proposal of the Chademo standard for enabling 10 kW V2G from EV. The three-port converter connected to the 50 Hz AC grid was chosen as the most suitable system architecture based on [12]. Since the cars are parked for long durations of 7–9 h at the workplace, fast charging of EV at 50 kW or more would be unnecessary. Solar power is the primary power source of the grid connected EV–PV charging system. The solar power is generated using a 10 kW_p photovoltaic (PV) array that is located at the workplace. The panels could be located on the roof top of the buildings or installed as a solar carport [8].

The EV–PV charger has two bidirectional ports for the grid and EV, and one unidirectional port for PV. The PV converter, grid