Office buildings with automated EV charging

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Abstract: The control of electric vehicle (EV) charging in office buildings is the subject of this study. In Helsinki, Finland, the percentage of EVs has increased significantly in recent years. Apart from charging at home, charging at work is a convenient alternative. In this study, loadings at the metering point were examined and models of EV charging in office buildings were constructed. Unwanted high power demands may arise from uncontrolled EV charging. If a pricing component based on a monthly peak power is included in the grid tariff, this means that the client will pay a higher distribution price. Higher loadings and losses are experienced by the grid, according to the distribution system operator. It can also be necessary to make investments in additional network capacity.

1 Introduction

In order to reach the important and ambitious goal of a carbon-free future, the electrification of traffic is crucial [1]. Therefore, in addition to increased rail traffic, a transition towards electric vehicles (EVs) is needed. When considering the electrification of private transportation, the necessary charging infrastructure must be created. Various EV charging possibilities already exist, including e.g. homes, workplaces, parking lots and department stores.

This paper discusses EV charging in office buildings. EV charging means increased electricity usage with higher maximum demands. Thus, there is a motivation to address solutions for controlling the maximum demands. In this paper, an algorithm for modelling EV charging load is created. One presented solution for controlling is smart charging. Additionally, as a more sophisticated solution, a battery energy storage system (BESS) is applied for the limitation task in a real demonstration case. Its' applicability is tested and discussed [2].

2 Demonstrated office case

The demonstrated entity is an office building in Helsinki, Finland. It has five office floors and an underground parking hall. The building is heated by district heating and its annual electricity consumption is ca. 400 MWh. The common electricity of the building (e.g. ventilation, cooling, lifts, lighting of shared areas) takes a share of the above mentioned 400 MWh being annually 230 MWh. Also, eight EV charging stations and a BESS (120 kW, 134 kWh) are connected to the common electricity. This electricity usage profile increases along the working hours recurring from Monday to Friday. Because of the cooling of the building during summer, the annual maximum consumptions are realised at that time (Fig. 1). The maximum demands without EVs and a BESS have been during winter ca. 30 kW, spring/ autumn 35 kW and summer 65 kW. The need for EV charging takes place simultaneously with the other electricity usage in the building.

3 Modelling of the EV charging load

Creating the algorithm

The objective of the EV load model is to present the total electrical energy needed for the EV batteries when they arrive at their destination; in this case, the office building. In order to simulate the stochastic nature, several parameters, like the total distance travelled and consumption of the EV and the related losses have to be considered. In addition, the charging powers and arrival times of the vehicles must be regarded. Distances travelled and consumptions are not discrete, rather they depend on the behaviour of the driver and the type of vehicle used. Because of this, a probabilistic approach is used to model the energy need.

Single distances travelled

In Finland, a national survey on driving behaviour and patterns is done periodically [3]. The city of Helsinki conducted an additional study during the latest national-level survey. Thus, it is possible to derive the single distances travelled typically in Helsinki as well as their respective probabilities. By sampling the distances with the corresponding probability, e.g., 100,000 times, a histogram of distances travelled by private vehicles can be made (Fig. 2). The 10−20 km distances travelled represent the highest probabilities.

Specific consumption

Specific consumption is the amount of electrical energy the EV consumes by travelling one unit of distance. It can be calculated from the battery capacities and ranges of the vehicles, by data provided by EV manufacturers. However, as the available data of different EVs varies in accuracy and in calculation methods, it is not very reliable to compare them. Therefore, specific consumption is assumed to follow a truncated normal distribution with a minimum value of 0.10 kWh/km and a maximum value of 0.30 kWh/km. The mean value is chosen as 0.20 kWh/km, which is a typical value used in smart EV charging stations planning in Finland. A standard deviation of 0.03 kWh/km is applied.

