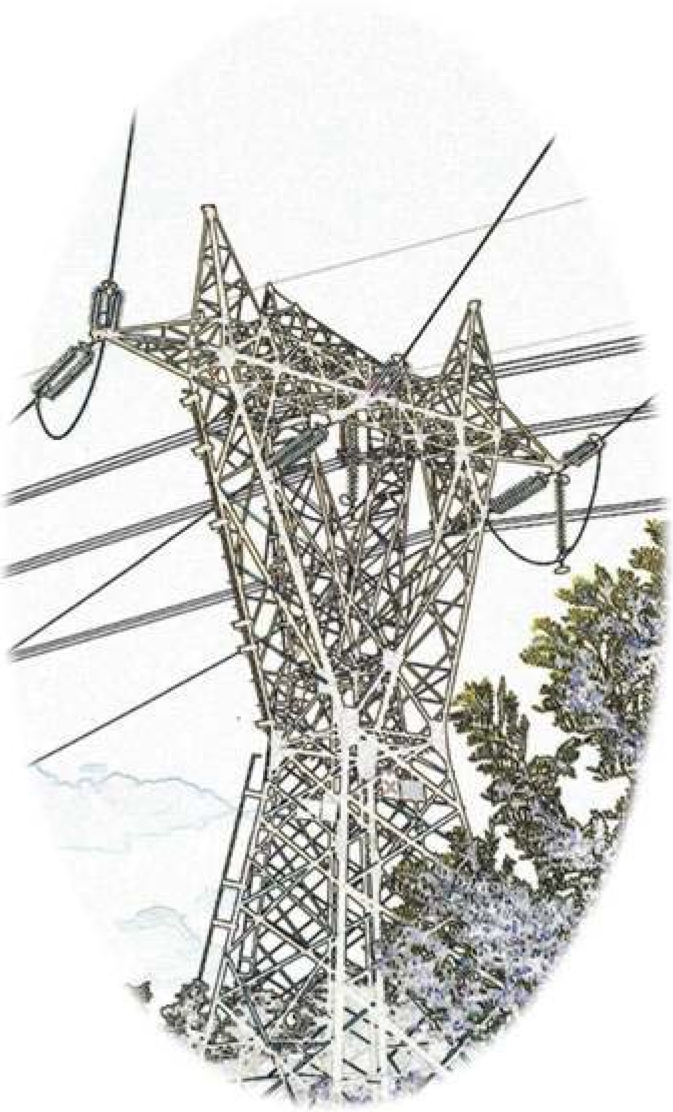
PHIDEL 3.31

REFERENCE MANUAL



http://www.phidel.it

R. 3

CONTENTS INDEX

I. GENERAL INFORMATIONS

1.1 – What is Phidel®?

Phidel® is a software which calculates the RMS induction magnetic field generated by power lines. It is based on an algorithm, well described in Chapter III, which implements the Biot-Savart law.

The field can be evaluated in points, paths and rectangular plane surfaces oriented in the space as specified by the user, or considering the terrain orography and setting the height on the ground, or in the grid points of a parallelepiped oriented as the reference frame axes. The calculation can be executed considering simultaneously aereal and underground power lines.

It is possible to determine the respect bands (Italian DPCM of July 2003, 8th) for the spans, at various heights or projected to ground level, and individuating the intersections of the desired field values volumes with buildings, by overlaying the outputs to the digital maps.

Some approximations are introduced:

- span approximated by a broken line done by a finite number of determined length segments;
- calculation not done in points closer than 5 cm from the segments approximating the catenary. This does not stop the execution and it is rilevable visualizing the output in GIS environment.

1.2 - Licence

The user, installing, copying, downloading, visualizing or otherwise using Phidel®, accepts the conditions in the present Contract.

Phidel® is protected by copyright international laws and treats, and by intellectual property laws and treats. Phidel®is licenced, not sold. It is forbidden to reproduce or distribute the Software, the Documentation, or a part of them.

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Moreno Comelli (the AUTHOR) guarantees a non exclusive and non trasferible licence to use Phidel (the SOFTWARE) and the enclosed documentation (the DOCUMENTATION) on the systems the user owns and exclusively controls, in compliance with this licence contract.

It is forbidden:

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2. decodifying, decompiling or disassemblying the SOFTWARE;
3. distributing, renting or transferring in every other way, all or part of the SOFTWARE or of DOCUMENTATION to third parts without the AUTHOR's agreement;
4. removing, alterating o obscuring every note about the property from the SOFTWARE or the DOCUMENTATION;
5. modifyiing, translating, renting, conceding in licence, adapting or creating derivates based on the SOFTWARE or the DOCUMENTATION;
6. using any software or hardware to remove or disable the SOFTWARE protection;
7. exporting the SOFTWARE or DOCUMENTATION violating the existing CE laws.

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The AUTHOR does not furnish any explicit or implicit guarantee the SOFTWARE satisfies to determinate characteristics, it doesn't contain any mistake and it works unintermittently.

The AUTHOR cannot be retained responsible in every way for the output obtained from the SOFTWARE usage. Who uses the SOFTWARE is responsable of supervision, administration and control of the SOFTWARE itself.

In no case the AUTHOR can be retained responsible for every loss, damage of every nature including losses of data, earnings and services, costs to cover the consequences of every incident caused, directly or indirectly, by a proper or improper SOFTWARE or DOCUMENTATION use. Such limitations to the product utilization are still valid in the case the AUTHOR has been informed on those losses or damages.

Accepting the present contract, the user accepts all the risks connected to the SOFTWARE and DOCUMENTATION use.

II. INSTALLATION

2.1 – Preliminary operations

The software setup is made with the USB key disconnected.
Inserting the CD-ROM, use the StartUp program window to install all needed components.

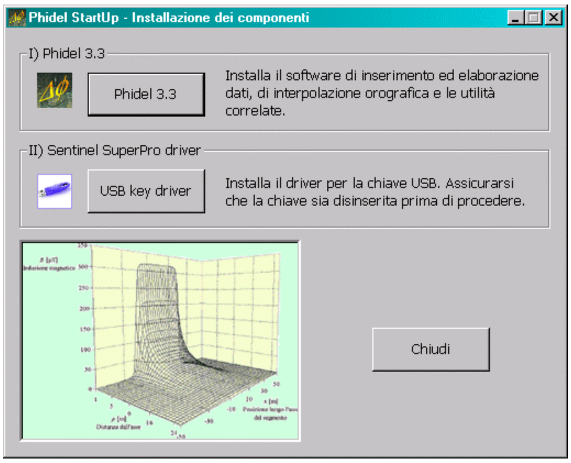


Figure 2.1 – Startup window.

Follow the instruction of setup programs:

1. install Phidel®, the utilities and all the libraries (Figure 2.2). To start it, double-click on the *Phidel 3.31* icon on the desktop;
2. install the USB key driver USB (Figure 2.3), which is still disconnected.

