Determination of power grid parameters between two electric mobility charging stations by measuring current and voltage

Leon Philipp Schaaf

Cologne University of Applied Sciences,
Institute of Electrical Power Engineering
Laboratory of Electrical Networks
Betzdorfer Straße 2, 50679 Köln, Germany
18.03.2020
philipp.schaaf@smail.th-koeln.de

***Abstract*—If many controllable loads like electric mobility charging stations are switched on at the same time the power grid could be overloaded. To avoid such an overload the knowledge of the network status and the line impedances is advantageous.**

The aim of this research project is to test if the grid parameters could be determined by measuring voltage and current. Therefore a network with two charging stations for electric cars is used and the voltage as well as the charging current can be measured at each charging station. Both charging stations can be switched on and off so that different measurements can be done. For a certain combination of these two states the voltages and the currents are measured to determine the grid parameters between the two measurement points.

Because the phase angle between the voltages is unknown a simplification is necessary. Instead of complex values the absolute value is used. This simplification can be used to determine the line impedances between the two charging stations as well as the load current if the connection of the two charging stations is a simple cable and there is no other load between. Also there should not be any imaginary loads in the following part of the grid because the derivation in determining the load current becomes bigger in this case.

Keywords—electric mobility; power grid; network parameters; voltage meausrement; current measurment

I. Introduction

The power grid could be overloaded by switching on many controllable loads, such as charging electric cars, at the same time. Therefore it is interesting to determine the network parameters respectively the network status, to detect if the power grid is at risk of congestion.

To identify possible risks the voltage and the charging current can be measured at two electric mobility charging stations. Afterwards the line impedances between the two charging stations as well as the load current can be calculated.

At first the network is simulated by using the software "LT-Spice". Afterwards a similar network is recreated in the laboratory to get measured values under real conditions.

II. Method of Solution

At first the network is defined. Two charging stations for electric cars are installed in the same network branch, as shown in **Figure 1.** They could be switched on and off.

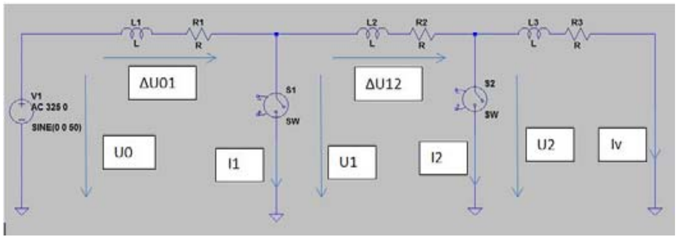

Figure 1: Circuit diagram of the network

To determine the line impedance between the two charging stations, the status of the first charging station has to be constant. That means it has to be switched off or on the whole time. In contrast the second charging station is switched off and on, for both states the voltage at both charging stations as well as the current to charge the car are measured, if the second charging station is switched on.

Afterwards the difference between the voltage at the first and the second charging station is calculated, if the second one is switched off (**Figure 2**) and if the second one is switched on (**Figure 3**). The change of voltage difference is caused by the additional current needed to charge the electric car at the second station (**Figure 4**).

$$U_{12_{off}} = U_{1_{off}} - U_{2_{off}}$$

Figure 2: Formula U12off

$$U_{12_{on}} = U_{1_{on}} - U_{2_{on}}$$

Figure 3: Formula U12on

$$\Delta U_{12} = U_{12_{off}} - U_{12_{on}}$$

Figure 4: Formula dU12

By dividing the complex voltage difference by the complex current to charge the car, the line impedance could be determined (**Figure 5**).

$$Z_{12} = \Delta U_{12} / I_{2_{on}}$$

Figure 5: Formula Z12

The current needed to supply the rest of the grid could be determined afterwards. Therefore the voltage difference in case the second charging station is switched off is divided by the line impedance (**Figure 6**). Following the impedance of the rest of the grid could be calculated by dividing the voltage at the second charging station, in case it is switched off, by the current for the network load (**Figure 7**).

$$I_L = U_{12_{off}} / Z_{12}$$

Figure 6: Formula IL

$$Z_L = U_{2_{off}} / I_L$$

Figure 7: Formula ZL

Unfortunately only the rms-values are measured, so that the phase angle of the measures is unknown. Because of this the amount is taken to get a result.

