PHASE TO PHASE

User manual Vision Cable 1.4.2

09-150 pmo

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Contents

1   Introduction

Vision *Cable analysis* is a practical computer program for calculation of the electric current rating of cables. The calculation method is based on both the IEC 60287 and the IEC 60853 standard. Thanks to the logical and user-friendly user interface the computer program is easy to learn.
The IEC 287 standard is used for calculation of the stationary cable current rating. The results are the basis for the dynamic calculations according to the IEC 60853 standard. Using this standard the cyclic and emergency current ratings can be calculated.

The user should concentrate on the hot spots in the cable connection, caused by dry ground and neighbouring heat sources. Also the correct ground temperature and ground thermal resistance should be chosen carefully.

With respect to the application of Vision *Cable analysis*, Phase to Phase BV can not be held liable for any misinterpretations of the IEC norms or incorrect use of the software.

Any questions or remarks can be made by e-mail to: [cable@phasetophase.nl.](mailto:cable@phasetophase.nl)

2   Installation

PC-hardware key

The right to use Vision *Cable analysis* is provided by the hardware key supplied with the software. The right of use is of unlimited duration.
Without a PC key or network key, Vision *Cable analysis* can only be used in demonstration mode. In this mode, the software does not allow the user to save user files, and calculations can only be made with one cable type.

For the use of Vision *Cable analysis the* Sentinel-driver has to be installed.

CD version:
- start the program "Autorun.exe", is it does not start automatically
- choose: **Sentinel Protection Installer**
- choose: **Custom**
- choose only: **Sentinel System Drivers**.

Internet version:
- download the sentinel-driver installation program using: http://www.phasetophase.nl/nl_vision_power_range/sentinel.html
- start this program
- choose: **Custom**
- choose only: **Sentinel System Drivers**.

Vision Cable installation

The installation process is as follows:
- start the installation from CD or download the installation program: http://www.phasetophase.nl/download/VisionCableSetup.exe.
- start VisionCable.exe
- If the installation program indicates that the Microsoft .NET Framework has not been installed, do the following:
  o close the installation program
  o browse to: http://www.microsoft.com/downloads
  o choose: .NET Framework Version 1.1 Redistributable Package
  o download the software (23 Mb)
  o start the program dotnetfx.exe and follow the instructions
  o start the program Vision Cable Setup.exe
  o follow the instructions to install Vision *Cable analysis*

Network installation

Vision *Cable Analysis* runs using the **Microsoft.Net framework**. Since Microsoft protects this framework at a high level it is not possible to run any software on the network using default settings. Vision *Cable analysis* can be run from the network after special settings have been made on your PC. For more information, please contact by e-mail: cable@phasetophase.nl.

3   Getting Started

Vision *Cable analysis* is a practical computer program for calculation of the electric current rating of cables. The calculation method is based on both the IEC 60287 and the IEC 60853 standard. Thanks to the logical and user-friendly user interface the computer program is easy to learn.
The IEC 287 standard is used for calculation of the stationary cable current rating. The results are the basis for the dynamic calculations according to the IEC 60853 standard. Using this standard the cyclic and emergency current ratings can be calculated.

The user should concentrate on the hot spots in the cable connection, caused by dry ground and neighbouring heat sources. Also the correct ground temperature and ground thermal resistance should be chosen carefully.

The user interface has been subdivided into two parts: the worksheet and the cable type editor. In the worksheet all cable connections can be defined in or above the ground. The cable editor is the tool to define the cables. All cables are stored in the cable database. Cables can be added, modified and deleted.

In 6 steps this Getting Started shows the shortest route from scratch to the first cable calculations.

3.1   Opening a new worksheet

Directly after starting the program, Vision Cable analysis shows a new empty worksheet, showing the ground with its temperature and the air with its temperature. In this worksheet all cables and results will be presented graphically.
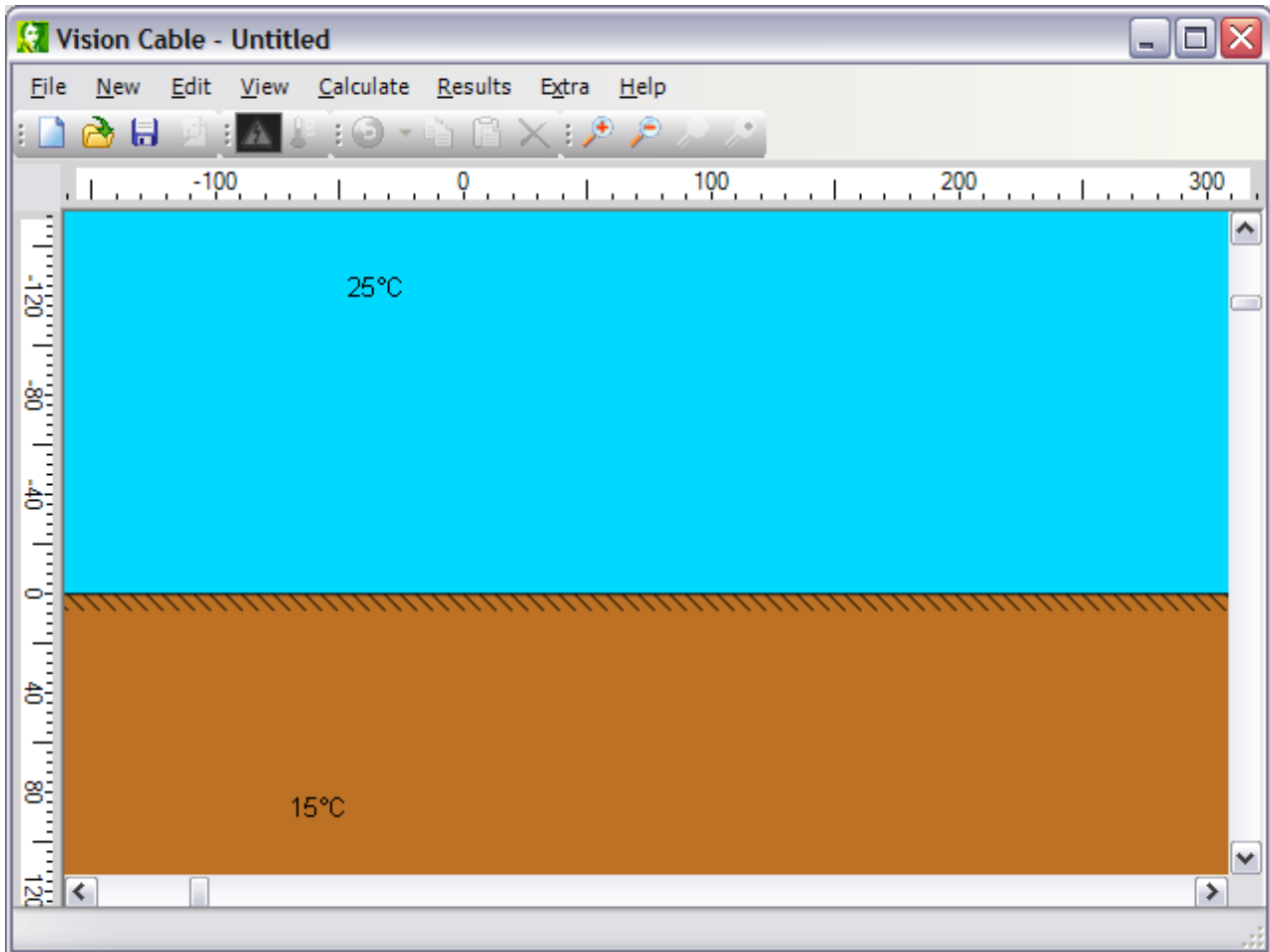
Figure 1:   Vision Cable analysis worksheet

In the worksheet all cable circuits and heat sources can be defined. The next configurations are possible:
- one circuit (or multiple) above the ground
- one or more circuits and heat sources in the ground

3.2   Defining the environment

It is always necessary to define the environmental conditions. The worksheet shows the environmental temperatures. Other conditions depend on the situations for buried cables or cabled laid in free air.

For cables laid in free air apply:
- environmental air temperature
- solar radiation: yes or no.

These conditions can be defined by right-mouse clicking in the worksheet on a spot above the ground level. A pop-up menu appears. Choose: **Edit** and **In air**. The air temperature can defined in steps of 1 degrees Celsius.
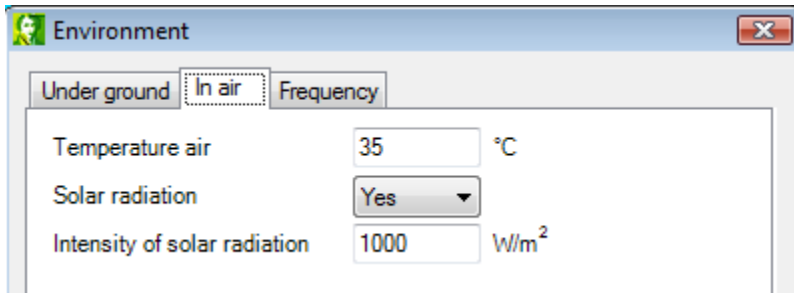
Figure 2:   Environmental conditions in free air

For buried cables apply:
- drying out of soil: none/partial/prevent
- environmental ground temperature
- ground thermal resistance

These conditions can be defined by right-mouse clicking in the worksheet on a spot below the ground level. A pop-up menu appears. Choose: **Edit** and **Under ground**. The ground temperature can defined in steps of 1 degrees Celsius.
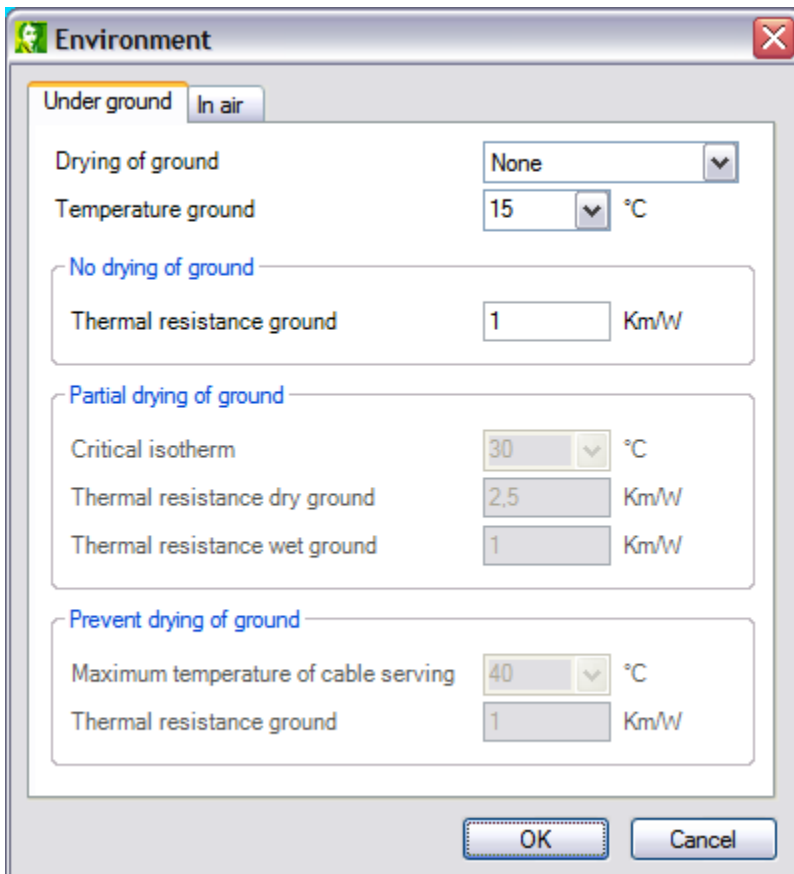
Figure 3:   Environmental conditions under ground

In most countries the soil can be moist. In cases of heavy loaded cables or crossings this soil can be dried out. This can lead to a "hot spot" in the cable connection, limiting the whole cable connection ampacity. The specific thermal resistance for dried ground can be 2.5 Km/W.

