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Revision History

Date	Author	Reviewed by	PF Version	Doc.Revision
14/02/13	S.Seeger	N. Wilson	15.0	Revision 2

Contents

1 Introduction

The purpose of these exercises is to introduce *PowerFactory*'s functions for power system harmonic analysis in power systems. The drills include setting up network models, running harmonic load flows and frequency sweep simulations, and plotting and interpreting the results.

The instructions in the exercises are deliberately brief to encourage a bit of trial and error while performing a certain task. The supervisor(s) will help you with the exercises. Additionally, the references between brackets point to detailed instructions to the exercises in the appendix.

Finally, do not hesitate to address the supervisor(s) at any time! They can provide answers to general questions regarding the topic of the training.

We wish you good success!

2 Creation of a first project and entering of network data

In this first exercise you will get introduced to the basic concepts of PowerFactory. You will start building a 110 kV grid from scratch and enter elements and types.

- Create a new project with the name ”PF Seminar”. [A.1].
- Name the grid ”110 kV grid”.
- Rename the diagram ”Scheme 110 kV grid”.
- Make the background layer visible and select the file ”PF Seminar 110 kV grid” as the background picture. [B.2]
- Change the drawing format from landscape to portrait.
- Enter the network elements of the 110 kV grid as given in figure 2.1 as follows:
- Add the single and double busbar elements to the 110 kV grid. Ensure that the busbar voltage is set to 110 kV.
- Change the names of the single and double busbar objects according to figure 2.1.
- Use a terminal element to represent the 380 kV busbar. Change the voltage to 380 kV.
- Use the short terminal element to represent the 10 kV busbars between the generators and the transformers.
- Connect the busbars with the line elements.
- Add the transformers, generators and the external grid to the network.
- Import the library folder *Types.dz*. This library folder contains some types. Others will be created by you. [A.3]
- Create the line types ”N2XS(FL)2Y 1x300RM/25 64/110kV it”, the transformer typ ”T-150 MVA” and the generator type ”46 MVA” by using the data sheets given in the attachment.
- Add the types to the elements as given in the tables 2.1 to 2.6 and enter the element data. Any parameters which are not provided should be left at their default values.

