# *Load flow computations with DIgSILENT Power Factory*

Because voltage in an electrical system or network varies with the load, it is very important for a system operator to keep under control this variation at all times and take the appropriate measures of correcting any unwanted deviation when it occurs. Such a system diagnostic can be obtained via a load flow calculation. The load flow analysis of an electrical system such as the Moldova section of the Romanian HV transmission system, depicted in Fig. 1 and Fig. 2, is, in a nutshell, the computation of all bus voltages, using

- the full real operational configuration of the system with all its branches and buses described by their electrical parameters, and
- the actual loading conditions, known through the bus loads and generated powers.

Because of the sheer complexity and duration of hand calculations that would be required even in small systems, electrical utilities use for this purpose professional software packages. This document describes the use of the Power Factory version 14.1 software for electrical systems analysis developed by DIgSILENT GmbH, for load flow calculations.

The steps required for performing a load flow analysis, regardless of the software package used, were outlined in the previous section of this document. Now, they will be described applied to the DIgSILENT Power Factory (DIGSI-PF) software.

## *1. Building of the one-line diagram*

For the analysis of electrical networks, their graphical representation is usually done using one-line diagrams, in which three phase equipment is drawn as one-phase, for simplifying the visualization. This is possible because the load flow calculus uses a series of simplifying assumptions, which ease the computation effort while keeping a satisfactory precision of the results. The most important of these assumptions are:

- electric and magnetic symmetry of equipment on all three phases
- omission of mutual electric and magnetic influences between nearby elements.

In real operation, these assumptions are not always correct, but the scenarios in which deviations occur (such as short-circuits or analysis of low voltage unbalanced systems) are analyzed with tools other than classic load flow algorithms. In normal operation conditions, voltages and currents are considered symmetrical and balanced and the analysis can be carried out on a single phase only, the system being represented with an one-line diagram.

In an one-line diagram, the system components (buses, lines, transformers, generators and so on) are represented with interconnected conventional symbols. The interconnection layout usually does not reproduce the actual distances and element placements found in the field, because of spatial constraints. Software packages usually have graphical user interfaces (GUIs) which allow an easy implementation of one-line diagrams. There are cases when GUIs for one line graphical representations are not available, in which case the data is read from files. This is possible because the load flow mathematical model doesn't actually need the graphical representation, and diagrams are built only for allowing an easier interaction of the user with the program.

In Figures 1-3 is drawn the Moldova section of the Romanian HV transmission system in three equivalent representation:

- a view on the geographical map of Romania, not taking into account the real line paths (Fig. 1)
- a "hand-drawn" representations, with conventional symbols for buses, lines and transformers
- an one-line diagram built in DIGSI-PF.

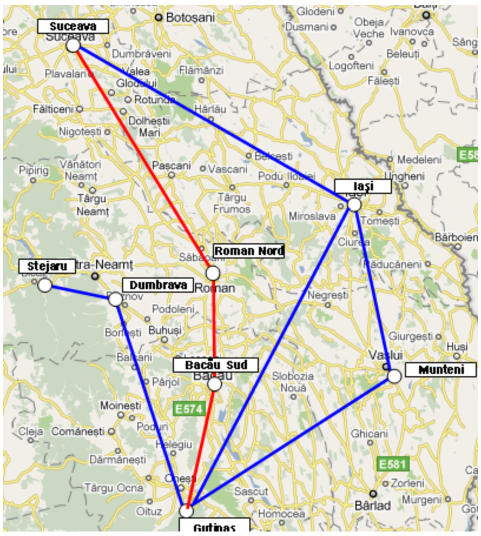



**Fig. 1 -** An one line diagram - geographical view

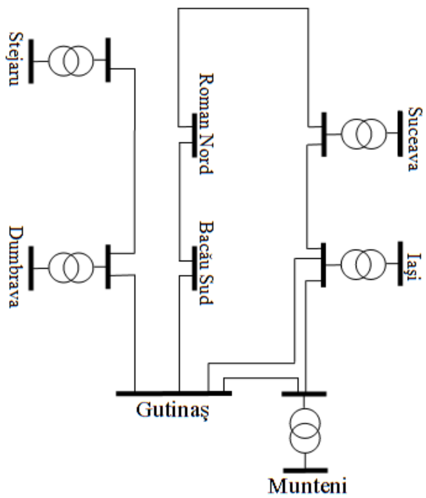



**Fig. 2 -** A drawn one-line diagram

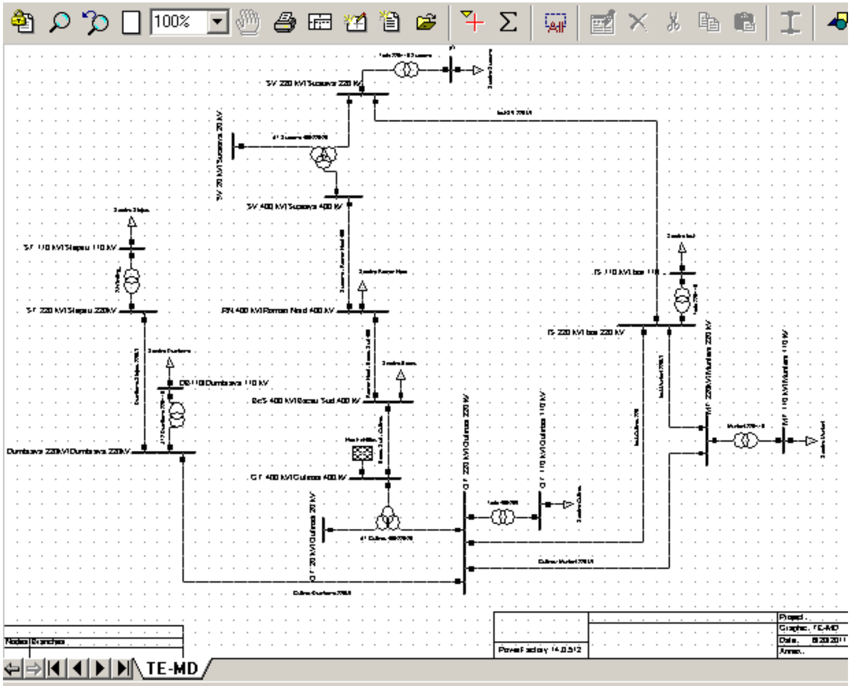



**Fig. 3 -** The diagram in Fig. 1 and 2 implemented in DIGSI-PF

*Implementation of one-line diagrams in DIgSILENT Power Factory 14.1*

Electrical systems are simulated in DIGSI-PF using projects stored in the program's database. New projects are created by users by clicking on the **New** item from the **File** menu, then choosing the **Project...** option. (Fig. 2).

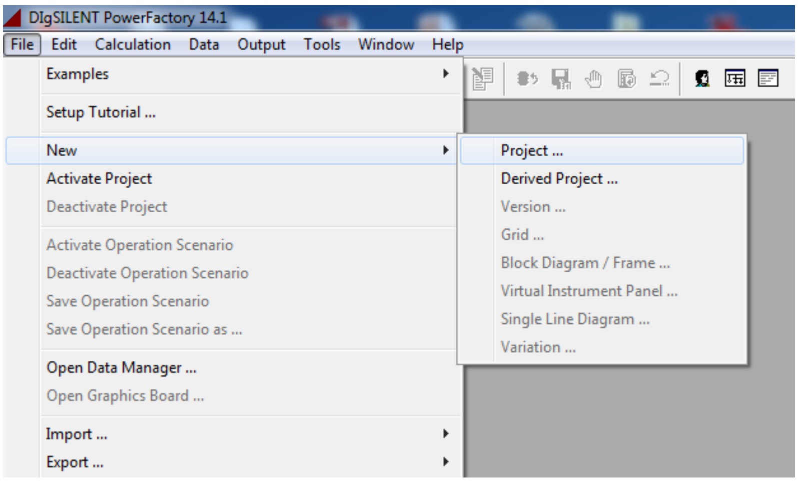



**Fig. 4 -** Creating a new project in DIGSI-PF

A windows pops up, in which the user must specify the project's name (Fig. 5). The example project was named here **TestRNA**. Because DIGSI-PF allows breaking of large systems into interconnected sections drawn on multiple pages, called *grids*, the program will ask next the name of the first grid (Fig. 6). In this window, the user must also specify the operating frequency of the electrical system (the default value is 50 Hz, the European setting) and the colour of the first voltage level used (by default, the program chooses is black).

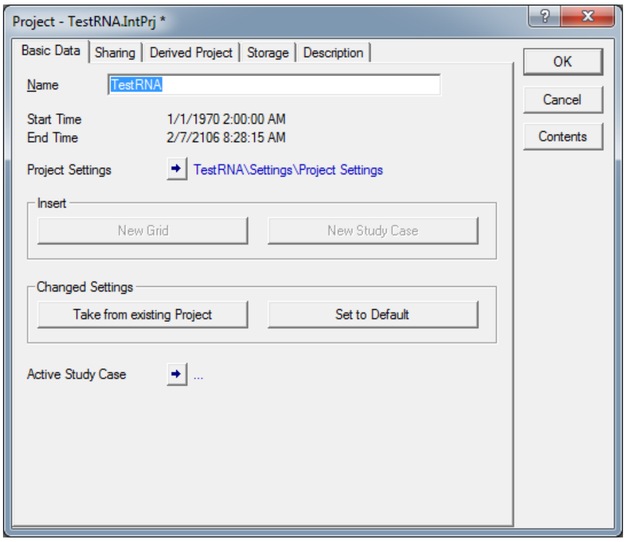



**Fig. 5** - Project initialization, name

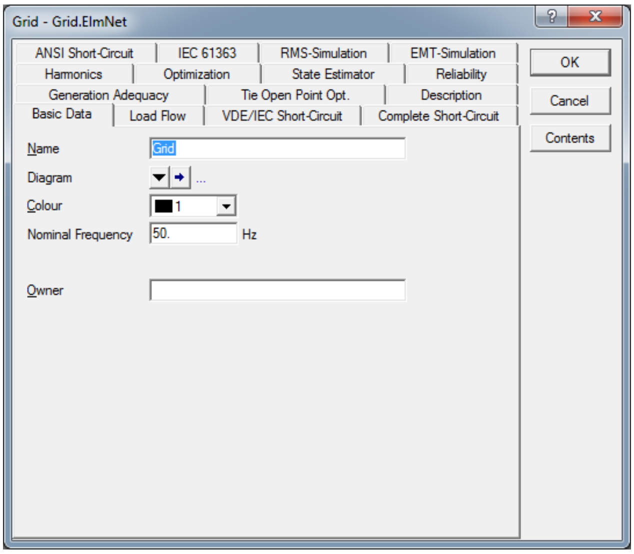



**Fig. 6 -** Project initialization, nominal frequency and diagram colour

After entering this data, a blank diagram opens up, waiting for the user to draw elements and define their electrical parameters.

Existing projects are loaded by using the **Activate Project** option from the **File** menu and then choosing the project by its name and clicking the **OK** button (Fig. 7).

