Institute of Electrical Power Systems

LFC Simulator V1.1 Documentation

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1 Introduction

This manual provides information about the low frequency current (LFC) simulation software, developed at the Institute of Electrical Power Systems of Graz University of Technology. The tool is a work in progress, therefore not all features are available yet, some options are still hard coded and bugs may occur.

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More information on the research project can be found at:

https://www.tugraz.at/en/institutes/iean/research/power-quality-supply-reliability/low-frequency-neutral-point-currents/

2 Installation

If version 9.6 (R2019a) of the MATLAB Runtime is installed on the computer, the application should start without any other installation steps and simulations are possible immediately. Simply start the application by running *GIC_Simulator.exe*.

If the requirements mentioned above are not fulfilled, the application can be installed by running *MyAppInstaller_web.exe*. Just follow the instructions to install the application on your computer. After the installation process finished successfully, the application *GIC_Simulator.exe* can be found in the previously selected directory, e.g. *C:\Program Files\Institute of Electrical Power Systems\GIC_Simulator\application.*

Note: Once the program was installed, it is not necessary to repeat the installation process of the MATLAB Runtime to run newer versions of the simulator. They should start immediately after running the executable file.

3 Methodology

Figure 1 depicts the basic method flow chart of the simulation. No further theoretical consideration is given at this point; for a complete description please refer to [1, 2]. The simulation results are currents in every transformer, line and substation grounding.

