Easy Grid Analysis Method for a central observing and controlling system in the low voltage grid for E-Mobility and Renewable Integration

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1 Introduction

In future more renewable energy sources, like photovoltaic panels, small wind turbines and little combined heat and power plants, as well as battery electric vehicles and other electric storages will be placed in low voltage grids. However, it is very important to keep the system in a steady state and to avoid any overload of the components. Every overstressing accrues ageing effects and therefore cables and transformers must be exchanged earlier.

One possible method to manage the consumption of the electric vehicles and also the generation of the renewable sources is to observe and control the devices by a **central system**. This data processing unit allocates all power values of the demand and sources in every time step. Therefore the low voltage grid can also be called **Smart Grid**. For scheduling the electric mobility demand and for controlling the renewable sources according to the weather forecasts the central processing system must **calculate the load flows** in the present grid section. This calculation, which is the main purpose of this paper, has to be **easy, quick** and should estimate the **available power** in several nodes.

This easy grid analysis method is developed in the project **KOFLA** "Kooperative Fahrerunterstützung für Lademanagement von elektrischen Fahrzeugen", which is funded by the program "**ways2go**" of the Austrian Federal Ministry for Transport, Innovation and Technology. This project considers the new mobility behavior induced by electric vehicles and their frequent need to recharge the batteries. The consortium propose a cooperative solution approach in which a centralized broker mediates between the moving electric vehicles (EVs) requesting service and the recharging stations offering recharge capacity. The broker finds the best match for each user and balances the service load and the electric grid load between recharging stations.

2 Methods

To reach an easy and quick algorithm some **assumptions** must be defined to simplify the calculation methods. In this case a **DC load flow analysis method including electric current iteration** with following adoptions is chosen:

- The demand and power factor of all consumers and sources in the low voltage grid from the past and the present are well known.
- All loads are symmetric and therefore the positive-sequence polyphase system can be used in the calculation.
- In the first iteration the voltages of all nodes are similar and equal to the rated voltage.
- This method can analyze only radial systems without intermeshing.

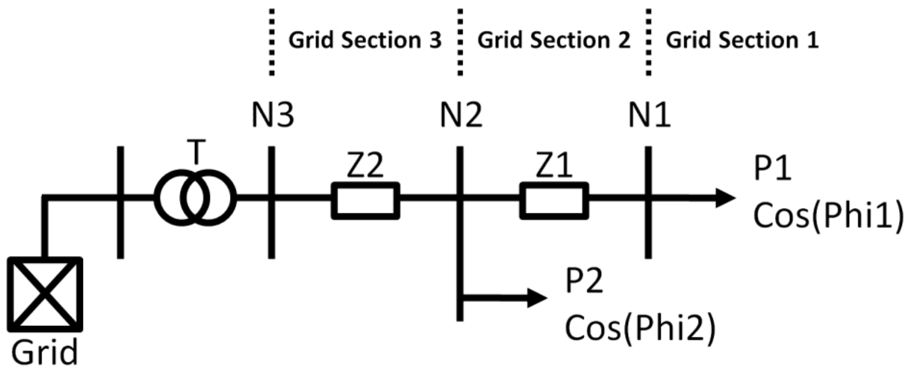

Figure 1: Model grid of a radial system

The principle of the analyze method is followed described with a simple model grid, as can be seen in Figure 1. First the low voltage grid is divided into **sections** from the load to the transformer. The whole easy grid analysis method has **five steps with one decision**. Figure 2 shows the flow chart summarized. Step 1 **initializes** components and node voltage values as well as load profiles of consumers to the correct node (Grid Section 1 in our model grid). Finally the complex apparent power and the electric current in the node (N1) are calculated.

2.1 DC-LF Calculation

Step 2 – The DC-Load Flow estimation starts at the load and ends at the transformer. Therefore the first calculation is situated in the Grid Section 2 of our model grid. The complex apparent power of the electric line (Z1) is calculated[1] with:

$$\underline{S}_{Z1} = 3\,\underline{Z}1\,I_{Z1}^2 \tag{1}$$

[1] See [1, p 426 ff.]

