E-MOBILITY IMPACT ON SUPPLY IN DISTRIBUTION GRID

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ABSTRACT

The paper evaluates the impact of chargers measured on the charger cable connection to the distribution grid.
The paper describes characteristic points and methods of charging electric cars with AC and DC current. The impact assessment focuses on the flow of active and reactive power, the proportion of harmonics in the current and the impact on the voltage assymmetry of the distribution grid.

INTRODUCTION

Electromobility is a highly discussed topic today. Nobody knows exactly how it will evolve or how many electric cars will be running for 5, 10 or 20 years. It is necessary to determine the places for charging electric cars and their average power consumption. Several charging stations were measured to determine the feedback effects. Based on the measurements, the individual charging steps were determined and the impacts on the distribution network were analysed.

CHARGING OPTIONS

Electric vehicle charging stations come in many different solutions. We can divide them into 1-phase, 2-phase and 3-phase. Stations can serve for public and non-public use. The third criterion is according to the AC or DC charging current. The last view is based on the charging rate on slow and fast charging stations.

Private AC charging

Night-time home charging or charging during the day in a corporate car park can take between 6 and 10 hours. Small charging power is sufficient. If the 230 V socket is used, the charging power is 2.3 to 3.7 kW. In the case of a faster charging requirement, it is possible to use a 400 V socket and outputs of 11 or 22 kW. 3-phase Wallboxes contain electronics, enable communication with electric vehicles and ensure faster charging.
In all these cases, charging performance is limited by an on-board charger in an electric car, which is most likely only 1-phase.
Private AC charging is slow but the most economical way.

Public AC charging

Public 1-phase or 3-phase low power charging can be used in places where electric vehicles stay longer. It will be used on night-time car parks and housing estates, where it is not technically possible for the owner to charge the electric vehicle at home. It still requires an electric car parking for several hours.
Higher outputs up to 43 kW 3-phase are available at public fast-charging stations. Currently, there are few electric vehicles that can use the available charging power. On-board chargers do not allow fast charging.
Public AC charging is still slow but more expensive.

Public DC charging

DC chargers allow you to charge with more power. They will predominate in places where cars stay short time, or they only need to recharge on their way. Chargers with moderate rated power will be placed at department stores, offices, and the highest available outputs will be at gas stations or in large charging hubs around transit roads.
Nowadays, it is possible to use the DC Wallbox with output of 10-20 kW, charging station with output of 50 kW, Tesla Supercharger 120 kW. New stations are being projected to starting with 150 kW and over 300 kW for buses and trucks.
Public DC charging is the fastest and most expensive way because the charging station provider pays high grid capacity fees.

Figure 1: Public DC charging in Jihlava (own photo)

ELECTRIC VEHICLE

In the Czech Republic, it is estimated that there are 2,000 electric vehicles. This number does not include plug-in hybrids and hybrids, which are more numerous. The number of electric vehicles and charging points in the Czech Republic and Europe is still growing. According to BASF, there are over 550,000 electric vehicles in Europe and more than 3 million in the world at the end of 2018. [1][2]

On the Czech market it is possible to buy 16 types of electric vehicles and 28 types of plug-in hybrids, a total of 44 electric cars from personal, sports and utility vehicles. [1]

Passenger cars have a battery capacity of 30 - 40 kWh and an average power consumption of 12 - 15 kWh / km. Range up to 300 km and price from 27,000 to 39,000 €.

When considering the typical daily drive 50 km, the way to work, to the shop and back home. The average power consumption can be set to 7 kWh, which needs to be recharged daily.

CHARGING STATION ABB TERA 53

TERA 53 from ABB is the most commonly used and measured fast charging station in the Czech Republic. It is a universal charger that can be purchased in several versions of charging connectors. It is possible to combine DC charging with CCS and CHAdeMO connectors on outputs from 10 to 50 kW, AC charging with Type 2 plug in cable type or socket.

Type 2 allows you to charge AC at a maximum output of 43 kW at a voltage of 400 V ± 10%. In the case of AC charging, the number of phases used is dependent on the onboard charger.