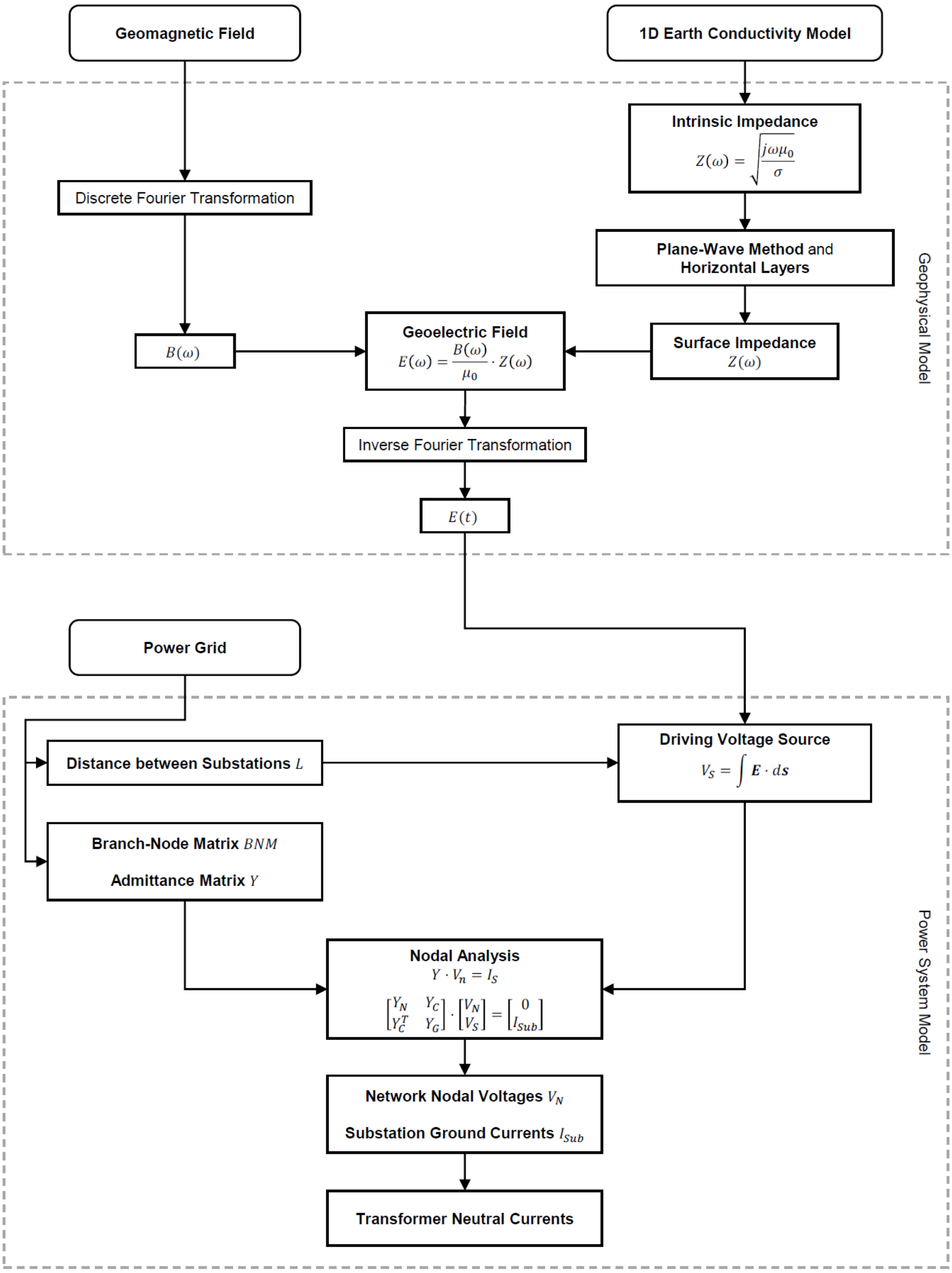

Figure 1: Method flow chart of the GIC simulation method [1]

A new feature in Version v1.1 is the calculation of additional reactive power of transformers. This is done in reference to [3] with a linear relationship between an effective transformer neutral current I_{eff} and the additional reactive power Q. However, as in European Transmission Grids most of the time only one neutral point per transformer is grounded, the I_{eff} calculation is changes to the sum of absolute currents of different windings. (Further description coming soon).

The linear relation between neutral point current and reactive power demand is split into to areas with two different slopes and a threshold current, as shown in Figure 2.

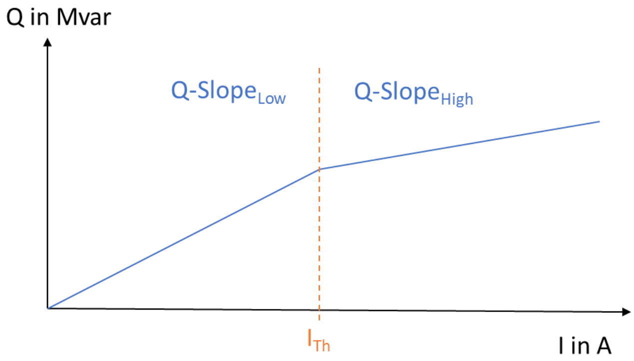

Figure 2: Graphical representation of reactive power calculation

$$Q(I_{eff}) = \begin{cases} k_1 \cdot I_{eff}\,, & I_{eff} \leq I_{Th} \\ k_1 \cdot I_{Th} + k_2 \cdot (I_{eff} - I_{Th})\,, & I_{eff} > I_{Th} \end{cases}$$

k_1 … Q-Slope$_{Low}$

k_2 … Q-Slope$_{High}$

I_{Th} … Threshold for changing slope

I_{eff} … Effective current

4 Input and sample data

The LFC Simulation tool needs three datasets for calculations: magnetic field data, earth resistivity layers and grid data. There are samples available, which show the needed data formats. All samples can be found in the *SampleData* folder. Please note that the structure of the files needs to be identical to the structure of the exemplary sample data shown in this section for the simulation to work properly.

4.1 Magnetic field data

Magnetic field data is available at https://www.intermagnet.org/. The software is built to use data sampled in seconds. An exemplary file is depicted in Figure 3. Please note that the first 18 header-lines will be ignored by the simulation tool, as they are not required to run a simulation.

wic20170905dsec.sec

```
1   Format                 IAGA-2002                                    |
2   Source of Data         Zentralanstalt fuer Meteorologie und Geodyna |
3   Station Name           Conrad Observatory                           |
4   IAGA Code              WIC                                          |
5   Geodetic Latitude      47.928386296                                 |
6   Geodetic Longitude     15.8620308482                                |
7   Elevation              1087.010000000                               |
8   Reported               XYZF                                         |
9   Sensor Orientation     HDZ                                          |
10  Digital Sampling       10 Hz                                        |
11  Data Interval Type     1-second (501-1500)                          |
12  Data Type              definitive                                   |
13  # gaussian filter with 0.30000003 Hz passband centered on the      |
14  # second                                                            |
15  # K9-limit             500                                          |
16  # V-Instrument         LEMI036_1_0002                               |
17  # F-Instrument         GP20S3NSS2_012201_0001                       |
18  # File created by      MagPy v0.3.99rc1                             |
19 DATE       TIME         DOY     WICX       WICY      WICZ      WICF   |
20 2017-09-05 00:00:00.000 248     21039.55    1541.30  43768.83  48587.58
21 2017-09-05 00:00:01.000 248     21039.53    1541.27  43768.81  48587.58
22 2017-09-05 00:00:02.000 248     21039.52    1541.24  43768.85  48587.58
23 2017-09-05 00:00:03.000 248     21039.50    1541.22  43768.85  48587.57
```

