Applied Energy 224 (2018) 330–339

Contents lists available at ScienceDirect

Applied Energy

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

# Effects of charging battery electric vehicles on local grid regarding standardized load profile in administration sector

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## HIGHLIGHTS

- Analysis of pool pattern of university charging station with real use case and data.
- Model to represent the fleet and daily pool pattern is proposed and validated.
- Strategy with delayed charging start to avoid local grid bottleneck introduced.

## ARTICLE INFO

*Keywords:*
Work&charge
Electric vehicle user behavior
Charging strategy
Peak load reduction

## ABSTRACT

Integration of battery electric vehicles (BEV) as load could have an impact on the stability of local grids. With the experiment conducted in a research project, real-time metering data of the charging points was collected, with which the charging process, user behavior and furthermore modeling of default pattern on a working-place charging station park are presented and further discussed in this paper. The simultaneity of load peak from uncontrolled charging processes and from the local load profile could cause local grid bottleneck. A BEV pool model to generate random charging sessions on a workday, which conforms the real behavior in this research case, is proposed. Charging strategies were developed and considered as centralized or decentralized. The simulation shows the influence of delay charging start time and demonstrate the potential of peak load reduction from charging of several BEV and furthermore of a large-scale construction of charging infrastructure.

## 1. Introduction

Energy storage capacities are very important in order to replace the conventional power plants by wind and PV without jeopardizing the grid stability, which means above all to balance generation and consumption in all time frames. For the foreseeable future, the problem of lacking flexibilities on the demand side will not be relieved.

Due to geography in Germany, installed generation capacity from wind and solar has the largest share among all the renewable energy sources, while the share of hydro-based generation and storage capacities are relatively low [1]. As a result, the increment of market share of installed generation capacity with high fluctuation in the German power system will still last, because the power generation from wind and solar are closely related to the real-time meteorological situation.

The parallel planning of traffic transition relying on renewable energy, the use of electric mobility (especially Battery Electric Vehicle-BEV) and thus the increasing construction of charging infrastructure will play an increasingly important role as integrated energy consumers in low and medium voltage grids [2].

In this paper the main topic will be pinned on the analysis of typical load behavior of a charging station park in the administration sector (office building). For energy consumers in administration or industrial sector, which have a high share of electricity consumption in Germany, the power supply will be out of technical reason directly connected to the grid through its own grid connection point, e.g. directly connected via transformer to the medium-voltage grid, the load profile will either be real-time measured or estimated with standard load profile (SLP) depending on the total annual energy consumption [3]. However for high annual energy consumption in the administration and industrial sector an additional connection price calculated with the peak load power will be charged, which is defined by the highest average load power in a quarter hour timespan of the year. This surcharge can easily exceed multiple thousand EUR [4].

With additional BEV charging in grids with simple structure (e.g. at the end of single line grids), it could cause problem like increment of peak load power, which can lead to significant voltage drops even at

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https://doi.org/10.1016/j.apenergy.2018.04.073
Received 29 January 2018; Received in revised form 29 March 2018; Accepted 26 April 2018
0306-2619/ 

**Nomenclature**

*Indices*

| | |
|---|---|
| $i$ | index of BEV |
| $t$ | time of day |

*Variables*

| | |
|---|---|
| $\lambda$ | time constant of BEV in CV-Phase |
| $BEVModel^i$ | BEV model of BEV i |
| $c^i$ | boolean state for BEV i of *Fleet* appearance on the charging point on the day |
| $E^i_{cap}$ | battery capacity of BEV i (kWh) |
| $E^i_d$ | energy demand of BEV i (kWh) |
| $Fleet$ | designated BEV fleet consists of BEVs |
| $N_{con}$ | number of connected BEV i on a day (kWh) |
| $P^i_{max}$ | maximum charging power of BEV i (kW) |
| $P^i_{t,chrg}$ | charging power for BEV i at t (kW) |
| $P^i_{t,max}$ | maximum charging power for BEV i at t (kW) |
| $P^i_{t,simp,chrg}$ | charging power with simplified battery model at t (Hrs) |
| $P_{max,load}$ | maximum load power appeared (kW) |
| $P_{max,SLP}$ | maximum load power of SLP (kW) |
| $P_{t,exce}$ | excessive load power at t (kW) |
| $P_{t,load}$ | total load power at t (kW) |
| $P_{t,pool}$ | BEV Pool load power at t (kW) |
| $P_{t,SLP}$ | SLP load power at t (kW) |
| $Pool^{Fleet}$ | daily pool pattern for BEVs from *Fleet* |
| $rnd$ | random number in range [0,1] |
| $SoC^i_s$ | starting state of charge of BEV i (%) |
| $SoC^i_t$ | state of charge of BEV i at t (%) |
| $SoC^i_{cc,cv}$ | state of charge of BEV i at CCCV-phase conversion (%) |
| $SoC^i_e$ | charging end state of charge of BEV i (%) |
| $T^i_{simp,chrg}$ | charging duration of BEV i with simplified battery model (Hrs) |
| $t^i_a$ | time of day for arrival of BEV i of (h) |
| $T^i_{chrg,cc}$ | charging duration of BEV i in CC-Phase (Hrs) |
| $T^i_{chrg,cv}$ | charging duration of BEV i in CV-Phase (Hrs) |
| $T^i_{chrg}$ | charging duration of BEV i (Hrs) |
| $t^i_d$ | time of day for departure of BEV i of (h) |
| $t^i_e$ | time of day for charging end of BEV i of (h) |
| $T^i_p$ | parking duration (duration of stay) of BEV i (Hrs) |
| $t^i_{s,central}$ | time of day for charging start of BEV i from centralized strategy (h) |
| $t^i_{s,decentral}$ | time of day for charging start of BEV i from decentralized strategy (h) |
| $t^i_{s,latest}$ | latest time of day for charging start of BEV i of (h) |
| $t^i_s$ | time of day for charging start of BEV i of (h) |
| $T_{exce}$ | nominated duration of excessive load appearance in % |

