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Assessment of EV hosting capacity in a workplace environment in different charging strategies

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Abstract: The study establishes a methodology to assess electric vehicle (EV) hosting capacity in different grid points under various charging strategies in a workplace environment. The methodology is applied to an actual distribution grid in the Helsinki central area. The EV penetration rate is calculated as the number of EVs over the number of parking places in the connection point. The results indicate that in the example grid, the EV hosting capacity is not limited by grid dimensions even in the case of uncontrolled charging. For the grid utility, the possible overloading can be regulated by a power-based tariff that guides the commercial electricity customers to avoid uncontrolled morning charging and spread the EV charging load evenly throughout the working day. According to the calculation results, integration of solar PV on the rooftops of office buildings decreases annual payments, but not significantly, owing to only a few sunny months in Finland.

1 Introduction

The decarbonisation of the power system goes hand in hand with a similar objective in the transportation sector [1]. The share of renewable energy systems is constantly increasing. Opportunities to charge electric vehicles (EVs) at workplaces are rapidly expanding and encouraged. Various studies have been carried out on assessing the synergy potential between EVs and solar PV systems and their technoeconomic feasibility [2]. However, little attention has been paid in the literature to the quantitative assessment of the impact of EV workplace charging in various distribution grid points so far.

The objective of the paper is to develop a methodology to define the EV hosting capacity in workplace charging scenarios at different voltage levels and grid points under different charging strategies. The EV hosting capacity means the penetration rate of EVs that the grid can host without being overloaded in relation to the nominal capacity of the grid point in question. The established methodology is made generic so that it is not fixed to any particular grid, grid point or charging strategy, and thus, it can be applied to any operating environment. The motivation behind these studies is to assess the impact of uncontrolled EV charging on the distribution grid and quantify the role of solar PV and the tariff system in the mitigation of undesirable grid impacts.

Three EV charging strategies are simulated: uncontrolled charging, charging within the peak power constraints and charging within the peak power constraints with solar PV integrated. The simulations are performed applying real grid and office building data and various assumptions of EVs. The EV hosting capacity, monthly peak power changes in the grid and economic issues of the study cases are reported and discussed. The paper is structured as follows. In Section 2, the methodology is presented. Section 3 describes the data and assumptions that are used for the methodology. In Section 4, the results of the simulations are presented. Section 5 draws the conclusions.

2 Methodology

The methodology established to define the EV hosting capacity is illustrated in Fig. 1. One of its main elements is the definition of the EV charging profile in the grid point. It includes compilation of the EV charging load profile in a connection point using assumptions of the number of parking places and EVs, distribution of workplace arrival times, charging power (kW) and the charging energy need (kWh) based on statistical data of driving patterns in Finland (see Fig. 2).

Essential case-specific data to be required are the EV penetration rate, which is calculated as the number of EVs over the number of parking places in the connection point.

In this study, the EV hosting capacity corresponds to an EV penetration rate at which the grid component loading rate is equal to 85% in one-hour resolution. The 85% limit is chosen to prevent overheating. The loading rate is calculated as the annual peak power divided by the rating of the grid component in question. For a transformer it is the nominal capacity, and for a connection point the fuse size.

The studies will take into account only the office buildings and will disregard the charging activities in the residential sector. This assumption is valid especially in urban areas where the residential parking places are limited, and preference is given to the usage of public transport. The studies are limited to one-hour resolution of the input data, and hence, the intra-hour phenomena, such as voltage fluctuations and quality impacts, are not considered.

2.1 EV charging load modelling

The developed methodology includes building of the EV charging load profile in a connection point relying on the assumptions mentioned above (see Fig. 2).

The generation of single EV profiles is performed at a 15-min resolution level for individual EV drivers using the model developed in [3].