3.3   Adding a cable

A new cable circuit can be added using: **New | Circuit** from the menu. A dialogue form appears for defining the circuit properties:

- cable type
- lay
- current

Cable type

On the tab-sheet **Cable type** the cable can be choosen from the cable database. A filter assists in the selection procedure. The filter criteria are:

- isolation (plastic or no plastic)
- number of cores (1 or 3)
- voltage level (phase-to-phase voltage)

If a cable type has been chosen, a picture of the cable cross-section will be shown. In this example: a single-core 10 kV XLPE-cable of 95 mm2.
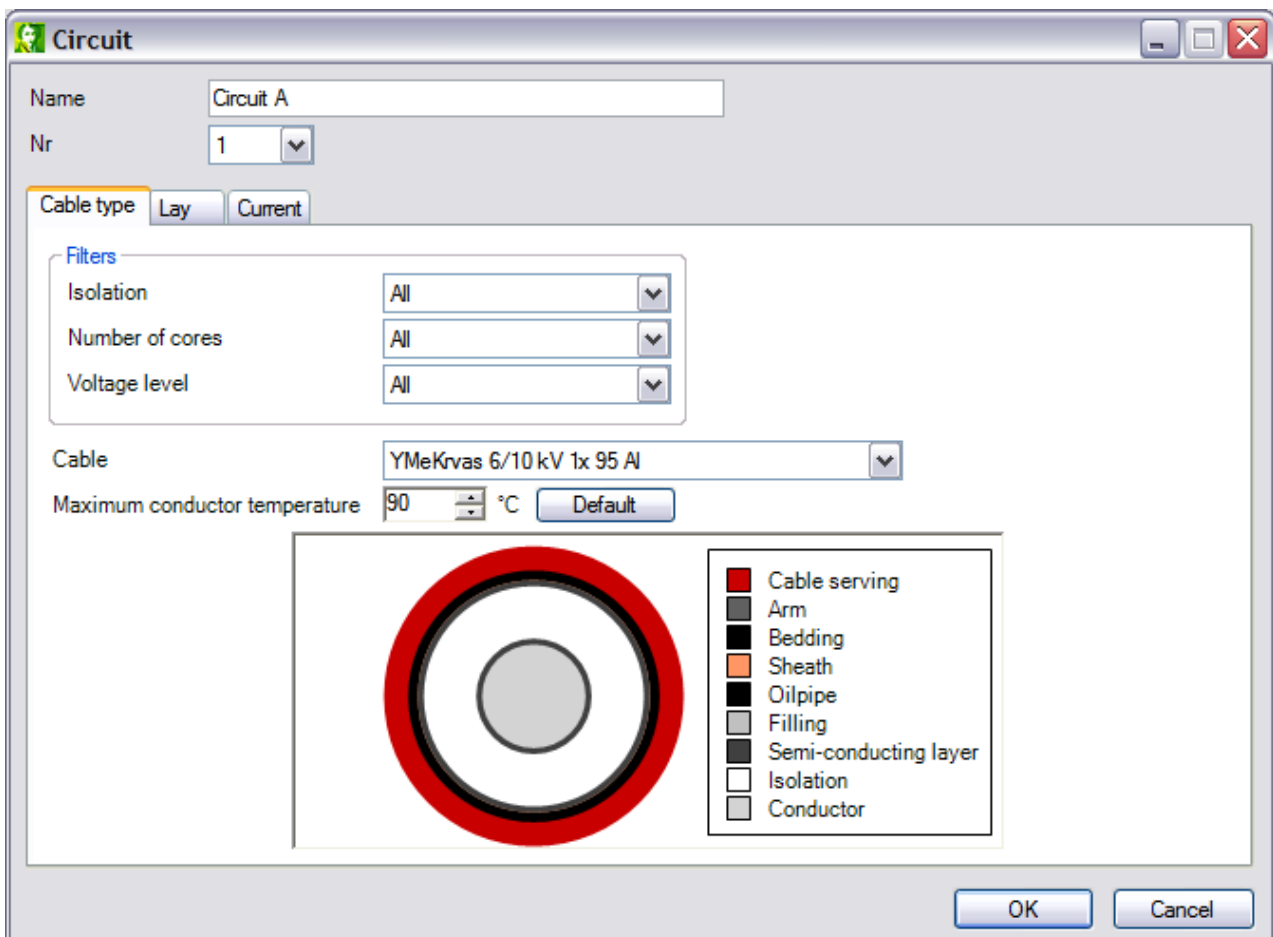
Figure 4:   Selecting a cable type

Lay

After selecting a cable type, the laying configuration has to be defined in the tab-sheet **Lay**. This also defines the laying in the ground or in the free air.

In this example the cable is buried at a depth of 1 m. The cables core-to-core distance is twice the cable diameter (button **2xDe**) in flat formation. The sheets have been bonded at a single point. Leave the form using **OK**.
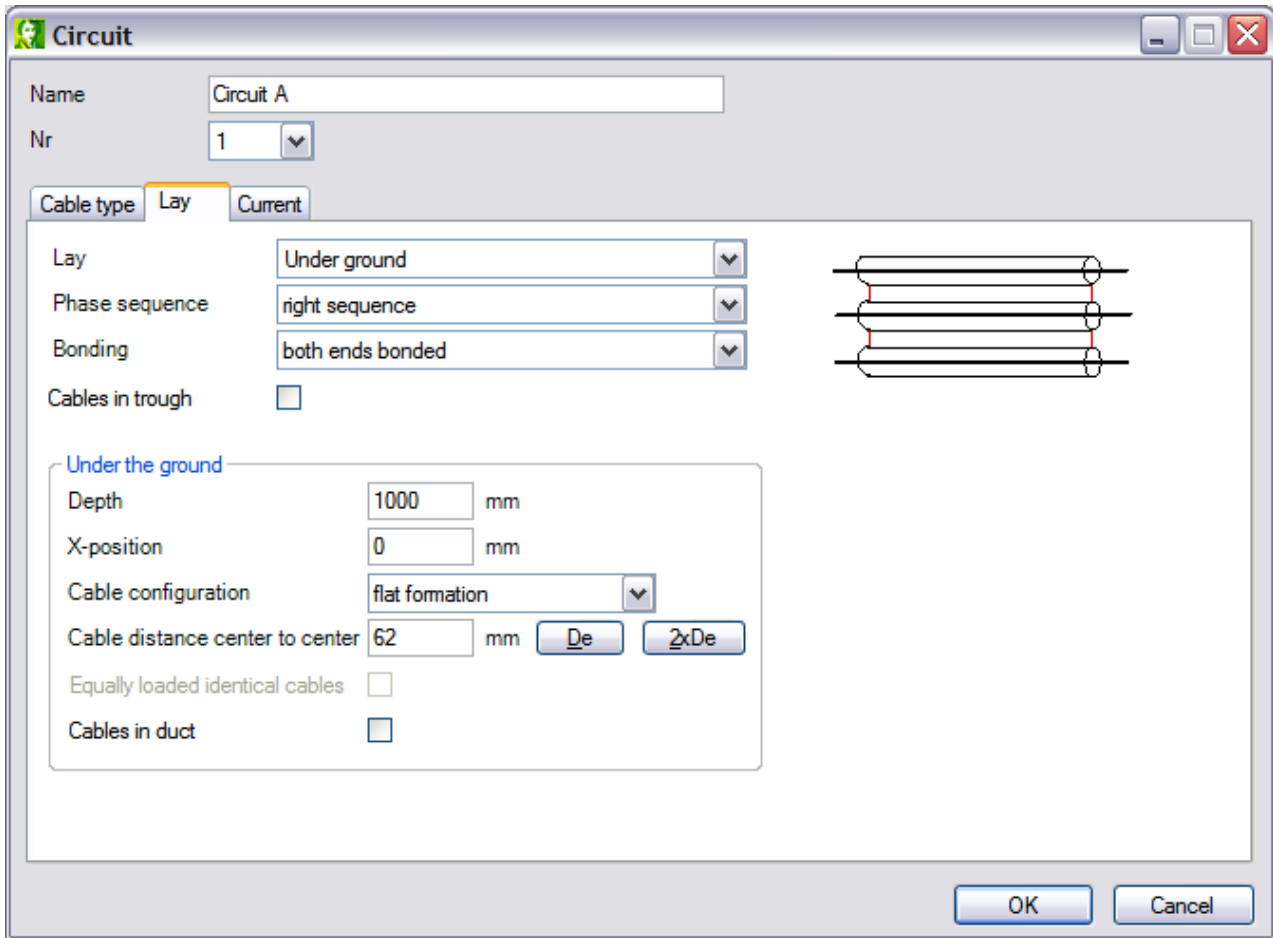
Figure 5:   Defining the lay

The cable circuit can be moved in the worksheet using the mouse. The cable ampacity will be calculated automatically.

3.4   Interpreting the results for the stationairy situation

After defining the cable type and the environment, Vision *Cable analysis* automatically calculates the stationary cable ampacities. All results will be presented in the worksheet. The zoom-functions are:
- use the zoom-buttons (+) and (-) or
- select the cable circuit (by clicking with the left-mouse button or by drawing a rectangle while the left-mouse button held pressed down) and choose the most right **Zoom selected** speed-button.
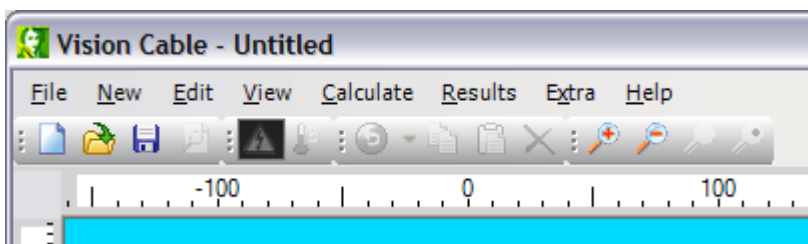
Figure 6:   Zoom functions

After zooming in the calculated stationary cable ampacity and the temperatures of conductor, sheet, armour and outer covering will be presented.
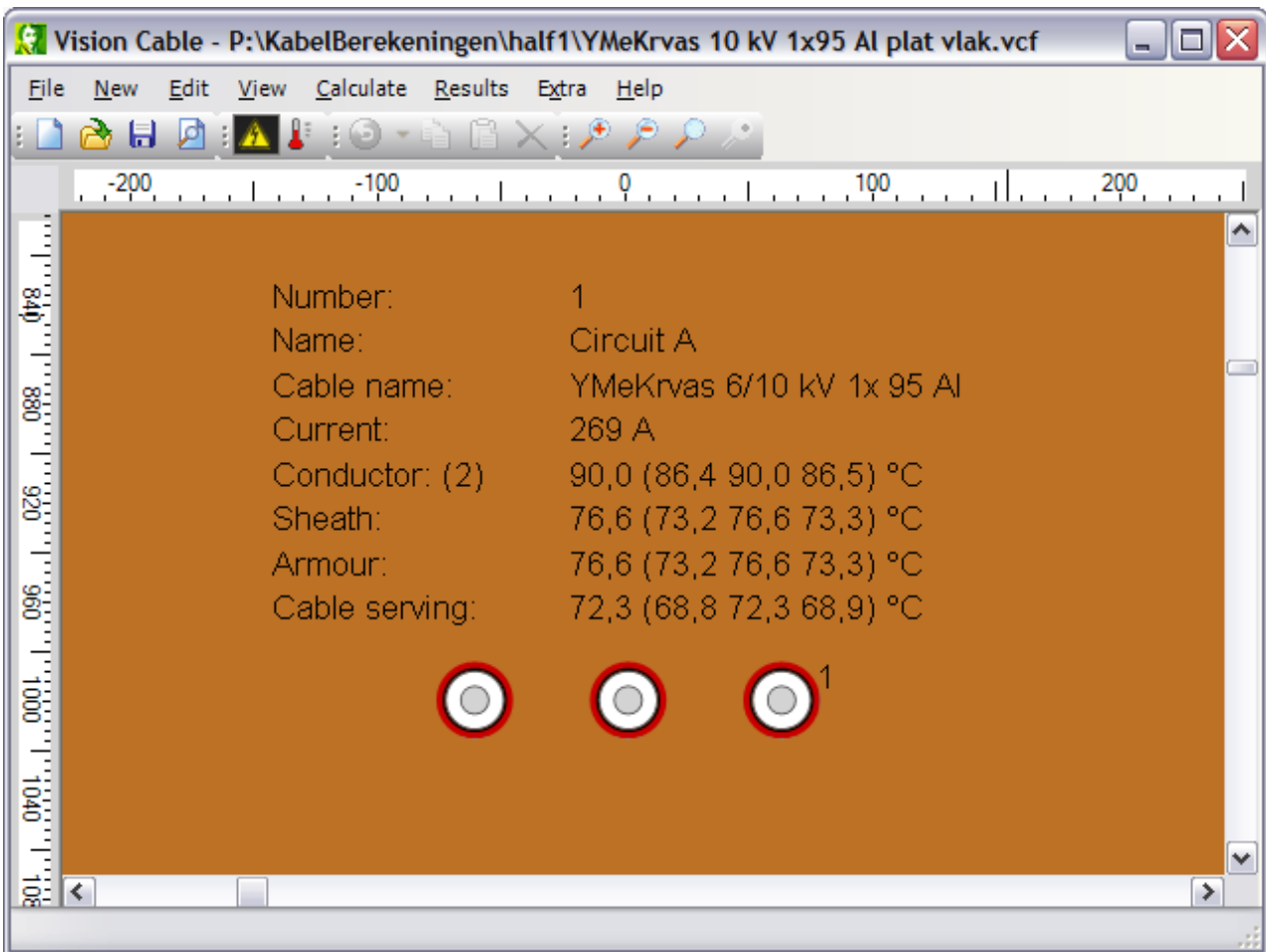
Figure 7:   Calculated stationary cable ampacity

The worksheet shows the temperatures of the hottest cable. Between brackets the temperatures of all cables of this circuit are presented. In this case the center cable is the hottest one. The results can be examined in detail by selecting the cable circuit and choosing: **Results | General**.