The DIGSI-PF working window is depicted in Fig. 8. The main tool using for picking, placing, moving, connecting and resizing objects is the mouse.

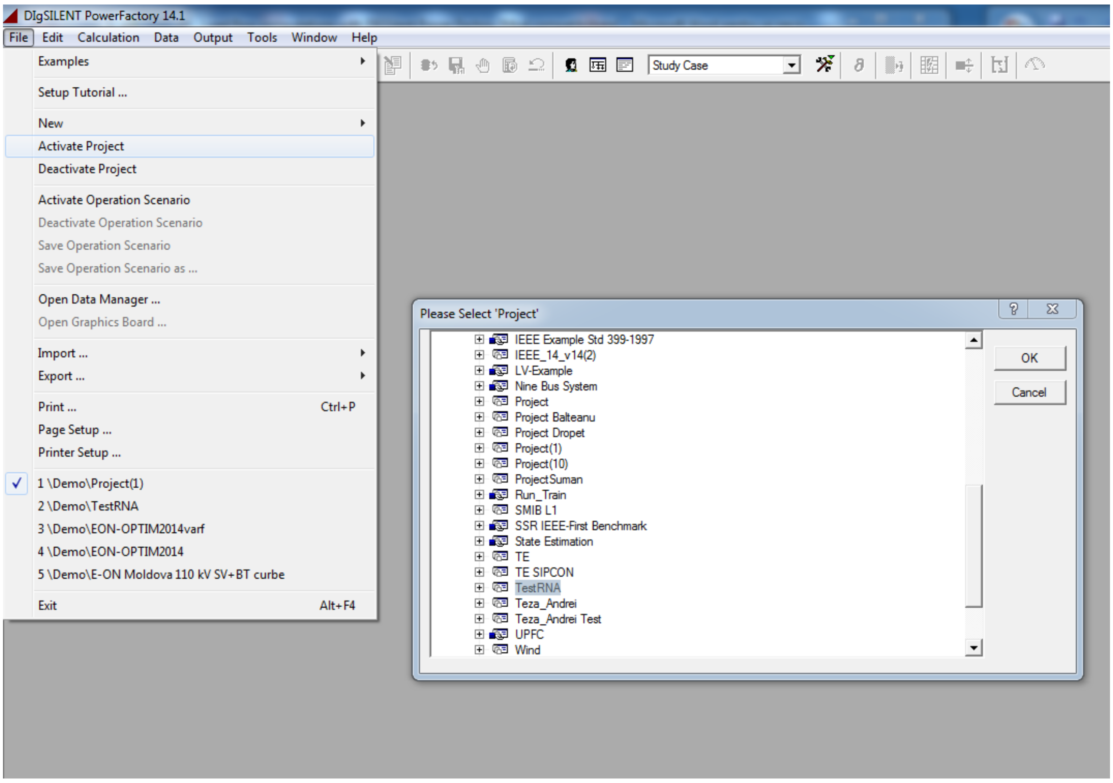



**Fig. 7** - Activating an existing project

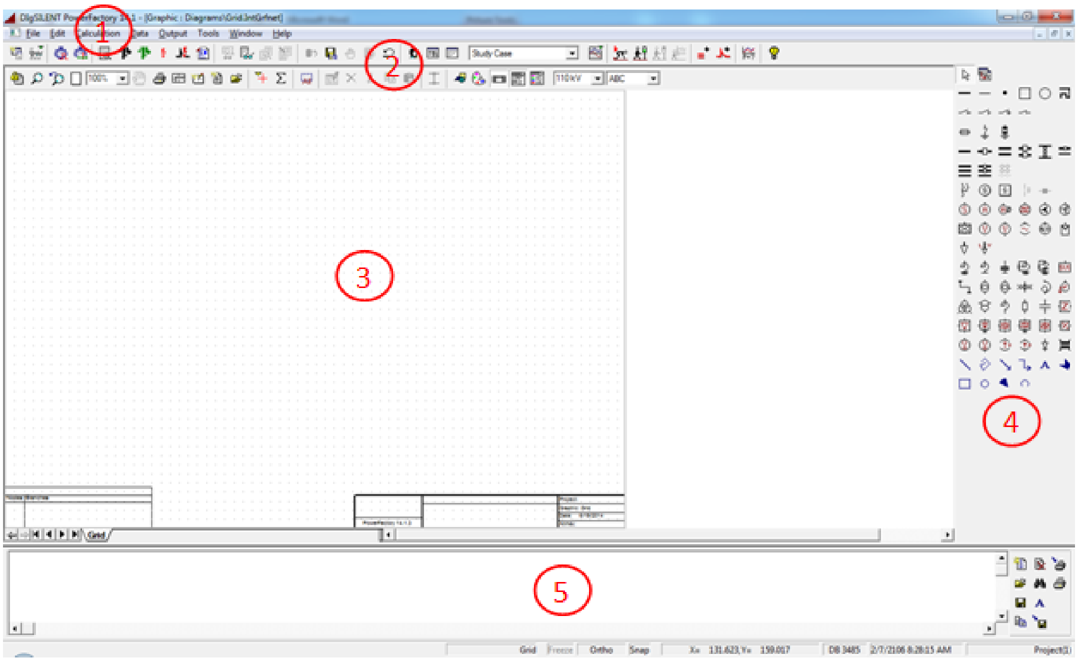
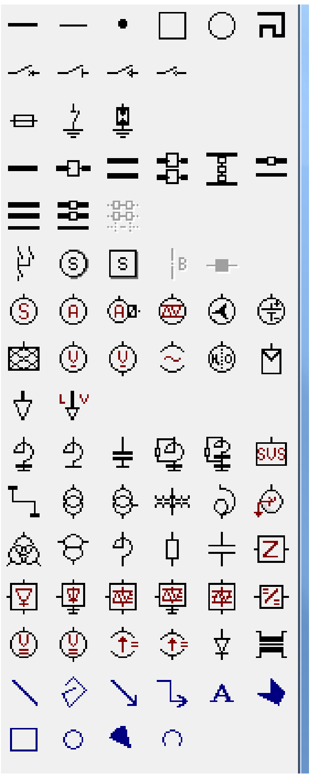



**Fig. 8.** – The main DIgSILENT Power Factory v. 14.1 window:
1 – Menu bar; 2 – Toolbars; 3 – main working area, where diagrams are drawn;
4 – Components panel; - 5 – Message area

The complete palette of objects that can be placed in an one-line diagram, together with a selection of the most used ones, is given in Fig. 9.

An element can be selected from the components panel by clicking on it with the mouse (normal left click). The selection is cancelled by pressing the mouse right button or the **Esc** key. While the selection is active, the mouse cursor will be followed by a small icon of the selected item (Fig. 10).

The element is placed on the working diagram by clicking with the mouse. If the element is to be connected on a busbar, a supplementary window opens when clicking on that busbar, and the element must be connected to a free cubicle (4 are available by default, new ones are created automatically when all are used) (Fig. 11).



| | |
|---|---|
| | bus (Single Busbar System) |
| | External Grid, used to define the slack bus |
| | Electrical line (Line) |
| | 2-Winding Transformer |
| | 3-Winding Transformer |
| | Synchronous Machine, used for defining PV buses |
| | load |

**Fig. 9 –** The components panel in DIgSILENT Power Factory

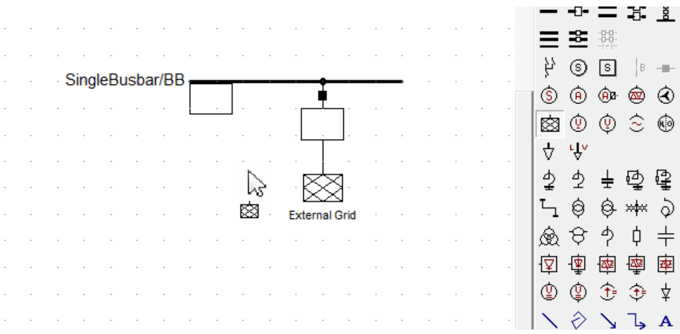



**Fig. 10 -** The selection of an External Grid element

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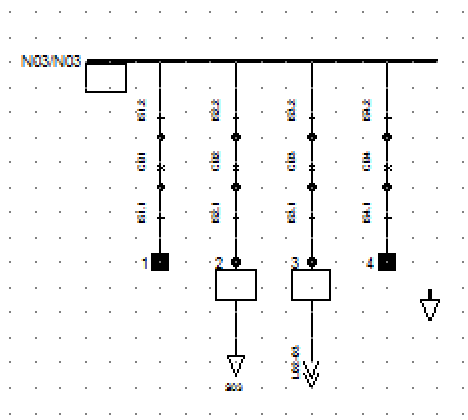



**Fig. 11. -** Connecting a load on a busbar

Next, the use of main elements for creating one-line diagrams is presented, with their graphical representation and the required electrical parameters that must be provided by the user in order to make possible a load flow calculation. Other useful options provided by the DIGSI-PF GUI are presented in between.

### 1. Buses

In an electrical system, buses are the places where electrical energy is drawn (consumed) or injected (generated for consumption). There are also buses with no load or generation, used only to connect system elements such as line sections or transformers. Figure 12 depicts the appearance of a **Single Busbar** type bus in DIGSI-PF. Other bus types such as terminals and complex busbar systems can also be used as buses.

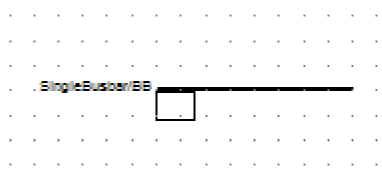



**Fig. 12 –** Busbar representation in DIgSILENT Power Factory

For an optimal layout of the graphic symbols, the drawn elements, including buses, can be rotated by right clicking with the mouse on the object and choose the **Rotate** option (Fig. 13). Rotation is possible only when no other elements are connected to the rotated item. The rectangular shapes attached to elements, as in Fig. 12, are result boxes which will be populated with numbers after a successful load flow calculation. These boxes can be hidden by accessing the **Tools** menu, then choosing the **Show Layer...** item from the **Graphic** option and moving the **Results** to the invisible object group (Fig. 14).