Figure 3: Magnetic field data (example)

In this example, data of the Conrad Observatory is used. WIC is the IAGA Code of the observatory; *WICX/WICY/WICZ/WICF* are the magnetic field data vectors in x, y and z direction and corresponding F vector in nT. DOY is the day of the year. For the calculation only x- and y-components are used.

4.2 Network/Grid data

Network details are stored in an Excel-File containing three different sheets: Substations, Transformers, and Lines. The exact structure of those files is shown in Figure 4. The example can be found in the sample directory and is called *LFC_Grid_Template_2Nodes.xlsx.*

Nr	Name	Substation	Country Code	Latitude	Longitude	Grounding Resistance	Voltage Level				Node					
				Degree	Degree	Ohm	V_1	V_2	V3	V4	N_1	N_2	N_3	N_4	Neutral	Ground
1	Substation 1	sub1	AT	48,256187	13,081307	0,08	380	220	0	0	1	2	3	4	5	11
2	Substation 2	sub2	AT	48,126221	14,474579	0,1	380	220	0	0	6	7	8	9	10	12

Nr	Substation	Type	Resistance HV	Resistance LV	GroundingHV	GroundingLV	Voltage Level		Q Slope Low	Threshold	Q Slope High
			(Ohms/phase)	(Ohms/phase)	nan	nan	V_HV	V_LV	Mvar/A	A	Mvar/A
1	sub1	GY-GY	0,452	0,194	1	1	380	220	0,2	20	0,15
2	sub2	GY-GY	0,19595	0,1431	1	1	380	220	0,2	20	0,15

Nr	Sub	Sub	Length	Resistance per km	Single Line Resistance	Voltage	Systems	Multiple Conductor
	from	to	km	Ohm/km	Ohm	kV	#	#
431	sub1	sub2	111,3	0,0217	2,411	380	1	1
432	sub1	sub2	111,3	0,0217	2,411	380	1	1

Figure 4: Network data (example)

At the moment, it is possible to simulate four different voltage levels, specified with V_1 to V_4. This makes it possible, to calculate e.g. 380, 220, 110 kV and temporarily grounded lines with 0.

The values of Q_{Slope} and Threshold correspond to neutral point currents. If there is no data available for the Transformers Q-Slopes or the threshold, it must be replaced by ‘x’.

The second example is the GIC model grid from [4].

4.3 Earth resistivity data

Earth resistivity data is stored in an Excel-File. Multiple conduction models can be stored in a single Excel-File. The File contains two sheets, one contains resistivity values (*R*) in Ωm, the other one the corresponding depth values (h) in meter. The last value in the R vector is then realised as half space. The exact structure of those files is shown in Figure 5. The example can be found in the sample directory and is called *LFC_Earth_conductivity_Template.xlsx*.

M01	400	1300	140000	170000
M39	55000	45000		

M01	40	3	2000	115	15
M39	1000	300	1000		

Figure 5: Earth resistivity data (example)

5 Usage

Using the simulator is easy, due to the available graphical user interface (GUI). The usage example given in this section can be used as a quick start guide for using the simulator.

