Charging of Electric Vehicles and its Influence on the Local Voltage Quality

Jonas Wetterström
Vattenfall R&D
Power Technology
Sweden, Stockholm
jonas.wetterstrom@vattenfall.com

***Abstract*—This paper focuses on charging of electric vehicles (EVs) and its influence on the voltage quality in the local grid. With the expected growth of infrastructure for charging of electric vehicles this subject is of large interest.**

In the paper it will be shown Total Harmonic Distortions (THD) of voltages and supra harmonics of voltages. These quantities have been measured in combination with the charging current on several electric vehicles from two substations. The two substations consist of several normal EV charging equipment (asymmetric) (Substation A) and one fast charger (symmetric) (Substation B).

The expected results are that the THD of the voltage is influenced very little from the electric vehicle charging, but there will be some unbalance between the phase voltages in the normal EV charging case, due to that the charger are one-phase loads and they charge at various times. It has been observed low distortion in the charging current due to the specific EV charger, but no distortion changes have been observed in the voltage quality (THD) compared to when no charging occur. The voltage quality follows instead the "normal" daily pattern of other loads in the facility that was already present before the EV charging started.

Even though it has not been possible to observe any problem at this facility so far, it is important to continue to do new measurements of EVs in weaker electrical grids.

Keywords-component; EV charging, harmonics, voltage quality, THD, supra harmonics. (key words)

I. INTRODUCTION

All electrical loads have impact on the voltage level and loads with distorted currents affect the Total Harmonic Distortion of for the voltage (THD). However, since the electrical network in many locations is strong, small disturbing loads have low or no impact on the voltage THD. Several loads with distorted currents together in one area in the electrical network aggregate to the total voltage THD. In a weak electrical network, the effect can be reached already with a few loads with distorted currents.

Since there are many different EV chargers at present and the number of electrical vehicles expect to increase rapidly it is important to continue measurements in this research area. [2]

II. HARMONICS AND THD

The most common current harmonics generated from EV chargers are 3, 5, 7, 9, 11 and 13, but generally the levels of current harmonics are low.

Total Harmonic Distortion (THD) in phase voltages are discussed in the paper. THD is defined as:

$$\mathrm{THDv} = \frac{\sqrt{V2^2 + V3^2 + V4^2 + \cdots}}{V1} \qquad (1)$$

where *V2*, *V3*, *V4*, … are the magnitudes of each harmonic in the phase voltage. *V1* is the RMS (root mean square) value of the phase voltage for the fundamental frequency component. [2]

III. SUPRA HARMONICS

In the frequency spectra 2 kHz up to 150 kHz disturbance can occur when electrical loads with switching devices are used and this may also have an impact on other loads. Examples of loads that generates such disturbances are LED (light emitted diode), PV (photovoltaic), EV (electrical vehicles) and several power converters etc. There may also be interactions in this frequency interval between connected loads in the local electrical network. Overheated and destroyed capacitors can be the result of high voltage levels of supra harmonics (2-150 kHz) since the capacitor normally is designed to operate at the frequency 50/60 Hz. [1]

IV. METHOD OF MESUREMENTS

Measurement have been performed in an indoor parking area under an office building at two substations, A and B. Substation A contains of several one phase EV charging equipment. Substation B contains mainly of a 3-phase EV fast charger of 50 kW.

The measurements were performed with a power quality analyzer PQube® 3 [4] connected to the busbar for voltage measure and to the outgoing cable with current flex probes. The instrument can measure all the earlier discussed power quality events such as: total harmonic distortion (THD), sags, swells, flicker, and supra harmonics. The measurements were performed during one week at each substation in 2017. Since the charging behaviour were quite similar each work day, only a few days was selected for presentation in this paper. For comparison examples of total harmonic distortion (THD) from a weekend day will be shown.