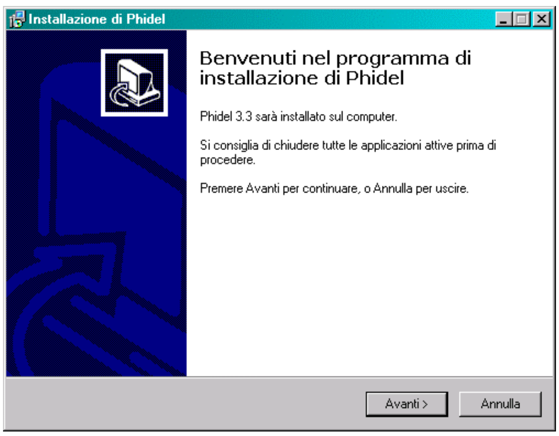


Figure 2.2 – Phidel setup.

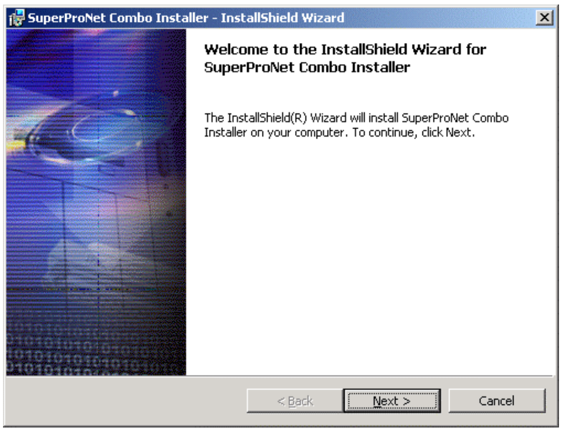


Figure 2.3 – USB key driver setup.

2.2 – Hardware key

The software has a hardware protection, a USB key (Figure 2.4), requred to start Phidel®. **The computer could need several seconds to recognize the hardware key**.

Figure 2.4 – The USB key.

In absence of insertion, or in case of disconnection during the software execution, you see an error message, and the program execution is stopped.

2.3 - Hardware and software requirements

The requirements to install and use Phidel® are:

- CD-ROM drive;
- USB port;
- 40 MB free space on disk;
- Video resolution 1024 x 768 pixel.

The system including Phidel® software, the setup programs and the accessory components has been tested on the OS Windows 95 and following.

To correctly execute the software and the utilities, select the point "." as decimal separator in international settings.

III. THE CALCULATION ALGORITHM

3.1 – Definition of the problem

The Root Mean Square (RMS) magnetic induction field generated by power lines is determined discretizing the problem: each span is divided into fixed lenght segments, and the magnetic induction vectors produced by each segment are then summed.

3.2 – Caracterization of the geometry of the system

3.2.1 Determination of the minimum of the span

The curve a hanging flexible wire assumes when supported at its ends is called catenary, and it is analytically represented by an hyperbolic cosine function:

$$z(x) = b + a\cosh\left(\frac{x - x_0}{a}\right)$$

Its form depends on a parameter (in the following indicated by a) defined as ratio between tension and linear weight. x_0 indicates the curve vertex coordinate, while the parameter b determinates the elevation.

When the coordinates of the suspension points, $(0, z_1)$ and (L, z_2) (see Figure 3.1, on the left), and the constant a are known, x_0 is analytically determined.

3.2.2 Coordinates of the extrems of the segments

When the curve is defined, the coordinates of the extremes of every segment approximating the catenary are shown in Figure 3.1 (on the right). The span of length L is divided into segments having projection l on the ground.

X_0, Y_0 and Z_0 are the coordinates of the first suspension point:

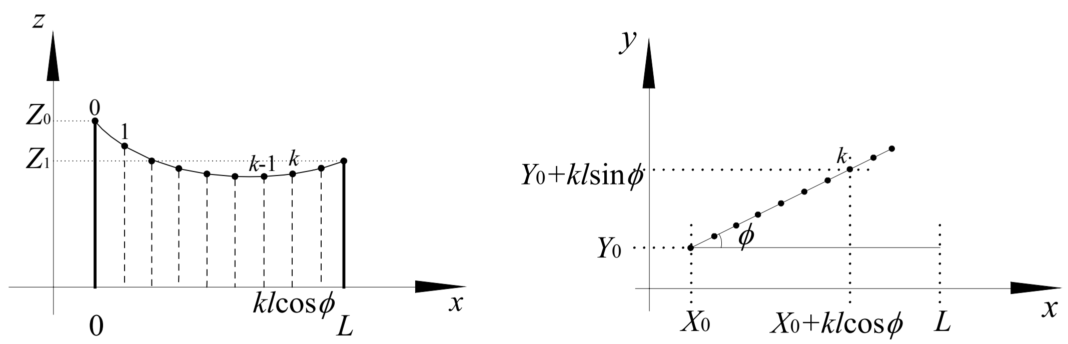


Figure 3.1 - Individuating the k^{th} segment on the span of length L (on the left) and determining the coordinates of the extremes of the segments having length l as projection on the xy plane (on the right).

while the pylon straddles are oriented accordingly the bisector the angle individuated by the previous and following spans, but a different choice by the user is possible (see section 4.5).

3.3 - Field generated by a current-carrying segment

To calculate the induction magnetic field generated by a current-carrying segment, the Biot-Savart law is applied:

$$\vec{B}(\vec{r}) = \frac{\mu_0}{4\pi}\int_C \frac{I(\vec{r}\,')d\vec{l} \times \vec{R}}{R^3}$$

where $\vec{R} = \vec{r} - \vec{r}\,'$ is the shift vector from the point $\vec{r}\,'$, in which the wire element $d\vec{l}$ carrying a current $I(\vec{r}\,')$ stands, to the point $\vec{r}$ where the field is calculated.

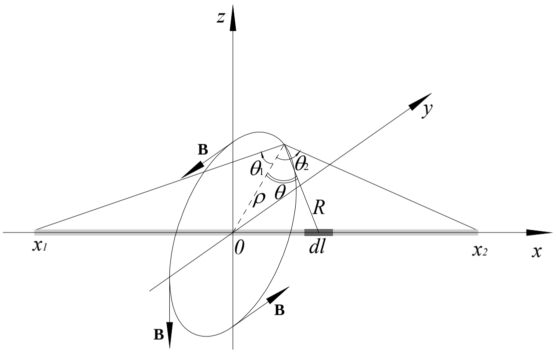


Figure 3.2 - Determinazione del campo nel piano *yz*.

Considering the case of a straight finite wire oriented along the x axis, the field produced by the current element $Id\vec{l} = Idx'\mathbf{i}$ is given by:

$$d\vec{B} = \frac{\mu_0 I dx'}{4\pi R^3}(y\mathbf{k} - z\mathbf{j})$$

where **i**, **j** and **k** are the versors referred to the Cartesian axes. Calling ρ the distance from the axis containing the wire and $\hat{\varepsilon}$ the field versor, we obtain:

$$d\vec{B} = \frac{\mu_0 I \rho dx'}{4\pi R^3}\hat{\varepsilon}$$

Using Figure 3.2 and integrating along the wire, we obtain:

$$\vec{B} = \frac{\mu_0 I}{4\pi}\eta\hat{\varepsilon}$$

where η is a geometric term.