III. SIMULATION

To get values to refer to, the power grid with the two charging stations is recreated by using the simulation software "LT-Spice". The simulation is done with different parameters for the grid load and the needed load for charging a car at the second station.

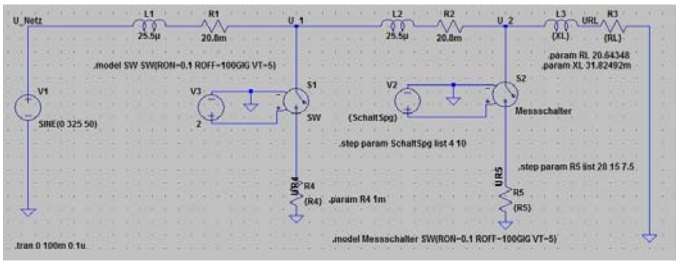

Figure 8: Circuit diagram from the simulation with LT-Spice

The line impedances that are used, are calculated for a line of the type "NAYCWY4X150/70 1kV-TT" [1] with a length of 100 meter. The load at the end of the line is not only varied in the relationship between real and imaginary part of the load. Also the type of imaginary load is changed between capacitive and inductive.

On top of this the values calculated with the method described in chapter II have to be compared to the simulated results.

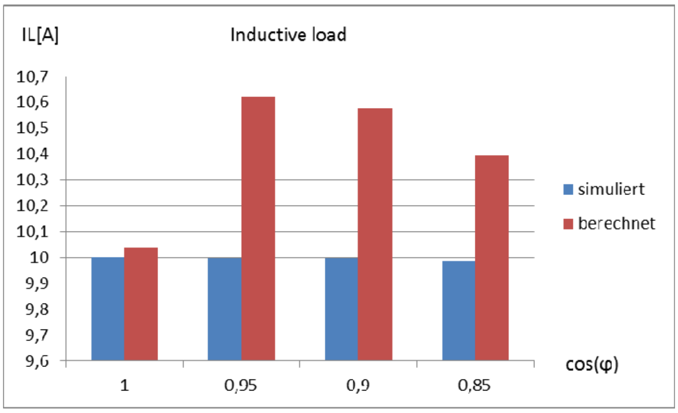

Figure 9: inductive load simulated and calculated

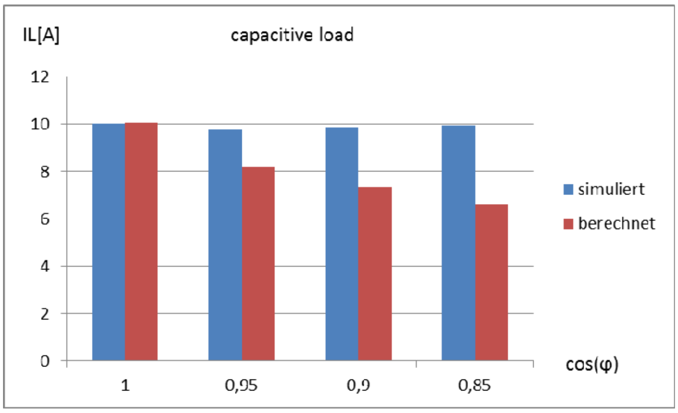

Figure 10: capacitive load simulated and calculated

As it can be seen in the two diagrams the calculated current is higher than the simulated if the load is inductive. If the load is capacitive the calculated current is lower than the simulated. This is caused in the line impedance that just has an inductive component.