5.1 GUI Overview

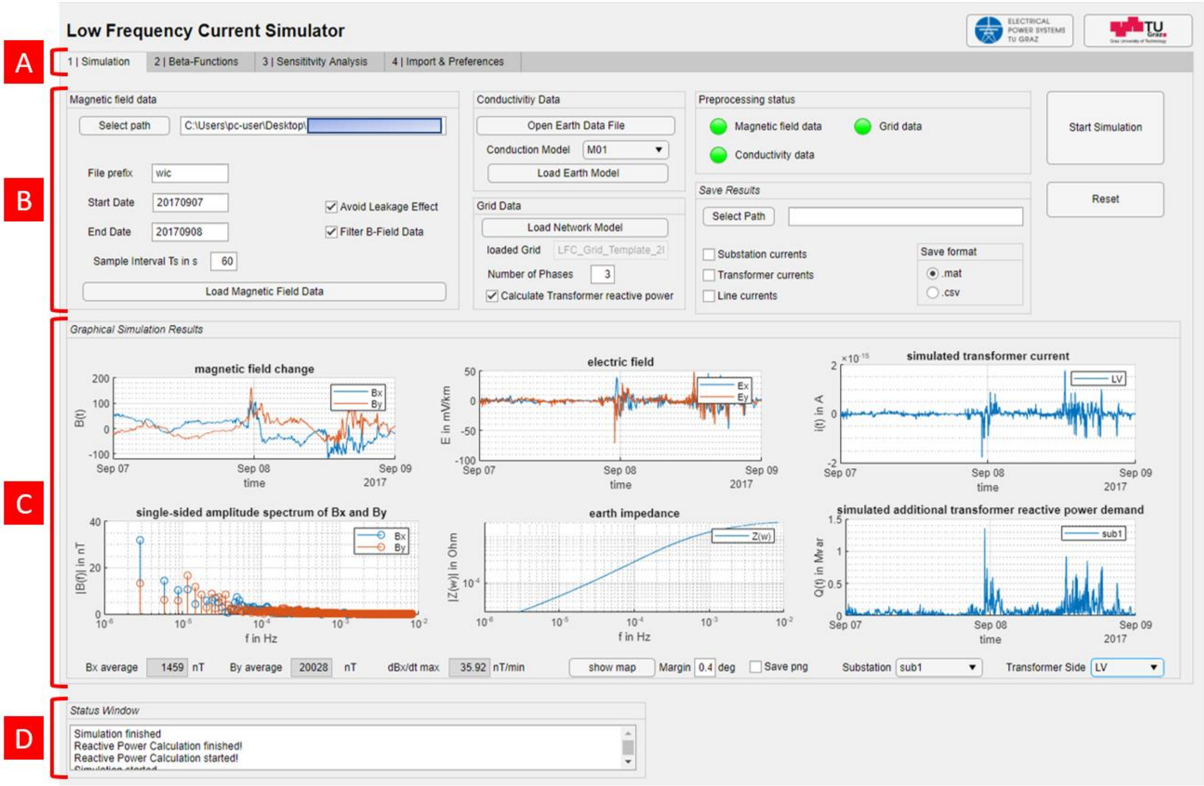

Figure 6: Graphical user interface

- **Switch between sections (A)**
  - Simulation
  - Beta-Functions *(not yet implemented)*
  - Sensitivity Analysis
  - Import & Preferences

- **Configuration of simulation (B)**
  This section is used to load input data and edit simulation parameters before conducting a simulation as described in section 5.2.

- **Graphical simulation results (C)**
  In this section, plots of simulation results are available. On the lower right corner, it is possible to switch between substations and voltage levels. In the middle bottom section, the feature to plot the results in a map can be started.

- **Status window (D)**
  The status window displays important information about active or completed processes as well as error messages if an error occurs.

5.2 Usage Example

The following example explains how to use the LFC simulator in a step-by-step way. All used data files (magnetic field data, grid data and earth layer data) can be found in the *SampleData* directory.

5.2.1 Data Import

As described in section 4, data needs to be organised in a particular way to be used for simulating. These files then need to be imported once in the simulators software environment to make them readable. This can be done in tab 4 (Import & Preferences) as shown below. All relevant sections are marked in Figure 7.

1. Go to tab 4 (Import & Preferences).
2. Import magnetic field measurement data:
    a. Enter the number of header-lines which are present in the data files. These lines contain no information which is relevant for simulating and therefore are ignored. In this example the data file contains 18 header-lines, as shown in Figure 3.
    b. Press *Import* and select data files (e.g. *wic20170905dsec.sec*). If multiple files are present in the directory, several files can be selected at once.
    c. After selecting all relevant files, the import process starts automatically.
    d. If the import process finished successfully, the resulting files (e.g. *wic20170905.mat*) can be found in the data file directory.
3. Import grid data:
    a. Enter the number of substations, transformers, and lines of the grid.
    b. Press *Import* and select the grid file (e.g. *LFC_Grid_Template_2Nodes.xlsx*).
    c. After selecting the file, the import process starts automatically.
    d. If the import process finished successfully, the resulting file (e.g. *LFC_Grid_Template_2Nodes.mat*) can be found in the grid file directory.
4. Import Earth layer data:
    a. Press *Import* and select the Earth layer data file (e.g. *LFC_Earth_conductivity_Template.xlsx*).
    b. After selecting the file, the import process starts automatically.
    c. If the import process finished successfully, the resulting file (e.g. *LFC_Earth_conductivity_Template.mat*) can be found in the grid file directory.