This quantity, calculated in a particular case, is shown in Figure 3.3:

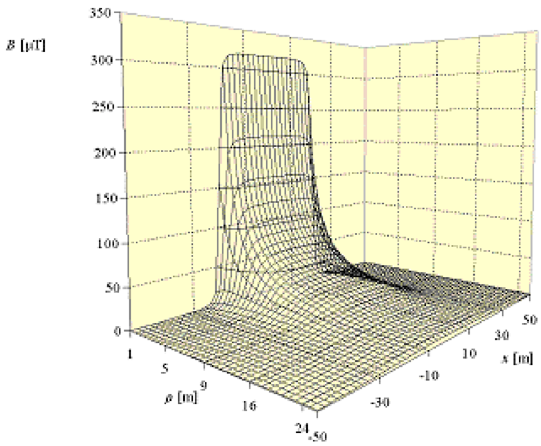


Figure 3.3 - Field generated by a 1600 A current-carrying segment in function of position.

3.4 - Root Mean Square Field calculation

In a sinusoidal alternate regime, as in the power line technology, the magnetic field amplitude changes cyclically with the same frequency of the generating current. In the case of many three phases power lines, the three spatial components of the field are not generally in phase among them, and the amplitude and direction of the resulting vector consequently change in the time.

Thus, the quantity needed, and given by the instruments, is the Root Mean Square (*RMS*) magnetic induction field, defined as:

$$B^{RMS} \equiv \sqrt{\frac{1}{T}\int_0^T B^2(t)dt}$$

Defining:

$$A_{ij} = \prod_{k=i,j} I_k^{eff} \eta_k \hat{\varepsilon}_k$$

and solving the integral under root square in (13), we finally obtain:

$$\boxed{B^{eff} = \frac{\mu_0}{4\pi}\sqrt{\sum_{i,j} A_{ij}\cos(\varphi_j - \varphi_i)}}$$

which represents the final equation for the *RMS* field employed in Phidel.

It is now possible to notice the dependence of the *RMS* magnetic induction on the term $\cos(\varphi_j - \varphi_i)$, depending on the relative phase among the conductors, and on the term A_{ij} depending on the currents and the system geometry.

IV. DATA INPUT

4.1 – The reference frame

The user defines the reference frame; it is possible to choose:

- a personilized reference frame, where the origin (0;0) of cartesian axes x and y is conveniently defined, and the coordinates of pylons and of sampling region are consequently defined;
- the use of Gauss-Boaga coordinate (or UTM, or else): the coordinates of every pylon (and of the sampling region) are directly determined from Numeric Technical Cartography in GIS environment.

4.2 – The sampling region

The sampling region is the volume where the magnetic induction fild has to be calculated. It is made by the points of a three-dimensional grid specified by user along the three axes directions. Such volume is not necessarily oriented as the axes of the chosen reference syframe, because the user can define (in the section *Plane Calculation*) an angle (called *phi*, which is the deviation from x axes), defining the orientation on the plane (the angle ϕ in Figure 4.1).

A further angle (called *psi*, which is the path inclination, ψ in Figure 4.1), is defined to evaluate field values on inclined planes. x' e y' indicate the transformed cartesian axes:

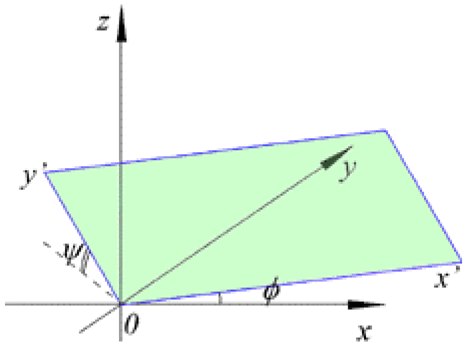


Figure 4.1 - Angles referred to an inclined calculation plane.

4.2.1 Aerial line reference frame

Figure 4.2 specifies the required quantities for an aerial power line. The base coordinates (*X*, *Y* and *Elevation*) are to be individuated for every pylon, accordingly to the chosen reference frame.

The values referred to the conductors are then specified: the catenary *Constant a [m]*, the *Height [m]* of struddle from the pylon base and the *Struddle [m]* amplitude.

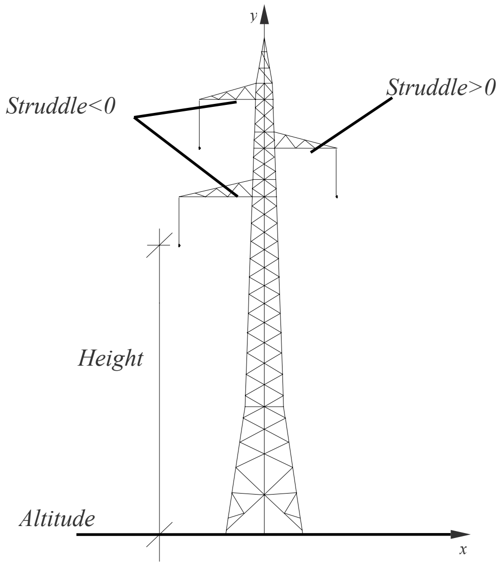


Figure 4.2 – Quantities relative to each pylon.

If the catenary constant value is not available, it is possible to calculate it using the geometrical data (see Paragraph 4.5).

The *Struddle* is positive or negative depending on the direction in the reference frame (see Paragraph 4.2.3).

4.2.2 Underground line reference frame

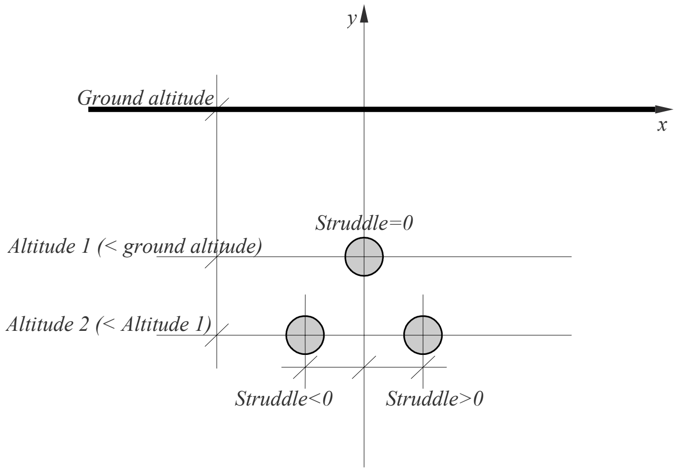


Figure 4.3 – Quantities relative to an underground power line.

The required data for underground lines are relative to coordinates and vertices (where direction changes took place).