A function has been added to calculate the underground temperature image for the stationary case. From the menu choose: **Calculate | Temperature range**. The temperatures are presented in steps of 5 degrees Celsius.
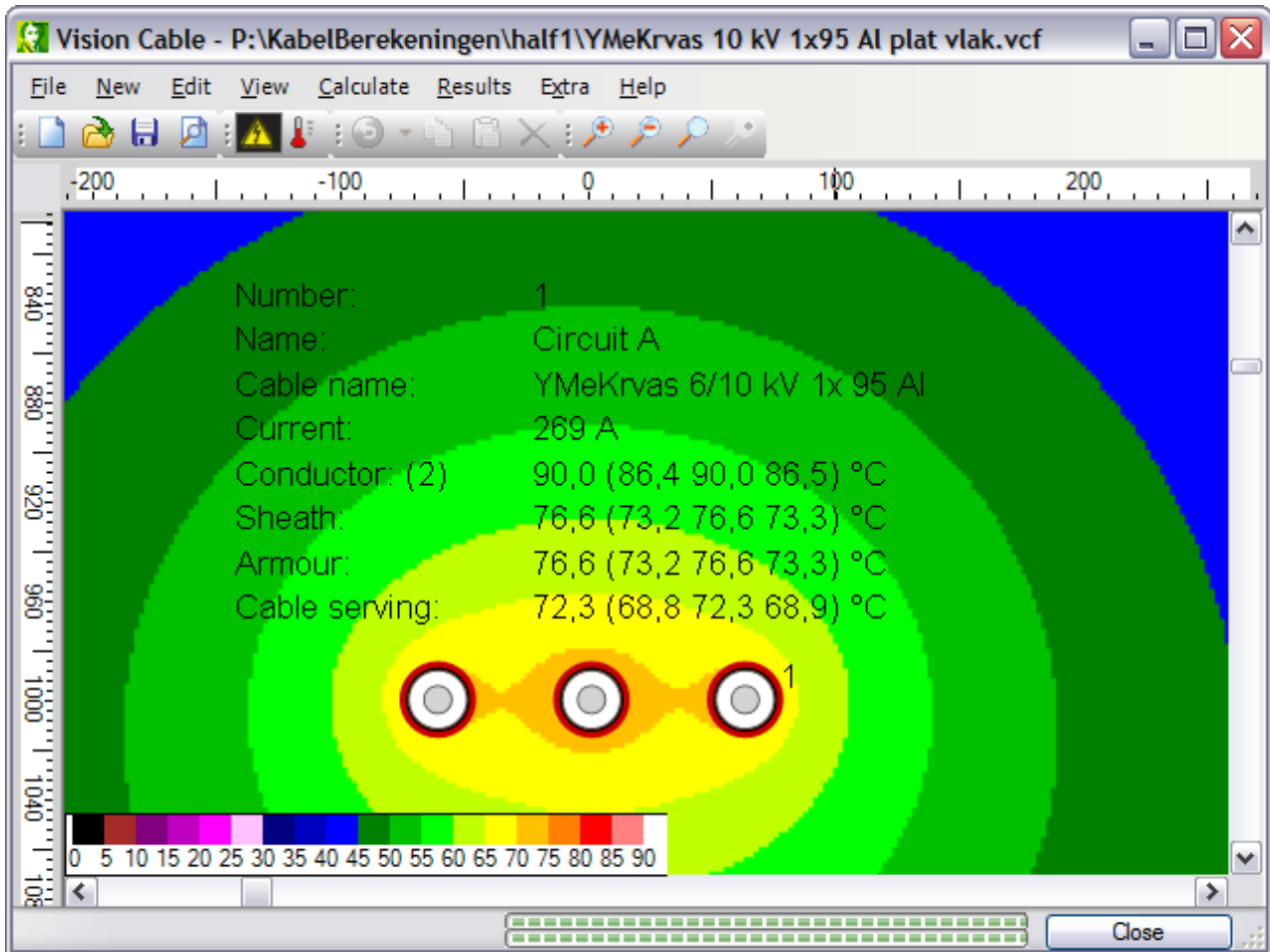
Figure 8:   Temperature image

3.5   Calculating the cyclic load

The cyclic load calculation determines the amount of extra load above the stationary cable ampacity, provided that the current follows a daily cyclic pattern of 24 values. According to the IEC 60853 norm the largest current of such a cyclic load can be larger than the stationary ampacity. To start this calculation, select the cable circuit and from the main menu choose: **Calculate | Cyclic current**.
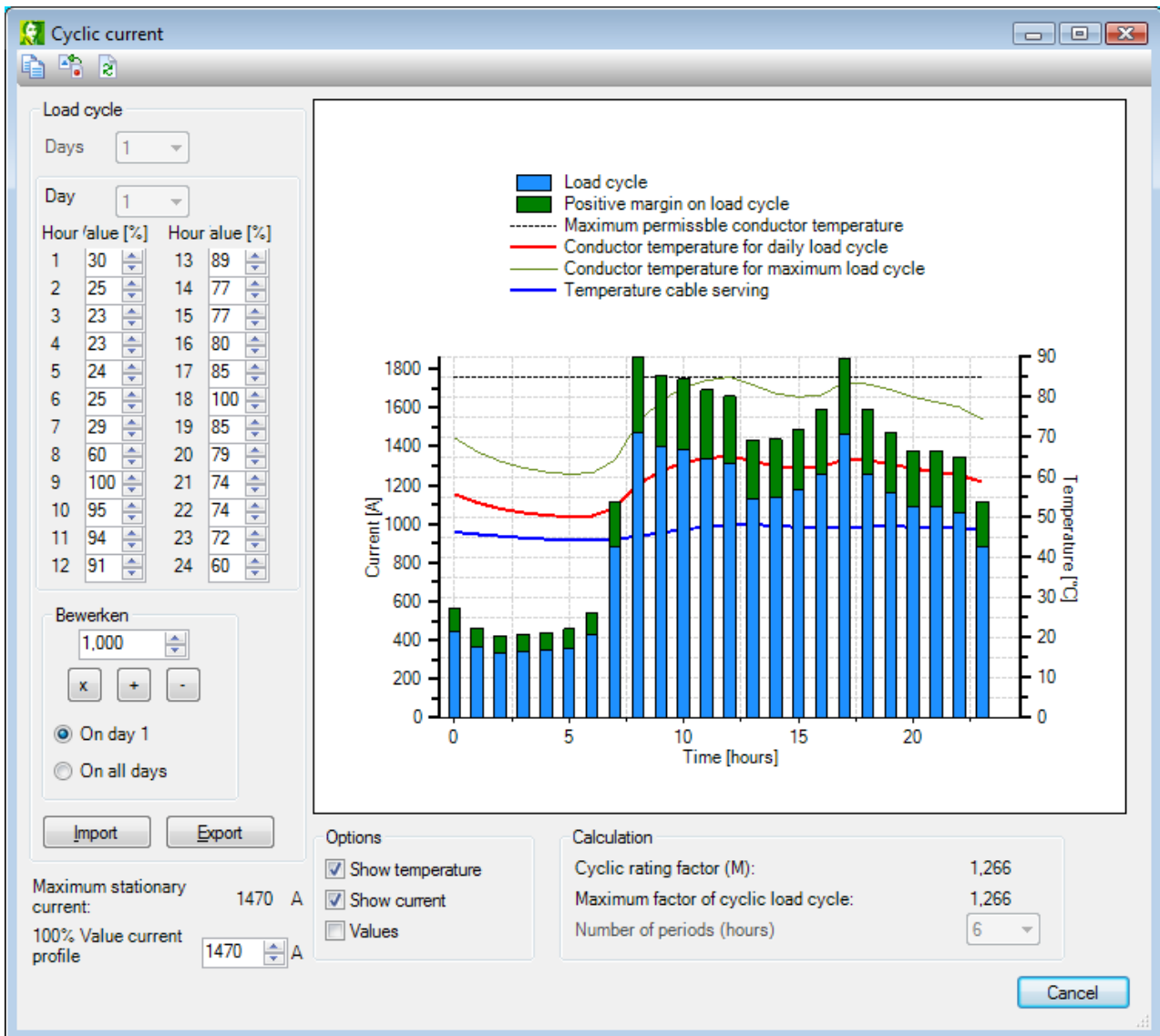
Figure 9:   Cyclic current calculation form

The screen shows the default load cycle in a bar chart. The values are presented on the left-hand side. These values correspond with the blue parts of the bar chart. Behind the bar chart the conductor temperature for this current profile has been plotted (orange line).

A user defined load cycle can be exported by using the button **Export**. Previously saved load cycles can be imported by using the button **Import**. All imported current values are limited to two times the stationary ampacity.

This example concentrates on the default load cycle.

The "Cyclic rating factor (M)" indicates the maximum value of the load cycle as factor of the stationary ampacity. In this example:

$$Imax,cyclic = M \times Imax,stationary = 1,189 \times 273 = 325\ A.$$

The "Maximum factor of cyclic load cycle" is the maximum multiplication factor for all values of the load cycle. In this example: 1.25.

The cyclic calculation is only possible for configurations of one circuit and for identical loaded cables.

3.6   Calculating the emergency load

The IEC 60853 norm describes the "Emergency Load" calculation, for determination of a maximum duration of a stepwise change of current in case of an emergency. To start the calculation, from the main menu choose: **Calculate | Maximum load**.
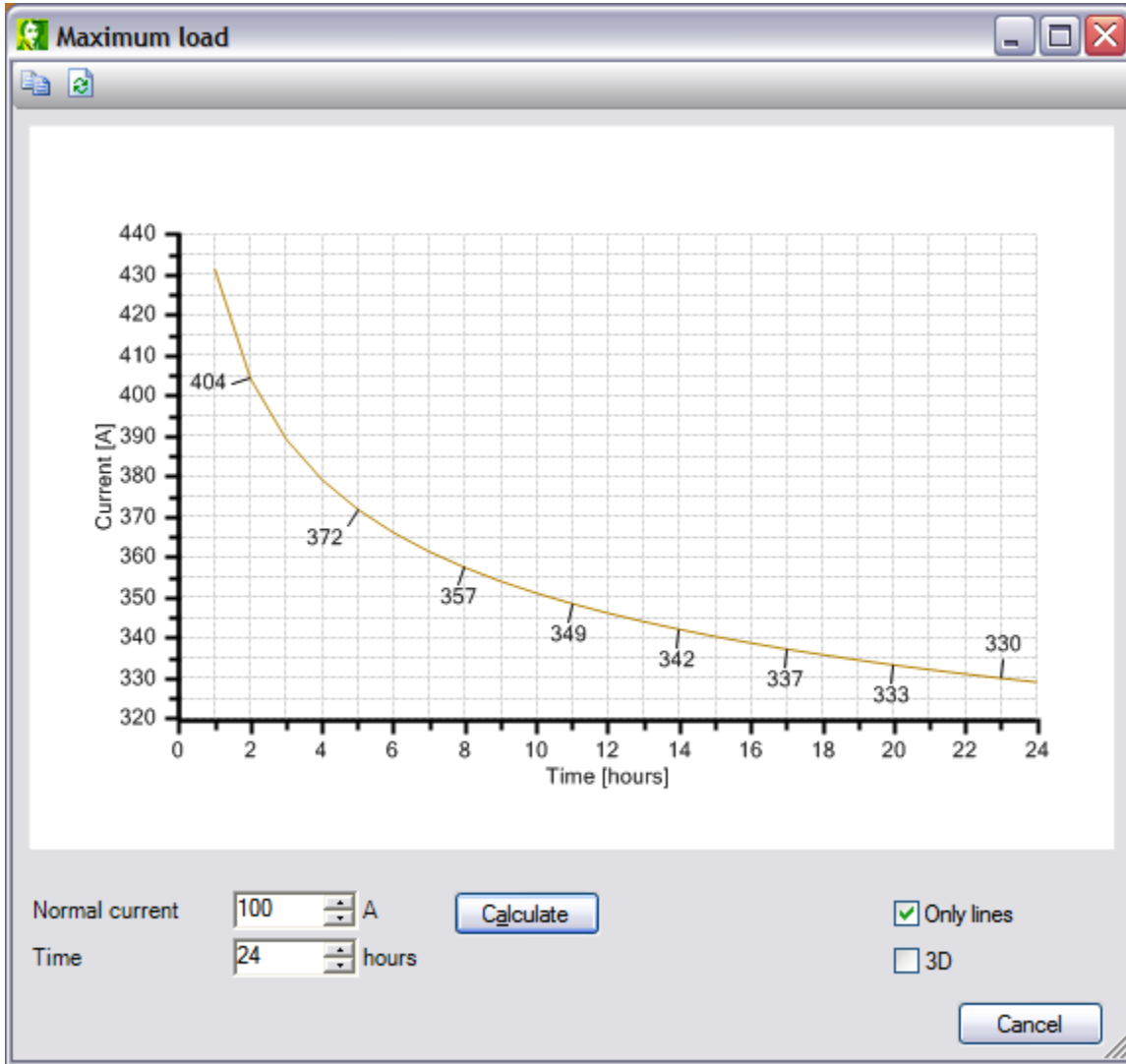
Figure 10:   Maximum emergency load

The result is a graph, presenting the emergency load a function of the emergency duration. In this example, starting with a pre-emergency load of 100 A, the 8 hours emergency load may be 363 A. After this emergency, the cable load must be less than or equal to the stationary ampacity.