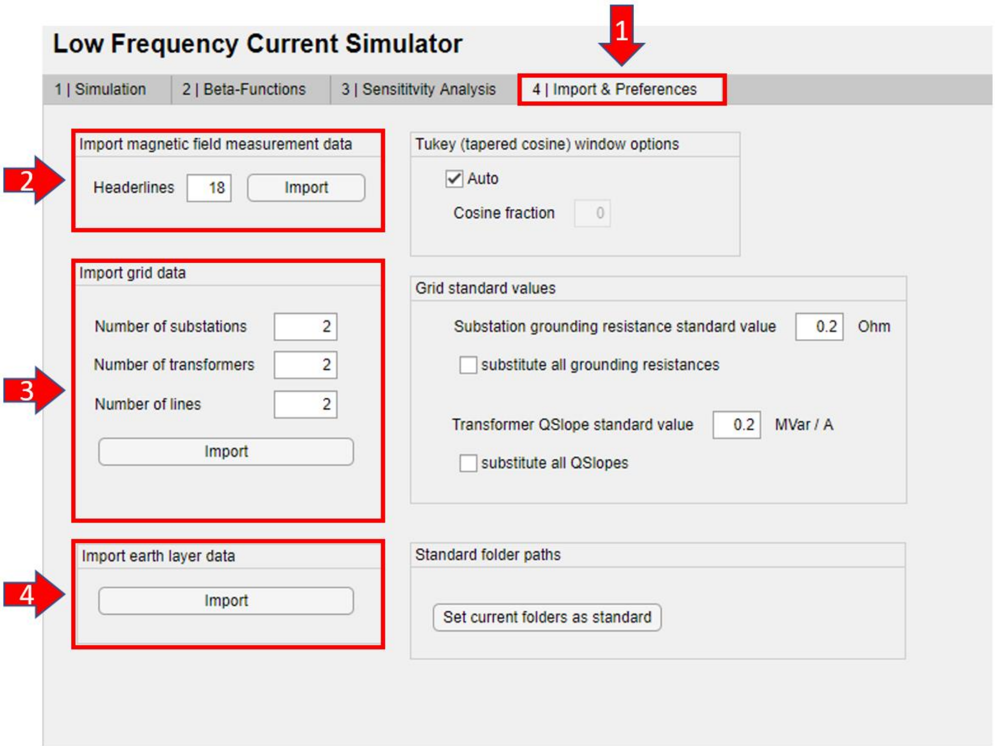

Figure 7: Data import process

5.2.2 Conduct simulation

To conduct a simulation, the previously generated files need to be loaded into the simulation tool. The *Preprocessing status* window shows if a specific data file is already loaded or not. After loading all files, the simulation can be started. All necessary steps are described below, and all relevant sections are marked again in Figure 8.

1. Go to tab 1 (Simulation).
2. Load magnetic field data:
    a. Press *Select Path* and select the folder/directory which contains the desired magnetic field measurement data (e.g. *SampleData/wic201709XX.mat*)
    b. Fill in the file prefix (case sensitive!) of the data files, as well as desired start date and end date.
    c. Select a sample interval, for instance *60*, which means that every 60th value of the data file is used for calculations in the simulation (downsampling).
    d. Select optional functions if necessary (e.g. filters).
    e. Press *Load Magnetic Field Data* to load data.
3. Load conductivity data:
    a. Press *Open Earth Data File* and select the desired conductivity model (e.g. *LFC_Earth_conductivity_Template.xlsx*).
    b. Select desired conduction model using the drop-down menu (e.g. *M39*).
    c. Press *Load Earth Model*.
4. Load grid data:
    a. Press *Load Network Model*.
    b. Select desired grid model (e.g. *LFC_Grid_Template_2Nodes.mat*).
    c. Fill in the number of phases (e.g. *3*).
5. Configure settings for result saving:

a. Select a path/folder to store results.
b. Select which components of the result should be saved and choose a data format.
c. If reactive power calculation is active, these values will be saved if transformer currents are saved

6. Press *Start Simulation* to start the simulation process. After a successful simulation, the results are shown in the GUI as depicted in Figure 9 and the results are saved (e.g. *LFC_Grid_Template_2Nodes_LineCurrents.mat*). On the bottom right corner, it is possible to switch between substations and transformer voltage levels.