For each wire the meanings of Height and Struddle are therefore the same of those specified in case o aereal lines, considering that Heights are usually negative.

See Figure 4.3: *Quote* is referred to superior wire, which Height is 0, while other wires have negative Heights and struddles signs depending on direction (see following paragraph).

4.2.3 Definition of struddles direction

The struddle direction must unumbiguously define the coordinates of suspension points of wires on pylons (these considerations are analogous for underground lines, with different terminology).

The cartesian plane defining the reference frame relative to considered pylon is divided into 4 quadrants, conventionally numbered as in Figure 4.4, having origin individuated by the pylon axis:

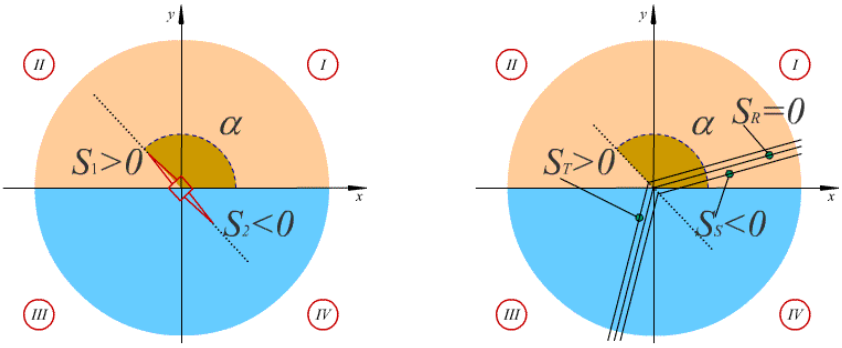


Figure 4.4 – Definition of the struddles sign for an aereal line (on the left) and underground (on the right).

Struddles are defined as positive in the superior half plane (I and II quadrant), negative in the inferior one (III and IV quadrants).

The only still undefined case is the one in which the pylon is parallel to the abscissae axis; in general, consider the relation:

$$Struddle \begin{cases} > 0 \text{ } when \text{ } \alpha \in [0;\pi[\\ < 0 \text{ } when \text{ } \alpha \in [\pi;2\pi[\end{cases}$$

where α is the angle between the struddle and the abscissae axis, as in Figure 4.4.

4.3 – Data input

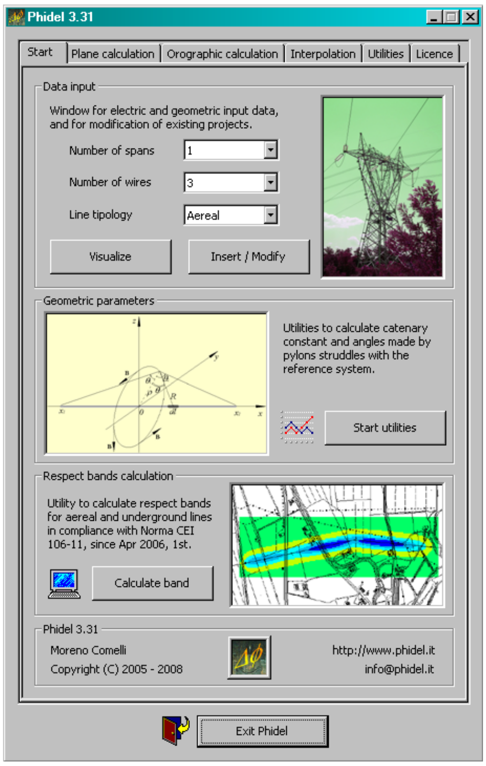


Figure 4.5 – Starting window in Phidel®.

When the program is started (see Figure 4.5), select the kind of line (*Aereal* or *Underground*), the number of spans (from 1 to 5) and wires (1, 3 or 6), and open the input data window clicking on the *Insert/Modify* botton. To calculate the field in case of lines with more pylons and/or wires, or for systems with several power lines, the user separately inserts each line (or section line) data, and at the end he unites them in an unique data file, as explained in Paragraph 5.5.

The functions the remaining parts of this window are concerned to will be later explained.

A typical example is shown here, considering a span of an aereal line with 3 wires.

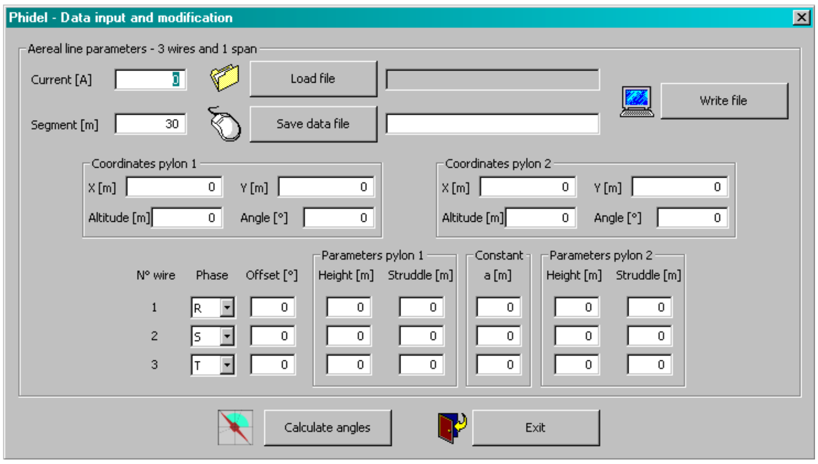


Figure 4.6 – Input data window for a span of an aereal line with 3 wires.

Insert data referring to the *Current [A]* , the length of th *Segment [m]* of the broken line (for aereal lines, only) approximating the catenary, path and name of the file where to save data.

For each wire it is necessary to specify the *Phase* (*R*, *S* or *T*) of voltage and the *Offset [°]* (positive, in degrees, schematized by ϕ_i angles in Figure 4.7) of the wire current respect to voltage.

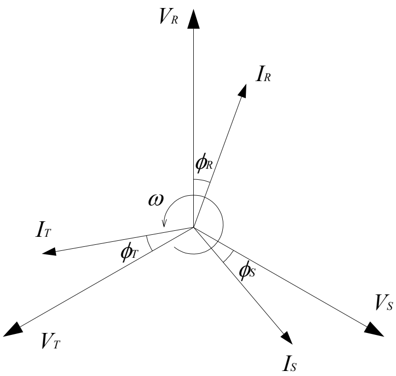


Figure 4.7 – Graphic representation of offsets in a three-phase system.

The offset is obtained by:

$$\phi = \arctan \frac{Q}{P}$$

where *P* and *Q* indicate respectively active and reactive power.

The user has then to specify the *Altitude* and the *Coordinates* for each pylon, and the angle of the struddles in the adopted reference frame, as in Figure 4.4 (for aereal lines, only).

It is then necessary to insert (refering to Figure 4.2 and Figure 4.3), for each pylon and wire the Height from the ground of the suspension point, the Struddle (the distance of the suspension point from the pylon axis) and the actenary constant for each span (for aereal lines, only).

