Power Systems I

Software Laboratory

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Preface

This laboratory is split into two parts, use two different test systems and the software ARTERE to perform the analysis. The general objective is to verify through simulations some of the theoretical results we had in the class. The specific learning objectives of each laboratory are listed in the descriptions below.

Software used

Simulation of electric power systems is an essential component of power system planning and operation. There exists a variety of dedicated commercial and free software solutions for this purpose. Such solutions usually provide a model library containing models of the main power system components (e.g., generators, loads, transmission lines and transformers) as well as a range of pre-implemented functions allowing to conduct power system studies. Typically, these comprise power flow calculations, short circuit and fault analysis, dynamic frequency and voltage stability assessment and economic considerations as well as contingency studies.

Within EEN320, we will use the software ARTERE to perform power system studies. ARTERE is an academic software developed at the University of Liége that has been widely used in research as well as in industry. It offers a large range of functionalities, allowing to implement and simulate vast real-world power systems with thousands of buses and components.

Power system simulation and analysis in ARTERE is based on descriptive text files that provide the data of the system to be analysed. The lab notes will guide you through the individual implementation and analysis steps. In particular, the projects containing the power systems studied in the labs have already been defined for you and are available on the website. Hence, you don't need to create new projects, but only import the existing ones. This is detailed in the respective task.

The main window of ARTERE and its different parts are shown in Fig. 1.

Laboratory report

The laboratory is assessed through a report:

☞

- It amounts for **30%** of the final grade.
- The report is **individual**. Any events of plagiarism will lead to the grade being annulled and the incident reported to the school ethics committee.
- The submission will be either in English or in Greek.
- You need to address all the tasks detailed in the lab notes below, in the right order, and referring to the specific task numbers.