3.7   Defining a cable type

Vision *Cable analysis* uses a database of cable types. This database can be user defined using the Cable type editor. The editor will be invoked by chosing from the main menu: **Extra | Cable type editor**.
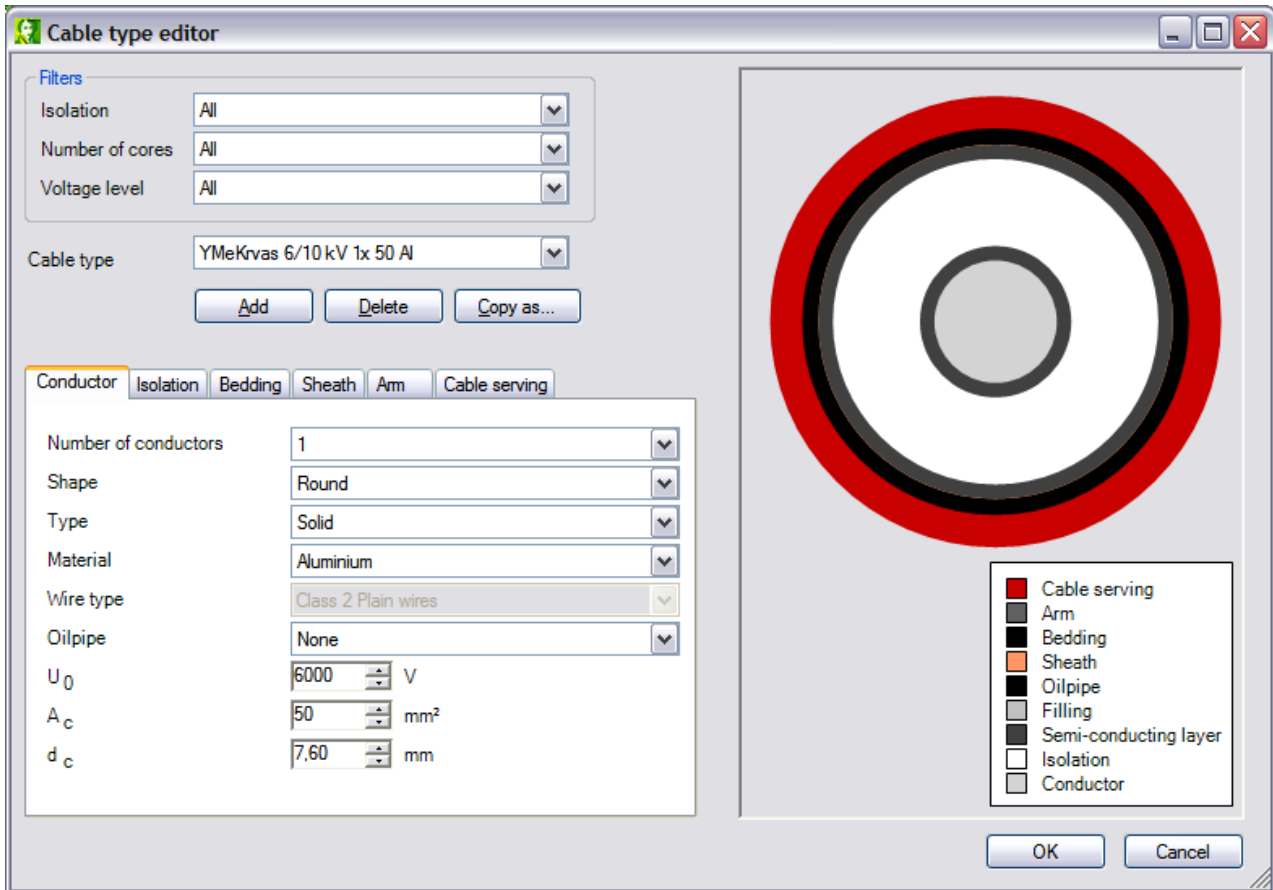
Figure 11:   Cable type editor

In the upper left part of the form an existing cable can be selected from the database. Once selected, this cable can be modified, copied or deleted. Also, a new cable can be defined and added to the database. In the middle part of the form the constructional sizes are presented. In the right-hand side of the form the material properties are presented.

Changes in sizes will be graphically presented in the cable cross-sectional diagram. The diagram is drawn with reference to the outer covering. This example schows:
- Uo   : Rated voltage (phase to ground)
- Ac   : conductor cross-sectional area
- dc   : conductor diameter
- t1   : isolation thickness
- As   : screen cross-sectional area
- Ds   : screen diameter
- ts   : screen thickness
- t2   : bedding thickness
- dAi   : armour internal diameter
- dA   : armour external diameter
- df   : armour wire diameter
- n1   : armour number of wires
- De   : outer diameter

In this example the screen has been constructed with a screen of copper tape and wires. The copper wires have been defined as "armour".

Changes, made in the cable type editor, will be saved after leaving the form with "OK".

4   Vision Cable Analysis

The Vision Cable Analysis user interface can be seperated in two parts: the workspace and the cable type editor.

On the workspace, circuits (a circuit is a 3-core cable or three 1-core cables) can be buried or in air. From this workspace all calculations can be performed.

The cable type editor can be used to define the cables used in the workspace. Changes in the cable type editor have an immediate effect in the workspace.

4.1   Mouse actions

On the workspace, several actions can be performed with the mouse. These actions are divided in three groups: scroll wheel, right mouse clicks and left mouse clicks.

Left mouse clicks

With a left mouse click, the following actions can be performed:
- Selection of an object by a single click. Multiple objects can be selected by holding down the Control key.
- Selection of 1 or more objects by clicking and dragging
- Deselection by clicking on an empty space on the workspace
- Moving objects. Left click an object an while keeping down the mouse button, move the mouse.

When objects are moved, certain restrictions are in order because of the IEC standard. Therefore it is not possible to put a cable too shallow or to deep. The width of the screen is also constrained.
- depth: minimum 250 mm; maximum 10000 mm
- x-position: minimum -2000 mm; maximum 10000 mm

Right mouse clicks

With a right mouse click, a popup menu is shown. This menu can contain different items. The content depends on the place the mouse click was performed and depends on the current selection.
- 1 circuit/heat source
- Several circuits/heat sources
- Duct bank
- Environment in air
- Environment in ground

Scroll wheel

The scroll wheel can be used to scroll the workspace, vertically (without pressing any keys) and horizontally (shift key pressed) and to zoom in or out (Control key pressed). See also Keyboard actions 18 .

4.2   Keyboard actions

On the workspace, several actions can be performed using the keyboard:

CTRL-A	Select all
CTRL-C	Copy
CTRL-O	Open
CTRL-P	Print
CTRL-S	Save
CTRL-V	Paste

CTRL-X	Cut
CTRL-Z	Undo
Del	Delete
F1	Help
Ins	Copy all (all circuits including workspace)
Arrow keys	scroll the workspace

Holding down the Shift and Control-key can be used to perform different actions:

Action	Key pressed	Result
Drag circuits	Shift	Circuits are moved horizontally only
Drag circuits	Control	Circuits are moved vertically only
Move scroll wheel	None	Workspace is scrolled vertically
Move scroll wheel	Shift	Workspace is scrolled horizontally
Move scroll wheel	Control	Workspace is zoomed in/out

4.3   Workspace

After starting Vision *Cable analysis*, an empty workspace is shown. The ground including temperature and the air including temperature are shown here, and the separation between ground and air. In this workspace, cable positions are shown graphically.

In the workspace, circuits and heat sources can be added. The following combinations are possible:
- one circuit (or a multiple of that circuit) in the air
- one or more circuits in the ground
- one or more heat sources in the ground

While moving objects, certain restrictions are in order because of the IEC standard and because of restrictions in the program itself. Therefore objects cannot be placed too shallow or too deep. The width of the screen is also constrained.
- depth: minimum 250 mm; maximum 10000 mm
- x-position: minimum -2000 mm; maximum 10000 mm

4.3.1   Environment

When adding a circuit, it is possible to adjust the surrounding conditions. In the workspace, the temperatures are shown, but other conditions can also be set in the options.

In the environment dialog, the settings for 'In air' [19] or 'Under ground' [19] can be chosen.

Because of restrictions in the IEC 60287, in some configurations it is not possible to calculate with more than one circuit:

Under ground:

No drying of ground	Multiple circuits possible
Partial drying of ground	One circuit only
Prevent drying of ground	Multiple circuits possible

In air:

No solar radiation	Configurations from standard
Solar radiation	Configurations from standard

Configurations can be switched, but not always:

From To	Under ground No drying of ground	Under ground Partial drying of ground	Under ground Prevent drying of ground	In air No solar radiation	In air Solar radiation
Under ground No drying of ground	-	Always	Always	Always	Always
Under ground Partial drying of ground	1 circuit only	-		Always	Always
Under ground Prevent drying of ground	Always	Always	-	Always	Always
In air No solar radiation	1 circuit only	Always	1 circuit only	-	Always
In air Solar radiation	1 circuit only	Always	1 circuit only	Always	-

In this table, the assumption is made that the circuit is not in a duct bank or trough. If the circuit is in a duct bank, it cannot be moved to 'In air'. When a circuit is in a trough, the filling setting determines the configuration: when it is sand filled, the configuration is 'Under ground', when it is unfilled, the configuration is 'In air'.

4.3.1.1   In air

When a circuit is 'In air', the following parameters can be set:
- temperature of the air
- solar radiation (yes/no)
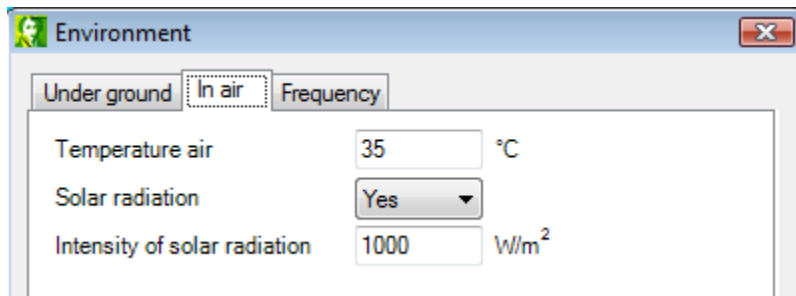
This dialog can be accessed by right clicking on an empty space in the air on the workspace and selecting 'Edit' on the popup menu which is shown. Another possibility is to use the menu **Edit | Environment**.

According to IEC, the solar intensity is 1000 W/m^2 for most latitudes. Depending on the circumstances, this may vary between 500 and 1400 W/m^2.

4.3.1.2   Under gorund

When one or more circuits are under the ground, the following parameters can be set:
- temperature of the ground
- thermal resistance of the ground
- drying of the ground

When choosing the drying of the ground, there are three possibilities:
- no drying of ground
- partial drying of ground (one circuit only)
- prevent drying of ground

When '*partial drying of the ground*' is chosen, the critical isotherm temperature (at which the ground dries out) can be chosen as well as the thermal resistances of dry and wet ground. If '*prevent drying of the ground*' is chosen, the maximum cable serving temperature and the thermal resistance of the ground can be chosen.

This dialog can be accessed by right clicking on an empty space under the ground on the workspace and selecting 'Edit' on the popup menu which is shown. Another possibility is to use the menu **Edit | Environment**.

When heavy loaded cables are used under roads or buildings, the ground may dry out very quickly or otherwise lead to a "hot spot" in the cable connection. This may be one of the restrictive factors when calculating the maximum capacity of the entire connection. If this is expected, one may need to use the thermal resistance of dry ground, which might be 2,5 Km/W.

4.3.1.3   Frequency

The frequency can be set for the entire configuration, being either 0, 50 or 60 Hz. If a value of 0 Hz has been chosen, the calculations will be made for a DC system.

4.3.2 Circuits

A circuit can exist of:
- a single 3-core cable
- three 1-core cables

New circuits can be added using the menu **New | Circuit**.

Because of the IEC 60287 standard, it is not always possible to calculate more than one circuit:

Under ground:
No drying of ground	Multiple circuits possible
Partial drying of ground	One circuit only
Prevent drying of ground	Multiple circuits possible

In air:
No solar radiation	Configurations from standard
Solar radiation	Configurations from standard

In the dialog used to add a circuit, certain properties can be set. These are:
- cable type [21]
- lay [22]
- current [25]
- duct [26]
- trough [27]

A circuit can also be given a name and a circuit number.

The same dialog is also using to change a circuit.

4.3.2.1 Cable type

On this tab a specific cable type can be chosen. A filter can be used to narrow down the selection of cables from the cable type database. Filters can be used with 3 criteria:
- isolation (plastic or no plastic)
- number of cores (1 or 3)
- voltage level

Filter for the voltage level:
The voltage levels are line voltages, however, in the cable type database, the phase voltage is stored.
Some PILC cables have a higher phase voltage (8/10 and 10/10 kV), so these cables will be in a higher voltage range.

If a cable type is chosen, a graphical representation of the cable is automatically shown.

The maximum allowed conductor temperature of the chosen cable can be adjusted if necessary.
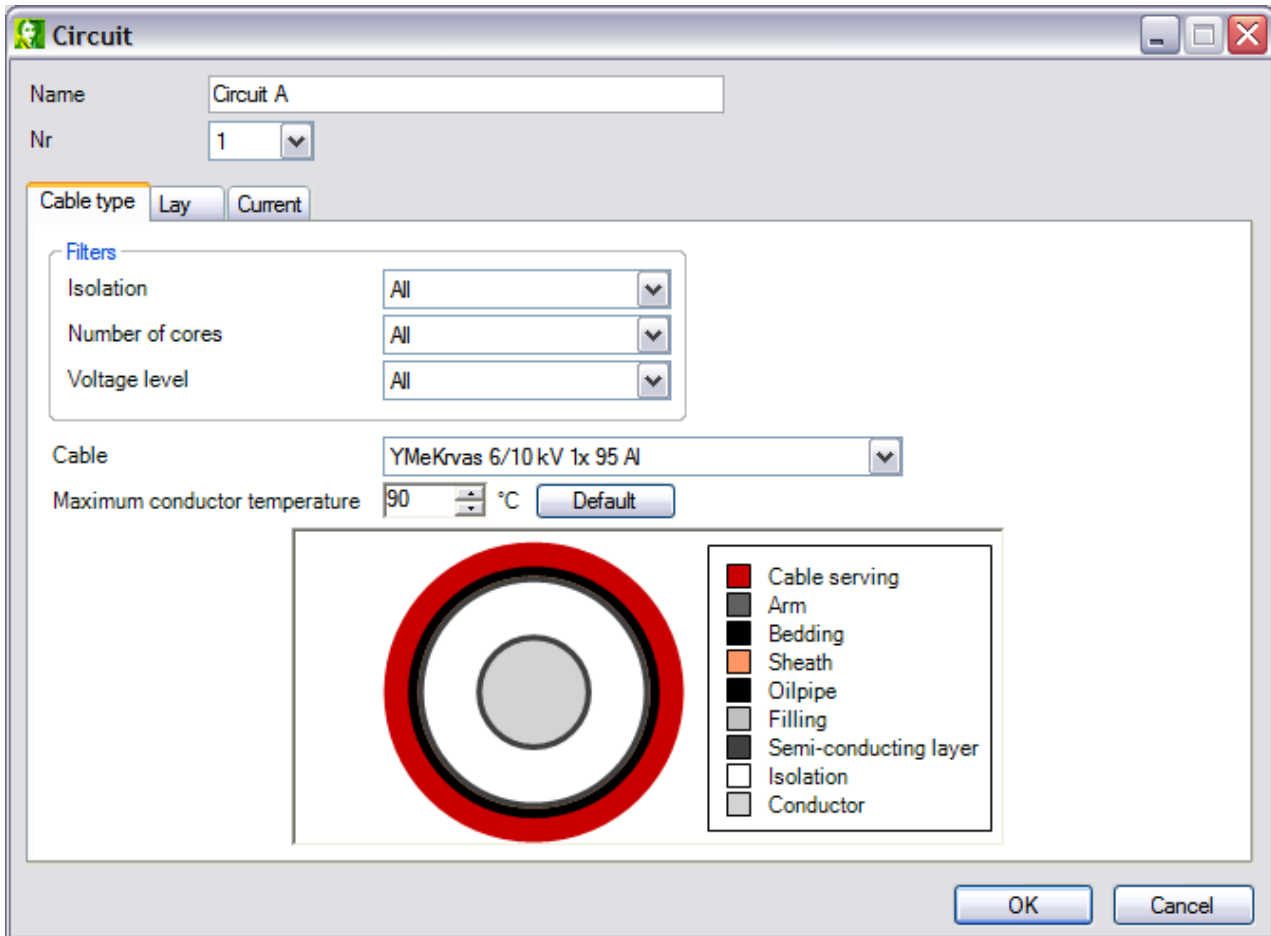
4.3.2.2   Lay

After a cable is chosen, the configuration of the cable has to be determined. This can be done on tab **Lay**. The dialog will adjust itself, depending on the chosen configuration.