At the end, clicking on *Write file*, data are saved in a *.phid file, which will be used in the elaboration.

This text file can be modified by user opening it by the same window, clicking the botton *Load file*.

When the struddles angles are unknown, it is possible to automatically fill the fields by clicking *Calculate angles*: the software determinates them using the bisector between the previous and following pylon. For the first and last pylons, the pylon head is set ortogonal to wires.

To manually calculate bisectors, when all the coordinates are known, it is possible to use the utility for geometrical parameters as shown in Paragraph 4.5.

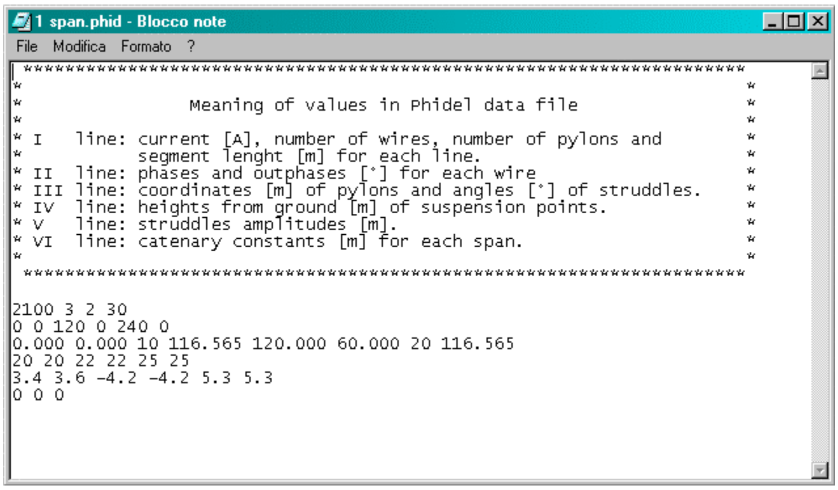
In case of underground lines, the segment length, the struddles angles and the catenary constant are automatically set to 0, and Phidel® correctly interprets them at the calculation time.

4.3.1 Data input limitations

Phidel® does not evaluate the field generated by vertical segments. It is anyway possible to intoduce a minimum coordinates shift (just 1 micron!), when needed.

4.3.2 Data file

Input data are saved in a text file *.phid, structured as in the example shown in Figure 4.8.


1 span.phid - Blocco note

File Modifica Formato ?

```
 ***************************************************************************
*                                                                           *
*                 Meaning of values in Phidel data file                     *
*                                                                           *
* I   line: current [A], number of wires, number of pylons and              *
*           segment lenght [m] for each line.                               *
* II  line: phases and outphases [°] for each wire                          *
* III line: coordinates [m] of pylons and angles [°] of struddles.          *
* IV  line: heights from ground [m] of suspension points.                   *
* V   line: struddles amplitudes [m].                                       *
* VI  line: catenary constants [m] for each span.                           *
*                                                                           *
 ***************************************************************************

2100 3 2 30
0 0 120 0 240 0
0.000 0.000 10 116.565 120.000 60.000 20 116.565
20 20 22 22 25 25
3.4 3.6 -4.2 -4.2 5.3 5.3
0 0 0
```

Figure 4.8 – Data file format.

The numeric values in the file are set in 6 lines, which meaning is described in the top of the file. In the first line there are 4 data for each line:

- current (**2100** A);
- number of wires (**3**);
- number of pylons (**2**);
- length of the segment used to approximate the catenary (**30** m).

The second line containes the phase values of voltages for all wires (in degrees: 0°, 120° or 240°) and the offsets between currents and homologous voltages.

The third line contains the pylons coordinates and the struddles angles, the fourth one the heigths of the suspension points, the fifth one the struddles amplitudes, the sixth one the catenary constants.

After the last numeric line the user can add some personal notes, not considered in the calculation procedures.

4.4 – Configuration visualization

A simple check of inserted data respect to real configuration can be done by clicking the button *Visualize* in the start window. The user can then access to *Configuration visualization*: here he has to select the data file, the ranges along *x*, *y* e *z*, and the *Visualization projection* (*XY*, *YZ* or *XZ*), and to click the *Visualize* button.

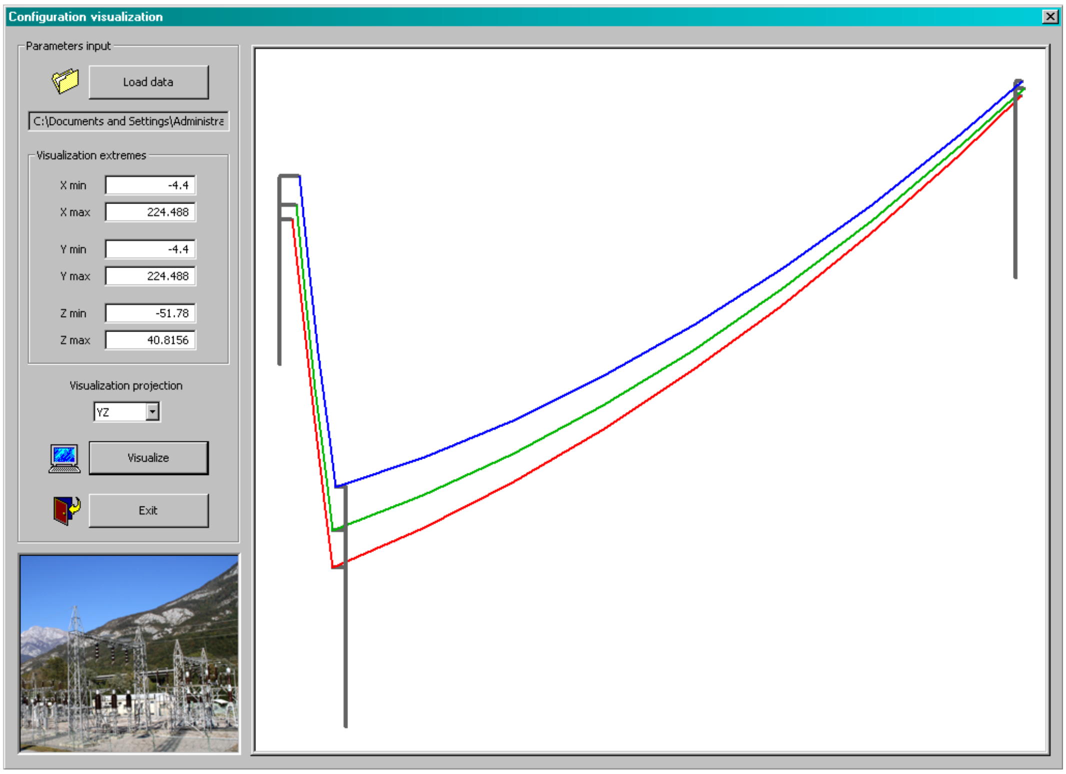


Figure 4.9 – ***Configuration visualization*** **window.**

4.5 – Catenary constant and struddles angles determination

The user, clicking the button *Start utilities*, activates a window where it is possible to calculate the catenary constant, to use when only the geometrical span parameters were known. In the following Figure the two possible cases are shown: the minimum point between the suspension points (on the top-left) or external (on bottom-left).

