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# LFC Simulator v 1.0 Documentation

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ELECTRICAL  
POWER SYSTEMS  
TU GRAZ

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# 1 Introduction

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

If any problems or questions or problems arise, please contact:

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More information on the research project can be found at:

<https://www.tugraz.at/en/institutes/ian/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].

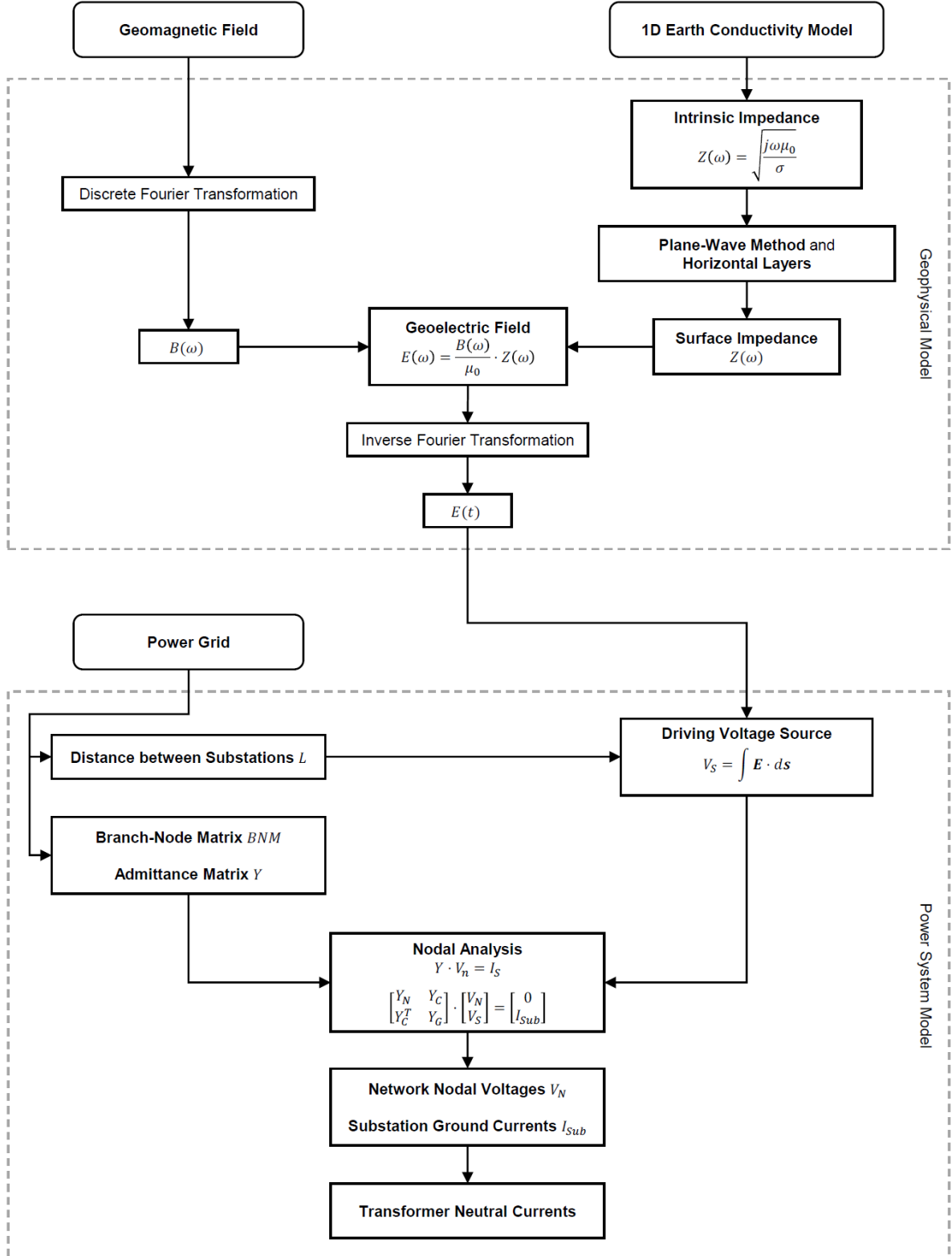


Figure 1: Method flow chart of the GIC simulation method [1]

## 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 2. 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 2: 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 3. The example can be found in the sample directory and is called *LFC\_Grid\_Template\_2Nodes.xlsx*.