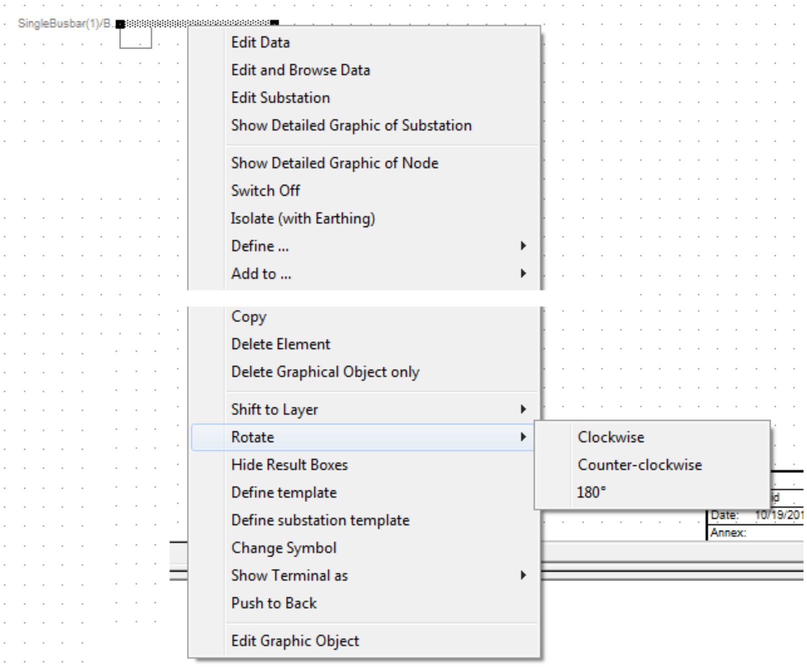



**Fig. 13 -** The rotation option for graphic objects

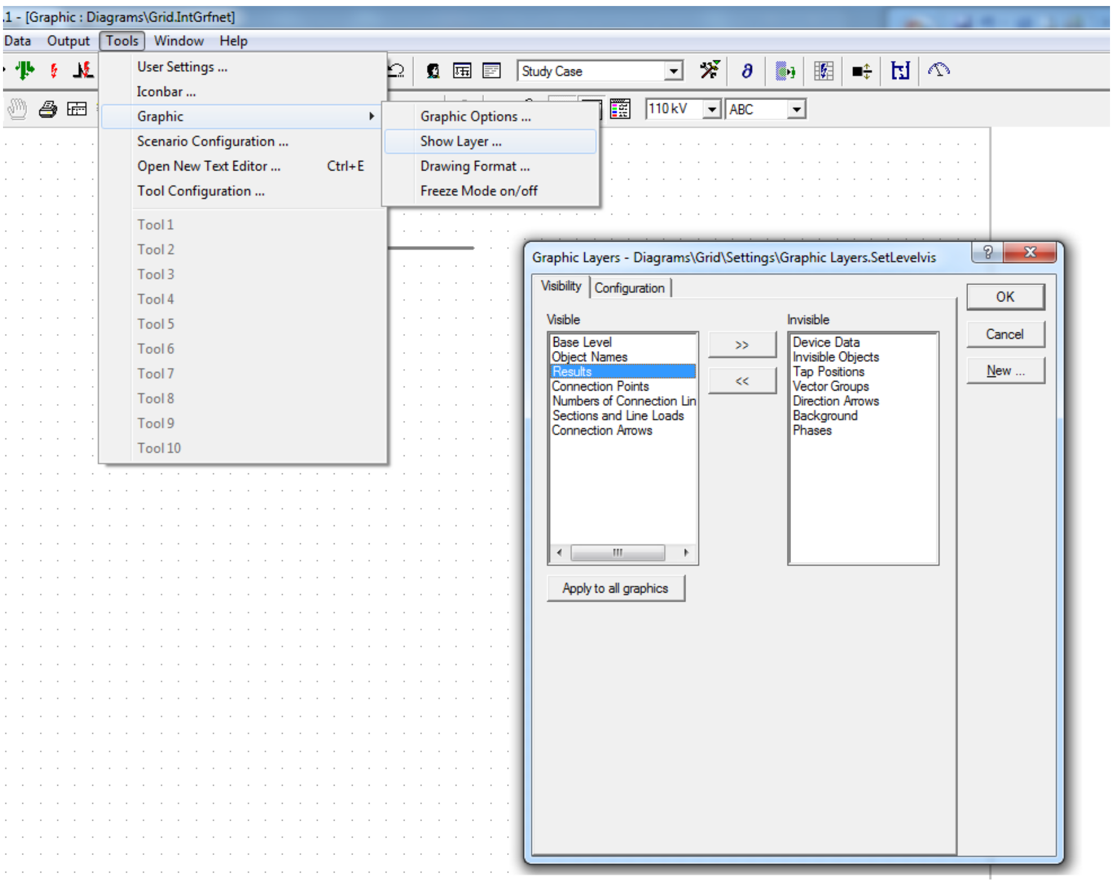



**Fig. 14 -** The hiding procedure for result boxes

In the graphical window, users have two main ways of changing object properties:

- by double clicking on the targeted object
- by right clicking on the object and choose the Edit Data option.

Both methods result in the display of the object properties window, which has some editable fields for user input and some uneditable fields. The uneditable fields are either calculated by the program based on other editable values or they are defined and edited elsewhere.

The third method of changing object properties uses the database inspector and will be discussed later.

The relevant parameters specified by users for a busbar are (Fig. 15):

- **Name** - the desired name
- **Substation -** the name of the substation to which the bus belongs to, useful if the diagram depicts complex station schemes.

The **Name** and **Substation** fields are displayed near the bus in the one-line diagram by default, in the 'name/substation' layout. In Fig 12, bus **BB** from the **Single Busbar** substation is represented. It is a highly recommended practice, although not mandatory, to choose relevant and consistent naming for buses and substations.

- **Type -** busbars can have general types associated to them, which can be chosen from the program's database or created by the user.

Unlike other elements, the specification of a type for a busbar is not mandatory. The type association procedure will be discussed later.

- **Nominal Voltage / Line-line is** the nominal voltage of the busbar, which must be specified.

**For a load flow calculation to work, the nominal voltages defined for the bus and its substation must be identical** (Fig. 15).

Other parameters of interest, for busbars, usually not requiring changing from their default values are the **System Type** (by default AC - alternating current) and **Phase Technology** (by default ABC - three phase). The user can also specify by checking the **Out of Service** checkbox if the busbar is not in operation.

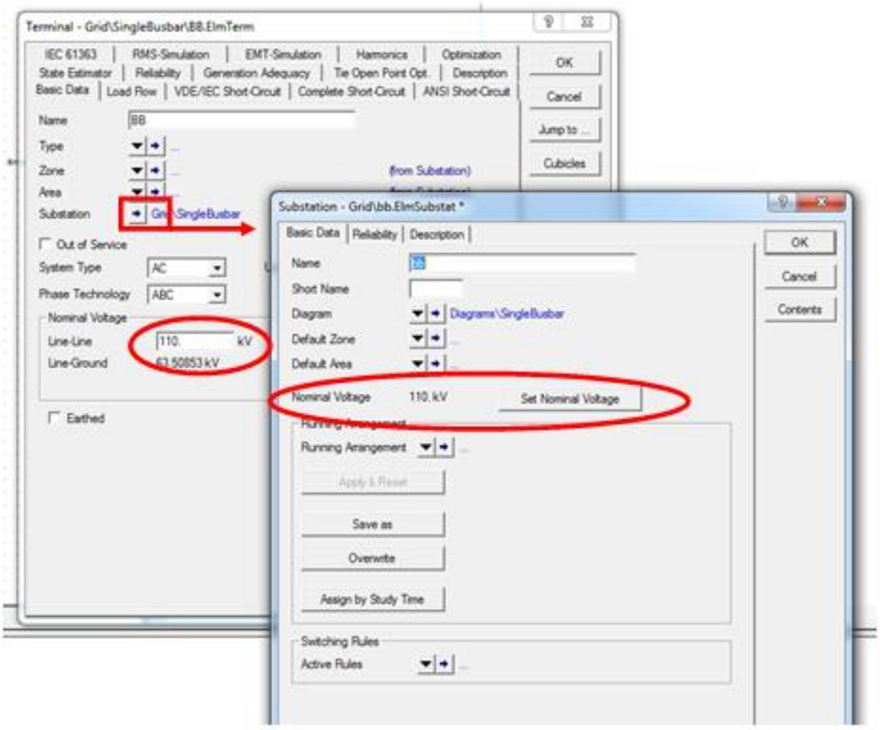


**Fig. 15** - The required parameters for busbars

### 2 . External Systems - Slack Buses

A special type of element is the **External Grid** (Fig. 16). An External Grid is used to define the slack bus required in load flow computations. The External Grid is the equivalent generator which supplies the analyzed system, keeping the balance between the required and available power. An electrical system usually has one slack bus, for which the voltage magnitude and angle are known and active and reactive power must be computed by the load flow algorithm.

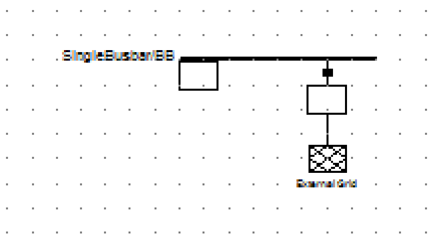



**Fig. 16 -** The External Grid element in DIGSI-PF

In order to define an External Grid as slack bus, the following parameters must be defined:

- **Name -** optinally, the user can provide a relevant name for the slack bus

- **Bus Type** as **SL** - slack
- **Voltage Setpoint** - the operating voltage magnitude, in per-unit values (p.u.) that use as base value the nominal voltage of the busbar to which the External Grid is connected. A value of 1 means the nominal voltage. A value of 0.9 means (0.9 * the nominal voltage).
- **Angle** - the reference nagle of the voltage, usually set at 0.

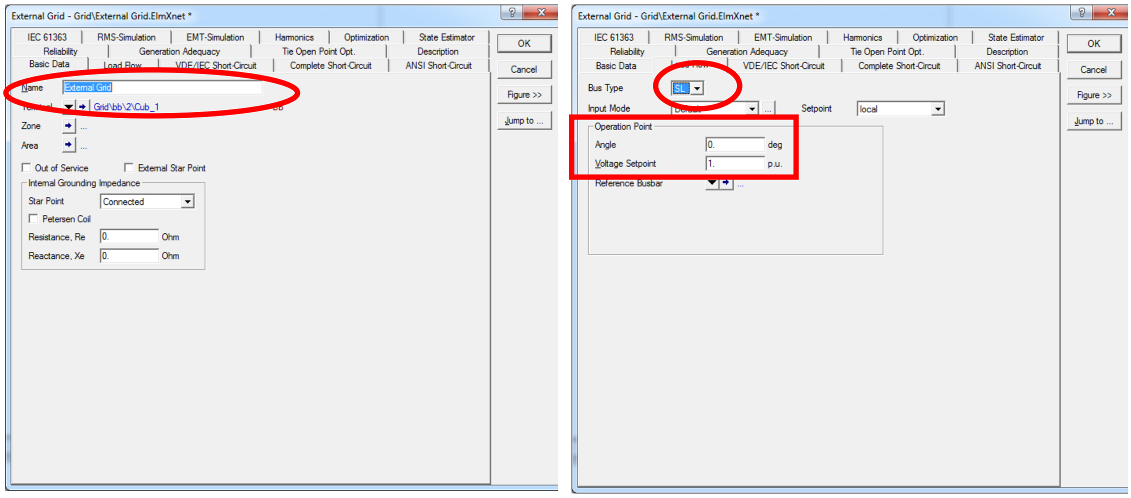



**Fig. 17 -** Parameters required for defining a slack bus with an External Grid

The name is defined in the **Basic Data** tab of the External Grid's properties window, while the voltages ad bus type are specified in the **Load Flow** tab.