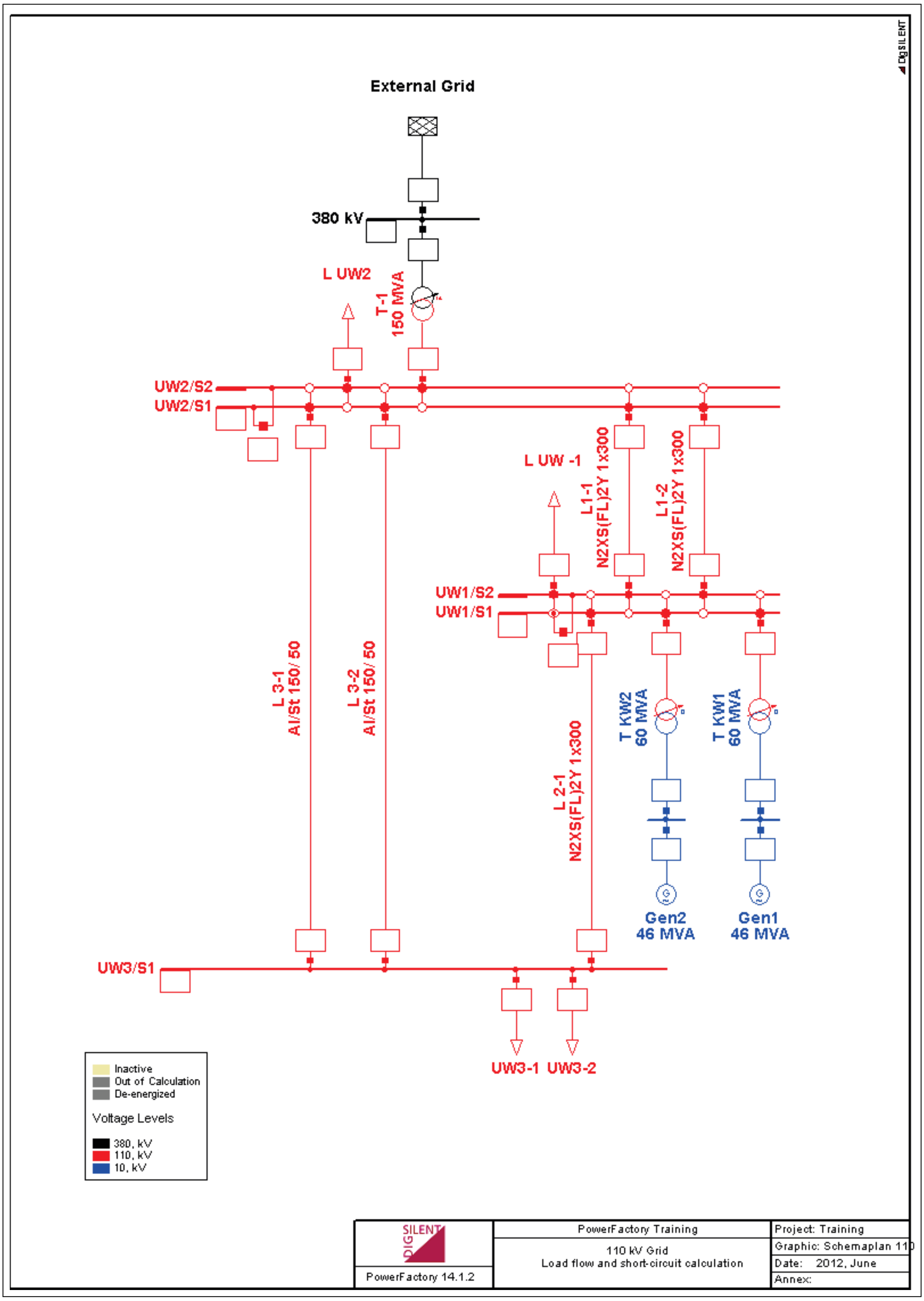

Figure 2.1: 110 kV network

Name	Al/St 185/30	"N2XS(FL)2Y 1x300RM/25 64/110kV it"
Rated Voltage	123 kV	110 kV
Rated Current	0,535 kA	0,47 kA
Line Parameters pos. Seq.	R′= 0,15 Ω/km	R′= 0,1939 Ω/km
	X′= 0,4 Ω/km	X′= 0,3563 Ω/km
Line Parameters zero Seq.	R0′= 0,31 Ω/km	R0′= 0,34 Ω/km
	X0′= 1,11 Ω/km	X0′= 1,576 Ω/km
Line Parameters pos. Seq.	C′= 0,009 μF/km	C′= 0,0103 μF/km
	Insulation Factor= 0	Insulation Factor= 0
Line Parameters zero Seq.	C0′= 0,005 μF/km	C0′= 0,0052 μF/km
	Insulation Factor = 0	Insulation Factor= 0

Figure 2.2: Line data

Name	46 MVA GT
Rated Apparent Power	46 MVA
Rated Voltage	10,5 kV
Power Factor	0,8
Connection	YN
Xd [p.u.] **Xq [p.u.]**	2,349 2,136
Reactive Power Limits [p.u.]	-0,44/0,83
x0 [p.u.] **r0 [p.u.]**	0,076 0,006
x2 [p.u.] **r2 [p.u.]**	0,185 0,039
xd' [p.u.]	0,219
xd" [p.u.]	0,169
xd"sat [p.u.]	0,134
xdsat [p.u.]	1,97
rstr [p.u.]	0,002

Figure 2.3: Generator data

Name	T-380/110-150MVA
Rated Power	150MVA
Rated Voltage	380kV/110kV
SC-Voltage uk	9,5%
Copper Losses	300kW
uk0 **ukr0**	10% 1,2%
Tap changer at high-voltage side	0,85% per step Position from -9 to 9
No Load Current	0,1%
No Load Losses	15kW

Figure 2.4: Transformer data

Table 2.1: Lines and Cables

Name	Type	Length
L-1-1	N2XS(FL)2Y 1*300	10.00 km
L-1-2	N2XS(FL)2Y 1*300	10.00 km
L-2-1	N2XS(FL)2Y 1*300	25.00 km
L-3-1	Al/St 150/50	50.00 km
L-3-2	Al/St 150/50	50.00 km

Table 2.2: Transformers

Name	Type	Tap position
T-1	T-380/110-150MVA	14
T-KW-1	T-110/10-60MVA	0
T-KW-2	T-110/10-60MVA	0

Table 2.3: External Grid

Name	Bus type	Voltage setpoint	Voltage angle	Sk”max	Sk”min
Ext-380kV	SL	1.02 p.u.	0.00ï¿½	8000.00 MVA	7000.00 MVA

Table 2.4: Generators

Name	Type	Mode voltage control	Active power	Voltage
Gen-1	46 MVA	voltage	30.00 MW	1.00 p.u.
Gen-2	46 MVA	voltage	30.00 MW	1.00 p.u.