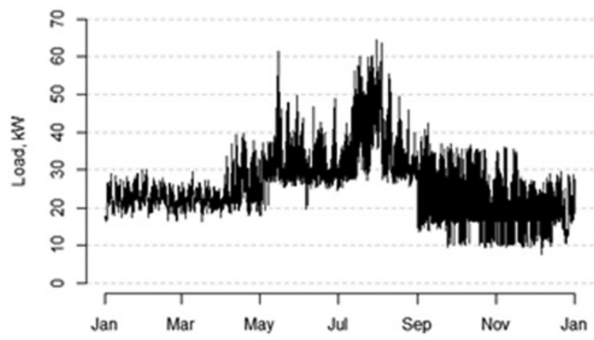

Fig. 1 *Hourly common electricity demand in 2018*

Electrical energy needs of the EV batteries

By taking the product of specific consumptions and the distances travelled, the electrical energy need of the EV batteries can be derived. In addition, the losses in the charging system and in the electricity distribution network need to be considered. The losses in the charging system are assumed to be 10%. For the grid losses, a value of 3% is used, which is based on the internal research done at Helen Electricity Network Ltd. The final distribution of the total energy need for a single charging event is shown in Fig. 3.

As only a very small amount of the energy needs presents a capacity that is larger than a typical plug-in hybrid vehicle energy capacity, the correlation of battery capacities to the vehicle types can be ignored to decrease the simulation time.

Charging powers

Charging powers have to be considered when studying uncontrolled charging. This distribution depends on the market share of hybrid and full EVs. As of this date, the amount of data is insufficient in Finland to form a coherent distribution. Thus, the authors of this paper propose a distribution, as shown in Fig. 4. This distribution assumes a plug-in hybrid EV majority. The minimum value is 3.68 kW (single-phase) and the maximum value is 11.09 kW (three-phase). Charging power of 22.17 kW is not considered in this paper.

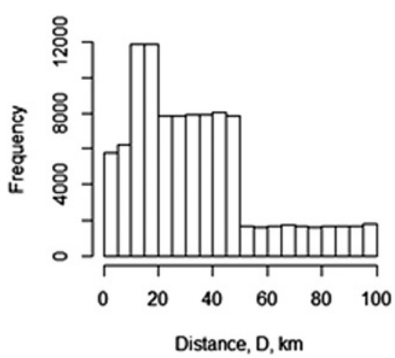

Fig. 2 *Distribution of distances travelled by private vehicles in Helsinki*

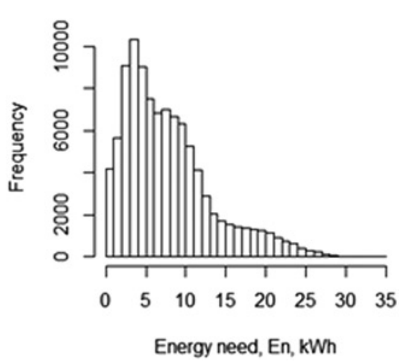

Fig. 3 *Distribution of energy of a charging event*

Arrival time

The arrival time is defined as the time when EV charging begins. Typically, in Finland, the working day in office buildings begins around 07:00–09:00 a.m. This assumption is used to simulate the different behaviour of office workers. In this model, it is chosen that 08:00 is the most frequent arrival time and can be therefore used as a mean value. A truncated distribution is also used in this case, having a minimum value of 06:00 and a maximum value of 09:00. The standard deviation is assumed to be 0.5 h.

Objective of the proposed algorithm

The studied charging methods are uncontrolled and smart charging where the energy need is divided to the full working day (8 h). The objective of the algorithm is to take samples from the distribution of the energy needs for every vehicle and derive their respective load behaviour. This is repeated according to the number of working days in question. This way the stochastic behaviour of the EV drivers and the effects of heterogeneous vehicle types can be modelled. The different steps are as follows:

1. Sample from the distribution of arrival times.
2. Divide the energy need by a sample from the distribution of charging powers, OR divide the energy need by the duration of the charging event, to calculate the amplitude and the duration of the charging event.
3. Add the charging load vector to the baseload vector.
4. Repeat steps 1–3 until every vehicle has been iterated.
5. Repeat steps 1–3 to iterate every workday.