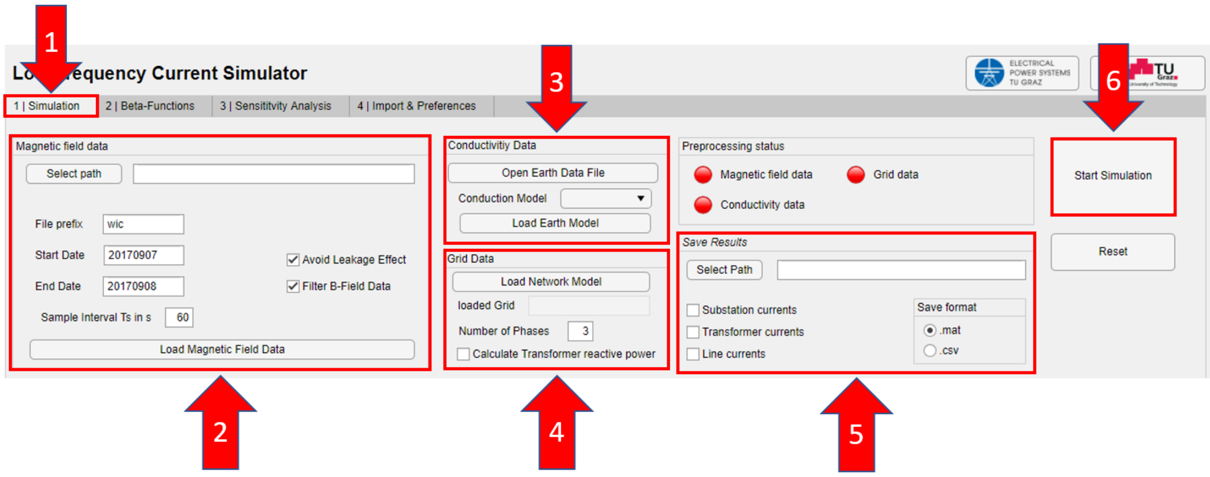

Figure 8: Simulation process

While performing a Fourier transform of the magnetic field data, leakage effects occur because of the discontinuous data. This can be prevented by adding additional data at the beginning and end of the magnetic field data. Therefore, if the checkbox “Avoid Leakage Effect” is selected, the two additional days need to be available for loading into the simulator. It is then tapered with a cosine bell window, options can be found in tab 4 | Import & Preferences.