The electric current of the line (I_{Z1}) is the same as in the node (N1). With the sum of the complex apparent power of the electric line and the node N1 as well as the voltage value at node N2 the new electric current is estimated.

$$I_{Z1} = \frac{|\underline{S}_{Z1} + \underline{S}_{N1}|}{\sqrt{3}\, U_{N2}} \quad (2)$$

Hence, the node N2 obtains:

$$I_{N2} = I_{Z1} + \frac{\sqrt{P2^2 + Q2^2}}{\sqrt{3}\, U_{N2}} \quad (3)$$

$$\underline{S}_{N2} = \underline{S}_{Z1} + P2 + jQ2 \quad (4)$$

Therefore the calculation of the Grid Section 2 is completed. In the Grid Section 3 the equations (1) – (4) are similar used. In case of more sections this routine is **repeatedly applied**.

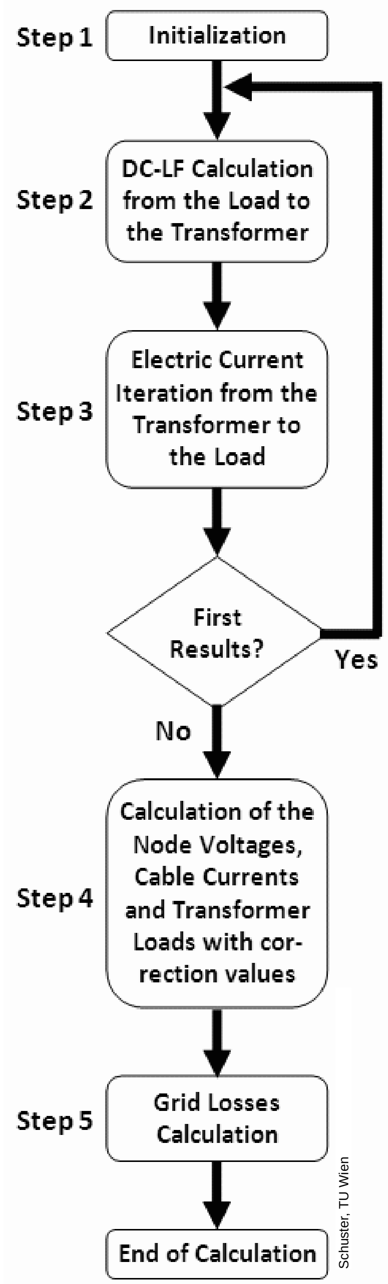

Figure 2: Flow chart of the Easy Grid Analysis Method

2.2 Electric Current Iteration

Step 3 – The Electric Current Iteration starts at the transformer and ends at the load. Therefore the first calculation is situated in the Grid Section 3 of our model grid. In general the Electric Current Iteration starts with the new calculation of the electric current in the line.

$$I_{Z2} = \frac{|\underline{S}_{Z2} + \underline{S}_{N2}|}{\sqrt{3}\, U_{N3}} \quad (5)$$

In case of the Grid Section 3 this computation is not necessary, because the electric current value of the last DC-LF calculation is already correct. The new voltage value in the node N2 is estimated with

$$U_{N2} = \frac{|\underline{S}_{N2}|}{\sqrt{3}\, I_{Z2}} \quad (6)$$

The Iteration in the Grid Section 3 is completed. For the other Sections the equations (5) – (6) are similar used.

Before the next step starts the DC-LF Calculation and the Electric Current Iteration is **repeated once again** with the initial values from the last calculation. The **results** of the second computation are very **stable**, because a third calculation changes the values only 0.0004 %. Therefore the results of the second computation are used further.

2.3 Load Calculation

Step 4 calculates the node voltages, electric line currents and transformer loads rated to the nominal values.

$$U_{Nx,\%} = \frac{U_{Nx}}{400V} \cdot 100,\ I_{Zx,\%} = \frac{I_{Zx}}{I_{Zx,max}} \cdot 100 \text{ and } S_{Tx,\%} = \frac{S_{Tx}}{S_{Tx,max}} \cdot 100 \quad (7)$$

To reduce the absolute failure of this easy grid analysis method **correction values** are defined and added to the results of equations (7). For more information see chapter 3.1.