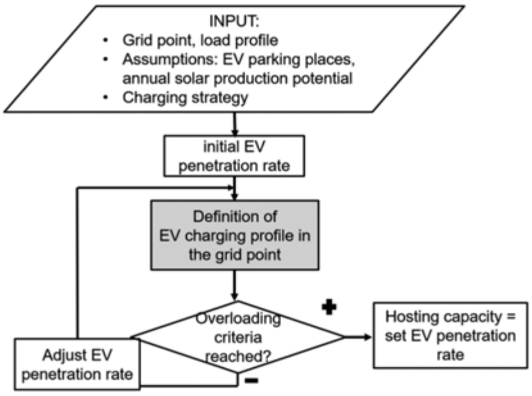

Fig. 1 *General methodology to define the EV hosting capacity in a workplace environment*

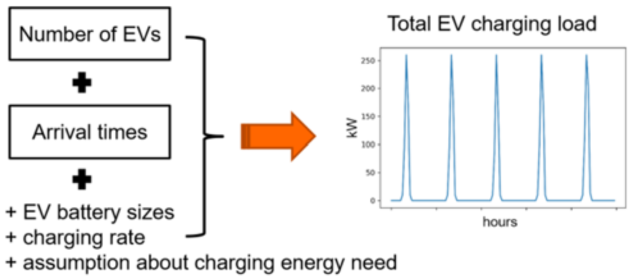

Fig. 2 *Definition of an EV charging profile in a grid point*

The arrival times of the EV drivers are assumed to be normally distributed around the morning peak hour at 8 am with the standard deviation of 30 min as an example for all office buildings. This, in turn, represents the worst-case scenario for the connection point and the distribution and main transformers, when the charging is synchronised around the same instant.

2.2 EV flexibility potential

In this study, the EV flexibility determines how much charging energy can be shifted and within which time period. The EV flexibility is assumed to be limited by two parameters: the minimum required state of charge (SOC) when departing and the departure time that is the hour by which the EV battery should be ready for use. Therefore, the longer the EV is parked and the more its battery can be left uncharged, the higher is the degree of freedom to shift the charging event. The sojourn time of the EVs was assumed to be equal to the working time of 8 h.

It was assumed that all the needed energy is charged at the workplace and not at home. This means that the batteries of all the EVs should be charged within the parking time of 8 h to the required SOC level. This is a strict assumption that may have an impact on the results. Nevertheless, the model allows to vary this parameter, but such a sensitivity analysis is outside the scope of the paper.

Further, smart charging without and with a PV system were modelled. In these options, the required charging energy was spread over eight working hours. Thus, the maximum charging demand compared with the uncontrolled charging was considerably decreased. When taking into account also the PV, the solar energy further decreases the demand and the energy needed from the grid during the times of PV production. The potential PV production is modelled using the roof area of the buildings and the profiles of real PV production units.

3 Input data and assumptions

The methodology was applied to an actual urban case network in the city of Helsinki. Only commercial and industrial customers were selected for the simulations. In total, 25 connection points, supplied by 23 distribution transformers, were used in the simulations. The number of parking places was obtained from the open-source database in [4] using the floor area of the buildings from [5]. For solar PV integration, the annual solar PV production potential for a connection point was obtained from [6] and the actual solar power plant measurements from [7].

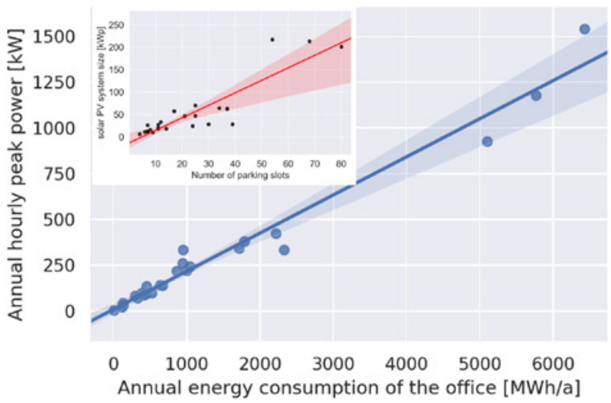

Fig. 3 *Background information of the electricity customers and estimation of solar PV and parking places*