### 3. Synchronous Generators

Synchronous generators are used in load flow computations to define PV buses, buses in which the voltage magnitude is regulated, thus imposed. PV buses have the role of keeping their voltage at the imposed value, and this is achieved by varying the generation of reactive power. If a voltage reduction effect is needed, the generator will generate less or will consume reactive power. If a voltage increase effect is needed, the generator will generate more reactive power. This is why for PV buses, the active power and voltage magnitude are known, together with the maximum and minimum values for the available reactive power for voltage regulation. The voltage angle and bus reactive power are computed by the load flow algorithm.

In load flow calculations, DIGSI-PF uses synchronous generators for modeling PV buses. Figures 19-23 depict the sequence of steps required to define a synchronous generator as a PV bus which generates $P_g$ =20 MW of active power, regulates the voltage at 1,1 p.u. and has the reactive power limits of $Q_{min}$= 10 Mvar şi $Q_{max}$ = 40 Mvar.

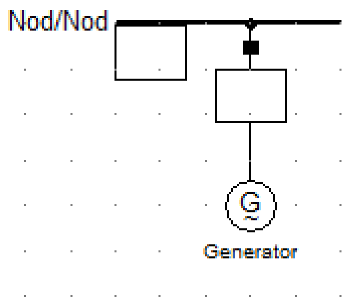



**Fig. 18 -** A synchronous generator symbol in DIGSI-PF

In the **Basic Data** tab of the generator's properties window, a relevant **Name** can be chosen, and a **Type** must be defined (Fig. 19). The type contains data essential for the load flow computation and cannot be skipped.

For any component, there are two kinds of types that can be used:

- Global Types
- Project Types.

Global Types are predefined and they are supplied in the DIGSI-PF installation package by the application's developer. Global Types cannot be modified, the user being warned that they are **Read Only**. (Fig. 22), and they can be used in any project.

For equipment non existing in the program's database, users can create Project Types and provide their electrical parameters. Project Types are defined at project level and they can be used only in the project for which they were created. In this example, a Global Type will be used.

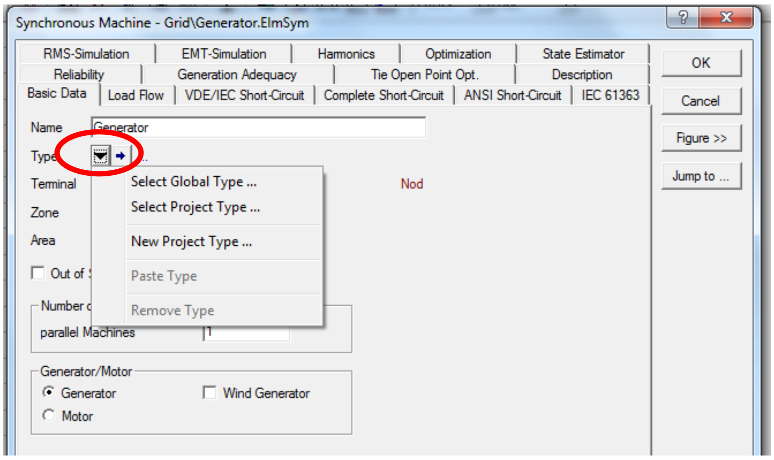



**Fig. 19** - Type association procedure for Synchronous Machines (PV buses)

Selecting a Global Type, as in Fig. 20, a type browser opens up and the user must choose the appropriate type. Because 20MW of active power are required, the **50 MVA ST** type is chosen.

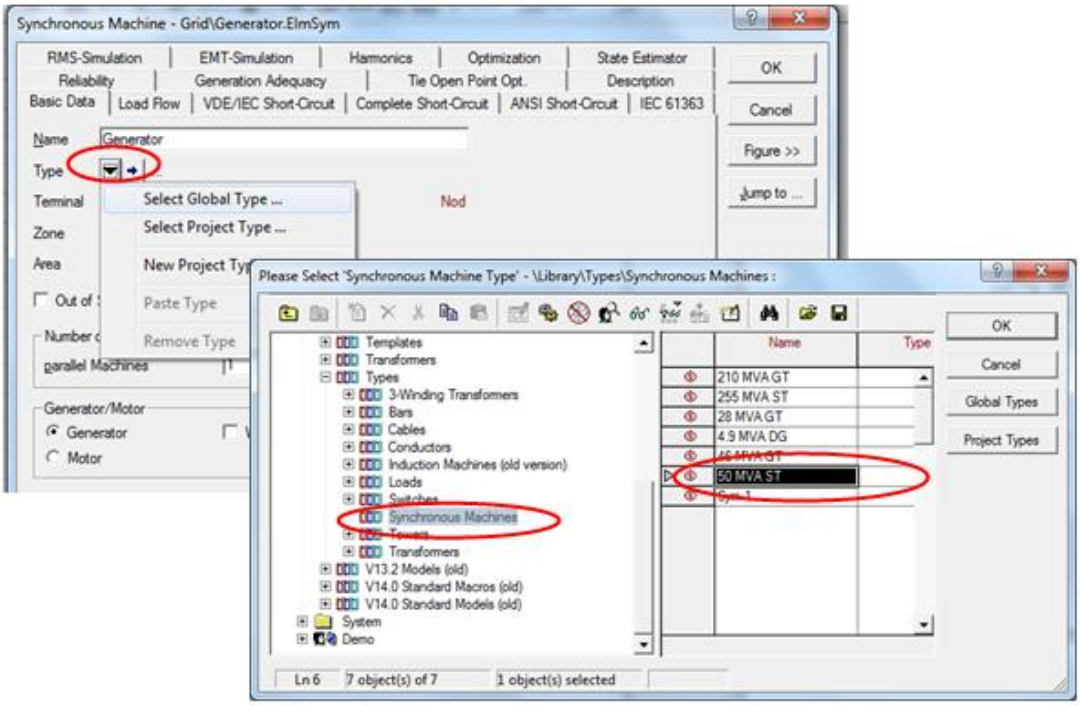



**Fig. 20 -** Choosing a Global Type for a Synchronous Machine.

The predefined parameters associated to this type can be visualized by clicking on the right-oriented blue arrow button near the type label, as seen in Fig. 21.

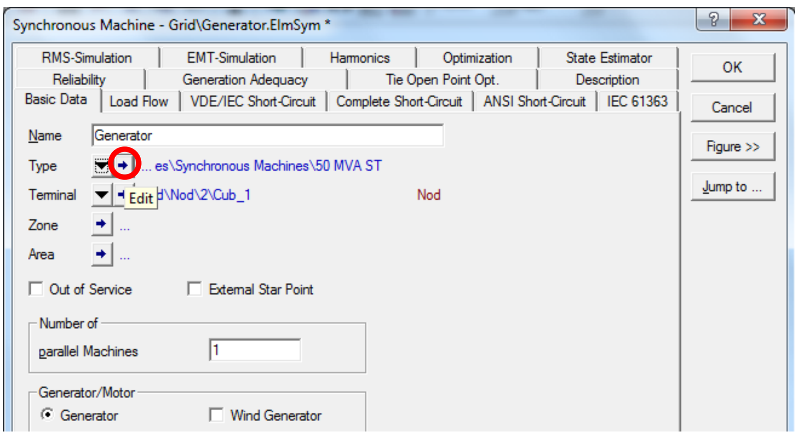



**Fig. 21 -** Visualization of element type parameters

When clicking on this button, the type properties window is displayed (Fig. 22). The chosen Synchronous Machine has a nominal apparent power of 50,34 MVA and works at a nominal voltage of 10,5 kV. In the Load Flow tab of the properties window, the maximum and minimum reactive power limits can be defined, but they are overridden by the actual machine settings if the user does not explicitly choose later to use the parameters defined in the type by ticking the corresponding box in the element properties, as shown in Fig. 23..

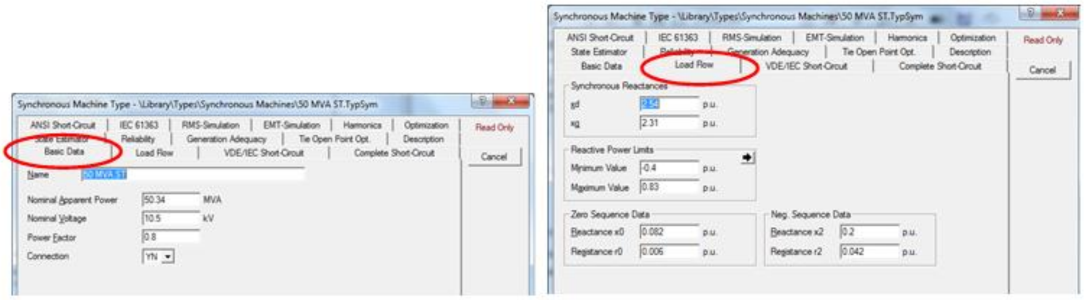
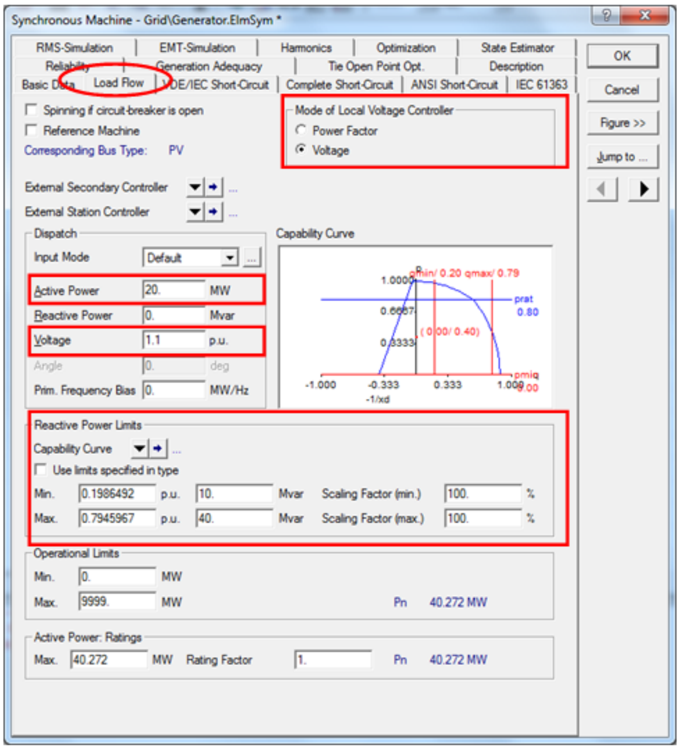


**Fig. 22 -** Visualization of element type parameters

Finally, in order to use the Synchronous Machine as a PV bus, going back to the element properties window from Fig. 21, the following settings must be made in its Load Flow tab (Fig. 23):



- set the mode of **Local Voltage Controller** to **Voltage**
- provide the value of the **Active Power** generated
- set the level of the bus **Voltage**, in p.u. as done previously for the slack bus
- provide the **Reactive Power Limits**

**Fig. 23 -** Setting a Synchronous Machine as a PV bus

All other available parameters can be ignored if their true values are not available.