2.4 Grid Losses Calculation

Step 5 calculates the grid losses of the whole low voltage grid with the actual demand. The complex grid losses are defined as:

$$\underline{S}_L = \sum_k (P_{Lk} + jQ_{Lk})\ ^2 \quad (8)$$

$$P_{Lk} = 3\ R_k\ I_{Zk}^2 \quad (9)$$

$$Q_{Lk} = 3\ X_k\ I_{Zk}^2 \quad (10)$$

The quality of the results compared to an extended Newton Raphson calculation is shown in following chapter 3.

With the **Steps 1 – 5** and the equations (1) – (10) the easy grid analysis method is **finished** and delivers the **loads** and also the **grid losses** of all components of **one load flow** (one time step). The whole calculation method is implemented in a MATLAB model.

3 Results

To evaluate and verify the grid analysis method a low voltage grid in the city of Bregenz, Vorarlberg (Austria), is used, which includes some households, a little company, several offices and an electric vehicle charging station. To **compare** the calculated values the simulation software NEPLAN with an **extended Newton Raphson** calculation is used.

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[2] See [2, p 17 ff.]

3.1 Comparison of the Load results

720 load flows with **random customer demand values** (households, companies and charging station) between 0.01 kW and the sum of declaration power values are calculated with the easy grid analysis method and **compared** with the NEPLAN results.

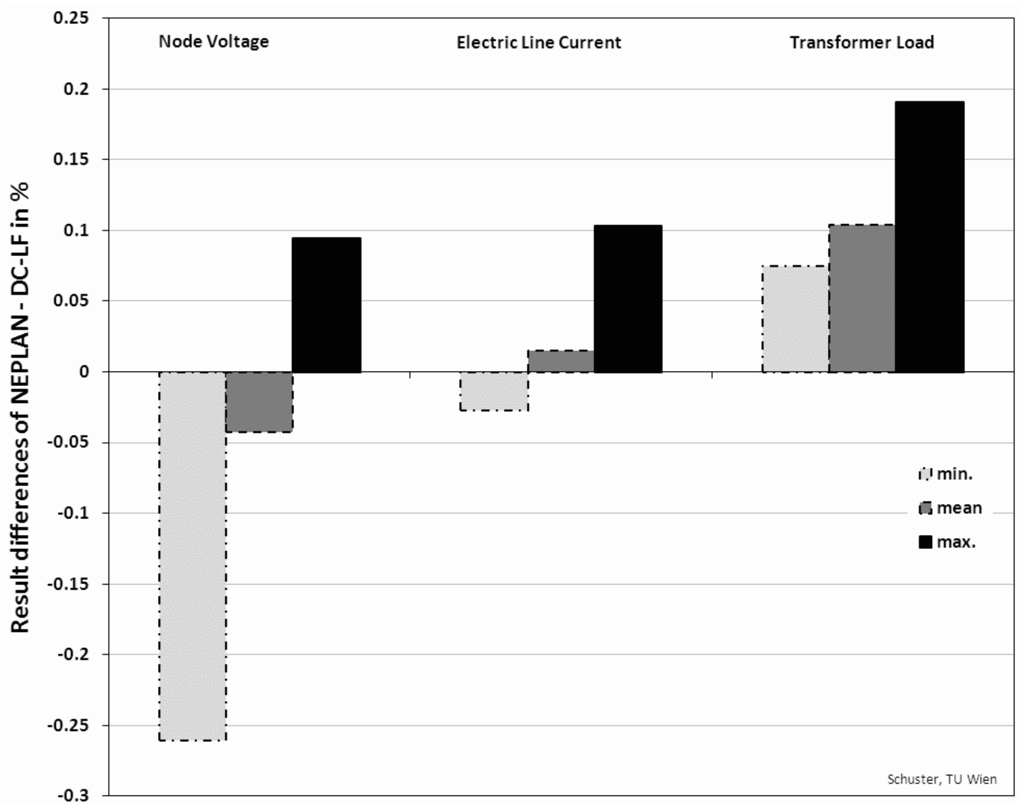

Figure 3: Comparison results of the load calculation without correction values

The comparison results (see Figure 3) shows that the **failures of the DC-LF** calculation with electric current iteration are **very small**. The **node voltage** is maximal **0.26 %** lower and the **transformer load** is maximal **0.19 %** higher than calculated. However, the mean **failure is between -0.04 % and 0.10 %** and therefore **correction values** for every node (exclusive the slack node), each electric line and all transformers are **defined**.