Assuming the average number of solar hours to be 800 h/a in Finland, the installed solar PV system capacity can be estimated using the annual solar PV production potential. Three-phase charging at 16 and 32 A current levels was assumed, which results in 11 and 22 kW charging powers at the nominal voltage of 230 V. Two groups of EVs were simulated: full EVs (FEVs) and plug-in hybrid EVs (PHEVs). The size of the battery varied between 40 and 60 kWh for FEVs and between 8 and 10 kWh for PHEVs.

The economic calculations considered a monthly power-based fee of 4.50 €/kW/mo used in Helen Electricity Network Ltd. for low-voltage power customers [8]. The data of parking places and the solar PV annual energy potential are presented in Fig. 3 along with the energy consumption data of the workplaces under study.

4 Results

The results showed that the EV hosting capacity is not limited by the grid dimensions at the connection point and distribution and main transformer levels, even if EVs are synchronously charged in the morning (uncontrolled charging). Hence, the EV hosting capacity is not limited by the grid dimensions, and each office can simultaneously host many more EVs than the number of parking places.

4.1 EV hosting capacity

This subsection presents the results for the EV hosting capacity at the connection point, distribution transformer, and main transformer levels.

Fig. 4 shows the EV hosting capacity at the connection point level. The results for the two charging rates and the FEV/PHEV groups indicate that these two parameters do not significantly affect the results at the one-hour resolution level, and the curves are located close to each other. However, the summation of the 15-min resolution EV profiles with the upsampled 15-min resolution measurement load data showed that the annual peak powers may increase up to 35% at the 11 kW charging rate and over 200% at the 22 kW rate, in comparison with the one-hour resolution results. These results were observed in the uncontrolled charging scenario and can be explained by the synchronised charging of multiple EVs during a short period of time (15 min). At the distribution transformer level, no overloading was observed with the EV fleet

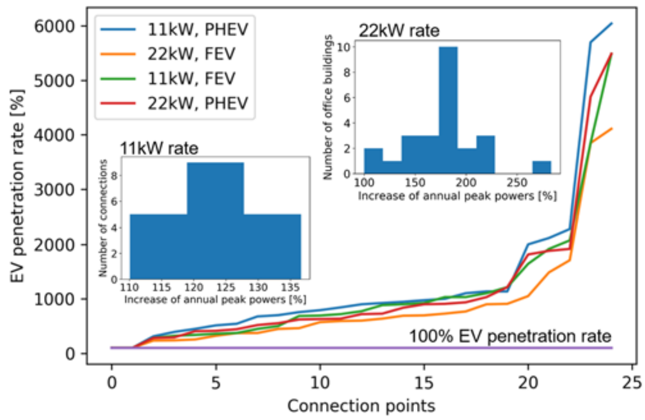

Fig. 4 *EV hosting capacity in the uncontrolled charging scenario*

size according to the number of parking places in the connection points as in Fig. 3.

At the primary substation level, the EV hosting capacity corresponded to the 3702 EVs in the uncontrolled charging scenario. This is enough to fit the charging load of EVs occupying the total number of 598 parking slots in the case area. Hence, it can be concluded that the EV hosting capacity is not limited by the grid dimensions in the case area even in the uncontrolled charging scenario.

Therefore, the results for the EV hosting capacity for the controlled strategies will not be discussed further. Instead, the economic calculations will be carried out in the presence of a power-based tariff (PBT). The results for the 11 kW charging rate will be discussed in the rest of the paper.

4.2 Economic analyses

The monthly peak power changes were calculated in different EV charging strategies, and the corresponding savings under the PBT applying smart charging instead of uncontrolled charging were assessed. The calculation took into account only the power-based fee of the distribution tariff.