	A	B	C	D	E	F	G	H	I
1	Nr	Substation	Type	Resistance HV (Ohms/phase)	Resistance LV (Ohms/phase)	Grounding HV	LV	V_HV	V_LV
2	1	sub1	GY-GY	0,452	0,194	1	1	380	220
3	2	sub2	GY-GY	0,19595	0,1431	1	1	380	220
4									
5									

	A	B	C	D	E	F	G	H	I
1	Nr	Sub from	Sub to	Length km	Resistance per km Ohm/km	Single Line Resistance Ohm	Voltage kV	Systems #	Multiple Conductor #
2	431	sub1	sub2	111,3	0,0217	2,411	380	1	1
3	432	sub1	sub2	111,3	0,0217	2,411	380	1	1
4									
5									

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	Nr	Name	Substation	Country Code	Latitude Degree	Longitude Degree	Grounding Ohm	V_1	V_2	V_3	V_4	N_1	N_2	N_3	N_4	Neutral	Ground
2	1	Substation 1	sub1	AT	48.256187	13.081307	0.08	380	220	0	0	1	2	3	4	5	11
3	2	Substation 2	sub2	AT	48.126221	14.474579	0.1	380	220	0	0	6	7	8	9	10	12
4																	
5																	
6																	
7																	
8																	

Figure 3: 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 second example is the GIC model grid from [2].

## 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  $\Omega\text{m}$ , 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 4. The example can be found in the sample directory and is called *LFC\_Earth\_conductivity\_Template.xlsx*.

	A	B	C	D	E
1	M01	400	1300	140000	170000
2	M39	55000	45000		
3					

	A	B	C	D	E	F
1	M01	40	3	2000	115	15
2	M39	1000	300	1000		
3						

Figure 4: 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 5: Graphical user interface

- **Switch between sections (A)**
  - Simulation
  - Substation Analysis (*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.
- **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 6.

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 2.
  - 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 6: 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 7.

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 60<sup>th</sup> 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.
6. Press *Start Simulation* to start the simulation process. After a successful simulation, the results are shown in the GUI as depicted in Figure 8 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.

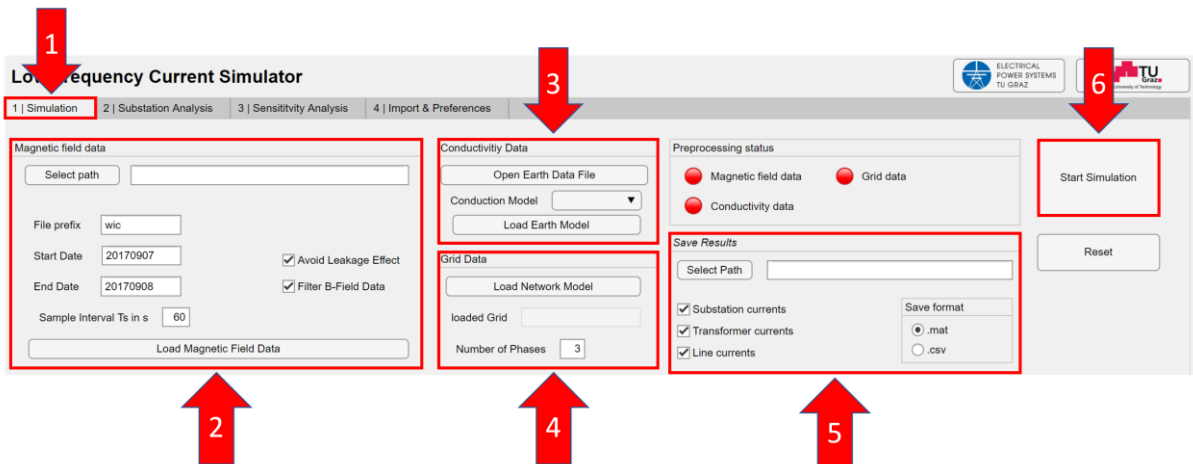


Figure 7: Simulation process

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.