V. RESULTS FROM SUBSTATION A

Substation A contains of several one-phase EV charging equipment. Measurement from the substation during charging of electrical vehicles shows that significant levels of voltage at the frequency of 44-46 kHz occur in phase L2, see Figure 1. The coloured lines in the graph represent the occurrences of different frequencies for one work day. The orange and blue line in the graph represent 44 and 46 kHz. Levels of supra harmonics in the other phases were low and is not presented in Figure 1. The specific occurrence could also be found in another work day see Figure 2.

High levels of supra harmonics can have severe impact to equipment in the local electrical network. The origin of supra harmonics can be complicated to track in the electrical system since they interact with other loads. [1] There is however no further information concerning any problem due to the measured disturbance at present in the local electrical network.

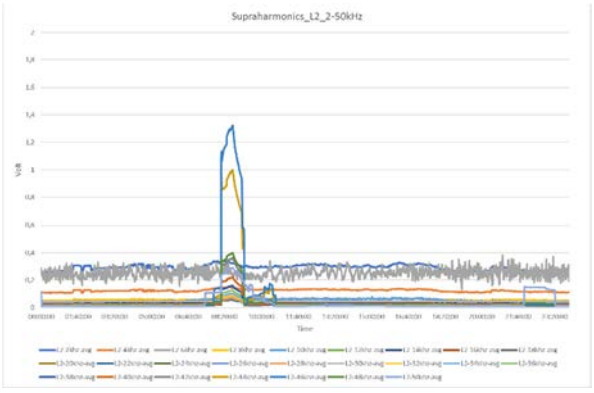

Figure 1 Supra harmonics in phase L2 at Substation A, significant levels of frequency 44 and 46 kHz originated from EV charging, work day 1

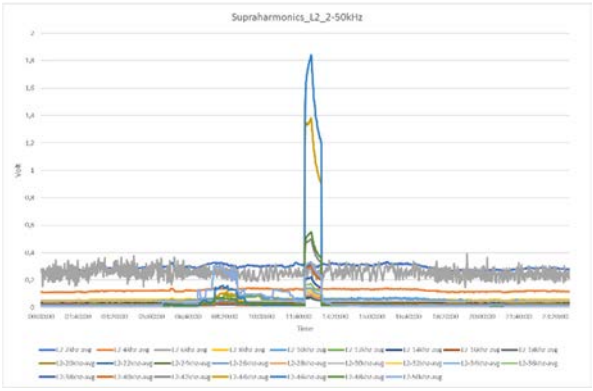

Figure 2 Supra harmonics in phase L2 at Substation A, significant levels of frequency 44 and 46 kHz originated from EV charging, work day 2

Generated current harmonics from EV charging in substation A were low, see Figure 3 and 4. The graphs for harmonic currents in Figure 3 and 4 corresponds well with the current in phase L2, see the orange graph in Figure 5 and 6. The specific occurrence in Figure 2, 4 and 6 originates from another day, work day 2. The peaks in supra harmonic 44 and 46 kHz in Figure 2 and current in Figure 4 corresponds exactly to an EV charging in phase L2 in Figure 6.

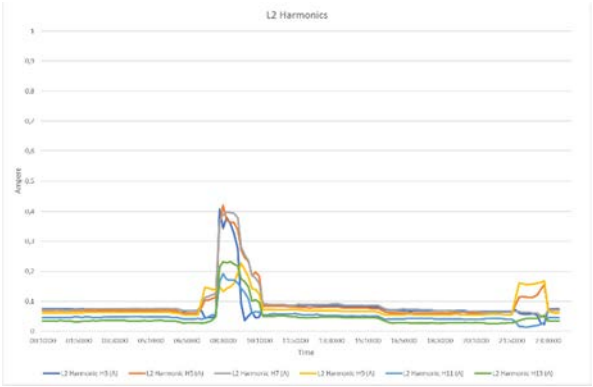

Figure 3 Current harmonics in phase L2 at Substation A, order 3, 5, 7, 9, 11 and 13, work day 1