Table 2.5: Loads

Name	Dispatch Active Power	Dispatch: Power factor cos( )
BL-UW1	22.00 MW	0.86
BL-UW2	35.00 MW	0.88
BL-UW3.1	46.40 MW	0.85
BL-UW3.2	50.00 MW	0.85

Table 2.6: Busbar type

Name	Voltage	ip	ith
SS 110 kV	110 kV	30 kA.	16kA 1s

- After the network data has been entered, make the background layer invisble again. [B.2]
- Define a title for the project and add the DIgSILENT logo to the title. [B.1]
- Add the transformer tap positions layer to the grid. [B.2]
- Change the colouring mode to voltage levels. [B.4]
- Activate the colouring tool bar and change the position so that it fits in the single line diagram.
- Run the data verification with the options *check topology* and *check input parameters* activated.
- Export the scheme as a .wmf file. Select *File* → *Export*→ *Windowsmetafile* to do so.
- Create a report for the documentation of device data.

3 Load flow analysis

In this exercise you will verify the entered data of your project and you will be introduced to the load flow calculation tool. In addition, you will learn how to access results.

3.1 Load flow calculation

- Run the load flow analysis . Deactivate all options beside ”AC load flow, balanced, positive sequence”.
- Check the messages in the output window to verify if there are any warnings or error messages (warning messages will be shown in red colour) and correct the mistakes if there are any listed.
- Once mistakes are corrected repeat the load flow calculation.

3.2 Evaluation of results

Results can be assessed and listed in the following ways:

3.2.1 Results in the network scheme

- Add the ”direction arrows” layer to the grid. The direction shown corresponds with the direction of active power flow. [B.2]
- Be aware that the colouring mode automatically changes after a load flow calculation to high voltage / low voltage / loading. [B.4]
- Evaluate the results shown in the result boxes.
- Add the legend for the results to the single line diagram. [B.5]
- Fill out Table 3.1 on the next page with the calculation results

Table 3.1: Calculation results

Calculation result	Value
Lowest voltage in p.u. / name of busbar	
Highest loading of a line / line name	
Active Power at HV side of T1	
Reactive power at Lv side of T1	
Total network losses Active power	

- Choose the ”loading” result box format for the edge elements (lines, transformers, generators, etc.) and evaluate the results.
- Select the ”power loading” result box format for edge elements and observe the changes in the listed variables.
- Add the voltage deviation to the result boxes for the nodes.

- Add the current to the result boxes for the edge elements. [D.2]
- Change the unit for the current from kA to A. [D.5]
- Create a textbox for the transformer T1 and add the variables active and reactive power losses to the transformer losses

3.2.2 Using the flexible data page to access results

- Open the browser to edit relevant objects for calculation. Select all busbars
- Go to the flexible data page and sort the list according to the voltages in p.u.
- Define a flexible data page for the busbars and include the listed variables for busbars:

Table 3.2: Flexible Data page 1

U	**Ul**	**u**	**u**	**du**	**U,angle**
kVï¿½	kV	p.u.	per cent	per cent	deg

- Define a flexible data page for the grid and select the listed results:

Table 3.3: Flexible Data page 2

Dispatch, Active Power	**General load, Active Power**	**Losses**	**Line losses**
MW	MW	MW	MW

3.2.3 Result documentation

- Create an ASCII report for the total grid summary and observe the results in the output window. [D.7]
- Create an ASCII report for the complete system report.
- Save the report from the output window into a text file. The output file name should have the file extension .out.
- Re-do the load flow calculation. This time enable the option ”Show verification report”on the outputs page of the load flow command. All elements with a loading higher than 60 per cent should be listed in the output window. [D.11]

4 Load flow calculation under consideration of voltage control and reactive power limits

As you may have realised in exercise 2, the voltage on some busbars in the 110 kV grid is relatively low. To support the voltage in the grid, we will use firstly use a station controller. We will then consider the reactive power limits and capability curves of the generators., The adjustment of transformer taps to find the best operation point of the system will also be examined. Finally we will get to know switchable shunts.

