RESULTS OF HARMONIC INTERACTIONS OF EV CHARGERS AND PV SYSTEMS

ABSTRACT

The number of Photovoltaic-Systems used in electrical power systems is constantly rising. The efforts of the European Union´s policy to increase the use of electric vehicles leads us to the question how photovoltaic inverters and electric vehicle chargers are interfering each other, if they are connected together. The major focus of this study is placed on the interaction of the harmonic current emission.

INTRODUCTION

This paper shows results of current harmonics measurement of a constellation where a charging station of an electrical vehicle (EV) and a photovoltaic system (PV) was connected to the grid at the same connection point. At this connection point, energy of the PV system is fed to the grid using a photovoltaic inverter. At the same time, energy for the EV charging station is taken from the grid.

A DEWETRON DEWE-2600 Power Analyser acquired the following parameters: Harmonics (amplitude and phase shift), Interharmonics, FFT full spectrum with 5Hz resolution, THDU, THDI, voltage unbalance, Flicker, load curve for charging process, active and reactive power and the power factor. Most of the calculations and analysis were performed with the measurement software on the instrument itself.

This paper is organized as follows, methodology describes the basic equations used to analyse the data. Measurement setup and location presents an overview of the measurement site. The sections results and conclusion summarize the key messages.

METHODOLOGY

As shown in section "Measurement Setup and Location", the measurement is performed at the lines of PV inverter and EV chargers. The advanced functionality of the measurement device enables the option, to calculate the sum of the current without any influence of additional load at the connection point. Therefore, all needed parameters can be estimated at once and synchronous with only one device.

The harmonic current measurement and grouping is

implemented in the measurement software according to IEC 61000-4-7 [1]. The output of the device is a vector with 10-period-values of each harmonic. Due to better visualisation and data handling, a 10-minute-time-frame is used for data interpretation. This mean value of the harmonic current as used in figure 2, is estimated with the following equation:

$$I_{H,i} = \sum_{L=1}^{3} \sum_{n=0}^{N} I_{H,i}[L][n] \qquad (1)$$

L .... Number of phase
n........ Index of 10-period interval
N .... Number of 10-period interval

For evaluation of the total harmonic load, the standard value of THD (Total Harmonic Distortion) is not capable because of its relative relation. In this experiment, the load and generation are variable and the THD values are not representative. In this case, the total harmonic current value (THC) is used, which is calculated as follows:
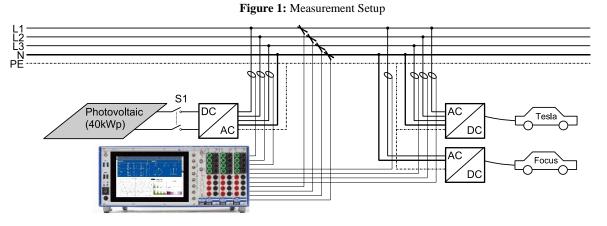
$$THC = \sqrt{\sum_{i=2}^{50} I_{H,i}^2} \qquad (2)$$

I_H,i.. Current magnitude of harmonic order i

The sum of harmonic load (PV and EV) is estimated via virtual current measurement points. This means, that the waveform data of the current sensor signals of load and generation are summed for each phase and calculated to harmonics.

$$i_{grid}(t) = i_{PV}(t) + i_{EV}(t) \qquad (3)$$

MEASUREMENT SETUP AND LOCATION

Figure 1 shows a schematic of the measurement setup. The measurement is done at a three phase system with a nominal voltage of 230V at the grid connection point of a PV system (40kWp). For temporary use, the charging conductors for the cars are also connected there. Each phase of the PV system and of the EV chargers is equipped with a current clamp. Table 1 gives an overview of the used clamps. The voltage is connected directly to the input channels of the measurement device.

Figure 1: Measurement Setup

The PV system is connected to the grid via 4 inverters (SMA Tripower 10000TL) and equipped with a load switch (S1) on the DC side for disconnecting. To simulate the absence of the photovoltaic system, the switch was opened. A Tesla S85 and a Ford Focus Electric were used. Tesla S85 was connected via 3 phase plug (max. 16A) and Ford Focus Electric via 1 phase plug.

The DEWE-2600 is capable of 16 individual input channels. For this specific measurement, only 10 channels were used. Three of them for the voltage measurement (voltage input up to 1400V) and seven for the current measurement (low voltage input up to 50V).

RESULTS

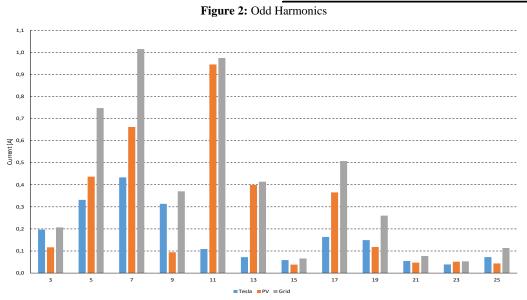### Harmonic Interaction between PV, EV and Grid

Figure 2 shows the harmonic interactions between EV charger, PV system and the grid. The average power load of the EV charger during the measurement was 8kW and the power generation of the PV system was 18kW.

The contribution of even harmonics is negligibly small and is not shown in the figure. The results shown in Figure 2 present the average values of the harmonic current of all three phases.