On this tab, the following settings can be made:

Lay
- Under ground. In Environment 18 the properties of the ground can be set (drying of ground, thermal resistances, temperature)
- In air. In Environment 18 the air properties can be set (temperature and solar radiation)

Phase sequence
The phase sequence is only applicable to 1-core cables under the ground. The possibilities are:
- left sequence
- right sequence

Bonding
Determines the method of connecting the sheath or the method to diminish the losses in the sheath. The possibilities are:
- Single point
- Both ends bonded
- Crossbonding
- Transposition

Cables in a trough
Determines if a circuit is in a trough. This option is only available if the circuit is the only circuit in the configuration.
The calculation method used with a circuit in a trough depends on the filling of the trough:
- if the trough is sand filled, the calculation will be the calculation for cables under the ground
- if the trough is unfilled, the calculation will be the calculation for cables in air

Under ground
For a buried circuit, the following settings can be made:

Depth
Depth of the circuit

X-position
Horizontal distance to a imaginary zero point; see the rulers in the top and left side of the workspace

Cable configuration
Flat formation or trefoil

Distance between cables
The distance between the cables can be the center-to-center distance or the physical distance between the cables, depending on the options 56. The buttons on the right side of this input (**De** and **2xDe**) can be used to quickly set the distance to 1 or 2 times the cable thickness.

Equally loaded identical cables
When the configuration only contains circuits with the same cable types, this option can be used to calculate the

current so that the current is equal for all circuits. If this option is not selected, all circuits will be calculated for their maximum conductor temperature.

Cables in a duct
This option puts the cables of a circuit in a duct; one cable per duct. A new tab page will appear to enter the duct settings.

In air
This configuration can only be chosen when the circuit is the only circuit in the configuration. For a circuit in air, the following configurations are possible according to the IEC 60287:
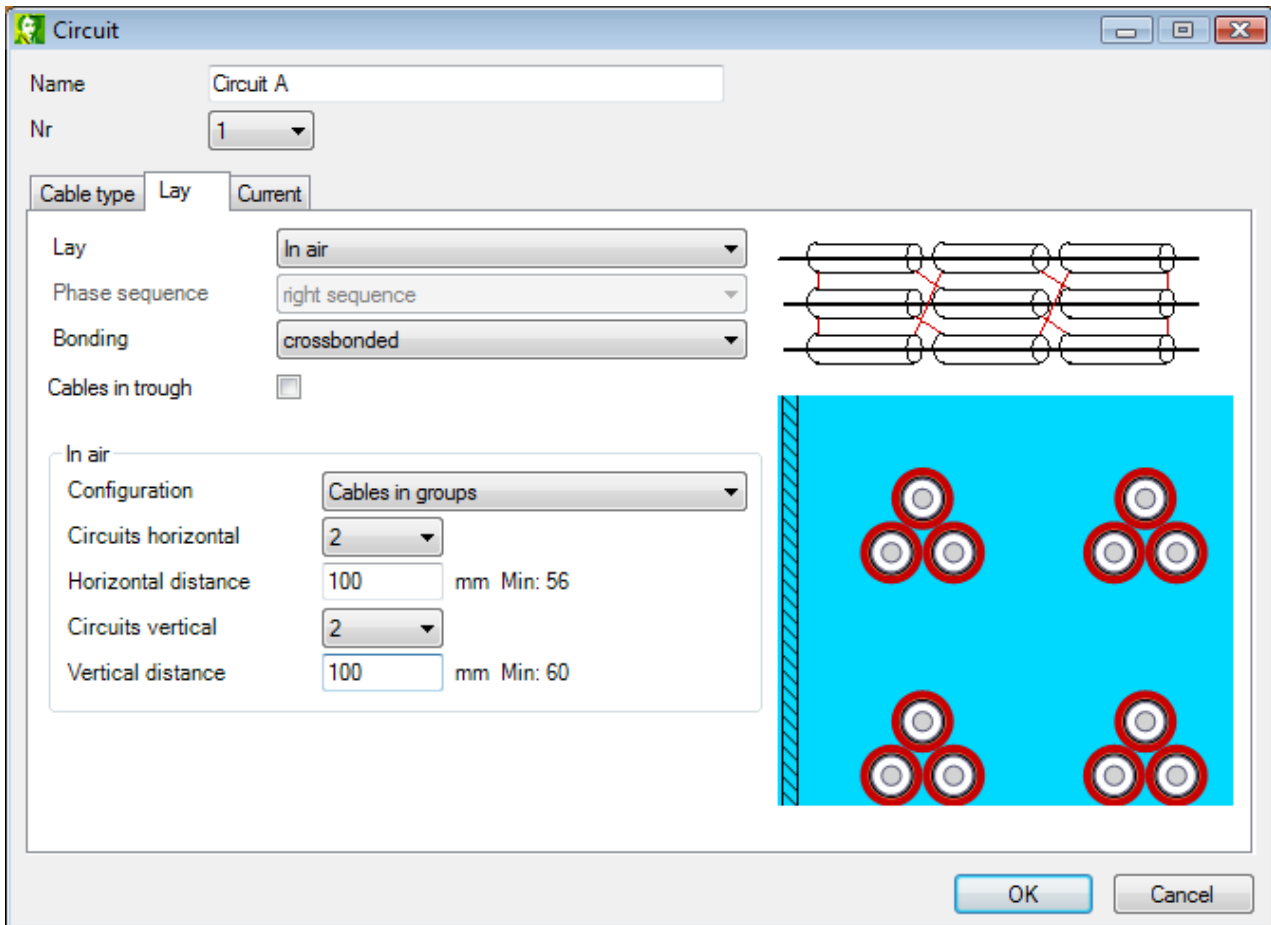
1-core cables:
- Three cables in trefoil
- Three cables touching, horizontal
- Three cables touching, vertical
- Three cables spaced De, vertical
- Three cables in trefoil formation, touching a wall
- Cables in groups:
  - 1, 2 or 3 horizontal
  - 1 or 2 vertical

3-core cables:
- Single cable
- Two cables touching, horizontal
- Three cables touching, horizontal
- Two cables touching, vertical

- Two cables spaced De, vertical
- Three cables touching, vertical
- Three cables spaced De, vertical
- Single cable against a wall
- Cables in groups:
  - 1, 2 or 3 horizontal
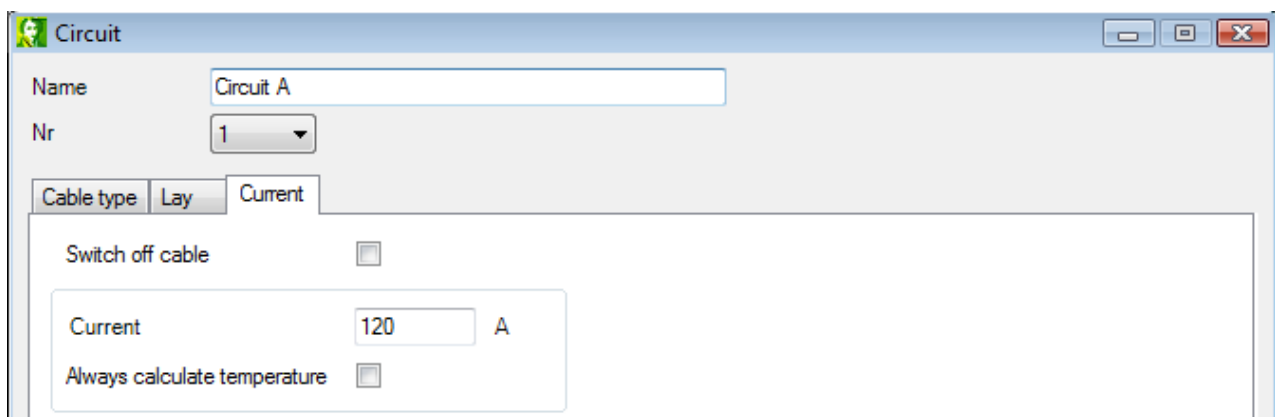 - 1, 2 or 3 vertical

4.3.2.3   Current

On the tab **Current**, the current can be entered which is used by the calculation method 'Maximum temperature' (menu **Calculate | Maximum temperature**)

The current will also be used with the 'Maximum current' calculation, if the checkbox 'Always calculate temperature' is checked. This way, two circuits can be placed, whereby the maximum current of the first circuit is calculated and the temperature of the second circuit.

The field 'Switch off cable' forces the cable to have no load and no voltage. The value entered in 'Current' will temporarily not be used, but it is saved.

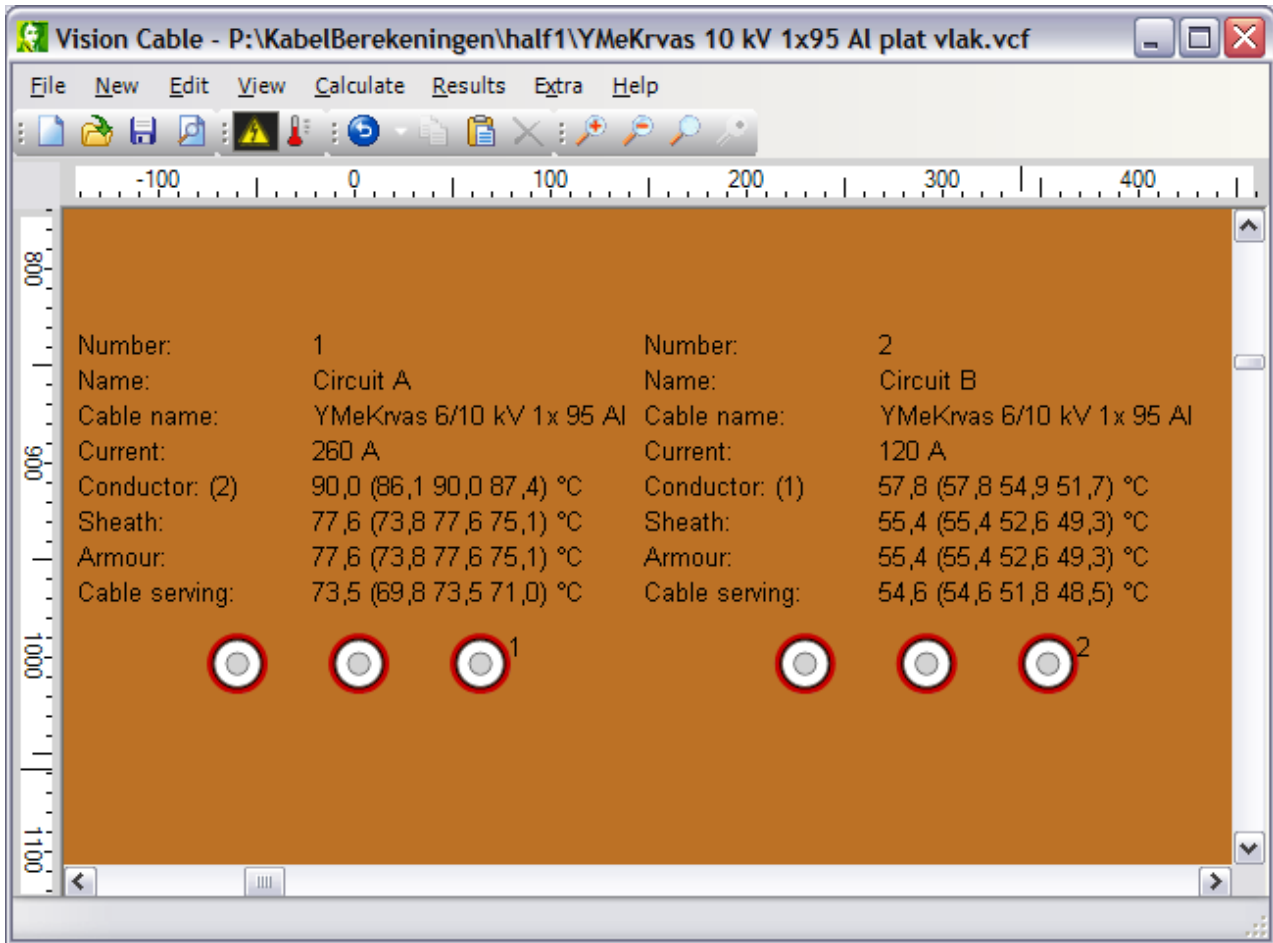The picture shows an example in which a circuit will be kept at a current of 120A.