4.1 Station controller

- Define a station controller for the generators Gen-1 and Gen-2. [C.1]The station controller should control the voltage of the busbar S1 of the substation UW-1. The voltage setpoint is 1.02 p.u. To achieve this, the reactive power provided by the generators, should be shared equally.
- Run the load flow calculation. Has the new setpoint be reached? Are there any overloaded elements?
- Deactivate the station controller by using the object filter. Re-run the load flow calculation. Compare the results. [C.2]
- Activate the station controller again and repeat the calculation.

4.2 Consideration of reactive power limits

- Set the reactive power limits of the generators "Gen-1" and "Gen-2" to -12 Mvar / +30 Mvar.
- Rerun the load flow calculation. Are there any warnings listed in the output window?
- Rerun the load flow calculation again. This time enable the option "Consider reactive power limits". Are there any changes in the results? Can the voltage setpoint of the station controller be reached? If not, why?

4.3 Generator capability curve

By considering the generator capability curve the reactive power limits can be entered precisely.

- Create a new capability curve for the first generator. Use the values given in table 4.1. Take care to use the limits in p.u. instead of in MVA. [G.1]
- Select the new capability curve for the second generator, too. [G.2]
- Run the load flow calculation again and check the output window for warnings.
- Open the input window of the generator Gen-1 and navigate to the load flow page to see the new dispatch point in the diagram.
- Rerun the load flow calculation and enable /disable the option "Consider reactive power limits".

Table 4.1: Capability Curve

Active power	Min. reactive power	Max. reactive power
p.u.	p.u.	p.u.
0	-0.4	0.86
0.3	-0.3	0.83
0.6	-0.19	0.72
0.8	-0.12	0.6
0.9	-0.08	0.4
0.95	-0.06	0.3
1	-0.04	-0.04

4.4 Automatic tap adjustment of transformers

The voltage can be controlled by changing the tap position of a transformer.

- Activate the option ”Automatic tap adjustment” on the load flow page of the transformer elements T-KW 1 and T-KW2 to control the voltage on the HV side: [C.3]
  - Controlled Node: HV
  - Tap changer: direct
  - Control mode: V
  - Upper voltage bound 1.05 p.u.
  - Voltage setpoint: 1.03 p.u.
  - Lower voltage bound: 1.01 p.u.
- ” Set the data for the transformer T-1:
  - Controlled Node: LV
  - Tap control: discrete
  - Control mode: V
  - Upper voltage bound 1.03 p.u.
  - Voltage setpoint: 1.02 p.u.
  - Lower voltage bound: 1.01 p.u.
- Run the load flow calculation with the additional option ”Automatic tap adjustment” enabled.
- Include the transformer tap position to the network graphic.

5 Short-Circuit Calculation

In this example you will perform several short-circuits and evaluate the results.

5.1 Short-circuit calculation in a medium voltage grid

5.1.1 Verification of limits

- Activate the project *PF Seminar with 20 kV grid enhanced*. Remove the *110 kV grid* from the study case.
- Run the simulation cases a) and b) that are listed below and add the results to table 5.1.

a) 3 ph. Max short-circuit calculation at all busbars for the given network topology. Are there any overloaded elements?

b) Change the network topology by closing the circuit-breaker at the line ”L UW1-UW3-3” (as shown in figure 5.1) and calculate a 3 phase short-circuit at all busbars. Fill out table 3.

Table 5.1: Results short circuit medium voltage grid

	Base case	**CB closed**
Skss max		
Ikss max		
Unsafe network components		
Infeed of wind farm ok?		
Ip max		
Configuration allowed?		
Ideas for improvement?		

Open again the circuit breaker at line ”L UW1-UW3-3” so that the original network topology is obtained.