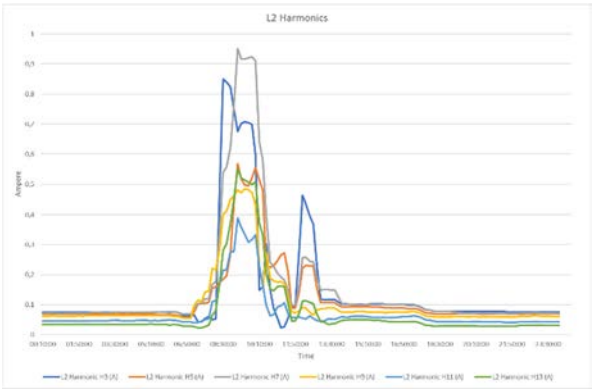

Figure 4 Current harmonics in phase L2 at Substation A, order 3, 5, 7, 9, 11 and 13, work day 2

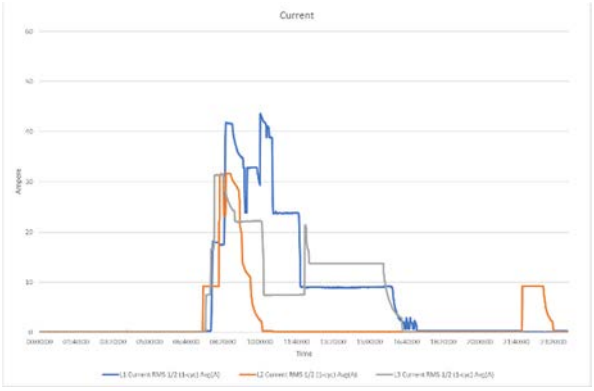

Figure 5 Current at substation A, phase L1(blue), L2(orange) and L3(grey), work day 1

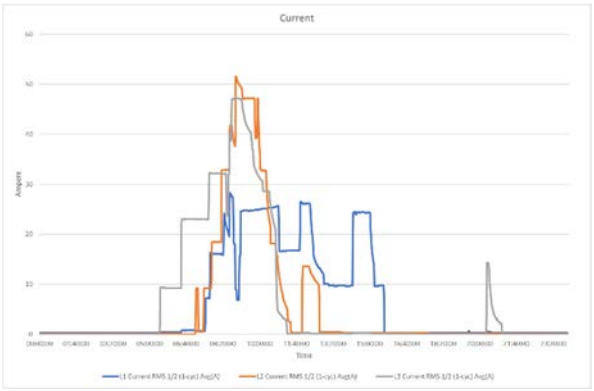

Figure 6 Current at substation A, phase L1(blue), L2(orange) and L3(grey), work day 2

As the levels of generated current harmonics from EV charging were low, the impact in voltage quality, THD, due to EV charging is expected to also be low. The voltage THD diagram clearly indicates that other loads have more impact to the voltage quality than EV charging, see Figure 7 and 8. Measured value of voltage THD are well below the limit of 8 %. [3] The origin to the shape of the voltage THD diagram will be investigated in future measurements. Note that the notches during night time in Figure 7 not appear in Figure 8 since the measurement originates from two different work days.