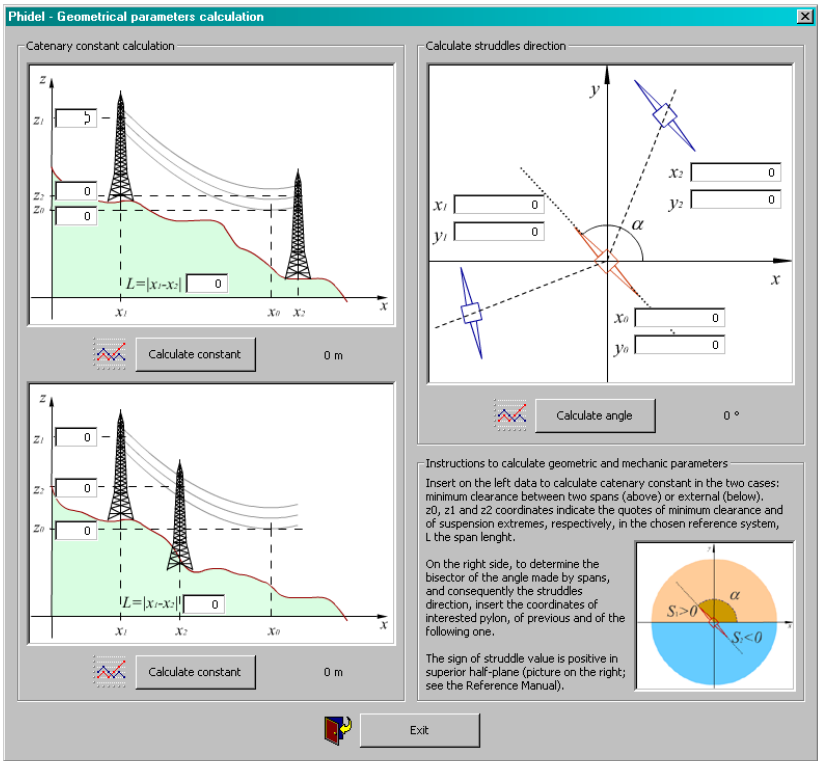


Figure 4.10 - Window to evaluate the catenary constant and the angle between the struddles and the reference frame.

The user must insert the span length, the suspension points and the minimum point elevations. The value, expressed in meters, is shown clicking *Calculate constant*.

In the same window the user can find the utility to calculate the direction of struddles as bisector of the angle made by the previous and the following span. To obtain it, insert the pylons coordinates and click the button *Calculate angle*.

V. DATA ELABORATION

The part of the software designed to data elaboration is divided in a window for plane calculation, one for orographic calculation, one for orographic interpolation, and one for system utilities.

5.1 – Respect bands calculation

From the main window, clicking on *Calculate band*, the user can open a further window, shown in Figure 5.1, to calculate the respect bands in agreement to the Italian Norma CEI 106-11.

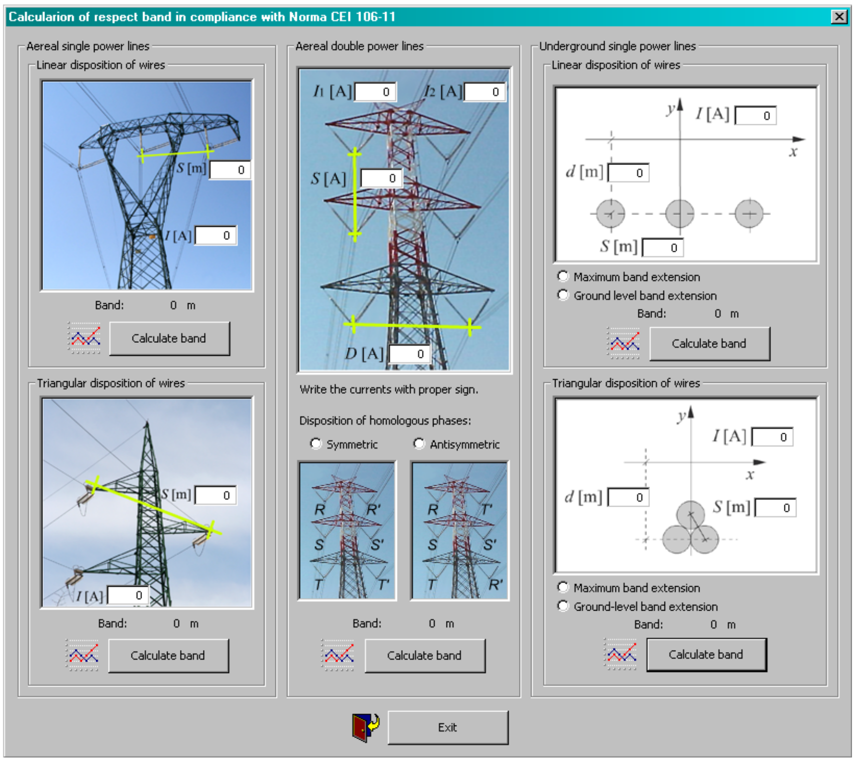


Figure 5.1 – Data input to calculate the respect bands.

This utility usage is really simple; just select the interested configuration, choosing among:

- aereal single power line:
  - linear disposition of wires;
  - triangular disposition of wires;
- aereal double power line:
  - symmetric homologous phases;
  - antisymmetric homologous phases;
- underground single power line:
  - linear disposition of wires;
  - triangular disposition of wires;

It is then possible, in case of underground power line, to choose if calculating the maximum extension of the band, or its projection to the ground level.

When all needed data are inserted, clicking *Calculate band* the output value is immediately shown.

5.2 – Plane calculation

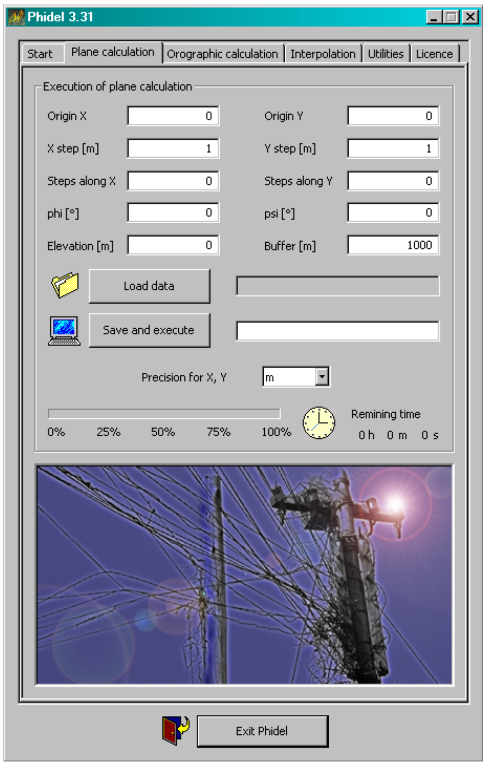


Figure 5.2 – Plane calculation window.