With these **correction values** the mean failures are nearly zero (see Figure 4). Also the minimal and maximal differences are smaller. The largest **failures** are **between -0.22 % and 0.14 %** of the node voltage. Therefore the **DC-LF calculation with electric current iteration with one computation loop is exact enough** for our calculations and can be used to get right node voltage, electric line current and transformer load values.

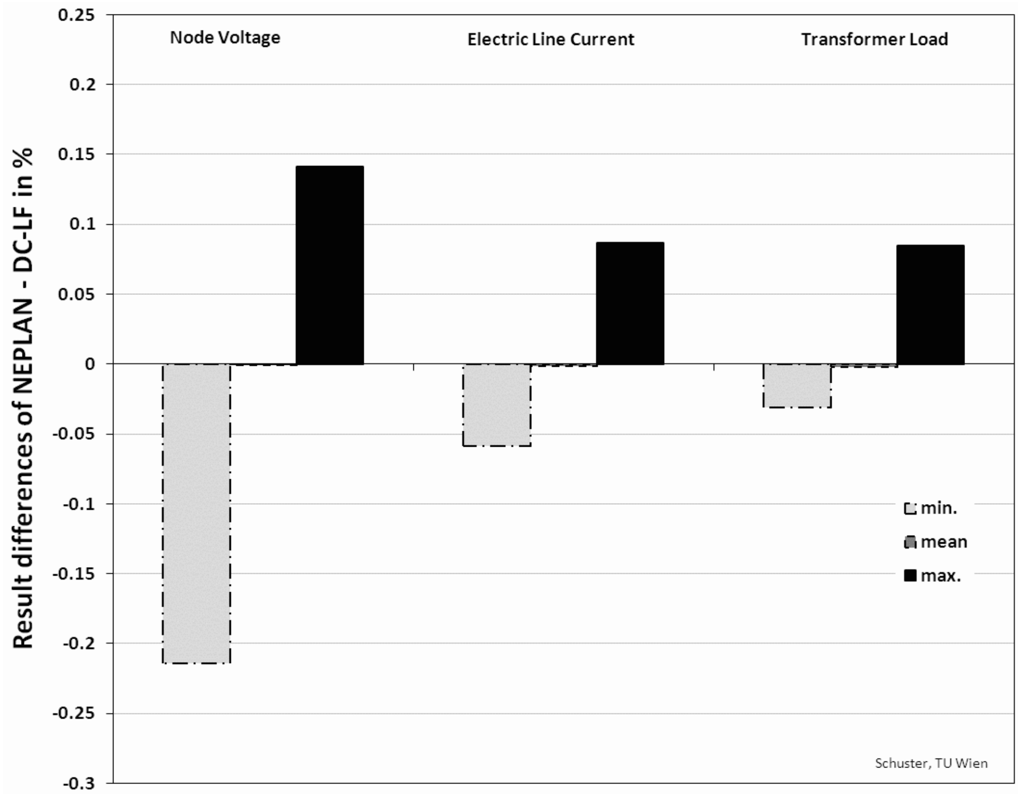

Figure 4: Comparison results of the load calculation with correction values

3.2 Comparison of the Grid Losses results

To evaluate the performance of the Grid Losses calculation (see chapter 2.4) 144 load flows are calculated and compared with the NEPLAN results. The comparison results of the **active power (MW) losses** are shown in Figure 5. **72 % of all calculations have a maximum failure of ± 5 %**. However, the **Grid Losses (MW)** results of the easy grid analysis can be up to **25 % lower** than the NEPLAN results.

The comparison of the **reactive power (MVAr) grid losses** shows, that these results of the easy grid analysis are **not accurate**. About **58 % of all calculations have a maximum failure of ± 25 %** and **10 %** have a failure of **more than 100 %** (up to 480 %).

The **values of the grid losses**, especially the reactive power, are **very low** (up to maximum 0,013 MW). Therefore the **failures are not huge**, but in the scope of overall losses for instance of **one year the failures are critical**.

Hence, the easy **grid losses calculation** is to get only a **recommendation** for **saving energy** in the grid. For more detailed information other load flow analysis methods must be chosen.