**4. Loads**

The electricity consumption in an electrical system is known as load. In transmission systems, a bus load is usually the power flow through the HV/MV or HV/HV transformer through which the MV or HV distribution system below is supplied. These aren't usually individual consumers, but complex loads, made from the aggregation of many smaller consumers which demand power simultaneously. The buses where loads are connected and no voltage regulation is provided are called PQ buses. Their active (P) and reactive (Q) load is known, and load flow algorithms compute their voltage, in magnitude and angle.

In DIGSI-PF, loads are represented graphically as in Fig. 24 and can be defined in two ways:

- as constant active and reactive power values
- as profiles variable over time

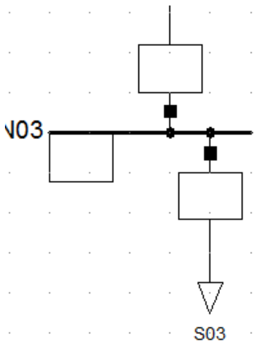



**Fig. 24 -** The graphic representation of a load in DIGSI-PF

Figure 25 shows the procedure of defining a 17 MW/8 Mvar constant load.

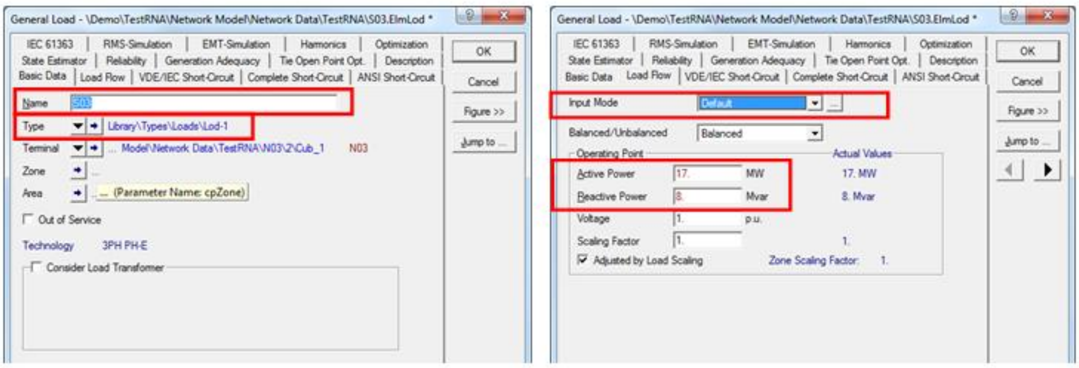


**Fig. 25 -** Load parameters

Again, both **Basic Data** and **Load Flow** properties tabs are used. The load **Name** nad **Type** are not mandatory. The default **Input Mode** is using the **Active Power** and **Reactive Power** numerical fields. Loads can also be defined as currents or impedance. In transmission systems, loads are considered balanced. In unbalanced loads are defined, then the Active and Reactive Power values must be specified for each phase.

### 5. Lines

Electrical lines are the pathways on which electricity flows from the generators to the consumers. In DIGSI-PF, lines are represented as in Fig. 26.

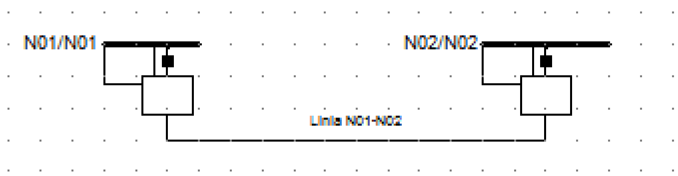



**Fig. 26** - The graphic representation of an electrical line in DIGSI-PF

By default, DIGSI-PF does not allow the drawing of diagonal lines, all turns being square, as in Fig. 26. This behaviour can be changed by repeatedly double-clicking in the program status bar on the **Ortho** field, until the setting changes to **Ortho Off** (Fig. 27).

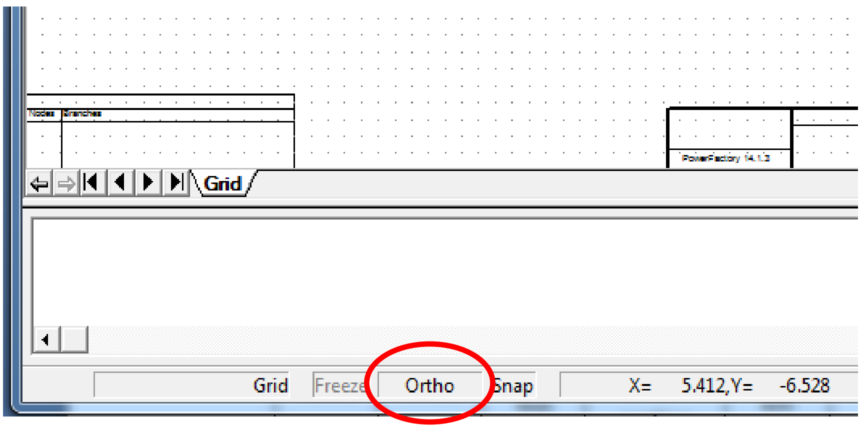



**Fig. 27** - The change of the orthogonal drawing setting

For defining lines, the following parameters must be provided:

In the element properties window (Fig. 28):

- **Name** (of free choice)

- **Type**. The type contains the electrical parameters of the elemental 1 km length line.
- **Number of parallel lines**
- **Length of line,** in kilometers
- **Laying** (Ground/Overhead) for specifying aereal or underground lines
- **Line model** - the mathematical line model used in the simulation
- The user can also specify an **Out of service** status, by ticking the appropriate checkbox.

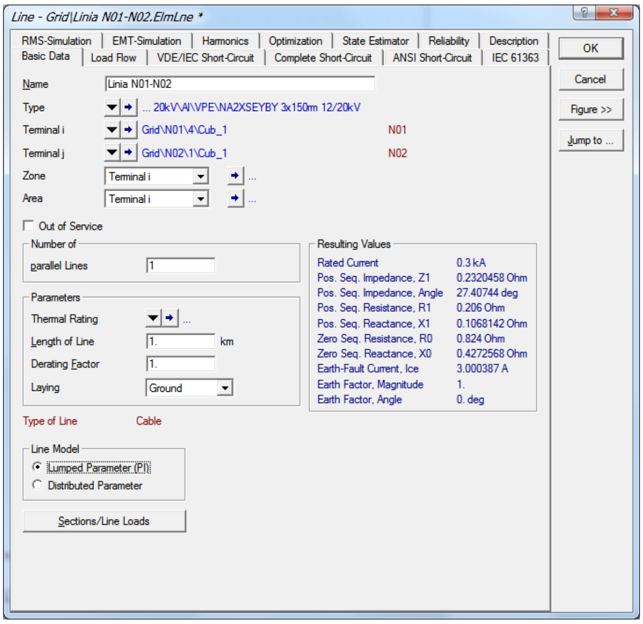



**Fig. 28 -** Line element parameters setting in DIGSI-PF

In the type properties window (Fig. 29):

- **Type Name**, optional
- **Rated Voltage**
- **Rated Current** - optional, for computing the line loading
- **Nominal Frequency**: same as the one defined for the Grid
- **Cable/OHL**
- **System type** (AC for Alternating Current), number of **Phases** and **Neutrals**
- Electrical parameters per kilometre: **Resistance R', Reactance X', Susceptance B'**. The Zero sequence parameters denoted with R0', X0' and B0' are necessary only if short circuit calculations are to be made.

The values R, X, B, electrical parameters are usually found in producer catalogues and are dependent on:

- wire material (aluminum, steel, copper)
- wire cross-section
- type of pole for OHL or insulation for cable lines

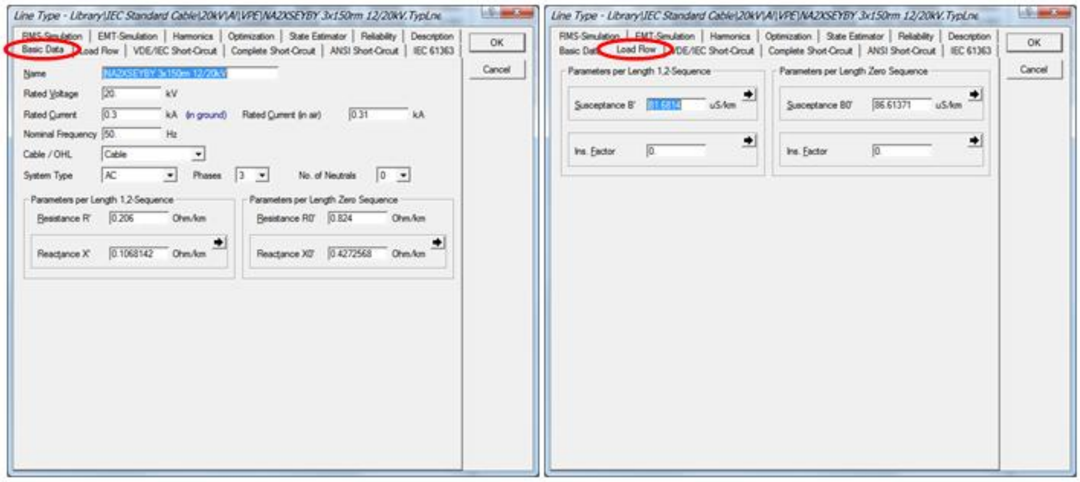


**Fig. 29** - Type parameters setting for lines in DIGSI-PF

Types are useful in DIGSI-PF because the same electrical parameters can be reused for more than one equipment, simplifying the task of defining the input data in a project. For instance, lines with different number of circuits per pole or different lengths, but using the same pole dimensions and wire cross-section, can be defined using the same line type, global or defined by the user.

## 6. Transformers

Transformers are used to change voltage levels across a power system. High voltages are needed for long distance transmission of electricity, while the consumer needs power at low voltage.

In DIGSI PF, 2 Winding Transformers, , 3-Winding Transformers and Auto Transformers can be defined.

A typical 2-Winding Transformer is depicted in Fig. 30.