The CCS and CHAdeMO DC connectors charge up to 50 kW. It is always possible to use only one connector, while the other is blocked during charging. Figure 2 shows the blog diagram of the DC side of the station. At the input there is a 3-phase rectifier, which ensures symmetrical current consumption from the distribution grid. It is re-switching to high frequency voltage (20 to 100 kHz) and imidietly re-directed to the voltage of the battery. The charger allows an output DC voltage in the range of 50 to 500 V.

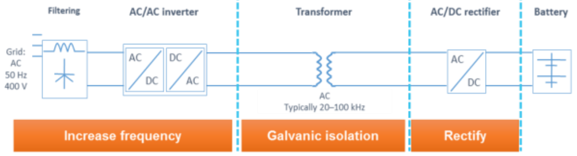

Figure 2: DC charging scheme [3]

CHARGING STATIONS MEASUREMENT

All measured fast charging stations are near distribution transformer stations and are connected by a separate cable directly from the low voltage switchboard. Measurements of power quality were performed at several charging stations. It was a charging station in Písek, Vystrkov near Humpolec, Jihlava and Ostrovacice. All effects on the distribution network are very similar and therefore only individual measurements are always presented. A complete comparison of all measurements is not included. Consequently, no voltage drops and other parameters related to the assessment of the quality of the electric energy from the view of standard ČSN EN 50 160 *"Characterization of electrical energy supplied from the distribution network"* are evaluated in the measurement. These parameters are within the limits of DTS connection and the only parameter that needs to be considered is sufficient transformer capacity.

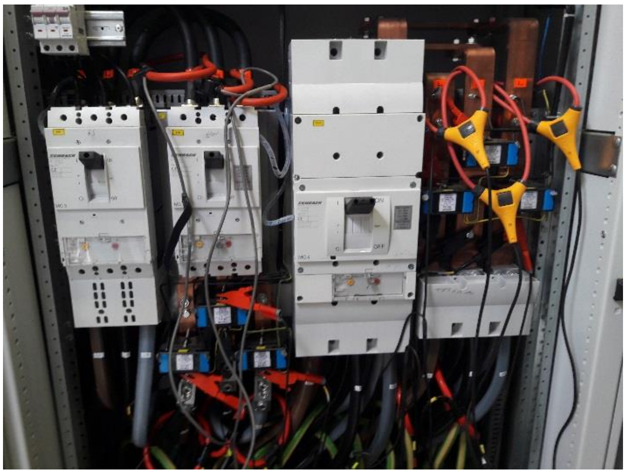

Figure 3: Set measurement (own photo)

Figure 4: Set measurement (own photo)

1-phase AC charging

All types of electric cehicles allow 1-phase AC charging. Cars differ only by the maximum allowed charging power which could be 2,2 kW (10 A), 3,6 kW (16 A) and 7,2 kW (32 A).

In this measurement, the output is 3.6 kW + the charger's own consumption (Figure 5). At the end of the charging cycle, the charging power is gradually reduced. During charging, a reactive power of 0.12 kVAr is supplied to the L1 phase. At the end of the measurement the reactive power supply increases to 0.27 kVAr.

In Figure 6 we can compare the total consumption with the value of harmonics. It is evident that during the whole charging process there are no harmonics in the drawn current.

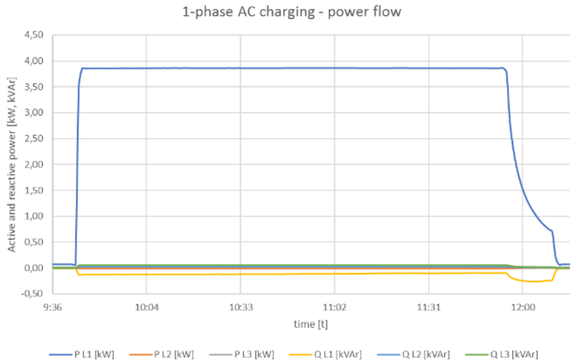

Figure 5: 1-phase AC charging power flow (own measurement)