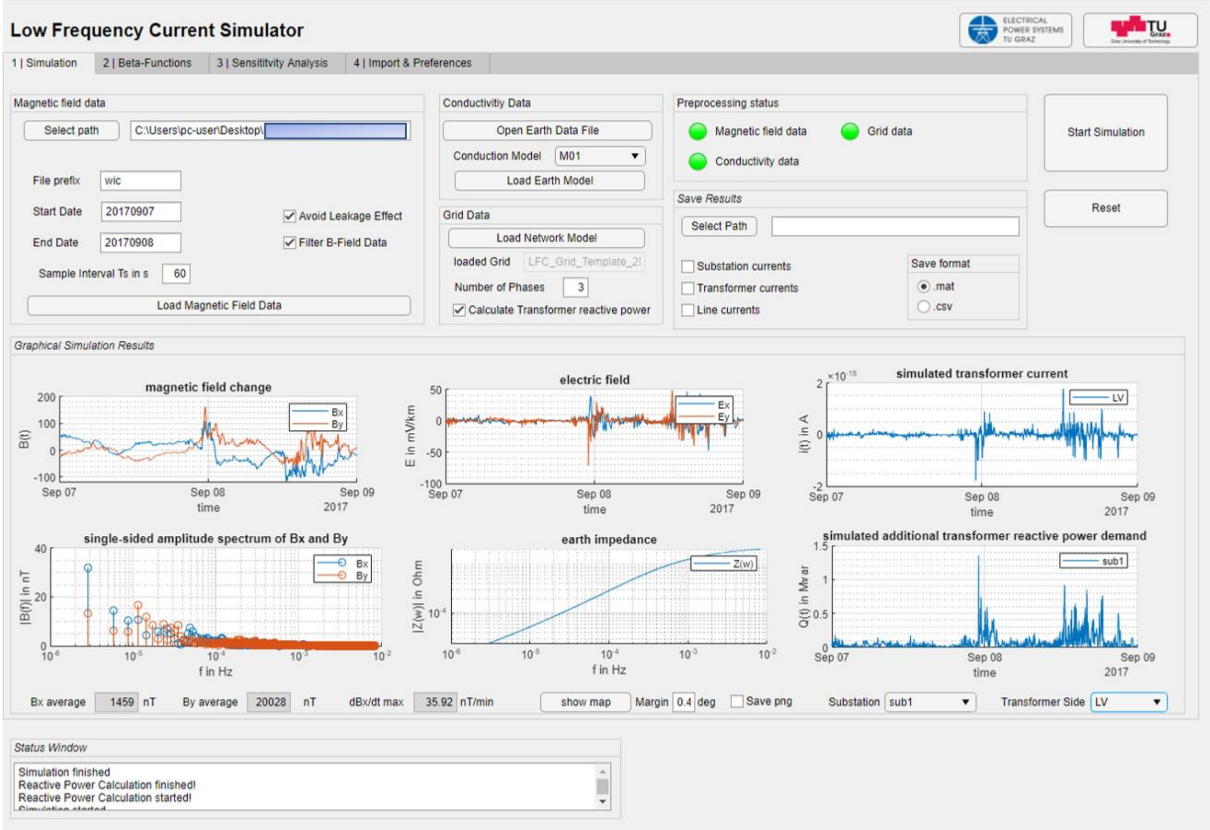

Figure 9: Simulation results

5.2.3 Sensitivity Analysis

In tab 3 (Sensitivity Analysis), it is possible to calculate the maximum value of transformer neutral currents depending on arbitrary electric field values.

For the calculation, previously loaded grid data is used. After changing the input parameters and pressing *Start Simulation*, results are shown on the right side of the simulator as shown in Figure 10. Substation and voltage level can be chosen arbitrarily. The results are saved at the path selected in tab 1.

It is also possible to import field data stored in a text-file. Therefore, check the “load data” option, push the “Load E-field” button and select the desired file. An exemplary file, called *E_field_100mV.txt* can be found in the sample data.

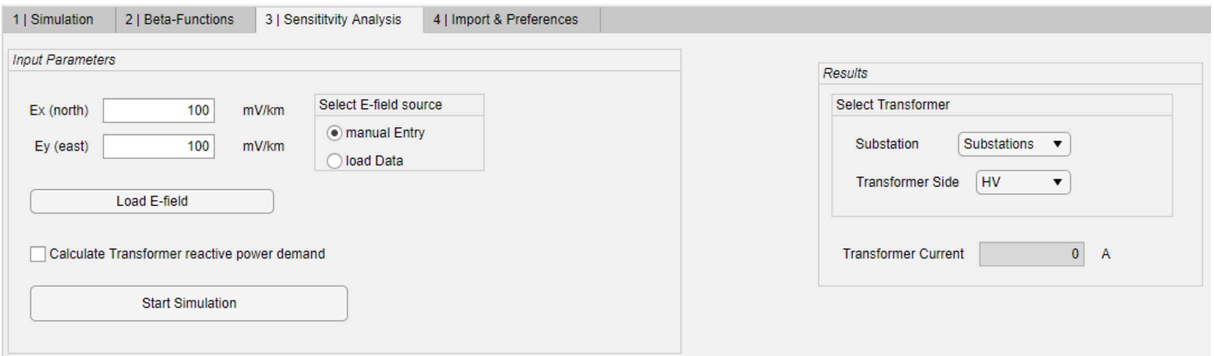

Figure 10: Sensitivity Analysis

5.2.4 Plotting results in a map

After a simulation has been successfully run, it is possible to plot the results in a map. A figure is created, which includes all substations of the grid plotted in the grid. For each timestep available, a separate figure will be created and, if the "save png" option is selected, every single figure will be saved as an image to the current working folder.