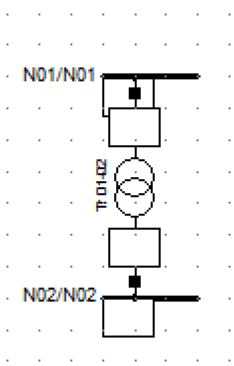



**Fig. 30 -** A 2-Winding Transformer in DIGSI-PF

The definition of a type is mandatory for transformers. Foe 2-winding transformers, the parameters required for a load flow calculation are:

in the element properties window (Fig. 31):

- **Name** (of free choice)
- **Type**
- **Tap position**
- **Automatic tap change**, only if it is desirable

All other parameters in the main properties window are to be changed only if precise information is available.

in the type window

- **Name**, of free choice
- **Technology** (usually 3-phase)
- **Rated Power**
- **Nominal frequency**
- **Rated Voltage** on HV and LV side
- **Vector group** and **phase shift**
- **Short Circuit Voltage**
- **Copper Losses**
- **No Load Current**
- **No Load Losses**
- **Tap Changer** settings

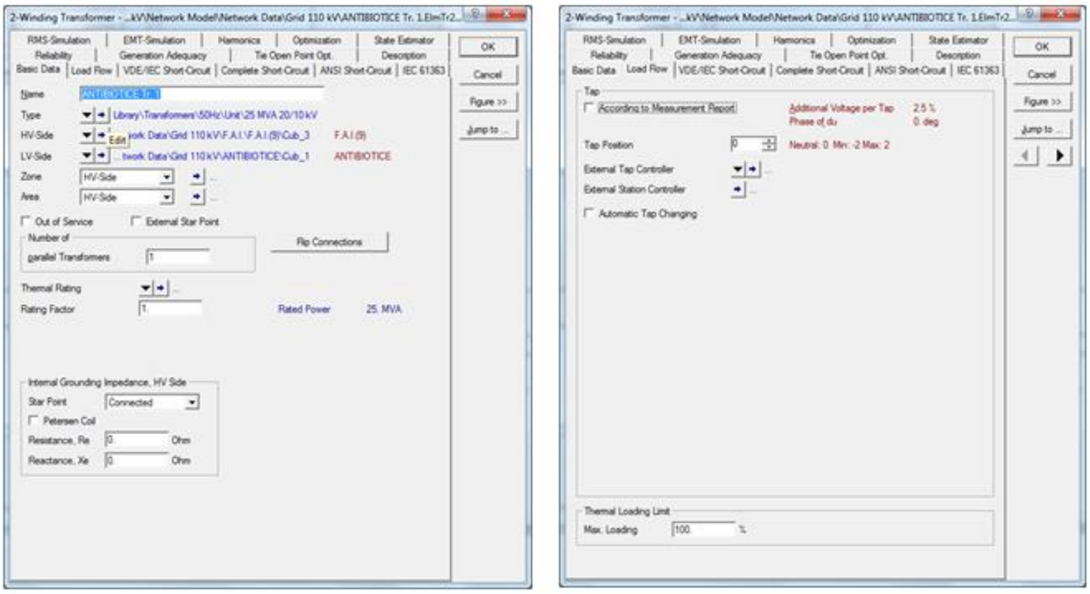



**Fig. 31 -** 2-Winding Transformer element parameters setting in DIGSI-PF

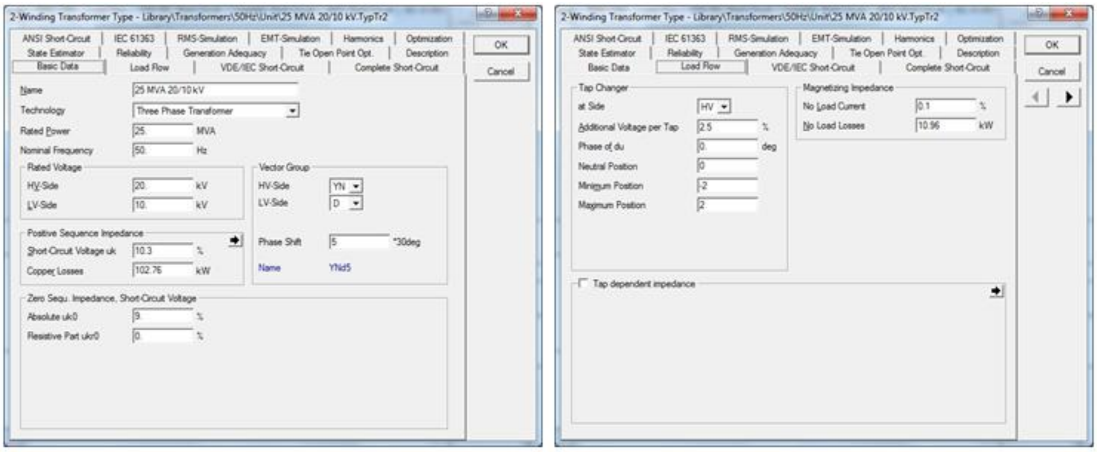


**Fig. 32 -** 2-Winding Transformer type parameters setting in DIGSI-PF

For all network elements described above, it is possible to enter or change data in two ways. The most common is the use of properties windows, described above. However, DIGSI-PF allows the use of Excel-like spreadsheets, in which data can be copied, pasted and deleted from table cells. This feature is activated when clicking on the **Edit Objects Relevant for Calculation** button from the toolbar (Fig. 33).

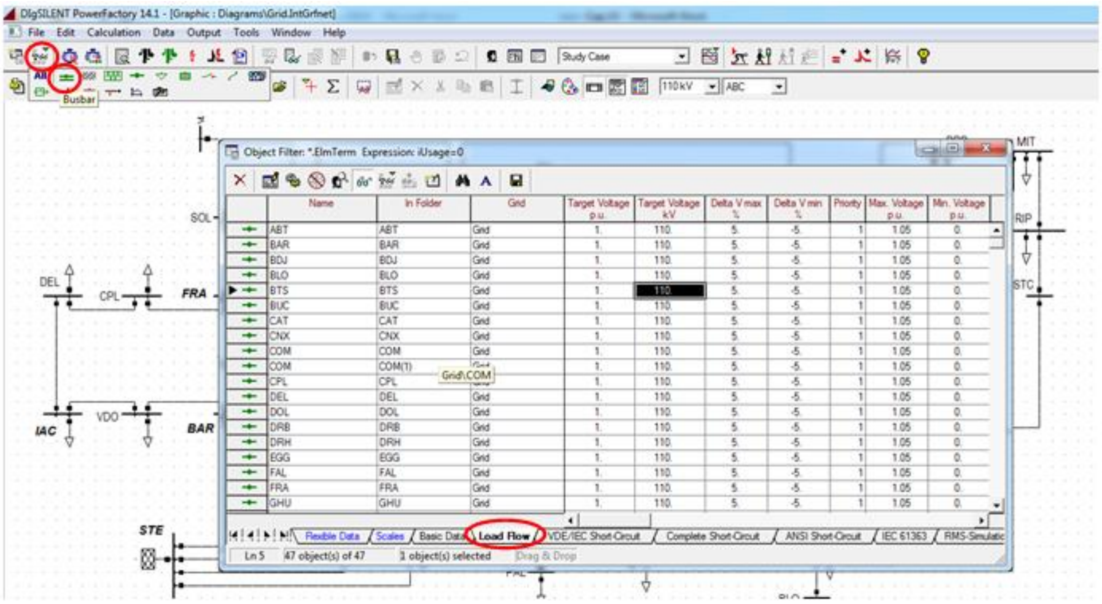


**Fig. 33 -** Changing data and accessing results in tabular form

From here, input data and results can be accessed grouped on element categories (buses, branches etc). Green icons represent actual elements. Purple icons represent types of elements. By clicking on an element or an element type icon, all elements associated to that icon are displayed in a table which uses Excel-like sheets reproduce the tabs from element dialog windows (**Basic Data**, **Load Flow** and so on). Calculus results are stored in the first tab, marked with a blue colour, **Flexible Data**.

In these sheets, editable fields use the black colour, non-editable fields are written in grey, while results are provided in green colour.

### Assignment

Build in DIGSI-PF the small system from Fig. 34. Use the branch and bus data from Tables 1 and 2

**Table 1 –** Branch data for the assignment electrical system in Fig. 33

| Name | IN bus | OUT bus | Conductor cross-section | Length km | |
|---|---|---|---|---|---|
| L01-02 | N01 | N02 | 150 mm$^2$ | 20 | $R_0$=0.198 Ω/km<br>$X_0$=0.433 Ω/km<br>$B_0$=2.66 μS/km |
| L01-04 | N01 | N04 | 150 mm$^2$ | 40 | |
| L02-03 | N02 | N03 | 150 mm$^2$ | 60 | |
| L02-05 | N02 | N05 | 150 mm$^2$ | 40 | |
| L04-05 | N04 | N05 | 150 mm$^2$ | 20 | |

**Table 2 –** Bus data for the system in Fig. 33

| Bus | Bus type | Nominal voltage kV | Pi MW | Qi Mvar |
|---|---|---|---|---|
| N01 | slack | 110 | | |
| N02 | PQ | 110 | 17 | 3 |
| N03 | PQ | 110 | 12 | 1 |
| N04 | PQ | 110 | 8 | 1 |
| N05 | PQ | 110 | 8 | 1 |

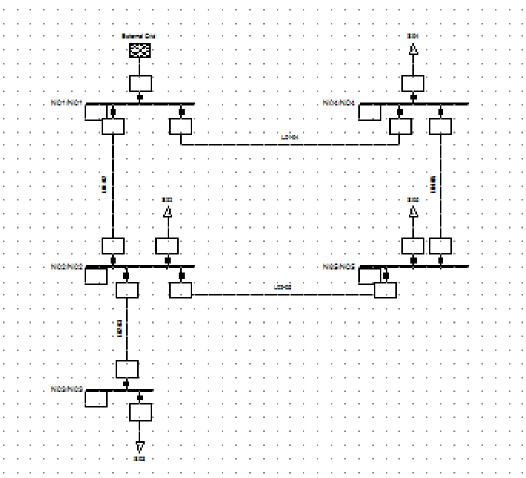


**Fig. 34 -** Assignment electrical system one/line diagram

*2. Building of the bus admittance matrix [$\underline{Y}_n$]*

Matrix [$\underline{Y}_n$] cannot be visualized in DIGSI-PF. However, other applications, such as the Power World simulator allow the access for visualization for this matrix.

### *3. The load flow computation and auxiliary results*

DIGSI-PF computes all auxiliary results such as branch power flows or branch loadings simultaneously with the main state variables, which are bus voltages in magnitude and angle.

There are two ways of visualising results: directly on the one-line diagram an by using the tabular window described above.

Results can be visualized only after executing a load flow calculation, which is done either by clicking on the  button on the toolbar or by accessing the Load Flow option from the **Calculation** menu (Fig. 35).

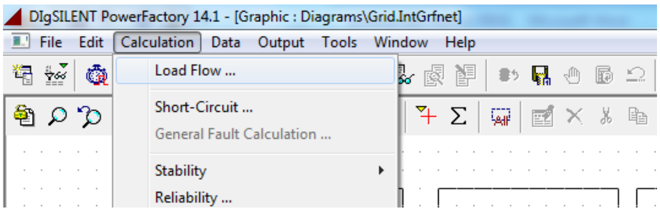



**Fig. 35 -** Running a load flow calculation in DIGSI-PF

In the load flow options window (Fig. 36), for a simple calculation usually it is not necessary to change the default options before pressing the **Execute** button. Only if there are PV buses defined, the **Consider reactive power limits** box should be checked, otherwise the Q limits defined for PV buses will be ignored.