In the next picture, for the left circuit the maximum current is calculated and for the right circuit, the temperature is calculated using a constant current of 120A.

4.3.2.4 Duct

If a cable is placed in a duct (select 'Cables in duct' in tab **Lay**), the properties of the duct can be entered in the tab **Duct**. The minimal sizes of the duct are placed next to the input fields as an input help

A circuit cannot be placed in a duct when it is already in a trough.
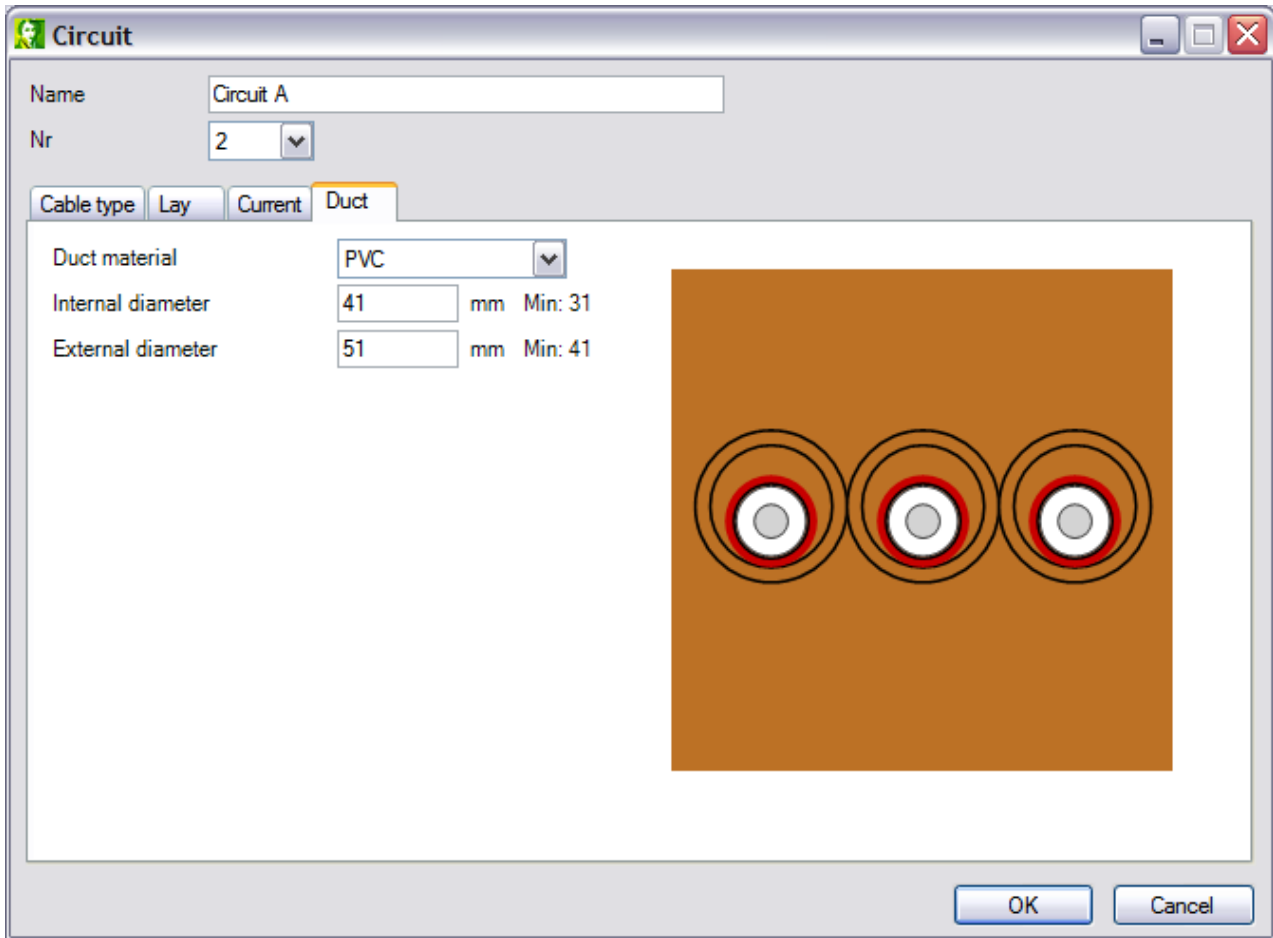
4.3.2.5   Trough

If a circuit is in a trough, having other soil conditions than the surrounding ground, the properties can be entered on the tab **Trough**. A circuit can only be placed in a trough if it is the only circuit in the configuration and if the circuit is not already in a duct(bank).

Caution:
- If the trough is unfilled, the calculation will be the calculation for cables in the air
- If the trough is sandfilled, the calculation will be the calculation for cables in the ground
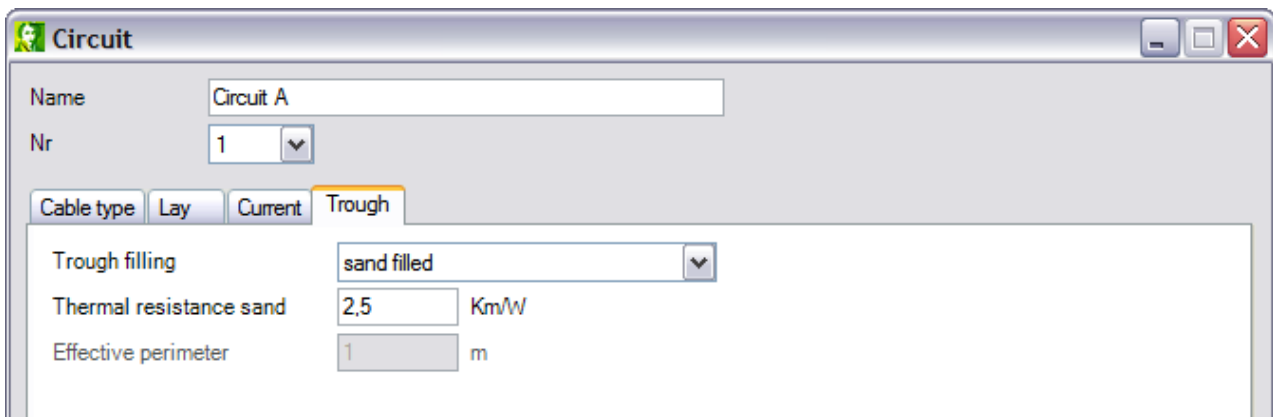
Sand filled
Thermal resistance sand: the thermal resistance of the filling can be different from the thermal resistance of the

ground.

Unfilled
The effective perimeter has to be entered if a trough is unfilled.

4.3.3   Heat source

Heat sources are hot pipes and can be added to the buried configuration.
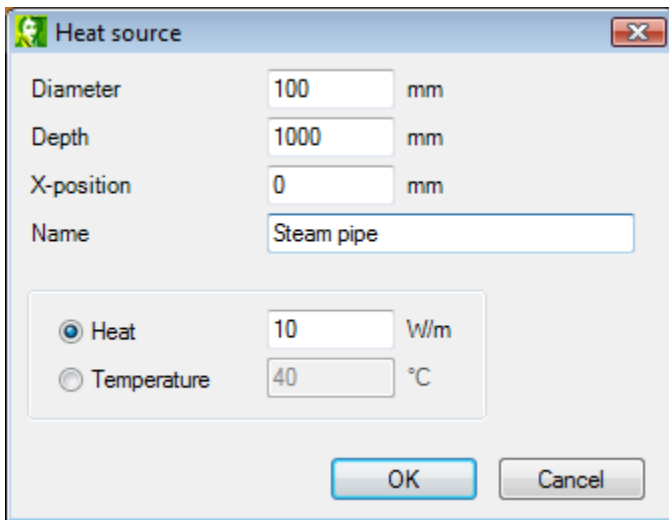
From a heat source, its diameter, position and name can be entered.
The heat production can be specified either for a constant surface temperature or for a constant heat flow.

Heat sources can not be entered is situations of:
- partial drying of soil
- a duct bank
- in air

4.3.4   Duct bank

Buried circuits may be placed in a duct bank. Adding a duct bank is only possible in an empty configuration. The duct bank is specified by height, width and depth.
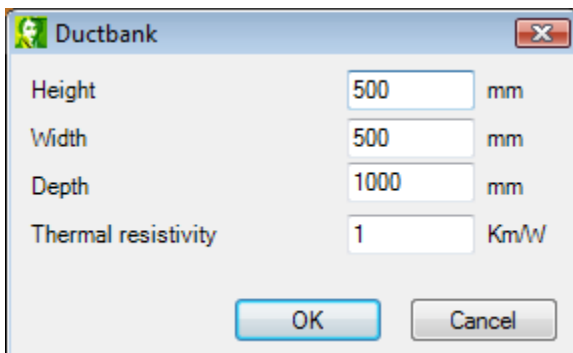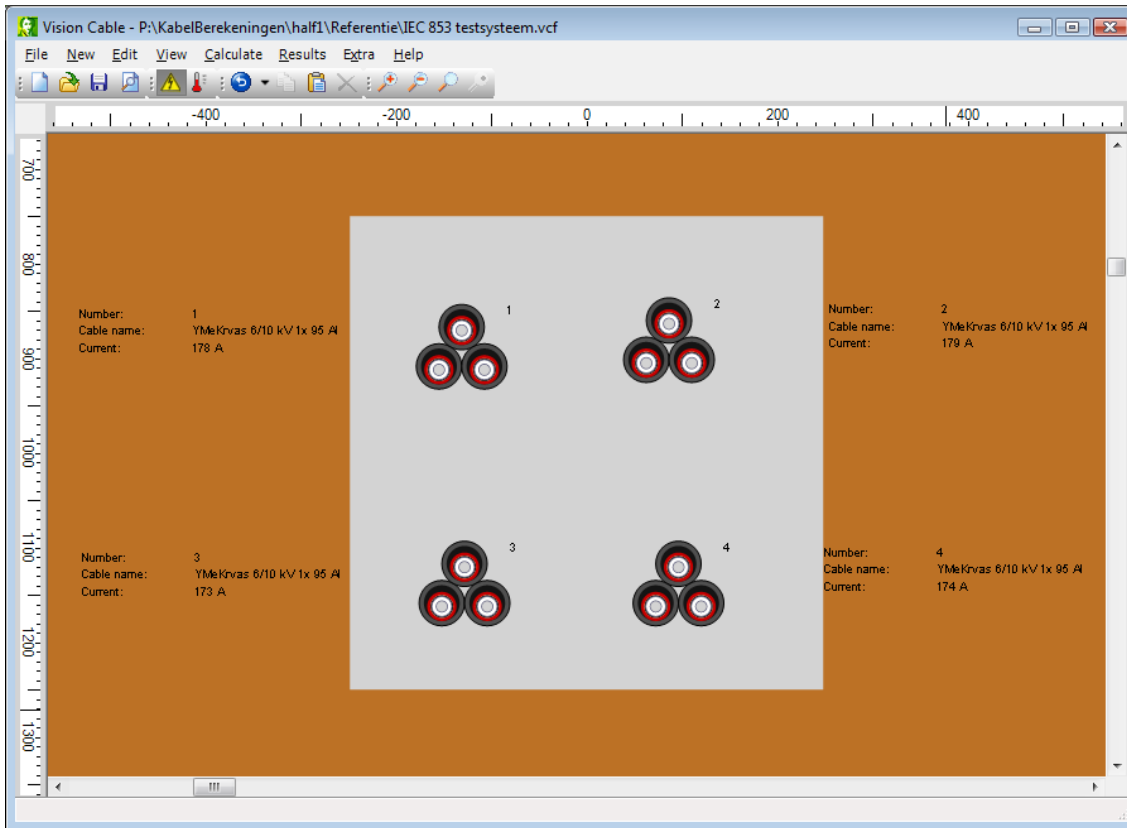
4.3.5 Menus

4.3.5.1 File
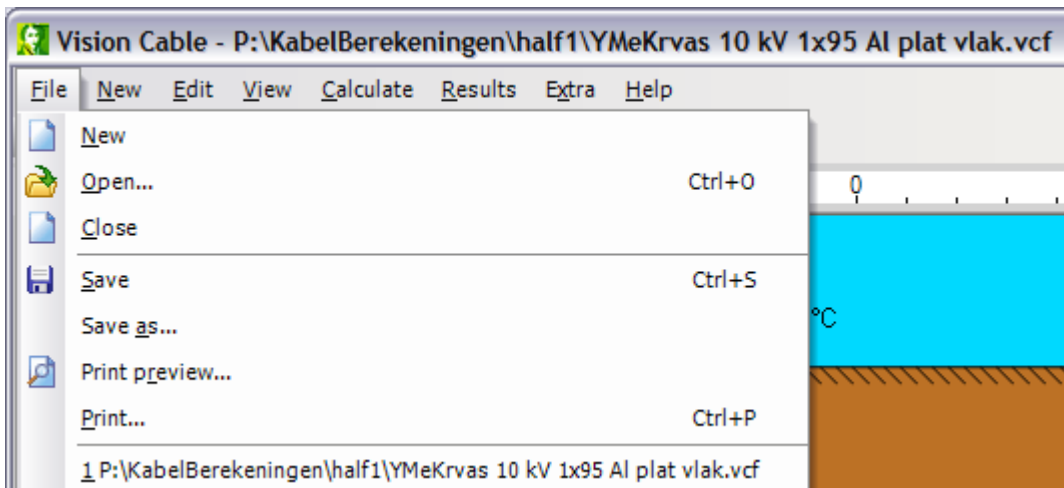
New
Create a new configuration.

Open
Open a saved configuration.
If this configuration contains cable types which do not exist in the cable type file, the program prompts to choose from existing cable types.