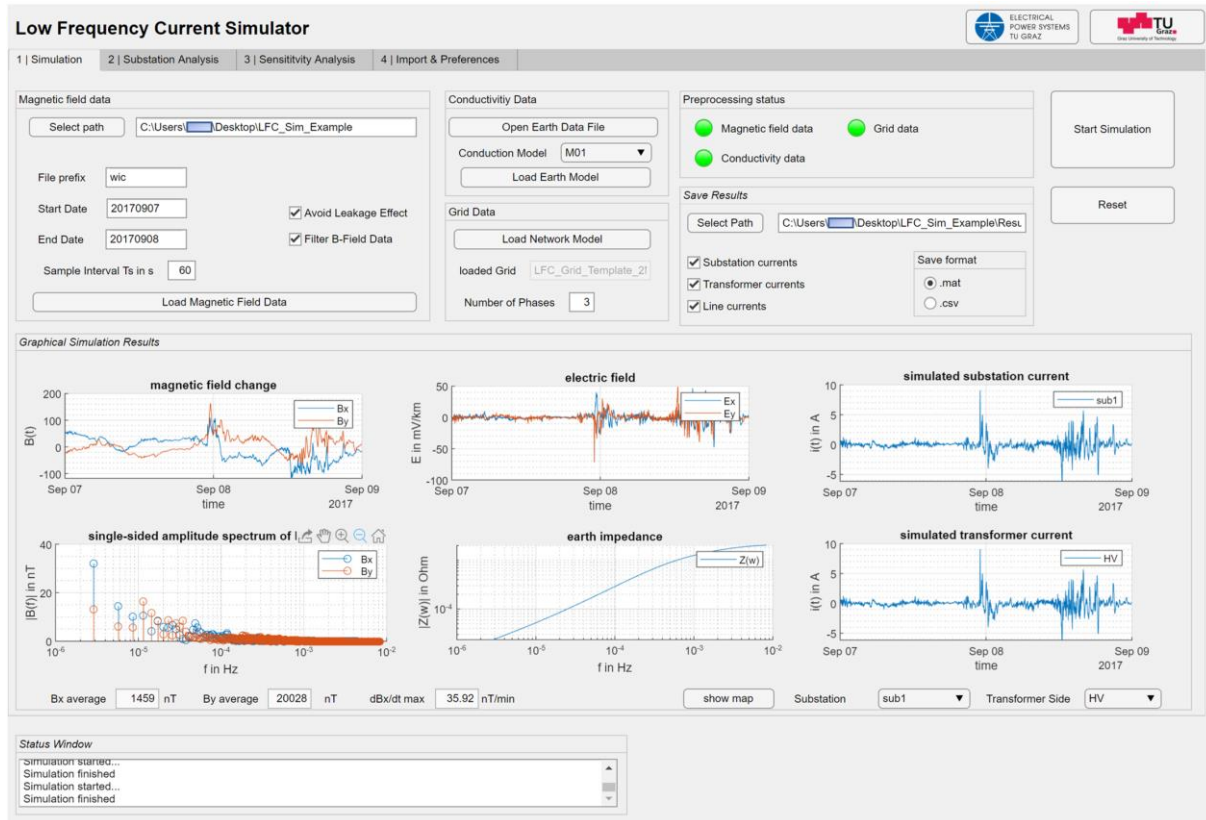


Figure 8: Simulation results

### 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 and earth 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 9. Substation and voltage level can be chosen arbitrarily. The results are saved at the path, selected in tab 1.

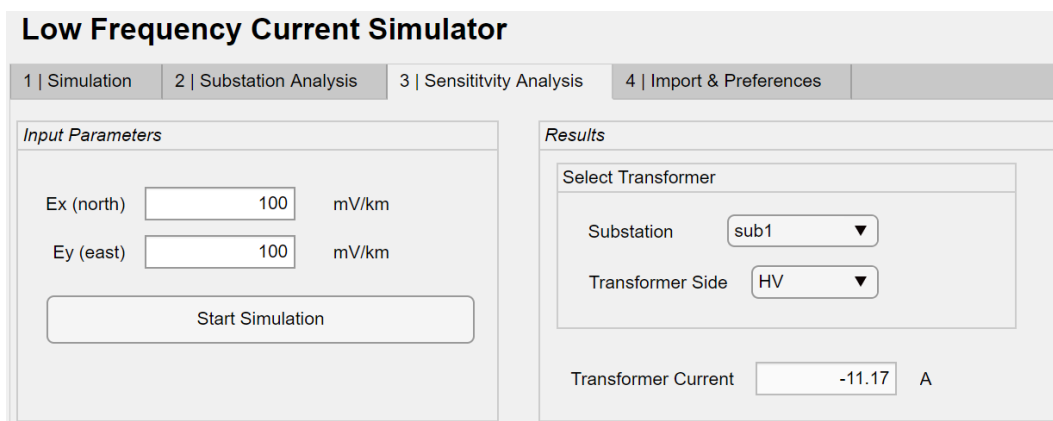


Figure 9: Sensitivity Analysis

## 6 Planned / upcoming features

- Detailed substation analysis with reactive power calculation
- Automatic geographical map of the grid

## 7 References

- [1] T. Halbedl, Low Frequency Neutral Point Currents on Transformer in the Austrian Power Transmission Network, Doctoral Thesis, 2019.
- [2] R. Horton, D. Boteler, T. J. Overbye, R. Pirjola und R. C. Dugan, „A Test Case for the Calculation of Geomagnetically Induced Currents,“ *IEEE Transactions on Power Delivery*, 2012.