low penetration levels [5,6] and also extra energy losses [7].

The data to be researched are originated from a charging station park consisting of 15 charging points and an aggregator, which undertakes SCADA tasks. 15 BEVs (vehicle data in Table 1) were assigned to employees of university for business and private use. The use as well as charging in the charging station park were free of charge.

As a result, journeys took place primarily in sense of shuttle between residence and the charging station park at BTU with additionally journeys for private purposes. The users can therefore be characterized as commuters in a work&charge use case. The charging processes were conducted uncontrolled, which operated via a plug&charge logic ('dumb charging'). Such a user pattern at an office charging station park can lead to problem like local overloading, as research in [8] indicates.

To avoid or minimize the increase of peak load power of load profile caused by uncontrolled BEV charging, the avoidance of simultaneity of load peaks is necessary. This can be optimized, e.g. by load shifting or peak shaving, as discussed in [9]. Other options are tariff charging or smart charging, as described in [10]. Different central managed charging strategies were already researched in [11]. The possible communication possibilities between charging station and backend are explained in detail in [12]. The development of a charging scheduler can be carried out by different means, e.g. Genetic Algorithm [12] and Markov Decision Process [13]. For the special application case of charging station in office building research works like [14,15,8,16] have been done. The general pool pattern at a business charing station was studied in [8]. In [14] a two-stage charging strategy for the combination of charging and renewable generation in which the main optimization goal is to response to electricity market and pv-forecasting. Momber et al. [16] studied the binding of plug-in hybrid EV into the building energy management system to minimize the operation cost with Distributed Energy Resources Customer Adoption Model (DER-CAM). In [15] a real-time water-filling algorithm for local peak shaving at non residential charging station was proposed and analyzed.

In this paper, a charging strategy is introduced, which essentially based on the influence of the charging start time of connected BEVs. The core of the strategy is to decouple the charging start time from the arrival time (connection of BEVs to charging points), consequently to start the charge at a later time. Unlike delayed charging strategy, presented in [17], this work also takes into account the limitation of the parking duration while working and the effects on the SLP G1 used for the administration sector in Germany. The cases to be discussed are limited on the charging processes which takes place on normal working days, during while high peak load power is expected, and mainly from those, who belongs to the employee group. Spontaneous charge, which can be categorized as charging with very short charging times and thus with less importance for flexibility purposes, will not be discussed. This paper is organized as follows: Section 2 the pool charging load pattern and the peak load problem caused by charging with additional SLP load will be reviewed. In Section 3 the user behavior of BEV pool will be modeled and generalized with statistical method for deeper investigation purposes. In Section 4 charging strategy is introduced and in Section 5 testified and analyzed with the project fleet and a more representative fleet of BEV.

## 2. Problem description

Each of the 15 charging points is equipped with a measuring device, which measures the active power in three phases over time. In order to investigate the impact of BEVs on the power system, all connected BEVs are considered as participants in a BEV pool and thus being analyzed. There were totally 1075 charging sessions recorded including their real-time active power and total charged energy over a seven months period.

### 2.1. Charged energy in a week

Due to the underlying behavior of vehicle users as commuters, BEVs

**Table 1**
German E-Cars CETOS technical data.

| Item | Value |
|---|---|
| Battery type | Li-ion |
| Useable battery capacity $E_{cap}$ | 17.1 kWh |
| Nominal range | 120 km |
| Max. charging power $P_{max}$ | 9.5 kW(3 ∼ ) |
| Phase | 1- or 3-phase |