To start the animation, just press the "show map" button in the bottom area of Tab 1 of the simulator. Depending on the size of the data, this may take some time. Please note, that a successful simulation must be conducted first, otherwise an error will occur. By modifying the "margin" value field right to the "show map" button, it is possible, to adjust the size of the animated map.

Figure 12 and Figure 11 show exemplary results of the "show map" feature, using the exemplary grid *LFC_Grid_Template_2Nodes.* In the top right corners, a reference circle is visible to indicate the size of a current of one ampere. Large currents are depicted as large circles, smaller values are drawn smaller.

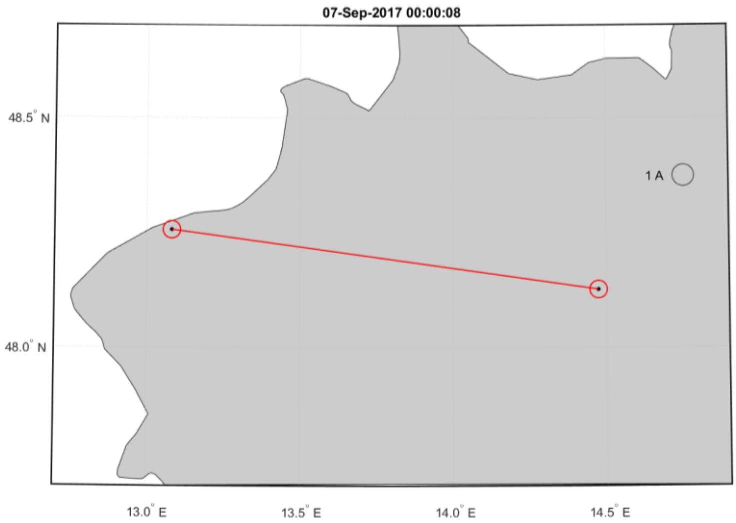

Figure 11: Representation of currents in a map (margin: 0.4 deg)

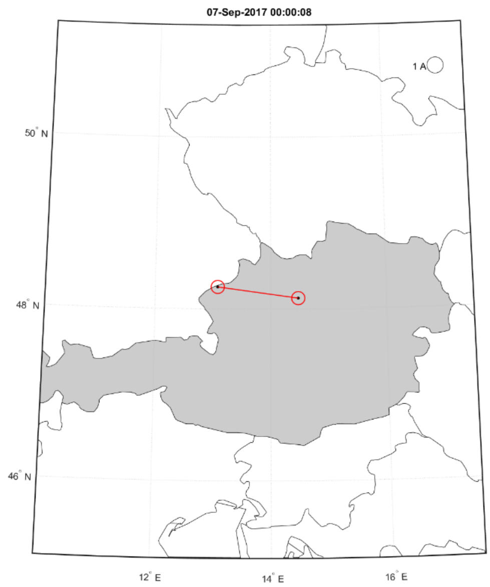

Figure 12: Representation of currents in a map (margin: 3 deg)

6 Planned / upcoming features

- Performance improvements
- Preference handling
- More Calculation options (e.g. leakage effect options)
- Neutral point switching optimizations

7 References

[1] T. Halbedl, "Low Frequency Neutral Point Currents on Transformer in the Austrian power Transmission Network," PhD Thesis, Institute of Electrical Power Systems, Graz University of Technology, Graz, 2019. Accessed: Nov. 11 2021. [Online]. Available: https://diglib.tugraz.at/download.php?id=5cc8220f5d096&location=browse

[2] T. Halbedl, H. Renner, and G. Achleitner, "Geomagnetically induced currents modelling and monitoring transformer neutral currents in Austria," e&i, 2018. Accessed: Dec. 7 2018. [Online]. Available: https://link.springer.com/content/pdf/10.1007%2Fs00502-018-0665-9.pdf

[3] K. Patil, "Modeling and Evaluation of Geomagnetic Storms in the Electric Power System," 2014. [Online]. Available: https://e-cigre.org/publication/C4-306_2014-modeling-and-evaluation-of-geomagnetic-storms-in-the-electric-power-system

[4] R. Horton, D. H. Boteler, T. J. Overbye, R. J. Pirjola, and R. C. Dugan, "A Test Case for the Calculation of Geomagnetically Induced Currents," *IEEE Trans. Power Delivery*, vol. 27, no. 4, pp. 2368–2373, 2012, doi: 10.1109/TPWRD.2012.2206407.