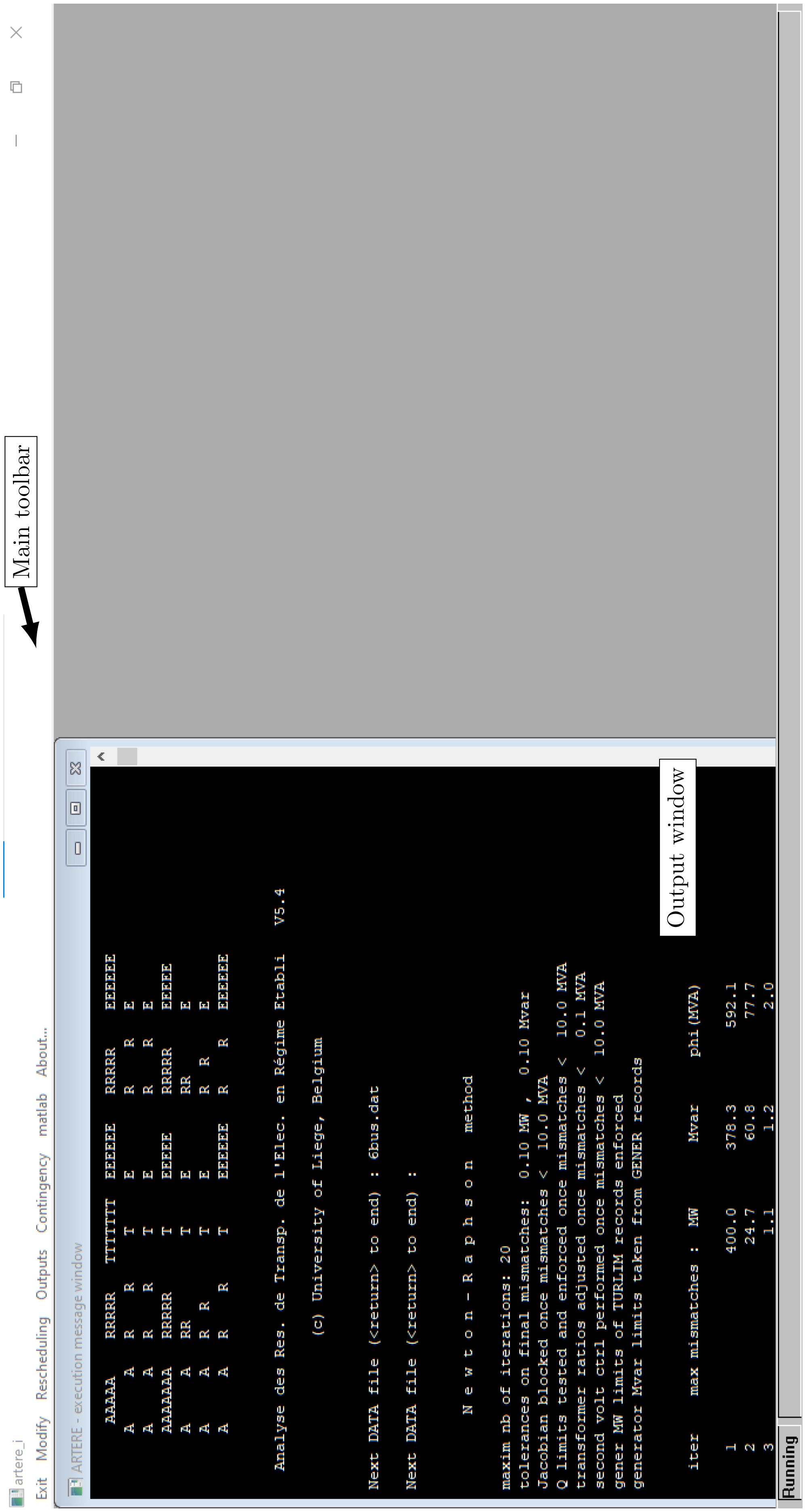

Figure 1: Main window of ARTERE

Laboratory 1

Single-Feeder Analysis

1.1 Review

Please **review** the following items before the lab:

- Characteristics of power lines;
- Surge impedance calculation;
- Surge impedance loading;
- Ferranti effect;
- Reactive power compensation.

1.2 Introduction

1.2.1 Problem Statement and Tasks

In this lab, we will analyse the electric network shown in Fig. 1.1. The network is composed of 3 buses: A, B, and C. Bus A has a generator connected while bus C has a load. The characteristics of the system are indicated in the tables below. We want to analyse the behaviour of a single line in different loading conditions. To accomplish the above objectives, you need to solve the following tasks:

Task 1 Familiarisation with ARTERE;

Task 2 Surge impedance and no load conditions on overhead lines and cables;

Task 3 Reactive power compensation.

1.2.2 Learning Objectives

After successful completion of this lab, you should ...

- ... be able to perform fundamental calculations and analysis using a specialised software;
- ... explain the performance of an overhead line and a cable under different loading conditions;
- ... implement static reactive power compensation devices.

	Description	R' (Ω/km)	L' (mH/km)	C' (μF/km)
OHL 110kV	185-Al/30-St	0.0155	1.37	0.009
Cable 110kV	120-Cu	0.017	0.414	0.25

Table 1.1: Line characteristics

1.2.3 Network Data

The data for the line and cable are given in the table below.

1.3 Task 1: Getting Started

This task will help you to familiarise yourself with the ARTERE software and the exemplary network that we study in this lab.

- Download the "EEN320_lab.zip" and extract on your desktop.
  - Inside Documentation folder, you will find the ARTERE user guide and data description files. These provide a guideline on how to use and load data in the software.
  - Inside the Data folder, you will find "3bus.dat" and "3bus.svg". These files describe the system we will analyse. The Dat file can be opened with any file editor and includes the system description and the SVG file is loaded in any browser to visualise the one-line diagram.
  - Inside the Data folder, you will find the ARTERE executable *artere_i.exe* (the i32 version is for 32bit computers).
- Start the ARTERE executable by double clicking on it. You should see a user interface like in Figure 1. **If you don't see anything, then contact the instructor.**
- Open the "3bus.svg" in a browser. You should see the Figure 1.1. **If you don't see anything, then contact the instructor.**
- Open the "3bus.dat" in a text editor and locate the *Bus*, *Network*, and *Generator* information.
  - What are the nominal voltages of the transformer, line, and generator?
  - How is the transformer modelled? What is the reactance of the transformer (in Ω on the low-voltage side)?
  - The line parameters are computed with the simplified Π model ($\ell < 300\ km$). Verify that it's an 80 km OHL from Table 1.1.
- Run a load flow simulation. To do this, you simply start ARTERE by double clicking on the executable. In the command window you give the name of the dat file (3bus.dat) and press ENTER twice.
- If your load flow calculation has been successful and you don't get any errors, you should see the same as in Figure 1.
- To view the results, select from the menu bar "Output"→"show listing". The window of Figure 1.2 allows to view the bus voltages, current flows, etc. (check *ARTERE_user_guide*).
- To view the results on the one-line diagram, select from the menu bar "Output"→"show on one-line diagram". Then, give the name of the one-line diagram file (3bus.svg) and press ENTER twice. Open the file "res_3bus.svg" in any browser and include it in your report.