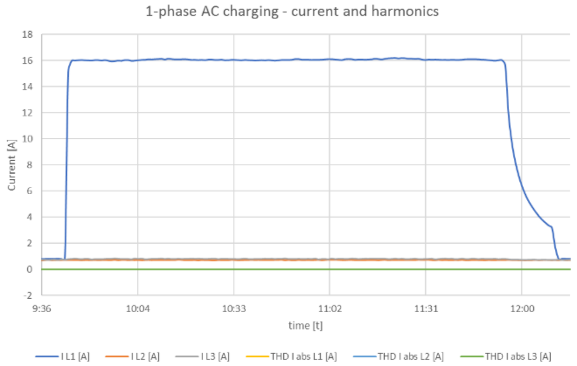

Figure 6: 1-phase AC charging current flows (own measurement)

Voltage changes in the low voltage are influenced by network behavior (figure 7), not by charging. There is no impact on voltage unbalance due to higher short-circuit power and low charging power.

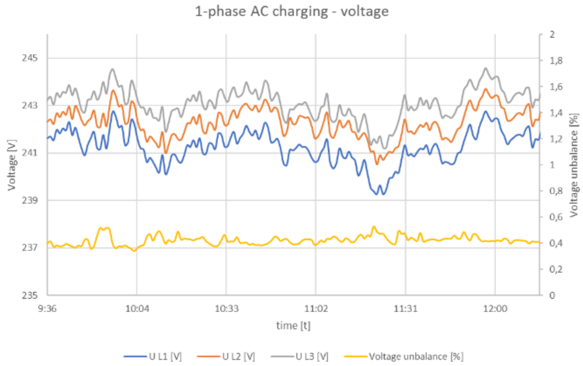

Figure 7: 1-phase AC charging power voltage and voltage unbalance (own measurement)

The blue line describes power factor during charging (figure 8). The power factor does not change and is constant, similarly to charging power. At the end of the charging process, the drop in active power and the increase of the reactive supply to the distribution network, it is markedly deteriorated (at an active power 2 kW and less).

There is no effect on the flicker, charging starts and stops smoothly.

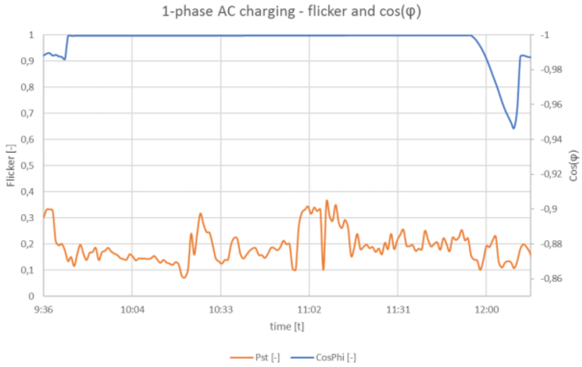

Figure 8: 1-phase AC charging effect on flicker and power factor (own measurement)

3-phase AC charging

Only some types of electric vehicles allow 3-phase AC charging. Chargers could be devided into severel groups according to the output power: 11 kW (16 A), 22 kW (32 A) and 43 kW (65 A). The highest charging power is achieved by Renault cars, which uses revolutionary technology to use inverter of the engine, instead of dedicated onboard charger.

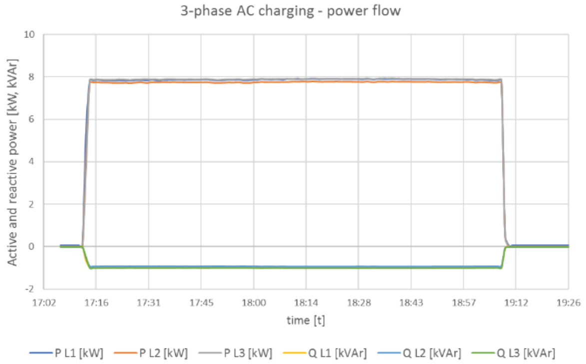

Figure 9: 3-phase AC charging power flow (own measurement)

In this case, charging power is 22 kW (figure 9). Charged car is, most likely, Tesla. Charging power is constant at all times. During recharging, a reactive power of 1 kVAr is delivered symmetrically to each phase. In total, when a 22kW take-off, 3 kVAr are supplied to the grid.