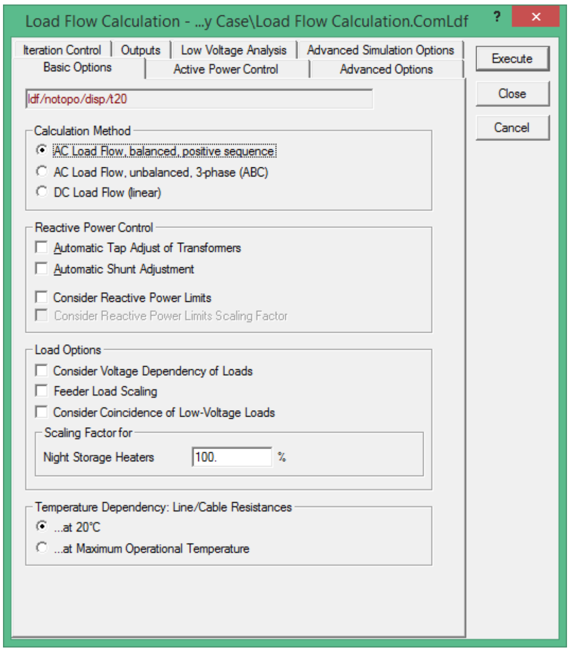



**Fig. 36 -** The load flow options window

On the one-line diagram, results are visible on the boxes placed on each element (Fig. 37). In tabular form, results are viewed for each element category in the **Flexible Data** tab, as mentioned above (Fig. 38).

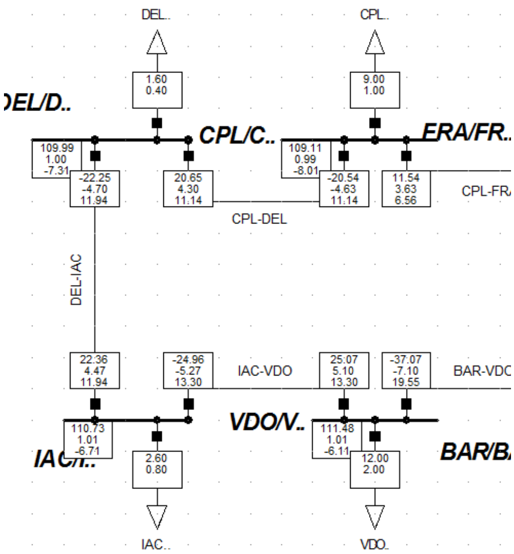
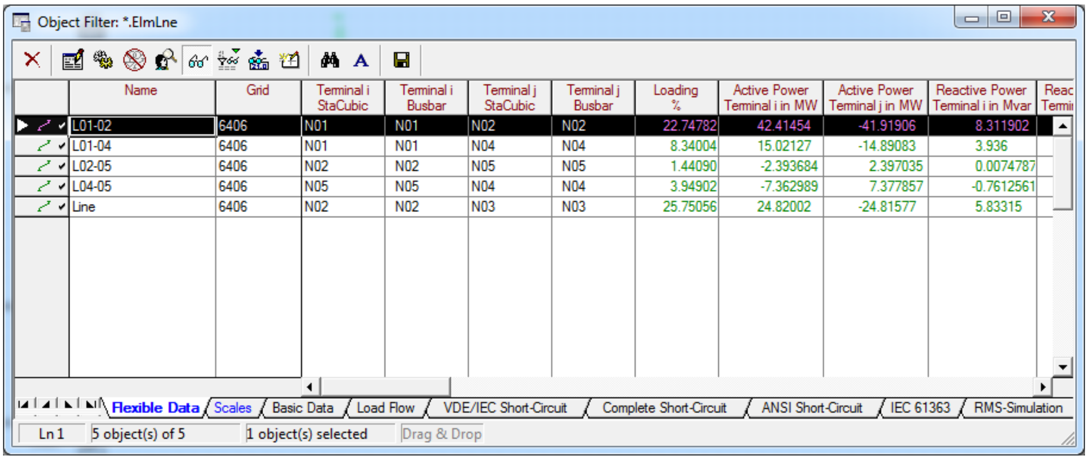



**Fig. 37 -** Results viewing on the one-line diagram



Object Filter: *.ElmLne

| Name | Grid | Terminal i StaCubic | Terminal i Busbar | Terminal j StaCubic | Terminal j Busbar | Loading % | Active Power Terminal i in MW | Active Power Terminal j in MW | Reactive Power Terminal i in Mvar |
|---|---|---|---|---|---|---|---|---|---|
| L01-02 | 6406 | N01 | N01 | N02 | N02 | 22.74782 | 42.41454 | -41.91906 | 8.311902 |
| L01-04 | 6406 | N01 | N01 | N04 | N04 | 8.34004 | 15.02127 | -14.89083 | 3.936 |
| L02-05 | 6406 | N02 | N02 | N05 | N05 | 1.44090 | -2.393684 | 2.397035 | 0.0074787 |
| L04-05 | 6406 | N05 | N05 | N04 | N04 | 3.94902 | -7.362989 | 7.377857 | -0.7612561 |
| Line | 6406 | N02 | N02 | N03 | N03 | 25.75056 | 24.82002 | -24.81577 | 5.83315 |

Flexible Data / Scales / Basic Data / Load Flow / VDE/IEC Short-Circuit / Complete Short-Circuit / ANSI Short-Circuit / IEC 61363 / RMS-Simulation

Ln 1 | 5 object(s) of 5 | 1 object(s) selected | Drag & Drop

**Fig. 38 -** Results viewing on tables

Results can be saved in tab-delimited text files by selecting them as in Excel, right-clicking and choosing from the context menu the **Write to File** item from the **Spread Sheet format** option (Fig. 39). Alternatively, data can be copied on the Windows clipboard by choosing the **Copy (with column headers)** option, which enables pasting in Excel or test files. Data is pasted together with column headers (Fig. 40).

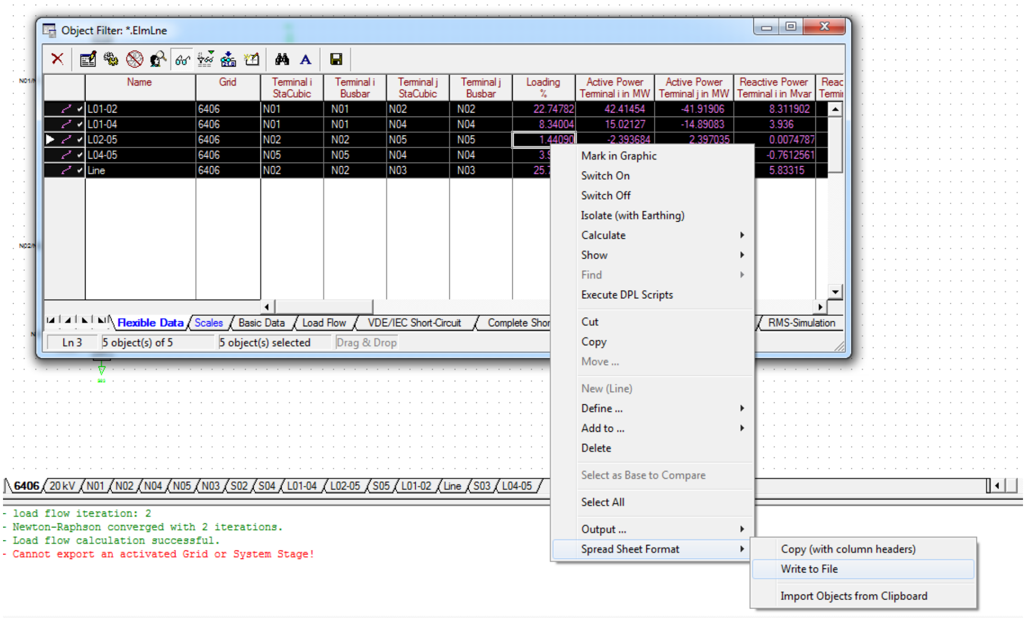


**Fig. 39 -** Exporting results from DIGSI-PF

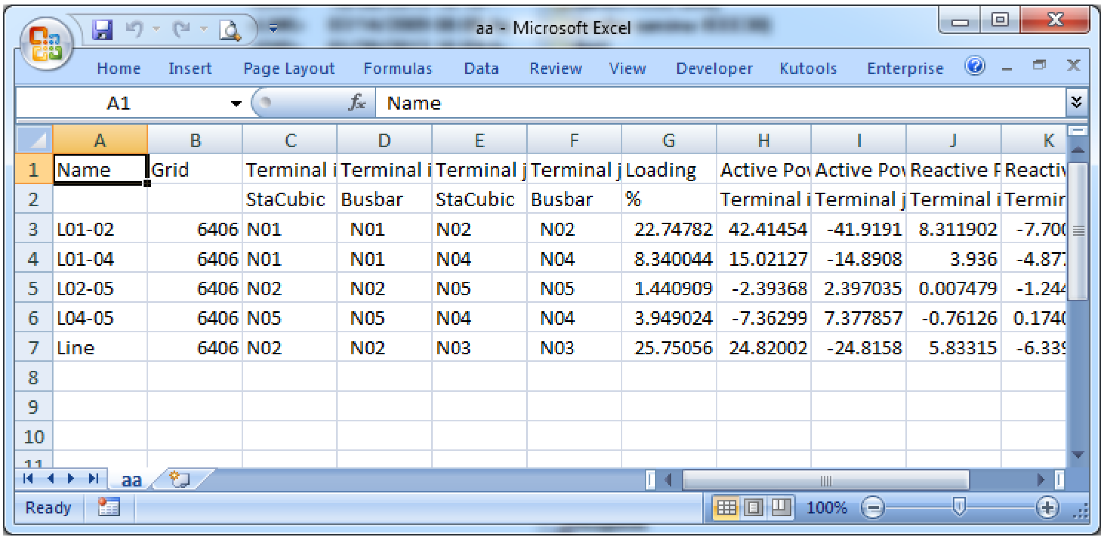


**Fig. 40 -** Example of data exported from DIGSI-PF

By default, DIGSI-PF does not display all computed variables. For instance, when performing load flow calculations, branch power flows and losses are not displayed when DIGSI-PF uses its initial settings. However, the user can choose what data to visualise and export by customizing the result tables. This is done by right-clicking on the Flexible Data sheet title and choosing the **Define Flexible Data** option. Alternatively, the **Define Flexible Data** button from the table toolbar can be used (Fig. 41).

