IMPACT OF FAST CHARGING AND HOME CHARGING INFRASTRUCTURE FOR ELECTRIC VEHICLES ON THE POWER QUALITY OF THE DISTRIBUTION GRID

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ABSTRACT

One of the main short term challenges for the distribution networks will be the rapidly increasing penetration with EVs. In this paper, the effect of EV charging stations on the power quality of the distribution grid has been analysed. The preliminary analysis has been performed in accordance to the European Standard EN-50160 and to D-A-CH-CZ Technical Rules for the Assessment of Network Disturbances. The evaluation of the investigations has shown that in both cases no significant impact on the voltage quality occurs. Due to the strong grid connections in the investigated cases and the relatively low penetration of charging stations, no general statement can be made. Both measuring campaigns have shown unbalanced load between the three phases. Even if the charging stations are properly all three phases installed this asymmetric load has been determined.

INTRODUCTION

In a referendum that took place in 2008, the citizens of Zurich committed themselves to ambitious decarbonisation goals. One of the main paths to achieve these goals is the decarbonisation of the mobility sector. Due to this and the rapid development in mobility and battery technologies, ewz expects a significant rise in the number of electric vehicles (EVs) in the city in the coming years and a penetration of 90% by 2050 (cf. figure 1). In a study performed in 2017 [4] four scenarios have been investigated regarding the development of electromobility in the city:

The charging infrastructure is expected to expand accordingly. The most common methods today are home charging and fast charging. For Zurich, the ratio of these methods is assumed to be approximately 85% home charging (< 22 kW per station) and 15% fast charging stations (>22kW per station). Fast-charging stations with high power rating are only expected in limited numbers in sites like gas stations or shopping centres.

Because the effects of the charging infrastructure on the power quality have not yet been investigated by ewz, it is important to examine the possible challenges this infrastructures can create. At first the impact of a single fast charging station of 60kW installed at a gas station in the suburbs of Zurich and secondly that of home charging infrastructure installed in a parking lot of ewz have been investigated.

POSSIBLE CHALLENGES FOR THE DISTRIBUTION GRID

The most relevant effects of EVs on the distribution grid are possible overloading of cables and transformers, voltage problems and asymmetrical loading.

Overloading

Increased load due to the charging of EVs could cause overloading of cables and transformers. This is mostly the case with retrofit charging stations which were not considered in the initial dimensioning of the grid- or house-connection. The main problems caused by multiple charging stations in the same building and fast charging stations are due to the high extra load they incur. If the charging infrastructure is incorporated in the initial planning, then these problems can be avoided.

Voltage Problems

Charging stations located at the end of long lines might lead to voltage problems. The lower limits, as defined in the European Standard EN-50160 [2] and the D-A-CH-CZ Technical Rules for the Assessment of Network Disturbances [3], could be reached or even violated. In order to identify potential voltage problems, the harmonics at the points of common coupling have been investigated by installing temporary measurements.

Figure 1: Electromobility scenarios for the city of Zurich [4]
Asymmetrical loading
A third effect often measured is asymmetrical loading between the three phases. Even with a properly installed three-phase charging station, cases where the vehicles mainly charge through one phase, creating asymmetries to the grid that could damage components and/or lead to voltage problems have been measured.

MEASUREMENT OF NETWORK DISTURBANCES
In order to observe and analyse the network disturbances we installed measuring instruments at the point of common coupling. The analysis was carried out in accordance with the European Standard EN-50160 [2] and the D-A-CH-CZ Technical Rules for the Assessment of Network Disturbances [3].

Fast Charging Infrastructure
First, the impact of a single fast charging station has been analysed. Even though only a small number of fast charging stations are expected, the analysis of their effect to the network quality is relevant because of the high power loading of the grid.

Fast charging stations serve to charge EVs within a short time. Thus, the area of application is primarily at main traffic axes, e.g. gas stations on highways.

Grid Connection
The analysed fast charging station is situated in the distribution grid of ewz and can provide a maximum power of 60kW by a direct current connection (DC).

The fast charging station is connected directly to the low voltage distribution board of the transformer station. The distance between the transformer station and the private distribution cabin of the customer is 288m. The connecting cable has a cross-section of 3x185/120 mm². The grid connection is illustrated in figure 2.