In Figure 10, we can compare the total consumption with the harmonics, which occur in the drawn current THDI abs [A]. During charging, current 33 A per phase is roughly constant. Harmonics, reach about 1.5 A of the total current. The value is constant throughout the whole charging process.

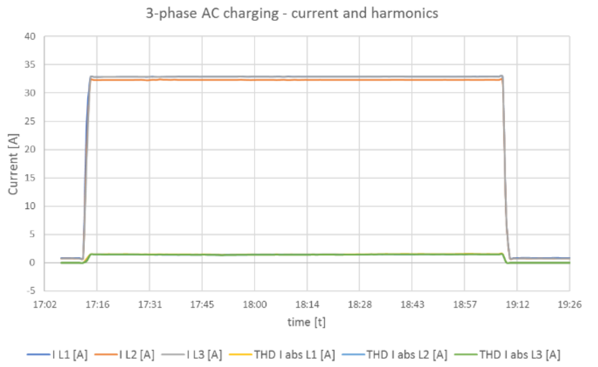

Figure 10: 3-phase AC charging current flows (own measurement)

In figure 11, the influence of 3-phase AC charging on the voltage in the distribution transformer, and on voltage unbalance (yellow line) is again negligible.

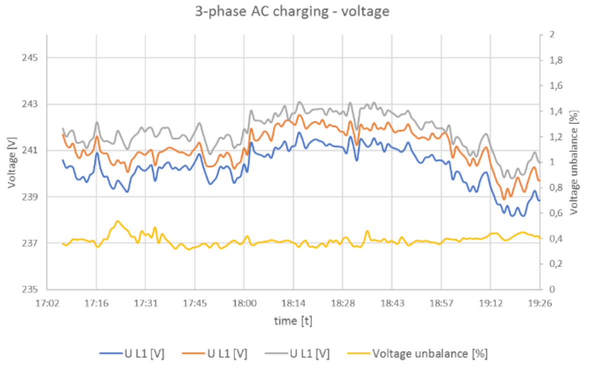

Figure 11: 3-phase AC charging power voltage and voltage unbalance (own measurement)

Figure 12 shows power factor of the 3-phase charging and the whole flicker measurement. Charging again has no effect on the flicker. The power factor is constant, with a short-term deterioration at the start of the charging process.

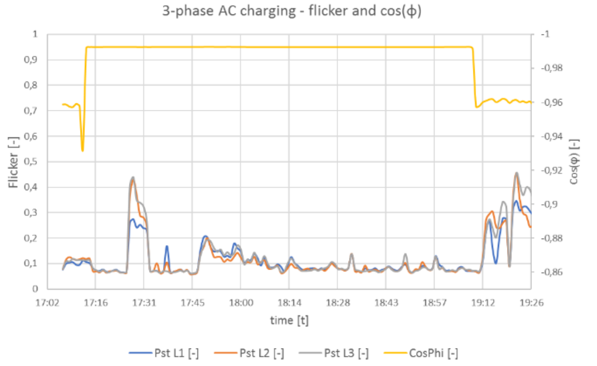

Figure 12: 3-phase AC charging effect on flicker and power factor (own measurement)

DC charging

DC charging is symmetric across all three phases based on the internal DC charging scheme on the distribution network. ALL electric vehicles enables DC charging. The charging patern is exponential. Every electric car that is fully discharged allows charging power of 50 kW. By gradually charging the battery, the charging power drops to nearly zero.

The power curve during charging is shown in figure 13. The power output is dependent on the initial battery status. The maximum active power of 51 kW is achieved in 5 minutes of charging and then decreases, the end of charging is only 6.8 kW. Reactive power supplied to the grid is also not constant. It changes throughout the charging process and oscillates between 3.4 to 6.3 kVAr, which are supplied to the distribution network.