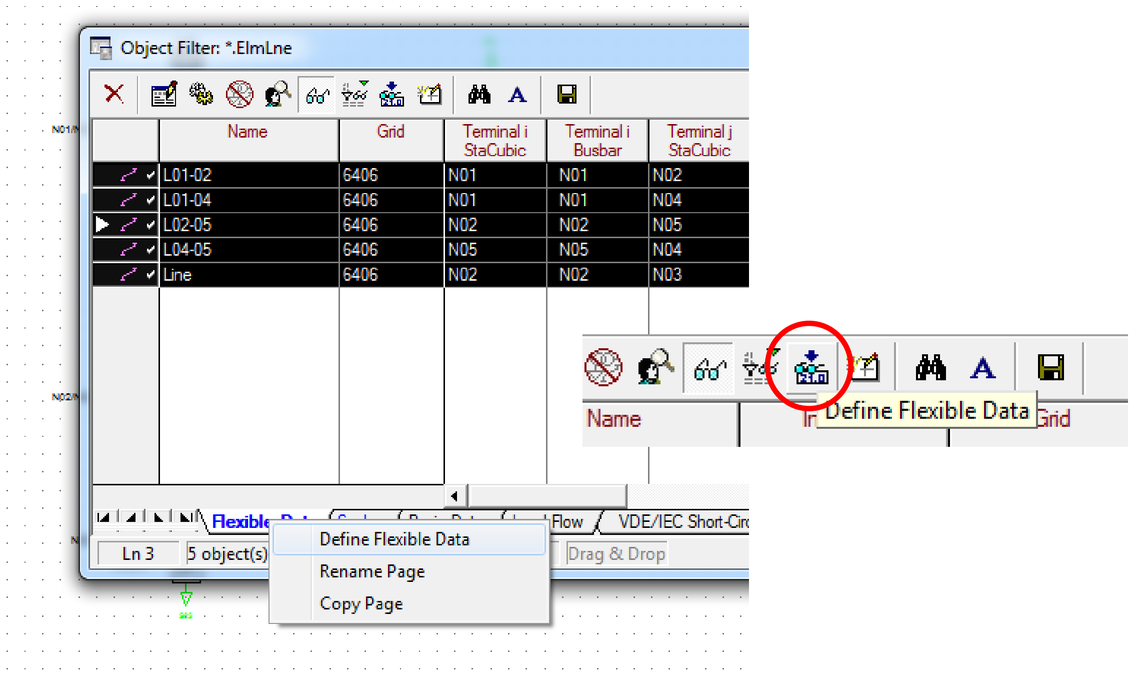



**Fig. 41 -** Customizing the results in the Flexible Data tab

Using the predefined **Variable Set** options and the >> and << buttons, the user can make his custom selection of variables to be displayed as results (**Selected Variables**). In Figures 42 and 43, for branches, the active and reactive power flows at each end and active power losses are chosen: P:bus1, P:bus2, Q:bus1, Q:bus2, Ploss:bus1.

Results can be sorted by clicking on each column head, in ascending or descending order.

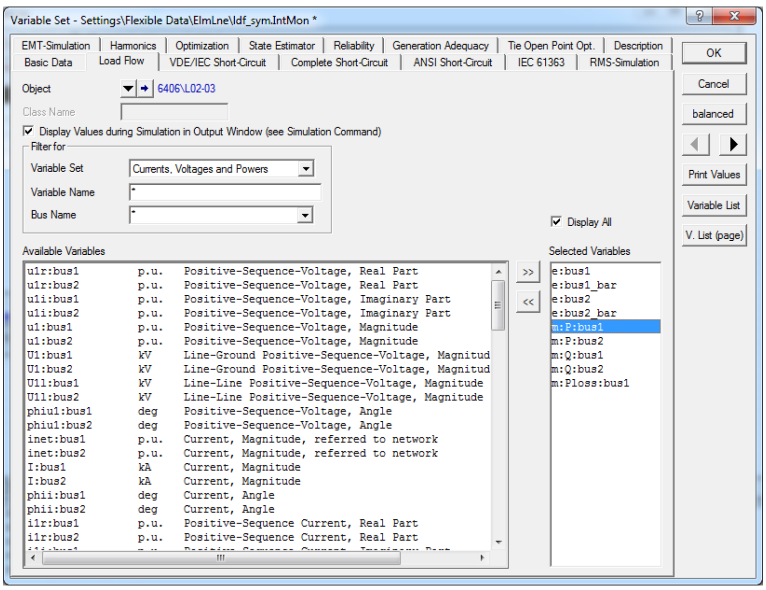



**Fig. 42 -** Choosing the variables to be displayed

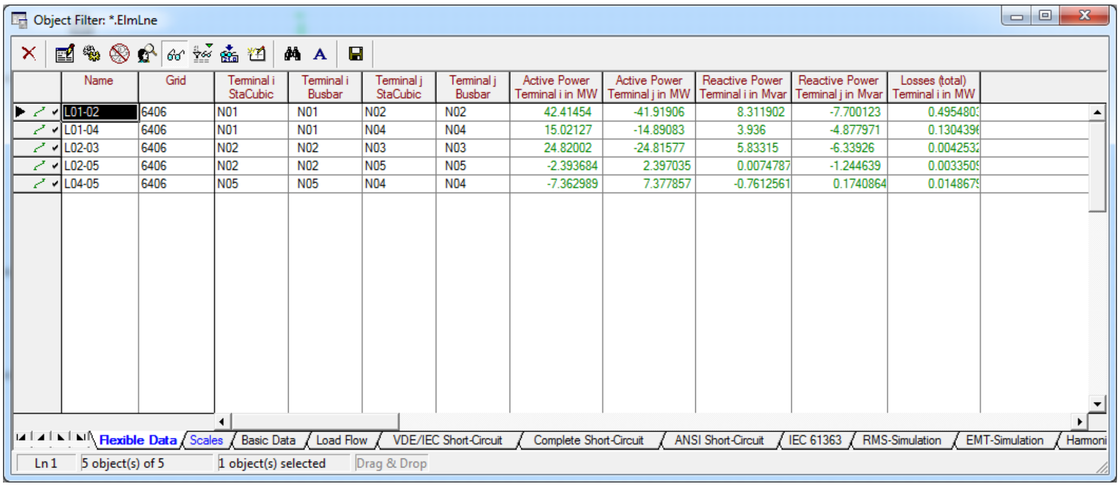


**Fig. 43 -** Displaying custom results for lines

Changes made to projects and their one-line diagram are saved automatically in the program's internal database in real time, without the user's intervention. Existing projects are opened or activated by using the **Activate Project** option from the **File** menu (Fig. 44). Then, the user can choose his desired project and click **OK**.

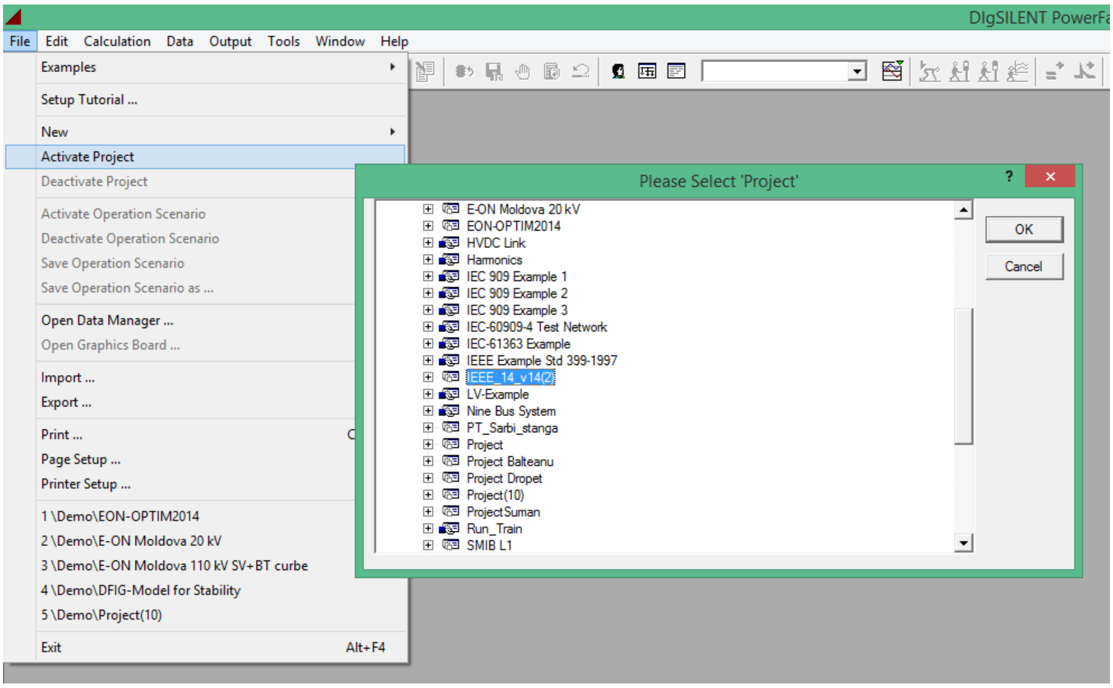


**Fig. 44 -** Opening an existing project

A project can be deleted from the database by right-clicking its name on the list and choose the **Delete** option.

Projects can be imported from other computers or exported by using The **Import...** and **Export...** options from the **File** menu (Fig. 44). Projects can be imported or exported only when no projects are activated.

When exporting in the default data format (Fig. 45). DIGSI-PF creates a standalone file with the **.pfd** extension, in which the one-line diagrams, the element parameters, project defined types and other user options are saved an can be imported later.

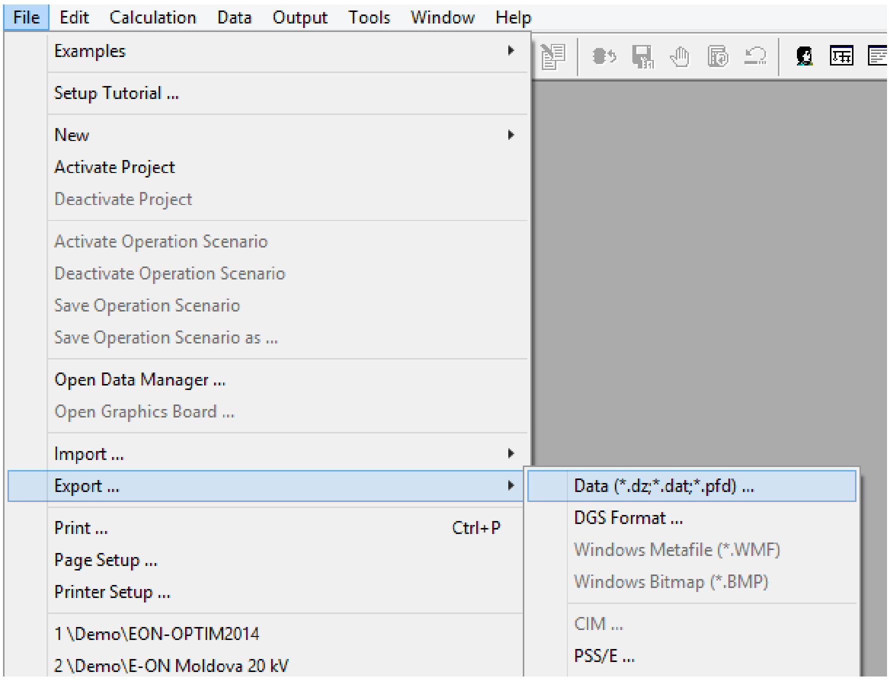



**Fig. 45 -** Exporting projects in DIGSI-PF