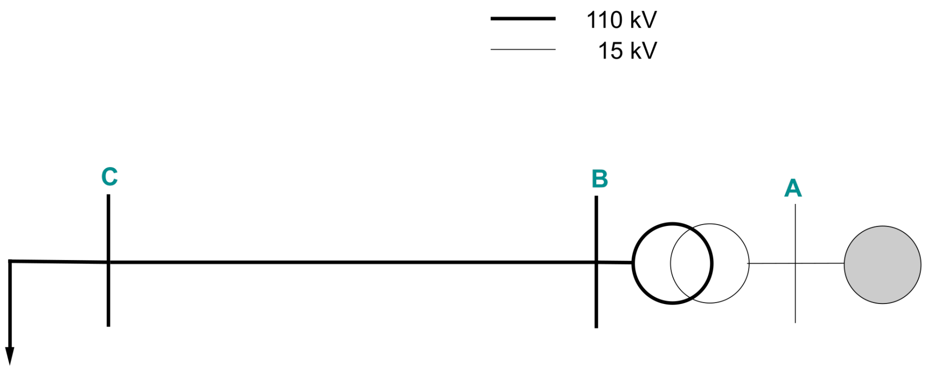

Figure 1.1: One-line diagram

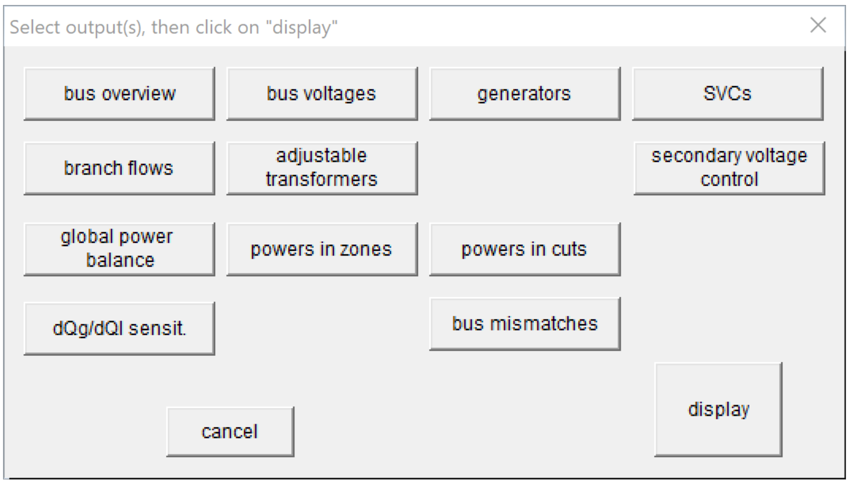

Figure 1.2: Output selection

1.4 Task 2: Surge Impedance and No-Load Conditions

Next, you will analyse the system behaviour under two special conditions: surge impedance loading (SIL) and no load (i.e., open circuit). You should relate your observations to the discussion of these two cases provided in the lecture material (Parts 5 and 6).

1.4.1 Task 2.1: Surge Impedance Loading (SIL)

SIL of an OHL

Task 2.1.1 Compute the surge impedance $\underline{Z}_W$ of the *lossless* overhead line, i.e., neglect the line resistance (see Lecture Parts 5 and 6 for help).

> ✍ In the lossless case, the surge impedance is given by $Z_W = \sqrt{\frac{L'}{C'}}$.

Task 2.1.2 Compute the *three-phase* SIL of the overhead line for $|V_L| = 110$ kV.

Task 2.1.3 Enter the SIL active and reactive load power values on *Bus C* in the fields for "Active Power" and "Reactive Power" (check the BUS record in *ARTERE_data_description*).

Task 2.1.4 Calculate the thermal power limit for the OHL. Assume the maximal long-term admissible current density for one conductor is $J = 3.5$ A/mm^2.

> ✍ The thermal current limit (per conductor, i.e. per phase) is given by:
>
> $$I_{\mathrm{Th,max}} = J \cdot A,$$
>
> where A is the conductor diameter of the conductor strand (see Table 1.1 and Lecture Part 5)
> The thermal power limit is then:
>
> $$S_{\mathrm{Th,max}} = 3V_{LN}I_{\mathrm{Th,max}}$$

Task 2.1.5 Run a load flow simulation and extract the one-line diagram as shown in Task 1.

Task 2.1.6 How large is the reactive power flow along the overhead line? How large is the line loading? Does the result coincide with your expectations? Explain why!

Task 2.1.7 Based on your results: Is the approximation $R' = 0$ that you used to compute the surge impedance $\underline{Z}_W$ admissible or rather not? Explain why!

Task 2.1.8 Increase the line length to 180 km and run a new load flow calculation. How did the reactive power flow on the line change? Does the result coincide with your expectations? Explain why!