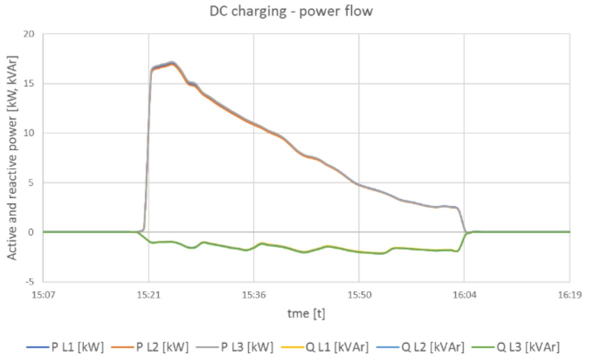

Figure 13: DC charging power flow (own measurement)

From the current graph (figure 14) we can compare the total consumption with the harmonics value, which is the THDI abs [A] is present in the charging current. The maximum value of the withdrawn current per phase is again reached in 5 minutes and is 70 A. At this point the highest value of the extracted harmonic current is reached and reaches 8 A of the total 70 A being taken. Interestingly, after 27 minutes of charging, the sampling of the harmonics completely ends.

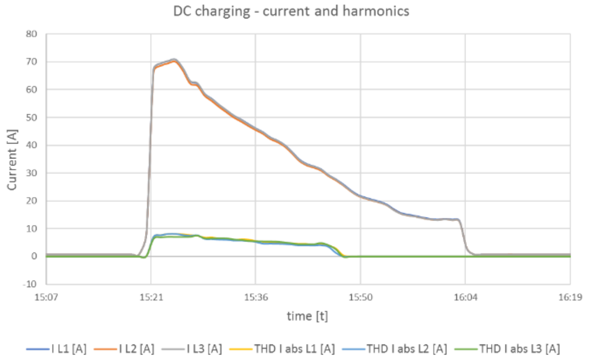

Figure 14: DC charging current flows (own measurement)

The last measurements are for DC charging. Even the output of 50 kW (figure 15) does not cause any change of voltage. There is a slight increase in voltage unbalance, which does not correspond to the start and end of charging. The power consumption and the resulting voltage changes are symmetrical.

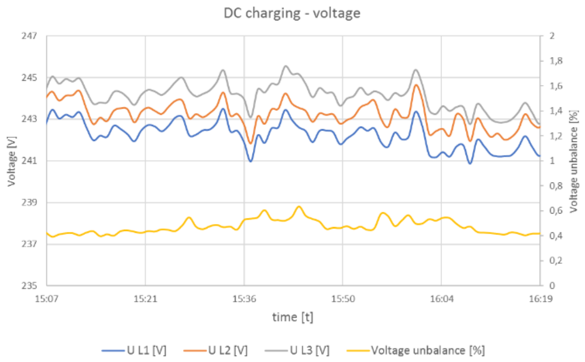

Figure 15: DC charging power voltage and voltage unbalance (own measurement)

Figure 16 shows a short-term power factor drop when charging starts. A more pronounced fall is at the end when the reactive power supply to the grid is still the same, but the active power is decreasing significantly. The power factor may fall below -0.2.

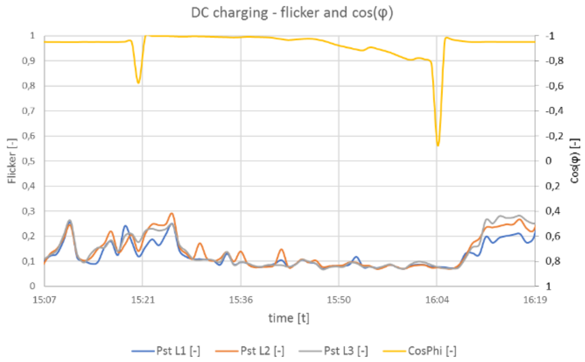

Figure 16: DC charging effect on flicker and power factor (own measurement)