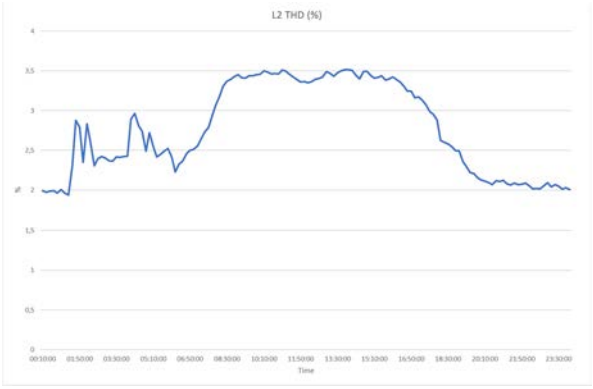

Figure 7 Voltage THD in phase L2 at Substation A, work day 1

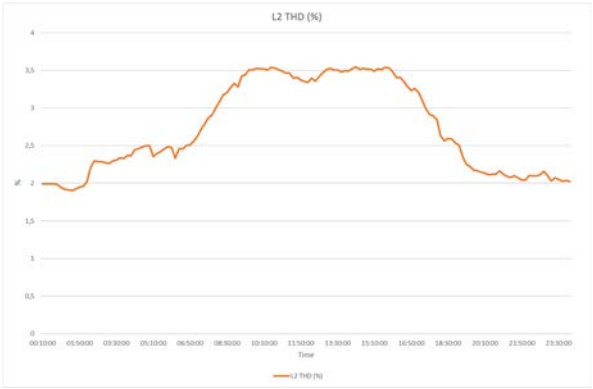

Figure 8 Voltage THD in phase L2 at Substation A, work day 2

VI. RESULTS FROM SUBSTATION B

Substation B contains mainly of a 3-phase EV fast charger. Measurement from this substation shows low levels of supra harmonics. The origin of the present levels of supra harmonics with frequency 2 kHz originates from other loads in the facility, see the blue line in Figure 9.

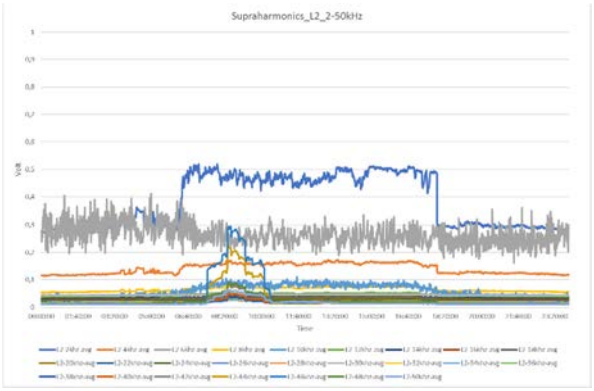

Figure 9 Supra harmonics in phase L2 at Substation B, significant levels of frequency 2 kHz, not originated from EV charging

The levels of generated current harmonics, see Figure 10, from the EV fast charger were low and has minimal impact to the voltage THD, see Figure 12. The occurrences of harmonic current in Figure 10 corresponds well with the current in phase L2, see Figure 11. Note that an additional one-phase EV charger were connected during 16:00 to 18:00 on phase L1, blue line, see Figure 11.

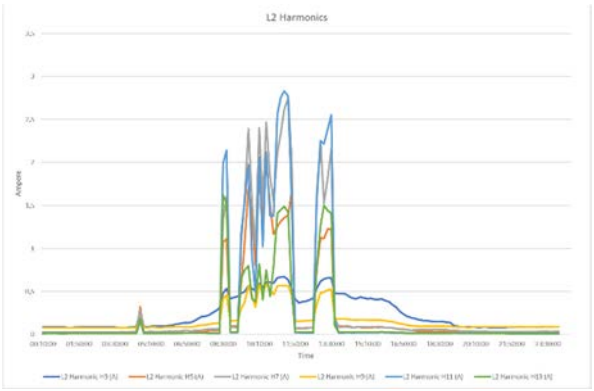

Figure 10 Current harmonics in phase L2 at Substation B, order 3, 5, 7, 9, 11 and 13

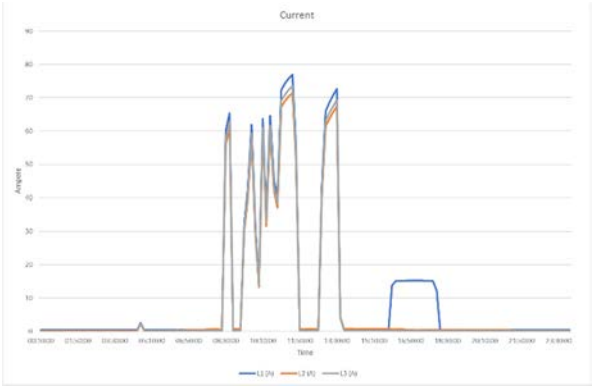

Figure 11 Current at substation B, phase L1(blue), L2(orange) and L3(grey)

The shape of voltage THD in Figure 12 is similar to the one in Figure 7 but the measurements origins from different work days and different substations A and B. Observe that the notches seen in both Figure 7 and 12 during night time not likely origin from EV charging since the absent of EV charging current at that time.