Close
Close and save the actual configuration.

Save
Save the actual configuration.

Save as
Save the actual configuration using a new name.

Print preview
Preview of a print.

Print
Print the actual configuration.

4.3.5.2   New
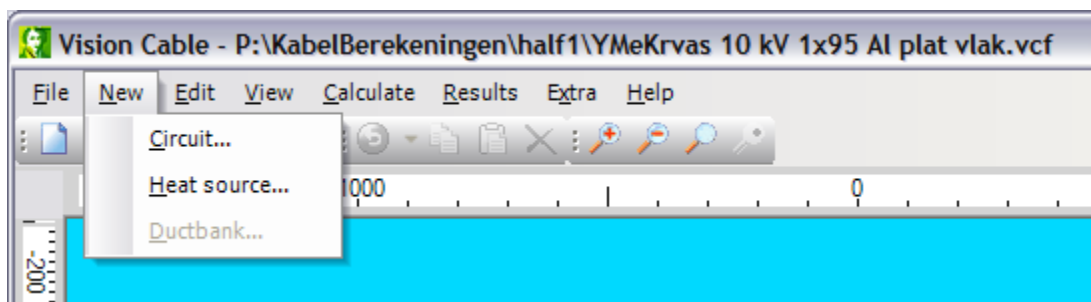
Circuit
Adding a new circuit. Adding is not allowed in the case of:
- an existing circuit in air
- an existing circuit in a through
- an existing circuit and 'partial drying out of soil' has been selected.

See also: Circuits 21 .

Heat source
Adding a heat source. Adding is not allowed in the case of:
- 'partial drying out of soil' has been selected
- a configuration with a duct bank
- lay in air

See also: Heat Source 28 .

Duct bank
Adding a new duct bank. Adding is only allowed in an empty configuration.

See also: Duct bank 28

PHASE TO PHASE

4.3.5.3   Edit
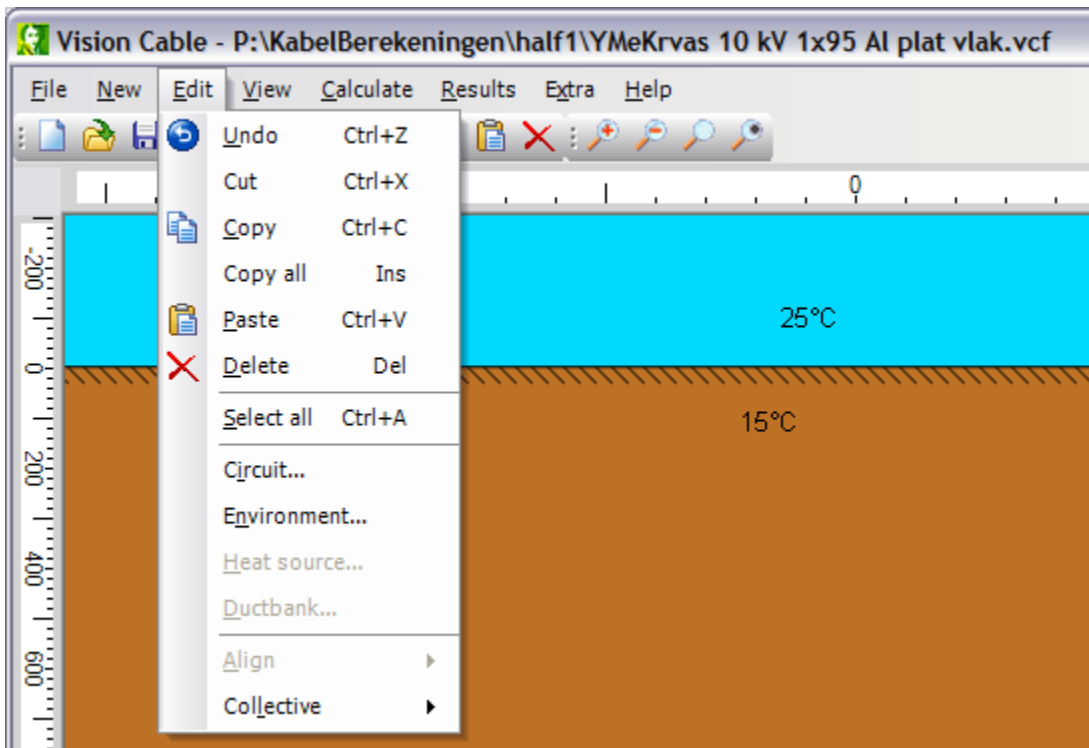
Undo
Undo the last action. This can also be invoked with CTRL-Z.

Actions that may be undone are:
- moving objects
- deleting objects
- adding objects
- changing objects
- changing environmental conditions

Cut
Copy and cut a selected circuit or a heat source. This can also be invoked with CTRL-X.

Copy
Copy a selected circuit or a heat source. This can also be invoked with CTRL-C.

Copy all
Copy all objects on the worksheet.

Paste
Paste a circuit or a heat source. This can also be invoked with CTRL-V.

Delete
Delete a selected circuit or a heat source. This can also be invoked with DEL.

Select all

Select all circuits and heat sources. This can also be invoked with CTRL-A.

Circuit
Edit a circuit. See Circuits 21 .

Environment
Edit the environmental parameters. Zie Omgeving 18 .

Heat source
Edit a heat source. See Warmtebron 28 .

Duct bank
Edit a duct bank. See Duct bank 28 .

Align

Align -> Horizontally, fixed distance between cables
Align all selected objects horizontally, prompting for the cable spacing.

Align -> Horizontally, center to center
Align all selected objects horizontally, prompting for the cable center to center distance.

Align -> Verticaally
Align all selected objects vertically.

Collective

Collective -> Current
Define current for all selected circuits.

Collectief -> Reset text position
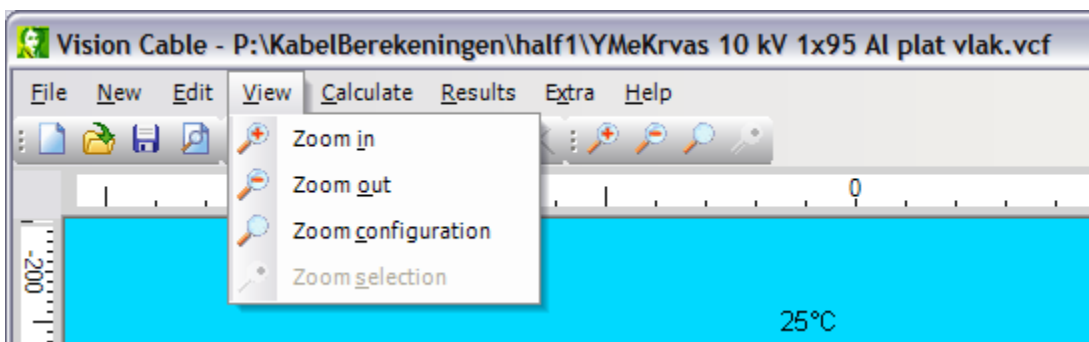Reset text position for all selected objects.

Collective -> Reset maximum conductor temperatures
Reset maximum conductor temperatures for all selected circuits to the standard values as defined in the options 57 .

4.3.5.4   View

Zoom in
Zoom in.

Zoom uit
Zoom out.

Zoom configuration
Zoom to the complete configuration.

Zoom selection
Zoom to all selected objects.

4.3.5.5   Calculate

The next two calculations always are active on the worksheet:
- Maximum current [33]
- Maximum temperature [34]

These calculations can be invoked using the menu and the speedbuttons.

Five other calculations are enabled depending on the situation:
- Temperature range [34]
- Cyclic current [35]
- Step current [37]
- Maximum load [39]
- Sensitivity analysis [41]

4.3.5.5.1 Maximum current

This menu item sets the standard calculation to 'Maximum current'. For all circuits their maximum currents will be calculated, depending to their lay, environment and other circuits and heat sources. Consequently, after every change on the worksheet, the calculation will be performed automatically.
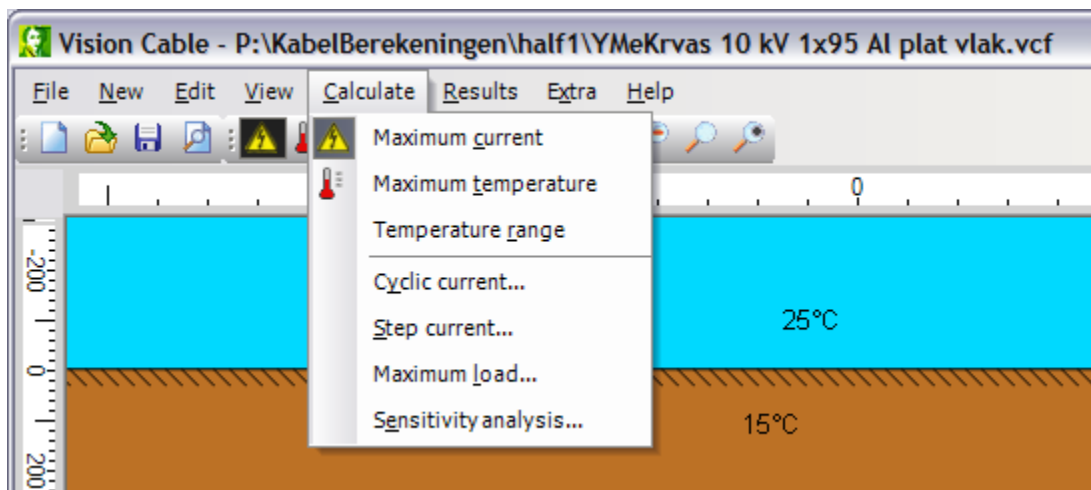
An exception will be made for circuits which were indicated to be calculated 'Calculate temperature only' (see: Current [25]).

The calculation of the maximum current is based on the maximum conductor temperature of the hottest cable. This temperature is defined in the *Options*, at **Calculation | Temperatures**.

In the 'Environment'-form, the frequency can be set for the entire configuration, being either 0, 50 or 60 Hz. If a value of 0 Hz has been chosen, the calculations will be made for a DC system.

PHASE TO **PHASE**

4.3.5.5.2 Maximum temperature

This menu item sets the standard calculation to 'Maximum temperature'. For all circuits their temperatures will be calculated for the specified currents, depending to their lay, environment and other circuits and heat sources. The currents are specified on the tab 'Current' from **Edit | Circuit**. Consequently, after every change on the worksheet, the calculation will be performed automatically.
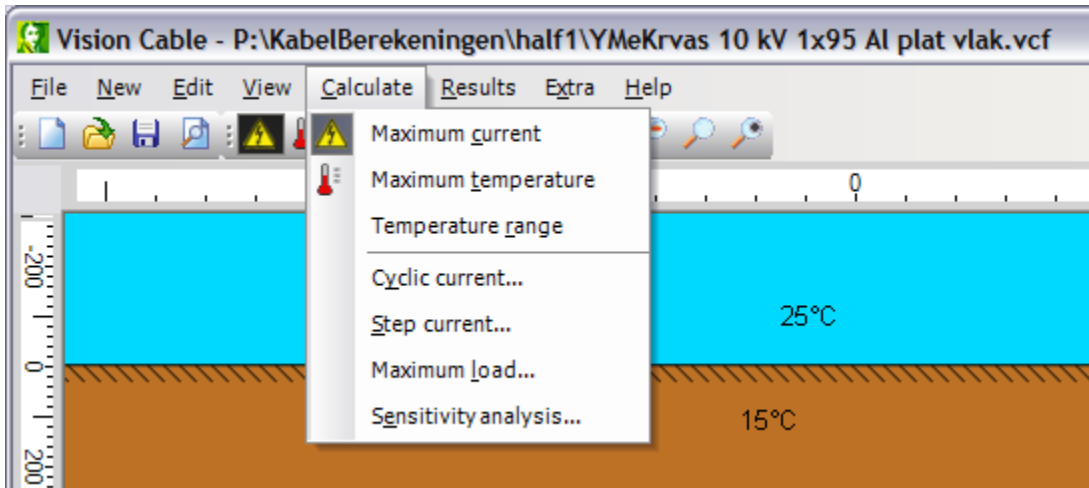
4.3.5.5.3 Temperature image

Calculation of the temperature image of the complete configuration, buried only. The results are presented in ranges of 5 degrees C.