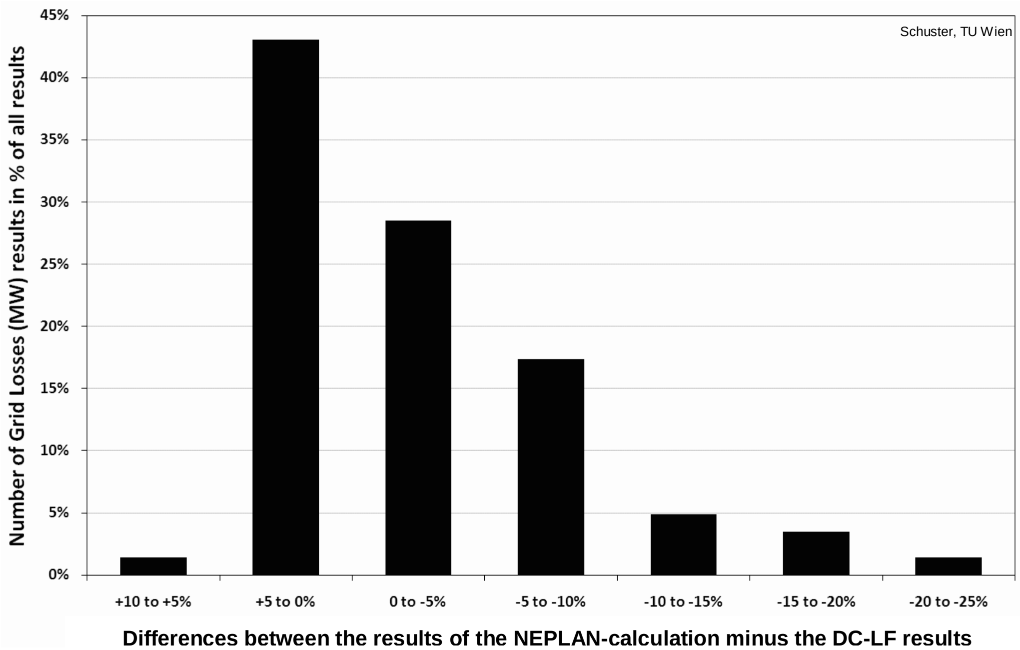

Figure 5: Comparison results of the active power grid losses calculation

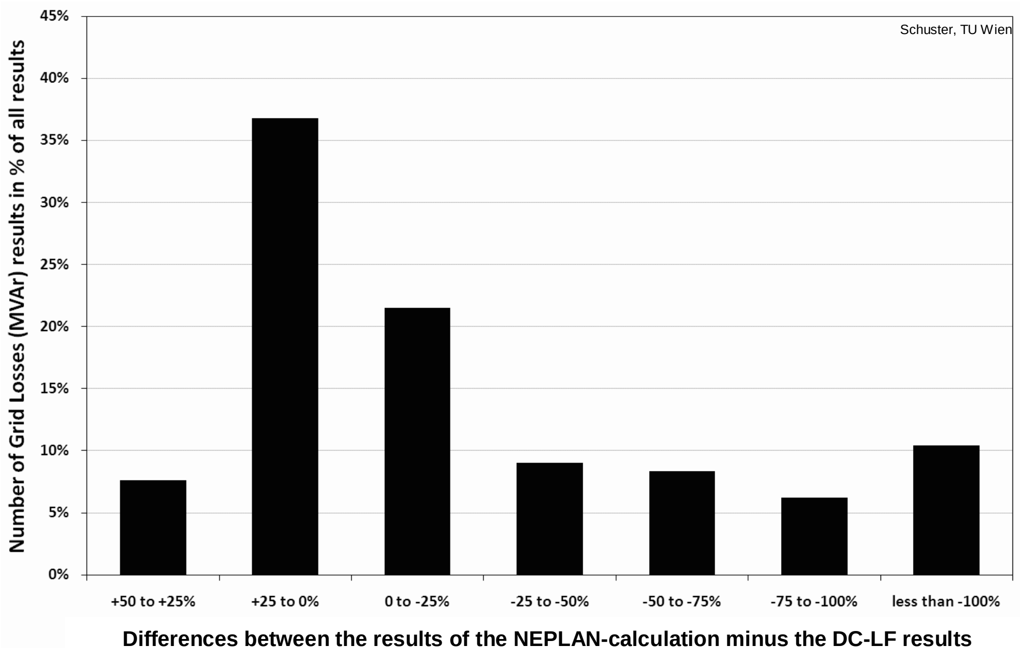

Figure 6: Comparison results of the reactive power grid losses calculation

3.3 Calculation Time

The easy grid analysis method must be fast, because of the repeated usage. **One load flow calculation inclusive grid losses computation takes 0.6 ms**. This is fast enough for our overall calculation. For example a load flow analysis of one year with a resolution of 10 minutes takes about 31 seconds.