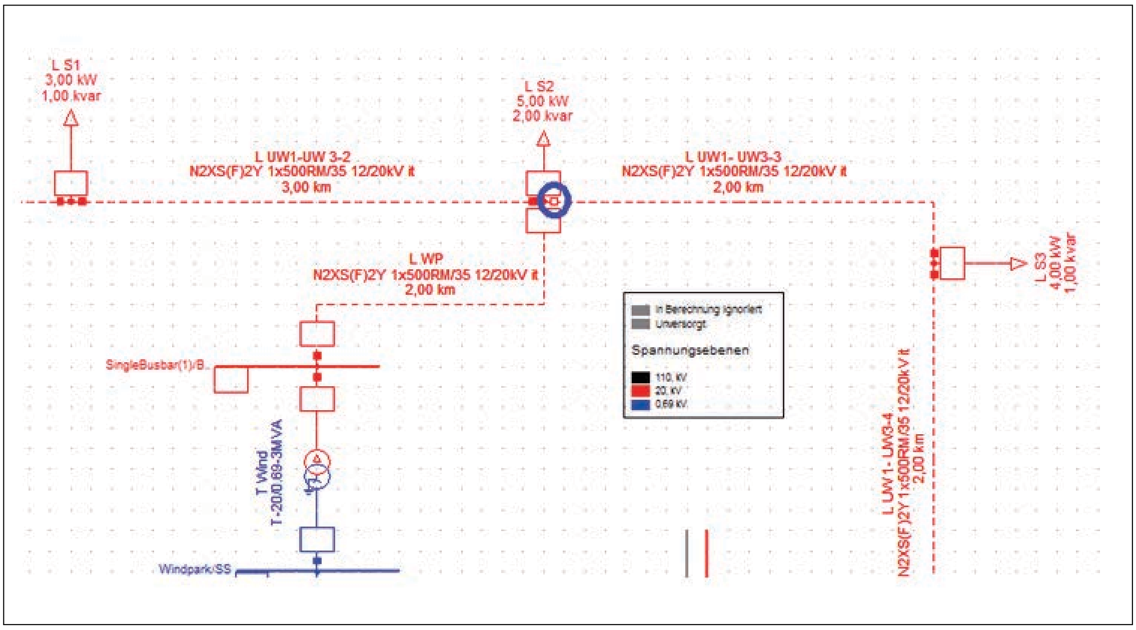

Figure 5.1: Configuration CB opened / closed

Now switch to they **110 kV grid**. Add the grid *110 kV grid* to the study case again.

- Calculate a 3 phase Short-Circuit at busbar *S1* of the substation *UW-1* in *110 kV grid*.
- Analyse the influence of the break time on the breaking current Ib. Use *Comparision of results* for the analyze. [D.8]
- Analyse the influence on the fault time on Ith. Add Ith to the results shown in the result box.

5.1.2 Short-circuit calculation on a line

- Switch over agin to the 20 kV grid.
- Calculate the 3 phase short-circuit on line "UW1-SW1-1" . The fault location should be at 70 per cent off the line. Mind to show the results in the box for *busshc* (short-circuit bus).

5.1.3 Single-Phase Short Circuit

Single-Phase short-circuits are especially problematic in medium voltage grids. Thus we will continue the short circuit training in the medium voltage grid imported earlier.

- The capacitance connected to the 20kV busbar "UW 1 -S1" represents a further cable capacitance. Disconnect the capacitor first.
- Calculate a single-phase short circuit current at "UW 1-S1" according to IEC60909.
- Determine the zero-sequence impedance for the NEC element, so that the network is compensated. Herewith please use the zero-sequence impedances (R0, X0) at the S/C fault busbar.

- Run the S/C calculation again and check if the magnitude of the current is small.
- Now please connect the capacitor to the system and calculate a single-phase S/C current at "UW1 -S1" again. Has the magnitude of the current changed much?
- Determine the new zero-sequence impedance for the NEC element, so that the network is compensated again. Either use the zero sequence impedance of the NEC itself or change the internal grounding impedance.
- Check if the magnitude of the current is again near zero.