HARMONICS

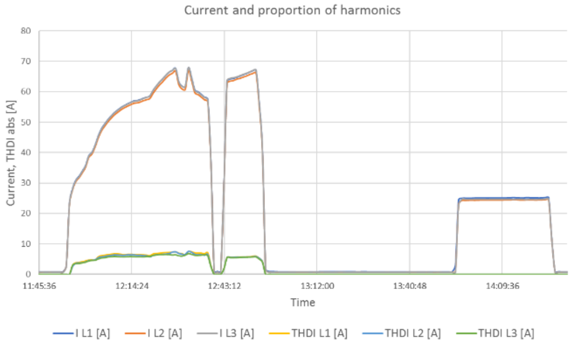

Figure 17: Current and THDI abs for DC charging - left side and AC charging - right site (own measurement)

Figure 17 shows 3 charging events: DC charging (first two events) and AC charging. During DC charging the current reaches a value of 67 A per phase and a total harmonic distortion of 6.8 A. In the case of a DC charging current, the current reaches 25 A per phase and the total harmonic distortion is close to zero. There is a significant influence of controlled inverters at charging stations.

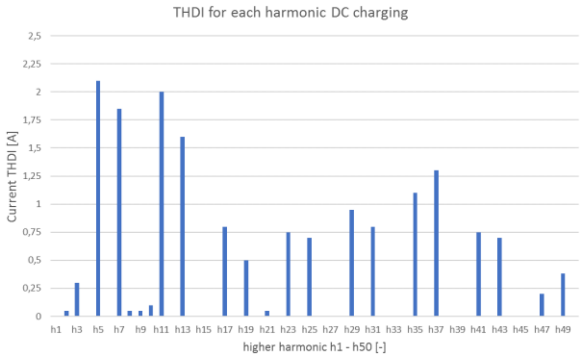

Figure 18: THDI abs from h2 to h50 DC charging (own measurement)

Figure 18 shows the distribution of the harmonics current at DC charging per individual multiples. Values up to 2 A are achieved for 3rd, 7th and 11th harmonics. All odd harmonics except multiples of three are more distinctive.

USE OF CHARGING STATIONS

The following paragraph describes measured locations and provides a preview of the most commonly used charging methods. In all cases, this was a Terra 53 fast charging station and therefore only DC charging prevails. Car owners used chargers to charge the batteries as quickly as possible and continue on their way.

The charging station in Jihlava (figure 19) is located in front of a large shopping center on the outskirts of the city. During the measurement period of 32 days, there were 83 cars. 74 cars used DC charging, 5 cars 3-phase and 4 cars 1-phase charging.

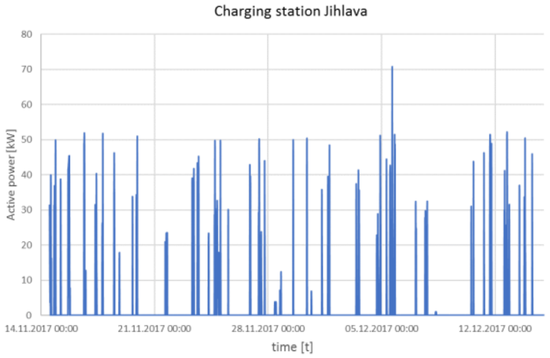

Figure 19: Use of charging station in Jihlava (own measurement)

The charging station in Písek (figure 20) is located near the car park in the city center near the rest zone. During the measurement period of 27 days, 53 cars were charged. 49 cars used DC charging, 2 cars 3-phase and 2 car 1-phase charging.

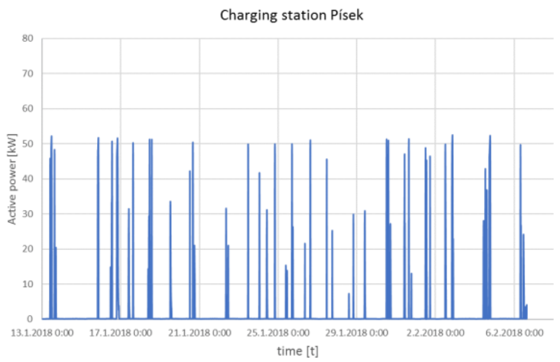

Figure 20: Use of charging station in Písek (own measurement)

The Vystrkov Charging Center is located at a D1 motorway exit. Measurements are taken from the charging stations from E.ON. During the measurement period of 23 days, there were 62 cars. 55 cars used DC charging, 2 cars 3-phase charging, 2 cars 2-phase and 3-car 1-phase charging.