SIL of a cable

Task 2.1.9 Replace the overhead line B-C with a cable of length to 40 km using the parameters of Table 1.1. Use the simplified Π model. What are the model parameters?

Task 2.1.10 Compute the surge impedance $\underline{Z}_W$ of the *lossless* cable, i.e., neglect the line resistance (see Lecture Parts 5 and 6 for help).

Task 2.1.11 Compute the SIL of the cable for $|V_L| = 110$ kV.

Task 2.1.12 Set the load demand on "BUS C" to the SIL.

Task 2.1.13 Run a load flow calculation and extract the one-line diagram.

Task 2.1.14 How large is the reactive power flow along the cable? How large is the cable loading? How do the results compare to those obtained with the overhead line? Provide an explanation for your observations!

1.4.2 Task 2.2: No Loading

Task 2.2.1 Replace the line B-C with an OHL of Table 1.1 of length 100 km. Use the simplified Π model. What are the model parameters?

Task 2.2.2 Set the load demand on "BUS C" to 0 MW and 0 MVAr.

Task 2.2.3 Run a load flow calculation. Inspect the resulting voltage at "BUS C".

Task 2.2.4 Increase the line length to 400 km and run a new load flow calculation. Inspect the resulting voltage at "BUS C".

Task 2.2.5 What can you observe? Provide an explanation for your observation (see Lecture Part 6 for help)!

1.5 Task 3: Reactive Power Compensation

Now, we will investigate how one can improve the bus voltages by providing *reactive power compensation*.

Task 3.1 Replace line B-C with an OHL of Table 1.1 with line length of 50 km. Use the simplified Π model. What are the model parameters?

Task 3.2 Set the load demand on "BUS C" to $P = 80$ MW, power factor 0.85, inductive.

Task 3.3 Run a power flow calculation.

Task 3.4 What do you observe in terms of the bus voltage at "BUS C" and the loading of the power line?

Task 3.5 You will now improve the system performance by regulating the bus voltage at "BUS C" using a constant power shunt compensation (check QSHUNT in the BUS record in *ARTERE_data_description*).

Task 3.6 Set the "QSHUNT" to 5 Mvar and run a new load flow calculation. How have the results changed?

Task 3.7 Try to find an optimal setting for your capacitor, i.e., a setting such that the voltage at the "BUS C" is approximately 1 pu. What effects has this on the line loading and reactive power flow along the line? Justify your answer!

Task 3.8 What positive effects will the installation of your shunt capacitor have on the network operation? Justify your answer!

Task 3.9 Suppose you were to implement your compensation unit with a fixed capacitor value in a practical power system. What technical and economical problems may you encounter? Explain why!

Laboratory 2

Network Operation and (N-1) Security Analysis

2.1 Review

Please **review** the following items before the lab:

- parallel power transformers;
- (N-1) criterion.

2.2 Introduction

2.2.1 Problem Statement and Tasks

In this lab, we will analyse the electric network shown in Fig. 2.1. The network is composed of 6 buses: A, B, C, D, E, and F. Buses A and F have generators connected while buses D and E have loads. The characteristics of the system are indicated in the tables below. We want to analyse the impact of the transformer connectivity on the system, verify the N-1 security of the system and propose mitigation strategies. To accomplish the above objectives, you need to solve the following tasks:

Task 1 Initialise data;

Task 2 Parallel transformer operation;

Task 3 Analysis and testing of (N-1) security.

2.2.2 Learning Objectives

After successful completion of this lab, you should . . .

- . . . be able to perform load flow calculations and load flow analysis using a software;
- . . . understand the impact of transformer connectivity;
- . . . understand the N-1 criterion an the practical implications.