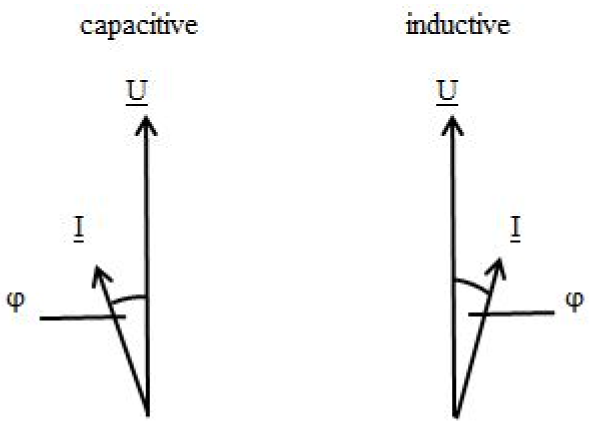

Figure 11: capacitive and inductive phase angle

So the combination of a line with just an inductive component and a load that is capacitive results that their effects are equalizing in parts as shown in the following graphic:

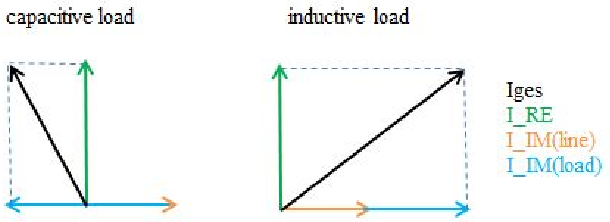

Figure 12: difference between inductive and capacitive load in a vector diagram

Even if the current can not be determined correctly the amount of the line impedances can be calculated with a tolerable deviation. This is shown in **Table 1**:

Table 1: Amount of line impedance

cos(φ)	simuliert	berechnet	
		induktive Last	kapazitive Last
1	0,02228939	0,02171745	0,021717445
0,95	0,02228939	0,02184296	0,021832883
0,9	0,02228939	0,02184274	0,021829348
0,85	0,02228939	0,02184202	0,021703464

IV. Implementation in the Laboratory

After simulating the circuitry is rebuilt in the laboratory. The grid is used as power supply. To control the voltage a transformer is used.

Figure 13: Transformer for voltage control

The connection is realized with a cable from the laboratory.

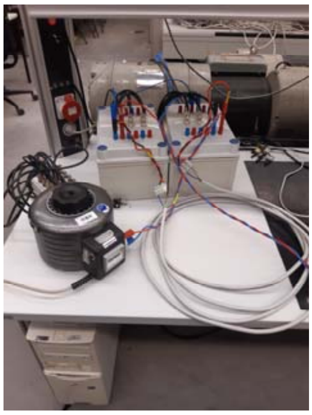

Figure 14: connection cable

At first the line coverings have to be determined. Therefore a frequency analyzer is used and the following values are detected:

Table 2: Line coverings

R'	27	mΩ/m
C'	100	pF/m
L'	0,75	µH/m

For a length of 5m the line impedances can be calculated:

Table 3: Line parameters

R	135	mΩ
C	500	pF
L	3,75	µH

The load of the grid and the second charging station is realized with the same adjustable resistor. Also the connection between the first charging station and the power supply is left out. That is why the circuitry has to be changed compared to the former simulations, as shown in the following picture:

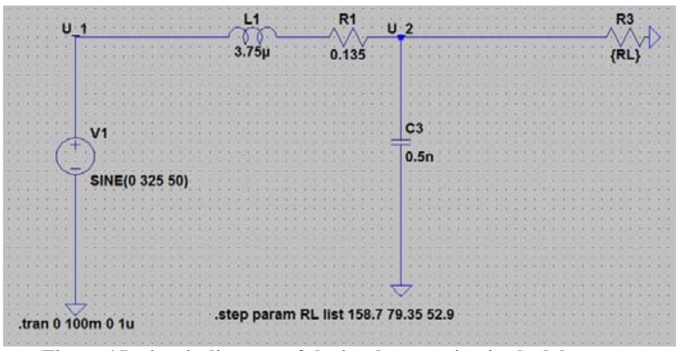

Figure 15: circuit diagram of the implementation in the laboratory

The adjustable resistor could be set by changing the needed three-phase power in a range from 0kW to 80kW. Because of the maximal current that could be used without damaging the transformer, it is not possible to set a power that is higher than 3kW.