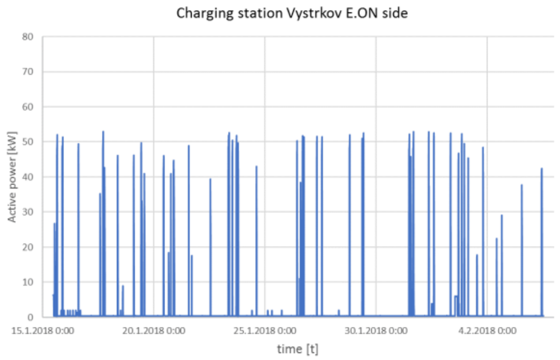

Figure 21: Use of charging center Vystrkov near Humpolec E.ON side (own measurement)

The last picture shows the number of cars charged at the second part of the Vystrkov power station. During the measurement period of 23 days, 169 cars were charged here.

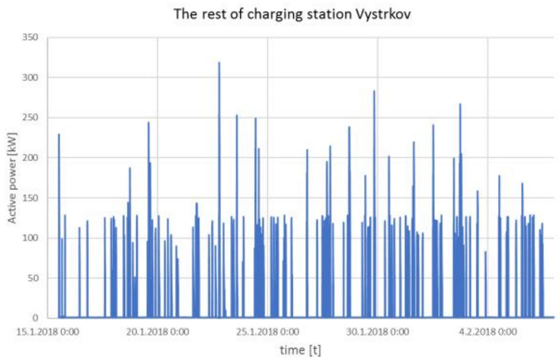

Figure 22: Use of the rest of charging center Vystrkov near Humpolec (own measurement)

CONCLUSION

Measurements show no significant negative impact of the electric car charger on the distribution grid. The main reason was the connection of all the quick-chargers directly into the LV switchgear in the transformer station, where the large chargers should also be placed. Only low-power chargers up to 22 kW should be placed within the LV distribution grid and regular phase shifting is necessary to avoid the possibility of voltage unbalance. Most of the electric vehicles are still only charged 1 phase today.

The 1-phase AC charging has no negative impact on the distribution grid. It supplies 3% of reactive power corresponding to the charging active power to the network. The proportion of harmonics is zero. The reason is probably an onboard charger that is designed for a precise battery voltage and has the potential to eliminate harmonics.

The 3-phase AC charging system supplies 13% of the reactive power corresponding to the charging active power. The harmonics fraction in the charging current is more significant and reaches 4.5% of the value of the drawn current. 3-phase charging has higher grid impact than 1-phase, even though the network is more suited to the symmetric load of all three phases.

For DC charging, 12% of the reactive power corresponding to the charging active power is supplied to the system. The value is not constant and changes during the charging cycle. The harmonics fraction in the drawn current is significantly higher, reaching a full charging power of 11.5%, but decreases to 0% in the second half of the charging cycle.

None of the charged methods caused measurable effects on voltage level. Due to the progressive start and end of charging, they do not increase flicker. In the case of 3-phase AC or DC charging, they do not impact the voltage asymmetry since all the phases are loaded symmetrically.

Significant negative feedback effects were not found. The individual charging curves are similar for all electric vehicles and charging stations. It is thus possible to verify each charging station by the calculation to ensure that its power does not overload the distribution network and does not exceed the permitted voltage dip. Based on the calculations, it is determined whether it can be connected to the distribution grid, whether the distribution grid will be strengthened or the connection request will be rejected. Other influences can be neglected based on measurements.

REFERENCES

[1] Luboš Srb, "*Počet elektromobilů v ČR roste. Meziročně o 66 procent.*", published July 13, 2018, https://elektrickevozy.cz

[2] International Energy Agency, "*Global EV Outlook 2018*, May 30, 2018, https://webstore.iea.org/global-ev-outlook-2018

[3] ABB - charging stations for electro cars, https://new.abb.com/ev-charging/en/