To calculate the field on a plane surface (Figure 5.2), the user must define the origin (along *X* and *Y*) of the sampling region, the step along *X* and *Y*, the number of steps along the two directions, the values of the angles defining the sampling region orientation in the space, the quote, the buffer value (i.e. the maximum distance from the calculation point to consider the spans in the magnetic field calculation) and the precision of *X* and *Y* coordinates (*m*, *dm*, *cm* or *mm*), while the quote has always centimetric precision.

The user selects then the data file (a text file having *.phid extenson) clicking *Load data* and the name of the the output file (having *.txt extension) clicking *Save and execute*.

Finally, the sotware reads the data, elaborates them and creates a text file made by a 4 columns matrix: the values of *X*, *Y* and *Z* coordinates and the RMS magnetic field.

Phidel® saves the output using the TAB space as delimiter between numeric fields.

5.3 – Orographic calculation

In the Orographic calculation window (Figure 5.3) the user specifies the quote (relative to the ground level), the buffer value and the number and width of steps along *Z*. In this way, it is possible to specify equidistant and parallel surfaces (referred to the ground level) where to execute the calculation.

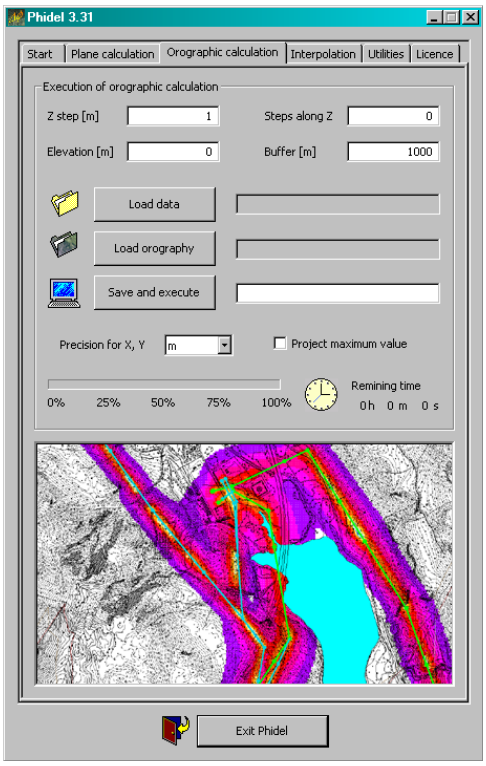


Figure 5.3 - Schermata preposta al calcolo orografico.

The user selects then the data file (a text file having *.phid extenson) clicking *Load data*, the file containing orographic data (having *.txt extension) clicking *Load orography* and the name of the the output file (having *.txt extension) clicking *Save and execute*.

Finally, the sotware reads the data, elaborates them and creates a text file made by a columns matrix with the values of *X*, *Y* and *Z* coordinates and the RMS magnetic field for each surface (depending on the number of the steps along Z).

Selecting the *Project maximum value* option two further colums are calculated, reporting the maximum field value calculated at all the quotas for each point (*X*, *Y*), and the quota where it appears.

The numeric fields of the orographic file can be delimited by every symbol (i.e.: space, TAB…) The software reads data starting from the second line: the file can then have every header in the first line. It is so compatible with several file formats, exported from different softwares (GIS, stylesheet...).

5.4 – Orographic interpolation

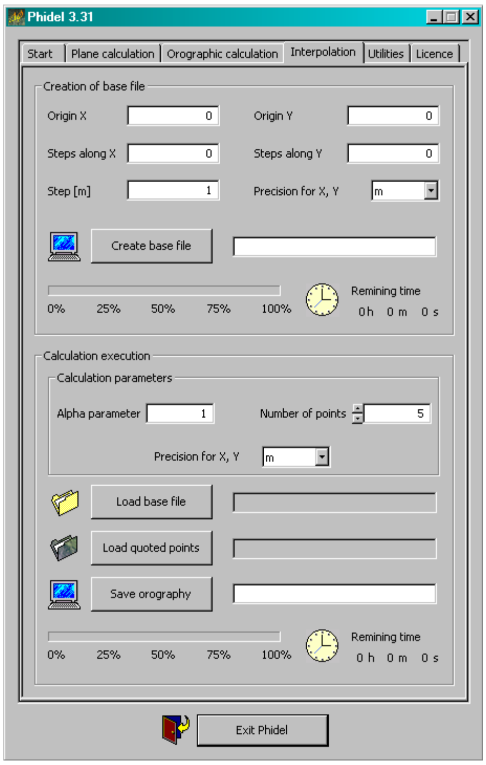


Figure 5.4 – Orographic interpolation window.

The user creates a *base file*, which defines the grid on which nodes the elevations are interpolated, using the top part of the window of Figure 5.4: he defines the coordinates of the bottom-left corner of the sampling region, the number of steps along the directions *X* and *Y*, the width of the step (in meters) and the precision for *X* and *Y*. He defines the file name (with *.txt extension) and the path where to save it clicking *Create base file*.

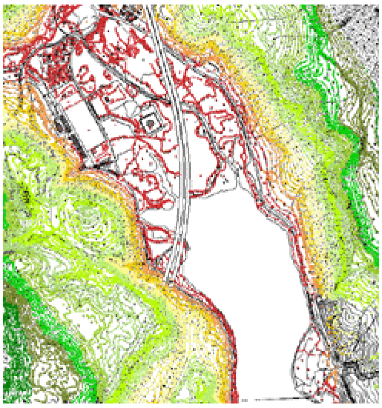


Figure 5.5 – Picture with elevation points, in a proper chromatic scale.

The user creates the, in a GIS environment, a text file with *n* quoted points, obtained by a numeric map, in the desired region (see Figure 5.5). The *(X, Y)* coordinates are assigned to these points using the GIS tools.

The two files are used in the bottom part of the window of Figure 5.4, selecting them with the bottons *Load base file* and *Load quoted points*.

The user indicates then the *Number of points* to use in the calculation, the precision for *X* and *Y* and the *Alpha parameter*, descrbed in the following. As found in the specialistic literature, typical values for Alpha are 1 and 2. Orography is finally created clicking *Save orography*.

5.4.1 The orographic calculation algorithm

Elevations are determined using the *inverse distances* algorithm: to every point of *base file*, made by m elements (X, Y), it is associated as elevation the mean of the elevations of the s nearest points from the total of the n which are quoted (X_0, Y_0, Z_0), wheighted with the inverse of the distance powered to an exponent choosen by the user (the *Alpha* parameter).