Figure 16: adjustable resistor

Measuring the voltage and the current with an oscilloscope is not possible, because the measuring units, which are used for voltages with amplitudes of 400V, are much bigger than the difference of the two voltages. So it would not be possible to determine this difference. That is why another measurement system has to be used. Therefore a system already installed in the laboratory is used. By using the software "LabView" and two measurement boxes the voltage and the current could be detected.

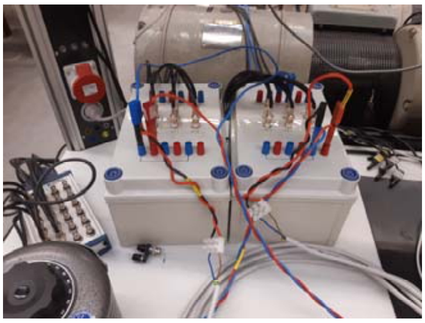

Figure 17: Measurement boxes

The voltages at the beginning and at the end of the connection cable as well as the current through the cable are measured for a load from 0kW to 3kW.

Figure 18: Implementation in the laboratory

By turning the load up the switching on of the charging station could be simulated. The difference of the current corresponds to the current that is used to charge the car. So every needed parameter is measured.

V. Measurments and Results

Voltages and current are measured in four different cases based on the load. That is why it is possible to calculate the voltage difference for every time step. Also the mean value is determined as shown in the following graphic:

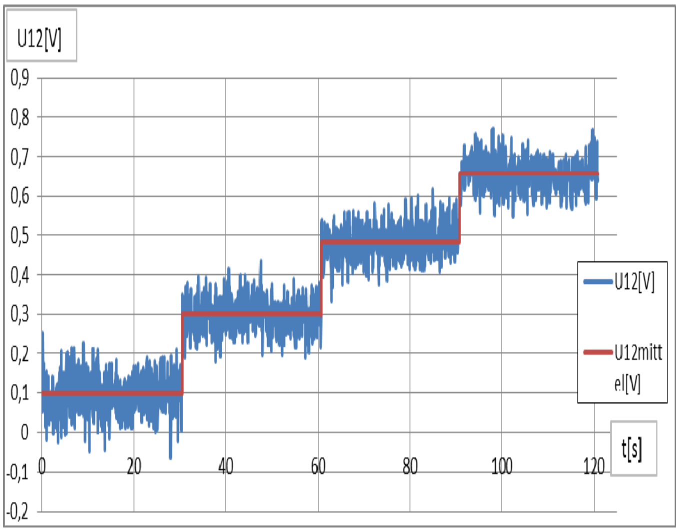

Figure 19: diagram voltage difference

Afterwards the amount of the line impedance is calculated as described in chapter II and with it the current can be determined and compared with the measured and simulated values:

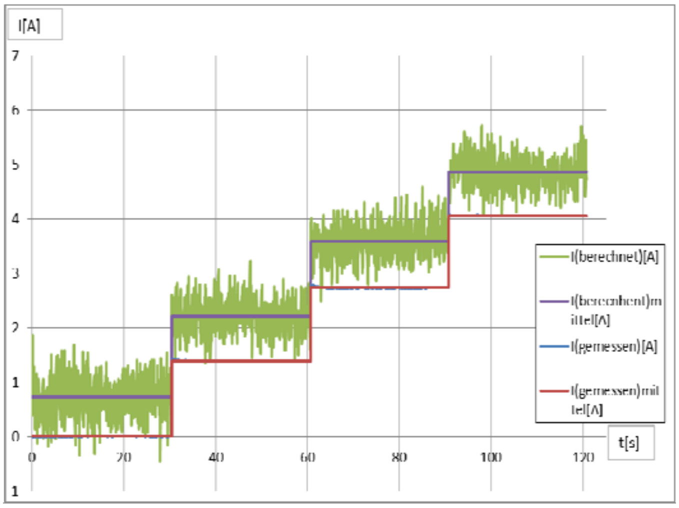

Figure 20: Comparison of measured and calculated current

Table 4: Comparison current

	Iges[A]		
Load	simulated	measured	calculated
0kW	0	0,01733961	0,72940087
1kW	1,44683	1,40614927	2,19945003
2kW	2,89119	2,75203451	3,56018932
3kW	4,33308	4,06364038	4,85719446

As shown in the diagram and the table the calculated current is always approximately 0,7A above the simulated and the measured values. This is caused by using the amount instead of the complex values. The small differences between the measured and simulated values are caused by the impedances of the supply lines and the different amplitude of the voltage. The voltage that is adjusted is not exactly the same as in the simulation. Because the voltage of the power grid and its frequency are not constant, it is not possible to adjust the same voltage as in the simulation with the transformer.