4 Conclusions and Outlook

The easy grid analysis method with its 5 Steps is **simple integrated** in a simulation environment. Furthermore the method is **fast enough** for our overall calculations. However, for every low voltage grid topology a new MATLAB code must be written.

The **comparisons** with extended Newton Raphson calculations (NEPLAN) show two following aspects. The **DC-LF calculation** with electric current iteration with one computation loop is **exact enough** for our calculations and can be used to get right node voltage, electric line current and transformer load values. The **easy grid losses** computations get **only recommendations** for saving energy in the grid and no exact values.

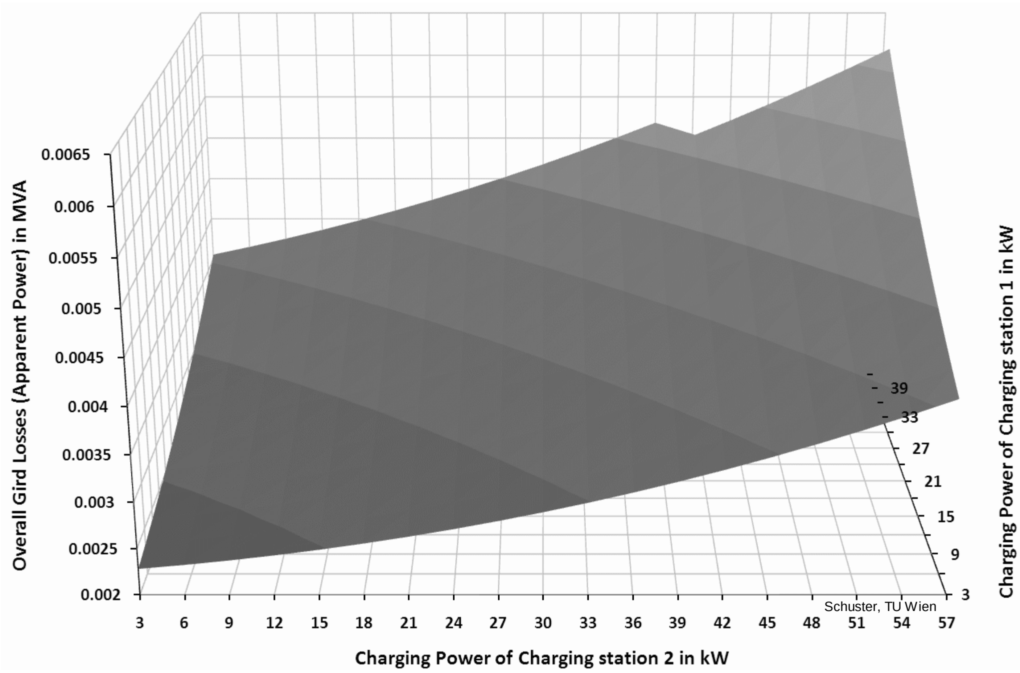

Figure 7: Overall Grid Losses (MVA) over the charging power (kW) of two charging stations

Important for energy scheduling the electric vehicles is the **available power** of the charging station. Figure 7 illustrates the possible charging powers of two charging stations in one low voltage grid. As shown in the drawing (right upper corner) the max. power of charging station 1 is not allowed if charging station 2 needs more than 39 kW. The Figure 7 also point up the overall grid losses as a function of the charging powers. Detailed analyses will be done in the project KOFLA.

References

[1] V. Crastan: *Elektrische Energieversorgung 1*, 2. Edition, 2007, Springer publisher, Berlin. (German)

[2] S. Kuhn: *Betriebsoptimierung von elektrischen Energieerzeugungsanlagen und Übertragungssystemen bei unvollständiger Information*, 2. Edition, 2008, Cuvillier publisher, Göttingen. (German)