The output of the above-reported algorithm is summed up e.g. to the measurements of electricity usage of the office building of interest.

4 Uncontrolled and smart charging

The developed algorithm is studied in the real office case. The simulation results of the developed algorithm are shown in Fig. 5. It can be seen how the uncontrolled charging of EVs results in unnecessarily high peaks due to a short charging period with high charging powers. This simulation result is added to the real demonstration case (measurement data in Fig. 1) resulting in a profile presented in Fig. 6.

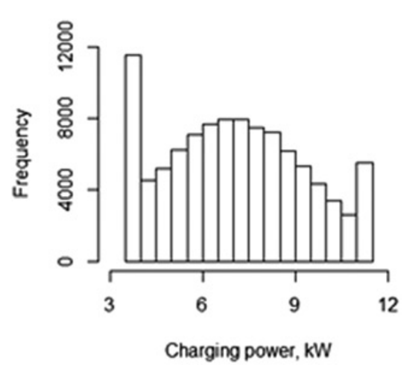

Fig. 4 *Distribution of charging power*

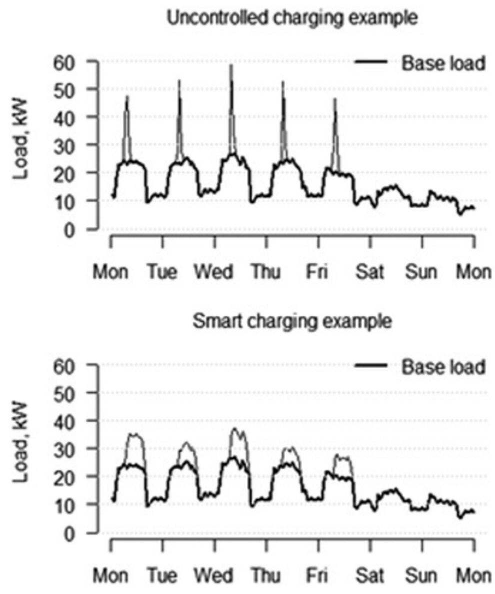

Fig. 5 *Examples of outputs of the algorithm for uncontrolled and smart charging with nine vehicles on a typical work week*

5 Battery energy storage system

BESS for peak shaving

In addition to smart charging, a BESS is a sophisticated solution for peak shaving. In the demonstrated case, the BESS limits the demand for common electricity to a determined level. The BESS discharges if the measured demand of the common electricity is higher than the discharge level of the BESS and vice versa.

Here, the aim is to limit the maximum demands of the common electricity of the office building. Typically, the summer peak demands are higher due to cooling. Thus, in order to optimally shave monthly varying peak demands, the parameters for discharge and charge were to be determined. With a genetic algorithm, an objective function to be minimized was a sum of peak powers of 12 months. As a result, two separate charge and discharge levels were searched: summer and winter. To optimally change between these two states, also a moving average temperature was determined. There were three parameters to search: summer and winter discharge levels, which works as charge levels after subtracting 1 kW, as recommended by the manufacturer, and one moving average of 6 h of outside temperature to optimally change the state between winter and summer levels. A year of hourly data was used in the search. Fig. 7 shows a successful operation of a BESS peak shaving, first to a level of 42 kW and later to 27 kW.