The ordered power rating for this connection point is 110kVA. Thus, in future demand, another charging station can be connected to the grid without increasing the power rating.

Measuring Setup
To be able to analyse the effect of the fast charging station to the voltage quality according to EN-50160 the mean 10-minute values were measured at the point of common coupling (PCC). A second measuring unit was placed at the outgoing cable in the transformer station for control reasons. The duration of the measurement has been three weeks. The measuring setup is illustrated in figure 2, where it can also be seen that the charging station is the only load connected to this cable.

In order to be able to evaluate the measuring values according to the D-A-CH-CZ-guidelines the short-circuit power at PCC has been determined. As shown in the equation 1, the limits for the harmonic current \(I_v\) depend on the short-circuit power \(S_{KV}\) at the PCC. The higher the short-circuit power, the higher the limits.

\[
\frac{I_v}{I_A} \leq \frac{P_u}{1000} \sqrt{\frac{S_{KV}}{S_A}}
\]

Equation 1: limits according to D-A-CH-CZ [3]

At the PCC a short-circuit power of \(S_{KV} = 3.2MV\)A was measured. This high value can be explained by the tight meshing and the relatively short cable lengths of the low voltage distribution grid of ewz.

Results
The measurement showed that the voltage quality at the connection point of the fast charging station complies with EN-50160 (cf. figure 3).

The spectrum of the voltage harmonics shows peak values at the 5\(^{th}\) and 7\(^{th}\) harmonic. A further analysis illustrates that these values already exist in the distribution network and the charging doesn’t affect the peak values. By evaluating the control measurement in the transformer station, the hypothesis that these levels

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**Figure 2: Measuring setup and grid connection (fast)**

**Figure 3: voltage quality according to EN-50160 [2] (fast charging station)**
are already present in the distribution grid could be confirmed.

The evaluation of the current harmonics according to [3] is shown in figure 4 and illustrates that all values comply with these technical rules. This can be explained with the high short-circuit power ($S_{KV} = 3.2MVA$) at the PCC in relation to the ordered power rating of $S_A = 110kVA$ (cf. equation 1).

![Figure 4: evaluation according to D-A-CH-CZ [3]](image)

Although there is no limit exceeded, the current profile during charging was analysed. This further analysis (Phase 1 compared to the 5th and 7th harmonics) illustrates that the current harmonics increase when the charging process starts (cf. figure 5).

![Figure 5: Current profile of L1 and the 5th and 7th harmonic](image)

The values of the current harmonics are relatively small and the charging of EVs has in this case no measurable impact to the voltage quality.

The measuring campaign also identified that the load on the phases can be unbalanced. This asymmetrical loading is caused by vehicles that can draw power up to 7.4kW single phase. Figure 6 shows the current of phase L1 with a value of 32A.

![Figure 6: asymmetrical loading at fast charging station](image)

Despite the three-phase feeding, asymmetrical loading can occur in a range which exceeds the limit of the applicable regulations [5] by 100%. These unbalanced loads could damage components or lead to voltage problems, especially if the penetration of the charging stations grows.

**Home Charging Infrastructure**

Second, the impact of a charging infrastructure in an underground parking area of the office building of ewz was analysed. Although the charging infrastructure is located in an office building, it is used with a similar time pattern as a home charging infrastructure. The electric vehicle fleet is on the road during the day and in the evening the vehicles return to the parking area and are charged. Therefore, the analysed infrastructure was considered as home charging infrastructure.

Home charging stations are devices with a rated power up to 22kW. Although the rated power of these stations is small compared to the power of fast charging stations, the analysis is relevant because it is expected that the penetration of home charging stations will be much higher (about 85%) than fast charging stations [4].

**Grid Connection**

The charging infrastructure is connected to the main distribution board of the building. The supply cable has a cross section of 5x16mm² and connects the main distribution board with the sub-distributor in the parking area, which in this case was defined as measuring point. Thus, the maximum power rating of the infrastructure is $S_A = 43kVA$. From the sub-distributor the stations are also connected by a 5x16mm² cable (cf. figure 7). The infrastructure includes 8 charging stations of 3.7kW to 22kW.