The amount of the line impedance that is calculated with the measured current and voltages is very close to the value that is determined with the measured data from the frequency-analyzer. This is shown in **Table 5**:

Table 5: Amount of line impedance in the laboratory

measured	0,13500514	Ω
calculated	0,13623015	Ω
	0,13475588	Ω
	0,13324308	Ω
mean	0,13474304	Ω

The calculated values have a small variance. This is caused by changes in the power grid voltage which is used as power supply.

VI. Measurement of the Phase Angle

To determine the phase angle between the voltages at both of the measurement points the sine-curves of the voltages are recorded several times. Afterwards the time points are determined, when a fluctuating voltage is equal to zero, and the time difference between both voltages is calculated. Unfortunately a determination of the phase angle between the voltages at the two measurement points is not possible as can be seen in **Figure 21**.

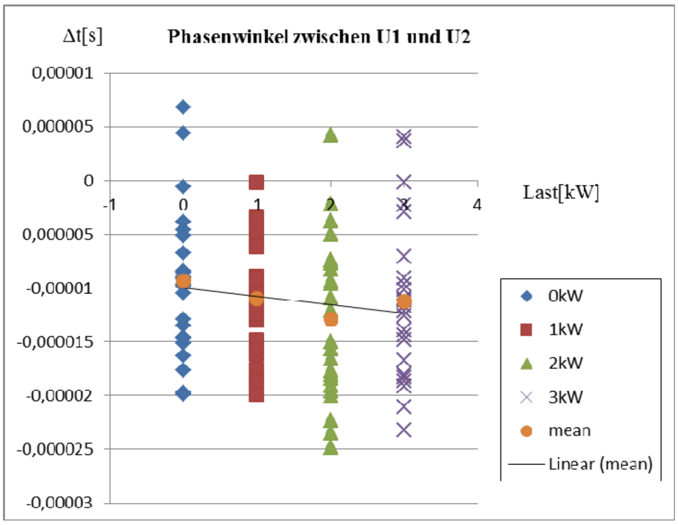

Figure 21: measured phase angle

The reason is that the frequency of the grid voltage is not constant. It should be 50Hz all the time but it is fluctuating in a tolerable range. The phase angle between these two voltages is very small, so that small changes of the grid frequency have a bigger influence.

For a higher load the phase angle gets bigger what can be seen by having a look at the trend line. A higher load implies a higher current through every part of the circuit. That effects a higher voltage over the connection line between the two measurement points and implies a higher phase angle.

VII. Conclusion

Determining the line impedances and the load current by measuring voltage and current at two electric mobile charging stations is possible. To calculate these parameters correctly the knowledge of the phase angle is necessary.

A simplification by using the absolute values of voltages and line impedances is possible if the connection between the two charging stations is a simple cable. For a load with no imaginary part the results have the lowest derivation. If there is an imaginary load the derivation becomes bigger depending on the load.

Even if there is no imaginary load the calculated load current in the network is higher than it is in real. This is caused not taking care of the imaginary parts of the line impedance between the two charging stations and by ignoring the phase angle between the voltages at the two stations.

A higher calculated load current means that the current that can be used to charge a car is lower than it could be. This implies that the network stays below the allowed maximum of current even if the maximal possible current, that has been determined, is used to charge the electric car.

VIII. References

[1] Prof. Dr. E.Waffenschmidt, Praktikum Elektrische Energieverteilung - Versuch 2: Netzwerkberechnungen. Cologne, Th Köln, 2017.