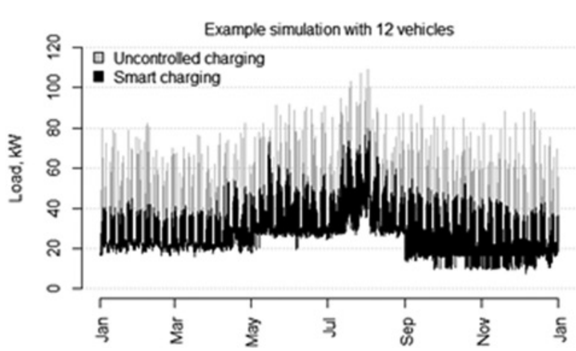

Fig. 6 *Example simulation of 12 EVs in an uncontrolled and a smart charging scenario*

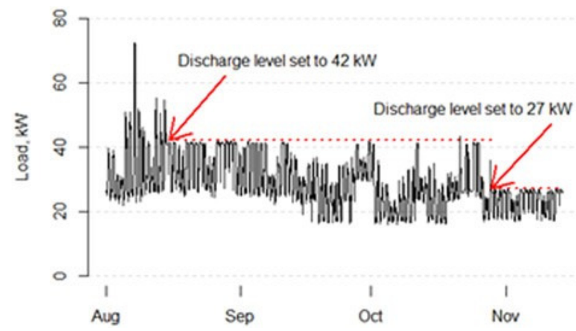

Fig. 7 *Measured data of EV charging and common electricity demand with the smart control of BESS from 2019*

Additional BESS operation in the frequency markets

In addition to peak shaving of EV charging, the BESS could further be utilised in the TSO's (transmission system operator) frequency markets. For the BESS owner and an aggregator, this means a possibility of additional economic benefits [4, 5]. In Finland, the market assets are now in the multi-megawatt scale. However, aggregation of smaller assets enables wider possibilities to small flexible sources to market participations. BESSes have been seen applicable e.g. to the FCR-N market (Frequency Containment Reserve for Normal Operation) [6]. In the demonstration, the BESS has as its' highest priority to limit the maximum demand of the common electricity. The BESS is needed for this task during working hours from Monday to Friday. Thus, it would be vacant for market operations, e.g. during weekends and nights and this would not compete with the main priority task of controlling EV charging during office hours. The profit of market operations should be divided between the aggregator and the BESS owner. Evidently, there is potential for benefits applying BESS as a secondary option in the markets. This will be demonstrated in the EU-SysFlex.

6 Results

With the developed algorithm, scenarios in the demonstration having uncontrolled and various controlling schemes and either 12, 24 or 39 EVs were performed resulting in profiles of electricity demands in the office building, similarly like in Fig. 6. The summary in Table 1 presents the sum of monthly peak powers and related costs. Uncontrolled charging considerably increases maximum demands and costs. These peak demands should be limited. It is apparent that the most techno-economically viable approach is to use smart charging by dividing the energy need of the EVs for the whole working day. It is also technically a simple solution. A more manifold arrangement is the studied real application with a BESS. In this case, savings in the grid tariff payments with BESS peak shaving are higher. However, when considering the high investment and lifetime cost of BESSes a smart charging is highly justifiable.

Table 1 Simulation results of the different scenarios

Scenario	Vehicles	Sum of monthly peak powers, kW	Annual power-based price, €
uncontrolled charging	12	1074	3912
	24	1745	9737
	39	2416	13,481
smart charging	12	672	3750
	24	819	4570
	39	1028	5736
uncontrolled and peak shaving	12	496	2769
	24	548	3056
	39	976	5448

7 Conclusion

According to the simulations and measurement results, EVs could be smartly charged without notably increasing the peak powers alongside the electricity usage and demand at the metering point and the supplying low-voltage network. This can be achieved by using a smart charging station. Alternatively, the control system of the EV may also provide a way to reduce the charging power. Additionally, in this research, a method to optimise the peak shaving levels of the BESS was presented. The BESS was successfully demonstrated in peak shaving. Evidently, a controlled system is needed to avoid extra costs to the customer and distribution system operator. Applying BESS to the frequency markets could bring additional benefits to the customer and the aggregator operating in the markets.

8 References

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