Future measurement will focus more in the origin of these notches. Total harmonic distortion (THD) from a weekend day, shown in Figure 13 shows clearly the differences compared to the one from a work day shown in Figure 12. It is believed that the absent of office activities during weekend day result in that the THD levels remains at the same value during the whole weekend day, see Figure 13. The shape of the distorted voltage THD origin from other loads in the facility than the EV charger in Figure 12.

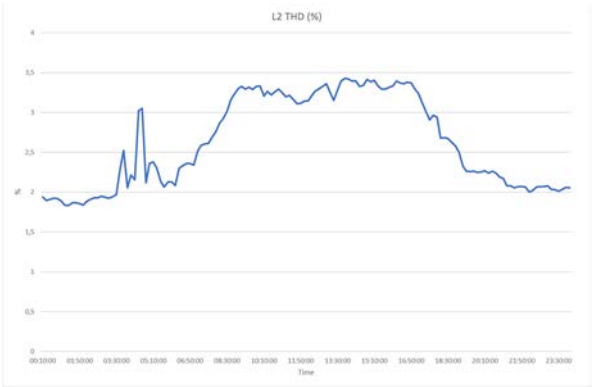

Figure 12 Voltage THD in phase L2 at Substation B, work day

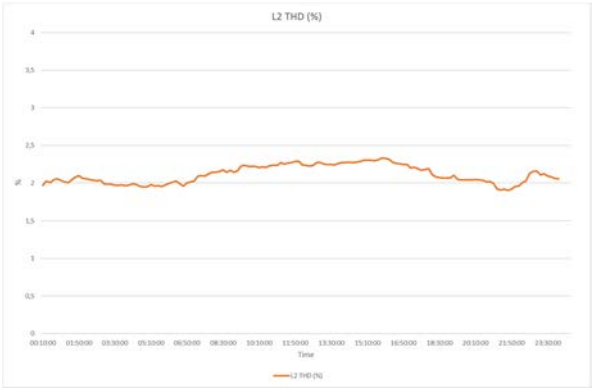

Figure 13 Voltage THD in phase L2 at Substation B, weekend day

VII. SUMMARY

Measurements from the two substations during charging of electrical vehicles show that the impact on voltage quality is low. The shape of the distorted voltage THD during work days origin from other loads in the facility. The occurrence of supra harmonics, 44 and 46 kHz, clearly origin from a certain EV charger have been detected.

Since there are many different EV chargers at present and the number of electrical vehicles expects to increase rapidly it is important to continue measurements in this research area.

REFERENCES

[1] S. Rönnberg, M. Bollen, "Propagation of Supraharmonics in the Low Voltage Grid", ISBN 978-91-7673-461-2 | © Energiforsk, December, 2017, Sweden.

[2] J. Persson, J. Wetterström, Y. He, "Measurement of Harmonics and Sags in Grid Voltages when Charging Electric Vehicles", 1st E-Mobility Power System Integration Symposium, October, 23, 2017, Berlin, Germany.

[3] IEEE Std 519-1992, "IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems", Institute of Electrical and Electronics Engineers, Inc. 1993.

[4] https://www.powerstandards.com/?product=pqube-3/highlights#anchor

BIOGRAPHIES

Jonas Wetterström was born in Eskilstuna, Sweden in 1968. He has studied Electrotechnical automation and control system in Norrköping/Linköping University of Technology from 1992 to 1995. He has been working at Vattenfall R&D in Solna, Sweden since 1995. During these years he has performed several measurement projects around power quality.