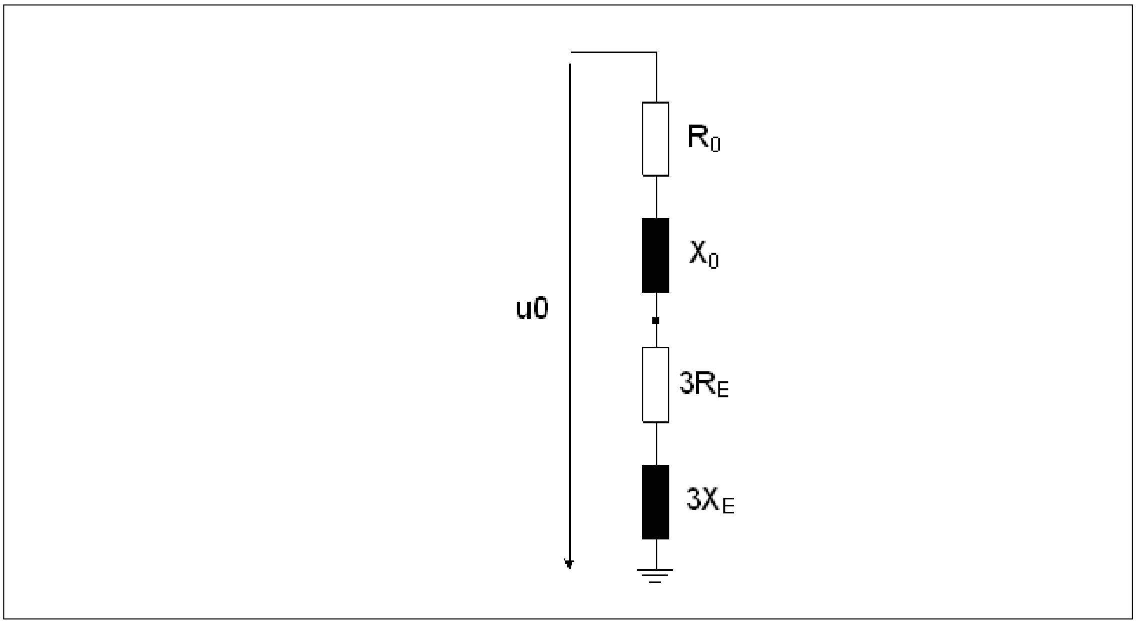

Figure 5.2: NEC - Equivalent circuit in the zero system

References

- LoadFlowTheory.pdf
- ShortCircuitTheory.pdf

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Appendix

Detailed Instructions

A The Project

A.1 Creating a new project

- Main Menu : *File* → *New*. This opens the *New* dialog.
- Tick the option *New* → *Project*. Enter the project's name. Make sure that the *Target Folder* points to the folder in which you want to create the project (normally that is your user account folder).
- Press **OK**. A grid is automatically created in the new project and a dialog will pop, enter a name for your network.

The empty single line diagram for the newly created grid will be shown. You can now start drawing your grid. You can change the size of the drawing area by pressing the button on the graphics window toolbar. If you select a sub-size for printing which is smaller than the drawing size, then the single line diagram will be split into several pages when printed. Otherwise, the drawing area will be scaled to the printer paper automatically.

You may change the name of the project after you have created it through the main menu : *Edit* → *Project*. This menu-option opens the project dialog. Be careful not to change any settings or buttons which you do not know.

You can change the name of the Study Case through the main menu : *Edit* → *Project Data*→ *Study Case*. Here you can change the name of the study case, but you can also change the settings of the Grids that are activated by the study case. To change the grids, press the button **Grids**. This opens a list of all Grids. You can either double-click the name to change it (press **return** twice to confirm the change), or you can select the Grid that you want to change (by left-clicking the icon in the first column), and press the **Edit Object** Button in the current window.

A.2 Activating and deactivating a project

There are several ways to open and close a project. The easiest way is via the main menu bar. The last 5 active projects are listed at the File menu on the main menu. The currently active project is the first one in this list. To deactivate the currently active project, select it in the list (left click it). Alternatively, you may choose the option *File* → *Close Project* from the main menu.

To activate a project, select it in the list of 5 last active projects. To activate a project that is not in the list of 5 last active projects, use the option on the main menu *File* → *Open project*. This brings a tree with all the project in your user account. Select the project that you want to activate.

Another way is through the Data Manager. Click the right mouse button on a project and select **Enable** or **Disable** from the context menu.

A.3 Import a project data file (*.pfd or *.dz file)

Press Main Menu: *File* → *Import*. Then select *Data (*.dz; *.pfd)...* and select the project that you want to export.

If required, press the black arrow button to select another path to which you want to import the objects in the file. This opens a tree with all the folders in your database from which you can select the correct target folder (normally, this would be your user account folder).