**Measuring Setup**

The voltage quality was analysed in accordance with EN-50160 [2]. Although this European Standard must not be satisfied at the measuring point that was defined, as it is within the customer infrastructure, it is used as reference.
to quantify the voltage quality. To be able to analyse the voltage quality according to [2] the mean 10-minute values were measured at the sub-distribution board next to the parking area. The duration of this measurement has been seven weeks.

As shown in equation 1 the short-circuit power has a high impact to the voltage quality and is required in order to analyse the measured values according to the D-A-CH-CZ-guidelines [3] at the connection point (PCC). The measured value of the short-circuit power is \( S_{KV} = 3.25 \text{MVA} \). The measuring setup is illustrated in figure 7.

\[
S_{KV} = 3.25 \text{MVA}.
\]

Results

In figure 8 the result of the evaluation according to [2] is illustrated. It can be seen, that the voltage harmonics exceed the limits. A detailed consideration showed violated limits at the 9\(^{th}\) and 15\(^{th}\) voltage harmonic. To find out, if these excesses are caused by EV-charging further investigations were performed.

Consequently, the current profile of L1 compared to the 9\(^{th}\) and 15\(^{th}\) voltage harmonics were analysed and illustrated in figure 9. This figure shows that the voltage harmonics have a daytime-dependent course, whereas the EV-charging processes normally start in the afternoon and finish around 7pm.

To verify the hypothesis that the voltage harmonics are independent of the charging processes, an additional measurement was installed. With this measurement the mean 1-Minute values were analysed. The charging process started in the evening, where the level of the voltage harmonics in the grid is lower. In this way, it was better visible if the charging has an effect on the voltage harmonics. In figure 10 the result of this measurement is presented. It can be seen, that the current and the 9\(^{th}\) current harmonic have a strong correlation, whereas the voltage harmonic is not affected.

The evaluation according to [3] was determined with the power rating of \( S_d = 43kVA \) and the measured short-circuit power \( S_{KV} = 3.25\text{MVA} \). All values comply with these technical rules.
Figure 11: asymmetrical loading

Additionally the measurement at the sub-distributor illustrated the asymmetrical loading problem (Figure 11). Although there are only cars in the electric vehicle fleet with a maximum charging capacity of 3.6kW, a strong unbalanced load was detected. The asymmetrical loading that occurs is up to 56A. It can be seen that phase L1 is very highly loaded while phase L2 and L3 are nearly without any load.

CONCLUSION AND OUTLOOK

In this paper, the effect of a single fast charging station and that of home charging infrastructure on the power quality of the distribution grid has been analysed. The analysis has been performed in accordance to the European Standard EN-50160 [2] and to D-A-CH-CZ Technical Rules for the Assessment of Network Disturbances [3].

Based on the evaluation of the measuring results, it was concluded in both cases that the charging of electric vehicles has no significant impact on the voltage quality at the points of common coupling. Since both measuring points have a high short-circuit power compared to the respective power rating, the grid connection in both cases is very strong. Due to this and to the relatively low penetration of charging stations no general statement can be made. In order to draw a generally valid conclusion, further investigations need to be made.

Furthermore, it is important to carefully check the connection points of fast charging stations, to prevent any overloading of cables or transformers due to the high charging capacity of these systems.

An important problem, which was identified during the measuring campaigns, was the unbalanced load between the three phases. Even if the charging station is correctly three-phase connected, asymmetrical loading was identified. These unbalanced loads could damage components and/or lead to voltage problems. This topic needs further investigation and measures to minimize the impact on the installation and/or the distribution grid.

This investigation highlighted the importance of observing the development of electromobility in the districts of Zurich. In this way, areas with a high level of electric vehicle penetration can be detected and further measures (e.g. new measuring campaigns, load management, etc.) can be taken. To receive further valuable inputs for future grid planning, it will be necessary to evaluate the behaviour of the electric vehicle users. Thereby, it will be possible to find out and potentially influence the simultaneity factor of the charging processes, which will be crucial for potential grid expansion in the future.

REFERENCES


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