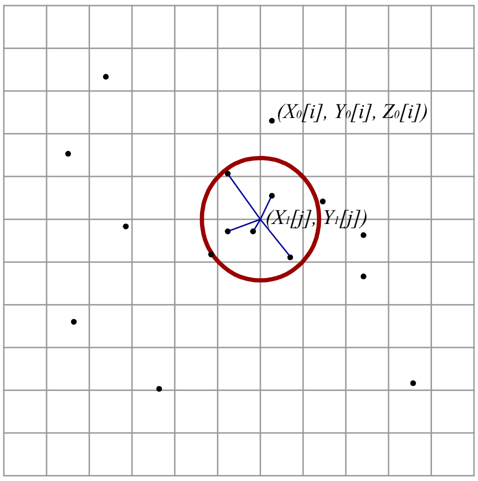


Figure 5.6 – Quoted points, *base grid* and determination of the closest *s* points to the calculation points.

n distances for each of the (X, Y) are so defined:

$$d = \sqrt{(X_0 - X)^2 + (Y_0 - Y)^2}$$

and among them the set with the s lower $\{d_1, d_2, ... d_s\}$ is extracted; an elevation Z_r corresponds to each one, with $1 \le r \le s$. The elevation corresponding to the considered point is obtained as weighted mean:

$$Z[j] = \sum_{r=1}^{s} F_r \cdot Z_r$$

and the weights F_r defined as $F_r = \frac{G}{d_r^\alpha}$ with $\alpha \in R^+$. The normalization $\sum_r F_r = 1$ implies:

$$G = \frac{1}{\sum_r \frac{1}{d_r^\alpha}}$$

with the vinculus:

$$d_r = 0 \Rightarrow F_r = \delta_{rt}$$

with r, t = 1, 2, …, s, which collapses the solution in case of calculus in the quoted point.

The software executes correctly the caculus in a radius of about 2000 km from the known points.

5.5 – Software utilities

The fourth window is divided in three parts, each of them is suitable to a specific utility.

The first one converts Phidel® output (GIS compatible) in a stylesheet format text file. The user must specify the steps along X and Y, the values of the inclinations used to create the data file and the precision for X and Y. He selects the output file clicking *Load file for GIS*, and the path and name of the new format file clicking *Convert and save*.

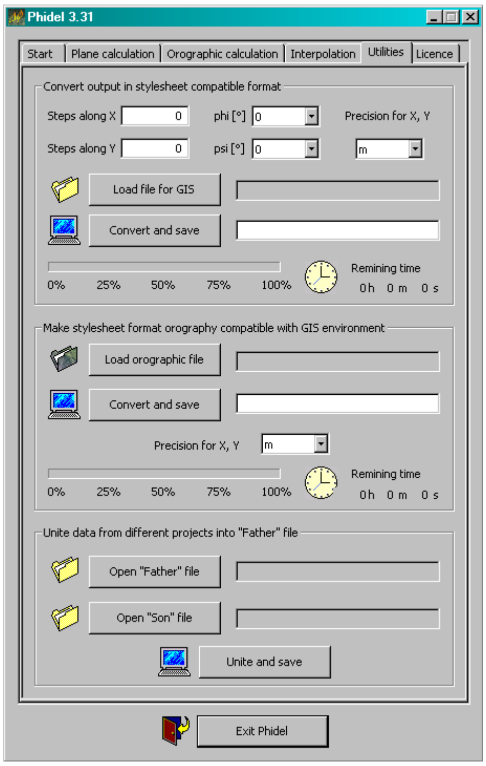


Figure 5.7 – Utilities window.

The conversion is possible only when the angles values are integer multiples of 90° (for compatibility reasons). A rotation can bring the axes of the new reference frame in a position different from that of the originary one, so consider Table 5.1, which specifies the calculation plane in all the possible cases:

ψ	φ	*plane*
0°, 180°	0°, 90°, 180°, 270°	*xy*
90°, 270°	0°, 180°	*xz*
	90°, 270°	*yz*

Table 5.1 – Calculation plane, depending on inclinations.

The conversion is not possible when there is an inconsistence between the file format to convert and the number of steps set by the user. This tooks place when the field is not calculated in points too close to the wire (closer than 5 cm), and consequently in the output matrix some points are missing.

The second utility allows to convert orographic files from a format which is stylesheet compatible. It is necessary to click *Load orographic file*, select the precision for di *X* and *Y*, and name and path of the output file clicking *Convert and save*.

The last utility allows to unite different data files. Click *Open "Father" file* to select the first file, which will be overwritten with all the data, at the end. Click *Open "Son" file* to select the second file, and click *Unite and save* to perform the union.

In this way, it is possible to insert data from several power lines in different files, to unite all them at the end, simplifying the operation.

5.6 – Output visualization

It is possible to visualize the output in a GIS environment (Geographic Informative System), to overlay the magnetic values to the digital cartography(Figure 5.8, on the left).

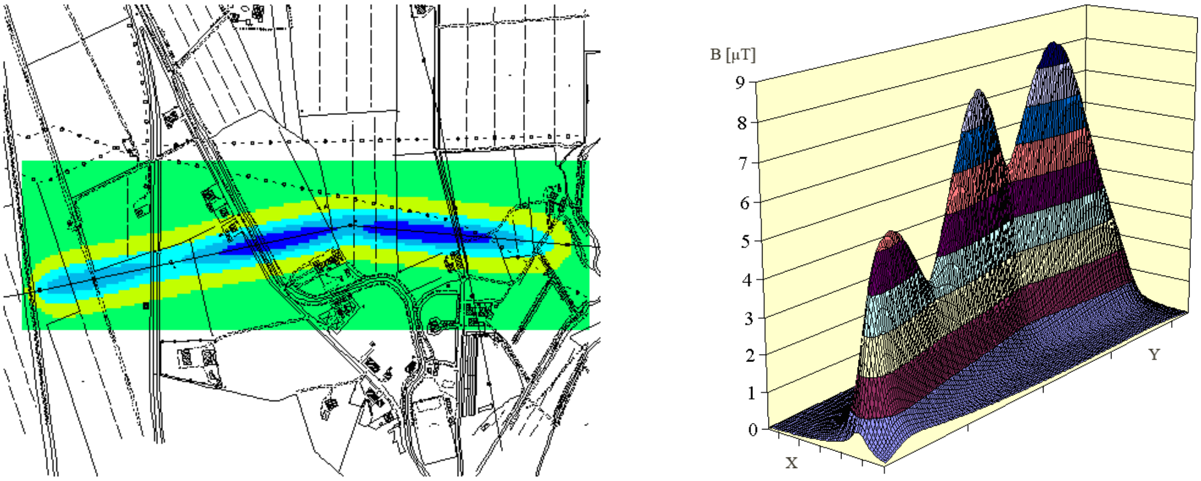


Figure 5.8 - GIS environment visualization (on the left) and in a stylesheet graph (on the right).

When needed, it is possible to convert the data to import them into a stylesheet (Figure 5.8, on the right), following the previously described procedure.