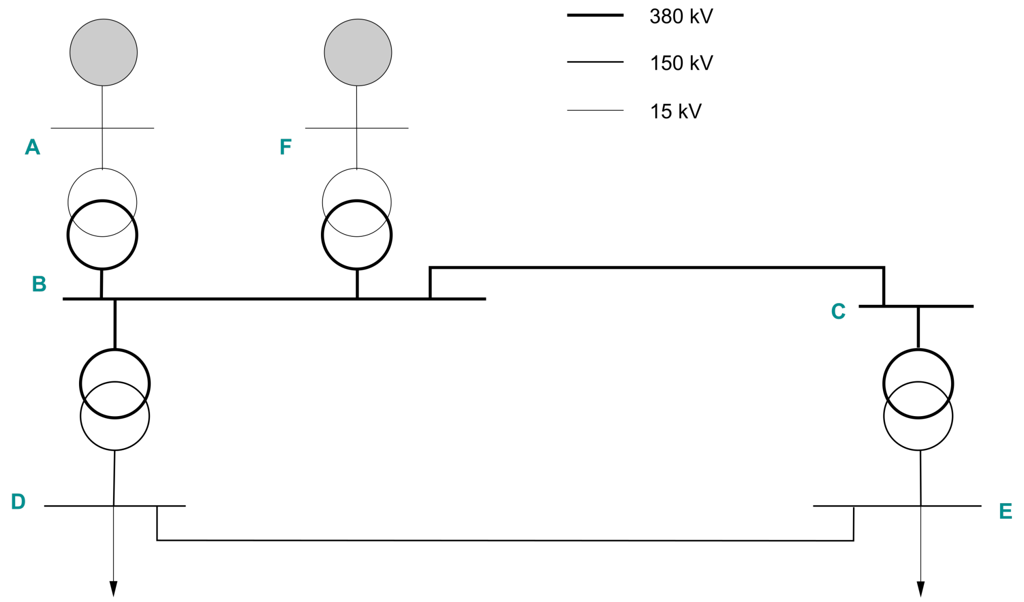

Figure 2.1: Considered grid

	V_N (kV)	X (Ω/km)	X/R	$\omega C/2$ ($\mu S/km$)	S_N (MVA)	Length (km)
B-C	380	0.3	10	1.5	1350	50
B-E	150	0.4	5	1.2	300	50

Table 2.1: Line characteristics

	R (pu)	X (pu)	B (pu)	S_N (MVA)	n (extr side)
A-B	0	0.14	0	500	1.08
F-B	0	0.14	0	250	1.08
D-B	0	0.14	0	300	1.00
E-C	0	0.14	0	600	1.00

Table 2.2: Transformer characteristics

	P (MW)	Q (Mvar)	S_N (MVA)
Gen A	?	?	500
Gen F	150	?	200
Load D	400	120	-
Load E	100	30	-

Table 2.3: Generator and load characteristics

2.3 Task 1: Getting Started

To get started, do the following.

- Download the "EEN320_lab.zip" and extract on your desktop.
  - Inside Documentation folder, you will find the ARTERE user guide and data description files. These provide a guideline on how to use and load data in the software.
  - Inside the Data folder, you will find "6bus.dat" and "6bus.svg". These files describe the system we will analyse. The Dat file can be opened with any file editor and includes the system description and the SVG file is loaded in any browser to visualise the one-line diagram.
  - Inside the Data folder, you will find the ARTERE executable *artere_i.exe* (the i32 version is for 32bit computers).
- Start the ARTERE executable by double clicking on it. You should see a user interface like in Figure 1. **If you don't see anything, then contact the instructor.**
- Open the "6bus.svg" in a browser. You should see the Figure 2.1. **If you don't see anything, then contact the instructor.**
- Open the "6bus.dat" in a text editor and locate the *Bus*, *Network*, and *Generator* information. Verify that the data in the file are the same as the ones in the tables above.

2.4 Task 2: Operation of parallel transformers

In this task you will analyse the behaviour of parallel transformers.

Task 2.1 Transformers D-B and E-C of type Yd11. Open the data file and find how this is represented with the phase shift (check the TRANSFO record in *ARTERE_data_description*).

Task 2.2 Run a power flow.

Task 2.3 What are the active and reactive power balances of the system? Display the one-line diagram.

Task 2.4 Check that line D-E and transformer C-E operate below their thermal ratings.

Task 2.5 Simulate the misuse of a transformer E-C of type Yy0, while transformer D-B is of type Yd11. Show that the resulting electrical state is unacceptable.

Task 2.6 Getting back to the correct configuration of the transformers, perform a new power flow computation in which the phase angles of the transformer ratios are set to zero. Comment on the results obtained.

2.5 Task 3: Analysis and N-1 security

In this task you will evaluate the performance of the existing network. Keep the phase angles of the transformers to zero.

Task 3.1 Run a load flow calculation for the system and evaluate the load flow results.

Task 3.2 Are the voltage magnitudes at all buses within satisfactory limits (i.e., ±5% of the nominal grid voltage)? Are the line and transformer loadings within their limits?

Task 3.3 Is the system N-1 secure? Show your answer analytical and through simulations.

✍ There always needs to be a generator defined as SLACK in the system. This is a variable power generator that will keep power balance. Originally, this is generator A. If you trip the generator, you need to define another generator as SLACK.

Task 3.4 If the system is not N-1 secure, propose and explain methods to make it N-1 secure. Include in your report a detail of changes and the equivalent dat file.