The results show that the harmonic load of EV charger and PV system never compensates. The harmonic currents of the PV system and of the EV charger are adding up. Depending on the phase angle of every harmonic, this sum is higher or approximately equal to the grid but never lower. 5th, 7th, 11th, 13th and 17th order, are delivering a significant contribution to the grand total of the harmonic current.

Table 1: Current Sensors used by Measurement

Channel	Sensor	Range
I_PV1	Clamp-150-DC	±125A
I_PV2	Clamp-150-DC	±125A
I_PV3	Clamp-150-DC	±125A
I_ECAR2	Clamp-150-DC	±100A
I_E1	A100-20-200	±50A
I_E2	A100-20-200	±50A
I_E3	A100-20-200	±50A

Figure 2: Odd Harmonics

Consider the 5th and 7th order harmonic, it is clearly shown, that the sum of harmonic current of EV and PV is higher than the measured harmonic current of the grid.

To acquire the influence of the grid, the PV system was switched off during the measurement for about 4 minutes. Figure 3 shows the trend of THC compared to the power of the PV system.
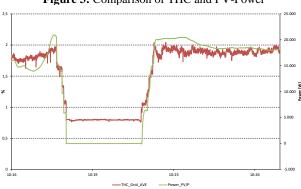
Figure 3: Comparison of THC and PV-Power

It can be seen that the harmonic load is reduced in the case the PV generation is zero. This leads to the statement, that the combination of a PV system and an EV charging station increases the amount of harmonic emission. The same behaviour can be seen in higher frequencies (2 – 9kHz).

Harmonic currents do not deliver any significant active power but uses system capacity and reduces the number of loads that can be powered. As part of the global trend using more electric vehicles, the impact of harmonic emission must be considered. Limits of harmonic currents up to the 40th order for a 50-Hz system are given in IEC 61000-3-2 [2] for currents up to 16A and IEC 61000-3-12 [3] for currents up to 75A.

Harmonic Emission of EV depending on PV availability

In the first step the harmonic load of the Tesla, during charging, is analysed with connected PV system. The charging power at this time was 12 kW and the power generation of the PV system 18 kW. Then the PV system was disconnected for 4 minutes. The harmonic load is analysed for all odd harmonics up to the 50th order. The contribution of even harmonics is negligibly small and is not shown in the figure. Figure 4 shows the harmonic currents (a) and the differences for the charging process with and without connected PV system (b).

Figure 4: Comparison of averaged harmonic currents of EV charger with and without PV generation and their differences
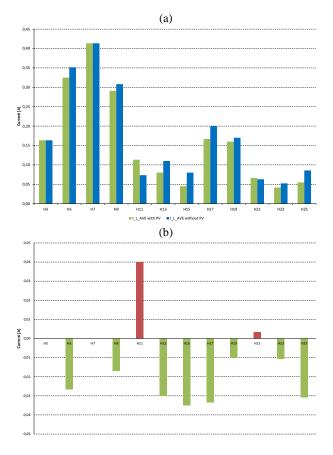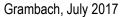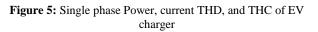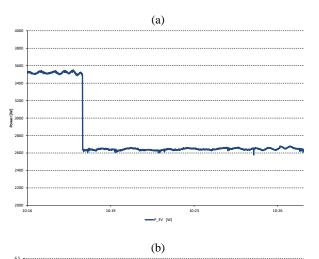
Figure 4 shows that the harmonic emissions of most odd harmonics are reduced if there is a PV system connected. Just a few odd harmonics are getting higher (H11, H21, H29, H47, H49). The reason for the change of the harmonic load is very likely the changed voltage harmonics due to the presence of the PV system.
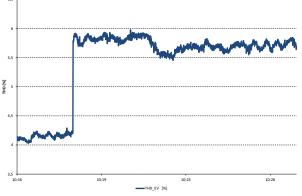
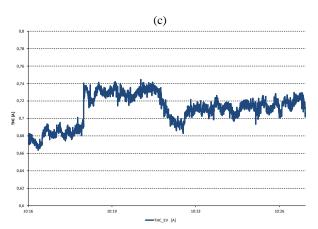**Harmonic Emission of EV depending on Charging Power**

The Tesla has a monitoring system installed which watches the voltages during the charging process. If the voltage at the charging plug falls below a certain level, the charging power decreases automatically. At a voltage of about 210V the charging power of the Tesla decreases from 12kW to 8kW. Figure 5 shows the single phase charging power (a), the current THD (b) and the THC (c) of the EV charger during the power reduction.

Figure 5: Single phase Power, current THD, and THC of EV charger

(a)

(b)

(c)

As soon as the voltage drops below 210V the charging power decreases from 3500W per phase to about 2600W. The current THD at this point rises from 4% to 6% while the THC stays constant at about 0.7A. Therefore, the reduction of the charging power does not decrease the harmonic load but leads to a lower power factor and lower efficiency.

CONCLUSION

The results show that the harmonic load of EV charger and PV system never compensates. The harmonic currents of the PV system and of the EV charger are adding up. The amount of the addition of both currents strongly depends on the phase angle of the according harmonic.

Further results show the harmonic emission of an EV charger with and without connected PV system at the grid connection point. It is shown that most harmonic currents are decreasing if the PV system is connected to the grid. This is very likely due to the voltage harmonics due to the PV system influence.

The harmonic emission of an EV charger for two different charging currents is compared. Lower charging current doesn´t reduce the harmonic current.

REFERENCES

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