Fig. 5 illustrates the changes in monthly peak power levels and their variations across different connection points for the two charging strategies: uncontrolled and controlled with solar PV integration. The boxplot represents the deviation of the changes, while the dots correspond to the 'outliers' that did not fit in the distribution of the peak power changes presented in the boxplot. It can be seen that the monthly peak power changes during the summer months are highest in the uncontrolled EV charging scenario and lowest in the EV controlled charging with solar PV integrated. This is due to the air-conditioning loads that produce

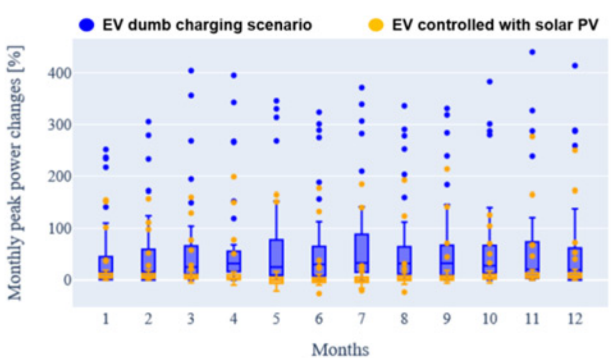

Fig. 5 *Monthly peak power changes in the connection points in two EV charging scenarios: uncontrolled and controlled charging with solar PV integration: 11 kW charging rate, FEVs*

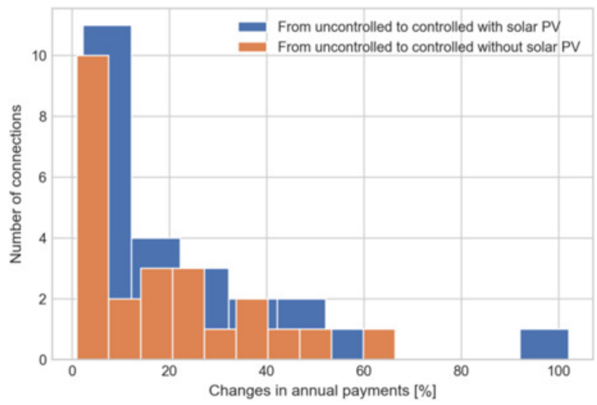

Fig. 6 *Economic benefits of the monthly peak power cut under the controlled EV charging strategy with and without solar PV*

annual peak powers in summertime in many office buildings in the case area. The impact of the solar PV integration can be best seen during the spring and summer months as the monthly peak powers are lowest then.

Fig. 6 illustrates the economic benefits of switching from the uncontrolled to the controlled EV charging strategy with and without solar PV. The changes in annual payments are calculated in comparison with the annual payments in the uncontrolled scenario. In the presented case, the difference between the two controlled EV charging strategies was minor because the change in peak powers was achieved in 2–3 months, and the results were calculated on an annual basis.

5 Conclusion

The results showed that uncontrolled EV charging does not cause overloading problems in any of the grid points, but rather produces large peak power changes and imposes high demand charges on the electricity customers. Furthermore, the largest savings in the annual demand charge can be seen when shifting from uncontrolled to controlled charging, whereas the economic impact of solar PV is minor because of only a few sunny months in Finland.

It is important to keep in mind that the presented results are case-specific and strongly dependent on the case grid dimensions, topology, customer load profiles, EV charging assumptions and resolution of the input data. The main objective was to build the methodology and apply it to a real case. The methodology not only allows to quantitatively perform EV hosting capacity assessment and grid impact at various voltage levels but also to conduct a sensitivity analysis on various input parameters. For example, the simulation results showed that the EV hosting capacity results are more sensitive to the resolution of the input data, rather than the charging rate and type of EV.

The further research questions include assessment of the grid impact when EV flexibility in a workplace environment is used not only for the customers' local interests, such as peak shaving and maximisation of the self-consumption rate of a solar PV system but also for system-level needs such as the provision of grid ancillary services.

6 Acknowledgements

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