This calculation is disabled in the case of:
- configuration in air
- buried configuration with ' partially drying out of soil'
- a circuit in a through
- a configuration in a duct bank
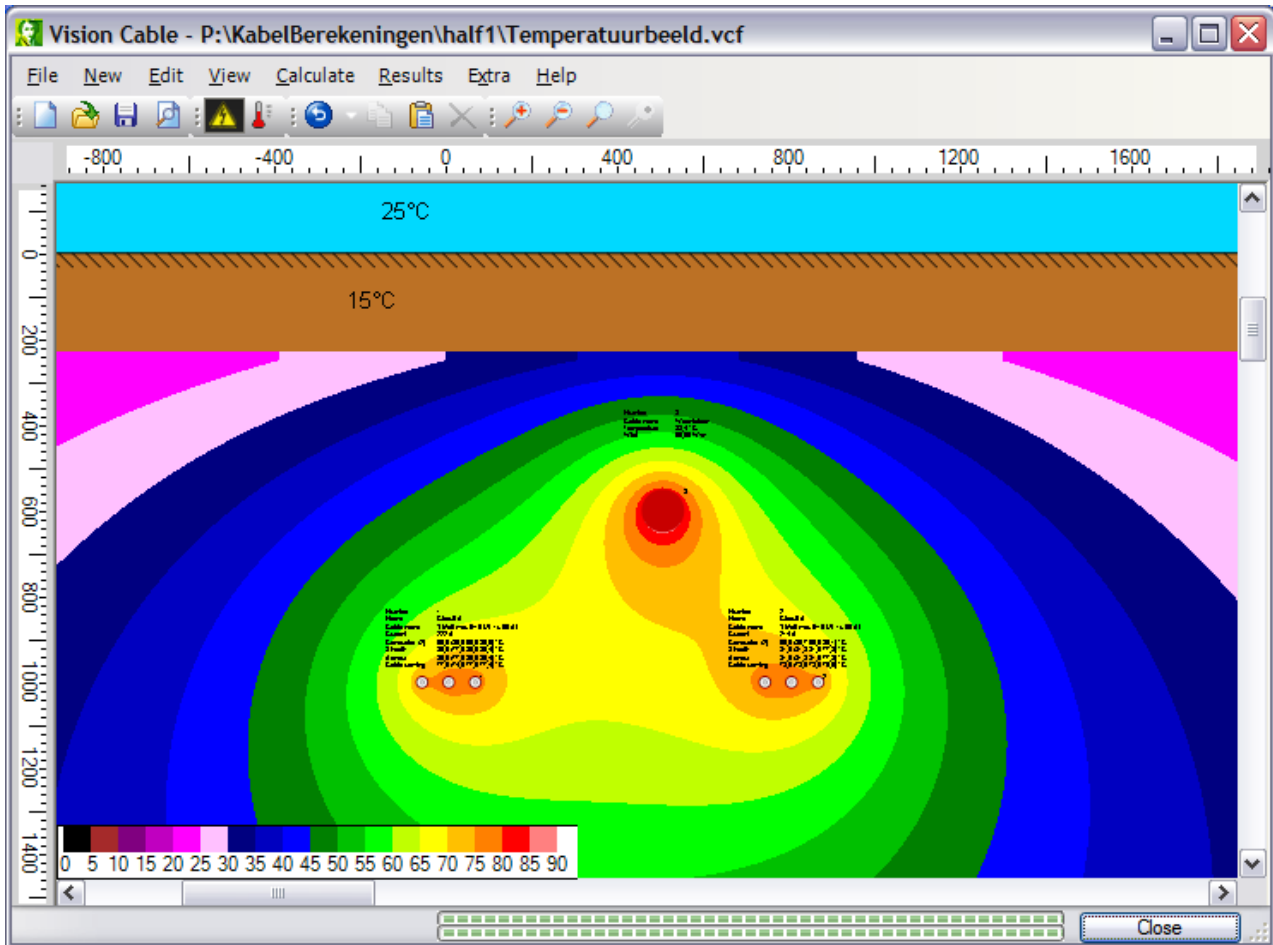
4.3.5.5.4 Batch

This function automatically performs a number of calculations for multiple configuration files. The calculations are:
- Maximum current
- Step current (temperature after 1 day and after 365 days)
- Maximum step load (current after 1 day and after 365 days)

The Batch-function can only be invoked in an empty configuration.

The results file will be stored in the same direction of the configuration files and has a unique name, based on the system date. The results file is an Excel spreadsheet file.

4.3.5.5.5 Cyclic current

The cyclic current calculation determines the maximum current for a circuit that is subject to a daily varying pattern of 24 current values. The method calculates a factor, by which the stationary current may be multiplied to obtain the peak value of the load pattern. The calculation complies to IEC 60853-2.

The calculation is enabled for configurations with one circuit or with multiple circuits of equally loaded identical cables.
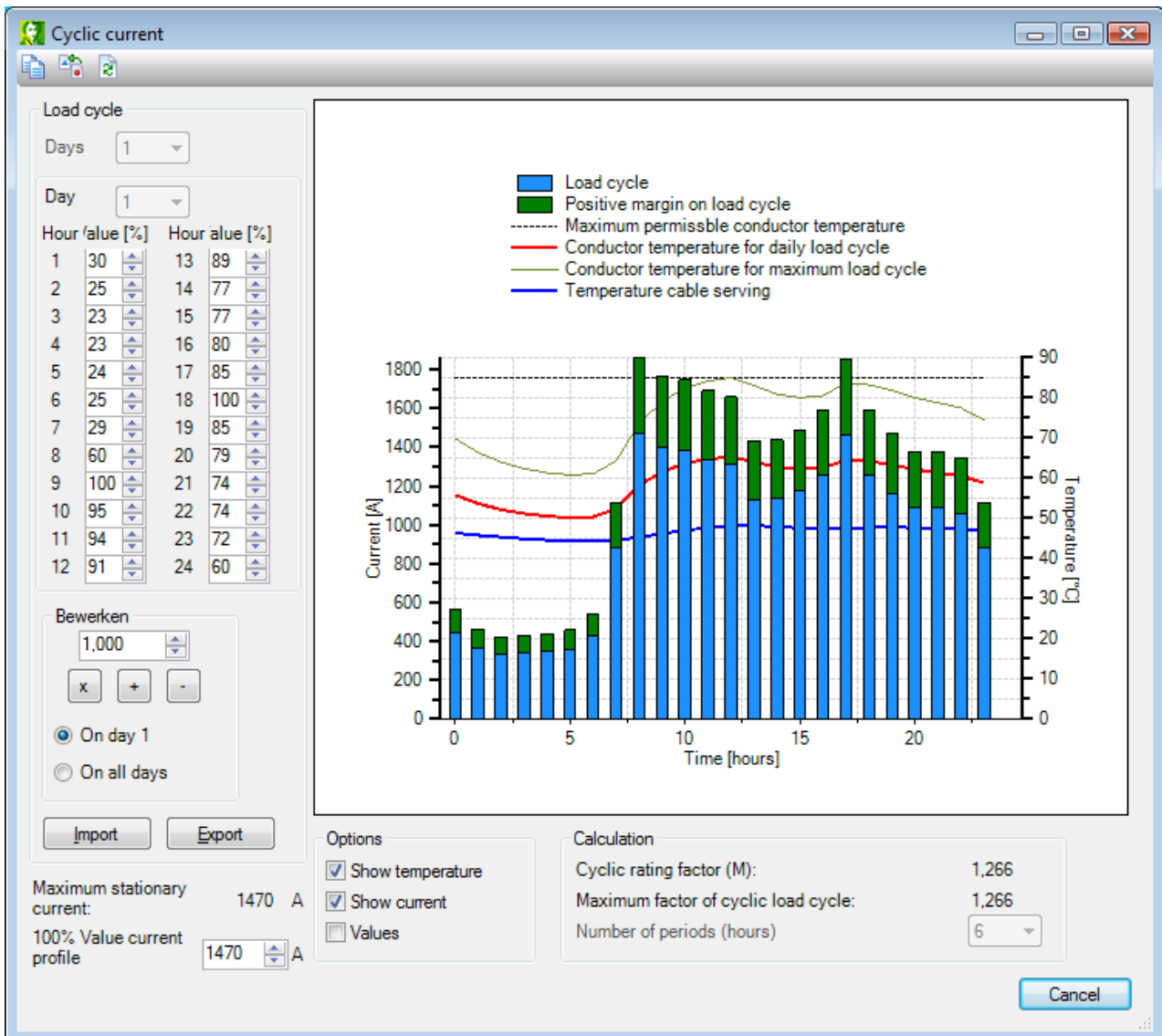
The current profile
- The screen shows, in blue, a default load cycle, based on the stationary maximum current. The percentage values can be edited on the left hand side.
- The green parts of the bar chart show the extra current margin for the particular load cycle.
- In the case that the load cycle is too high, the red parts of the bar chart indicate the corresponding negative margin.

Temperature profile
Also presented are the conductor temperatures:
- for the defined load profile (orange line)
- for the maximum load profile (grey line)
- for the maximum stationary current (red line).

Import and Export
The load profile can be imported from and exported to a file, using the buttons **Import** and **Export**.

Editing a load profile
The load profile can be edited by changing the numeric fields, named 1 to 24:
- numeric fields: fill in the percentages
- the profile can be multiplied, added or subtracted by using a factor.

Options
These checkboxes enable presenting the temperature graphs, load cycle bar chart and temperature values.

Calculation
The results are presented as:
- Cyclic load factor (M). This is the factor M as described in IEC60853-2. The "Cyclic load factor (M)" is the value that indicates how high the maximum of the load cycle may be, expressed in M times the maximum stationary current.
- Maximum factor of cyclic load cycle. This is the factor by which all actual load cycle values may be multiplied, to obtain the maximum load cycle.

4.3.5.5.6 Step current

The IEC 60853 describes an "Emergency Load" calculation, to calculate the maximum step load during a given time period. The calculation is based on the dynamic temperature change after a step increase of the cable load current. The calculation is enabled for configurations with one circuit of multiple equally loaded identical circuits.

Normal current
This value indicates the cable current before the "Emergency Load" step increase. The higher the normal current, the lower the emergency load current can be.

Step current
This value indicates the current at time t = 0. This value has to be larger than the normal current value.

Calculation time
This value indicates the total simulation time.

Result

The calculation result is a temperature graph, starting at the stationary values for the normal current and growing according the step current. Presented are:
- orange line: conductor temperature
- green line: serving temperature
- red line: maximum allowed temperature for this conductor.

The example below shows a circuit with a normal load of 100 A and a step current of 269 A. In 24 hours the conductor temperature increases from 23 to 61 degrees C. The serving temperature increases from 22 to 48 degrees C.

3D
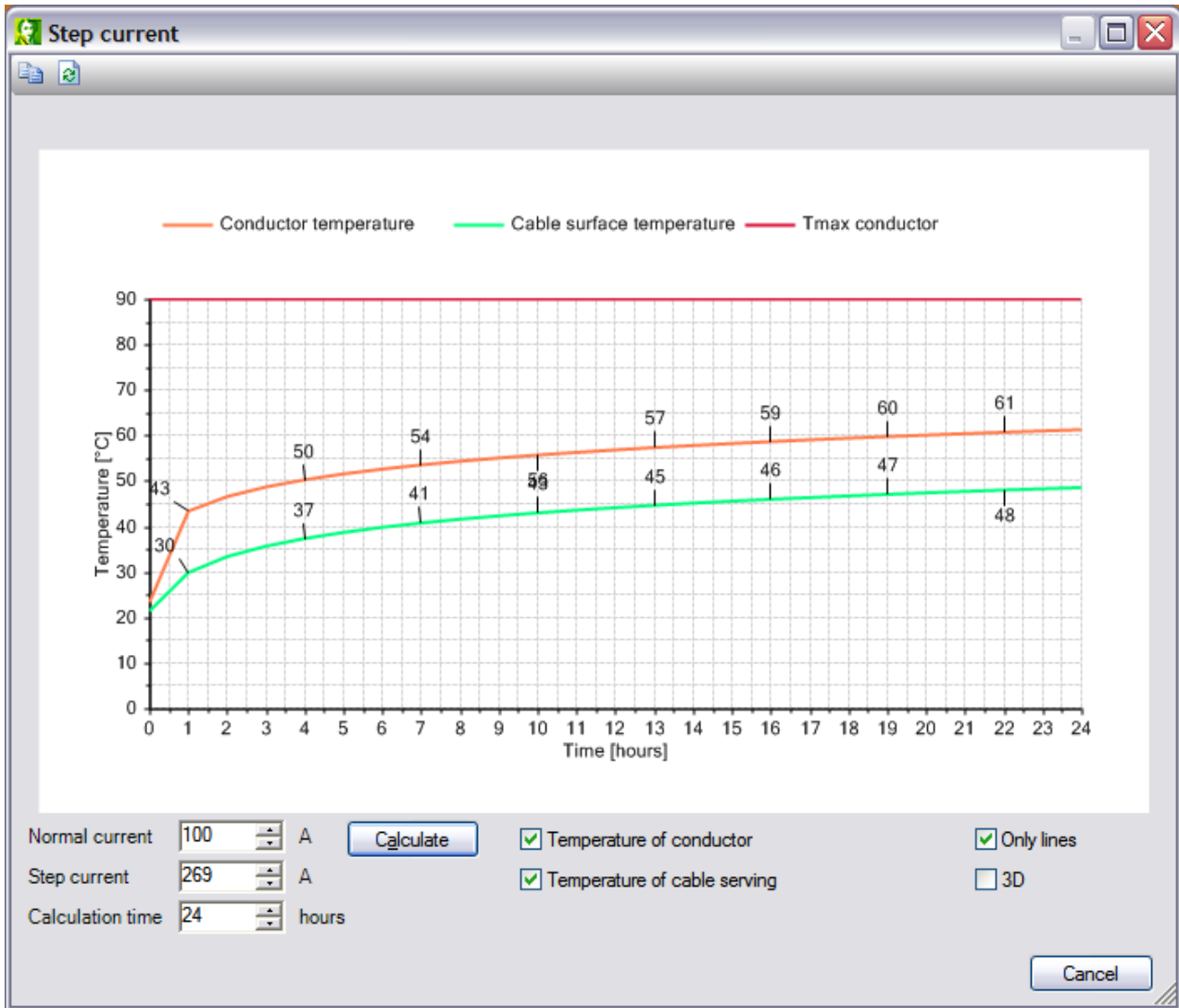
In a three-dimensional graph the temperatures are presented for values of the normal load, varying in 10% steps from 0 to 100% of the defined step current.

The example below shows the results for a circuit with a step current of 269 A. A normal load of 0% of the step current results in a low ascending graph. A normal load of 100% of the step current results in a not ascending high graph. The fourth curve, with a 40% normal load, almost matches the previous example with a 100 A normal load.
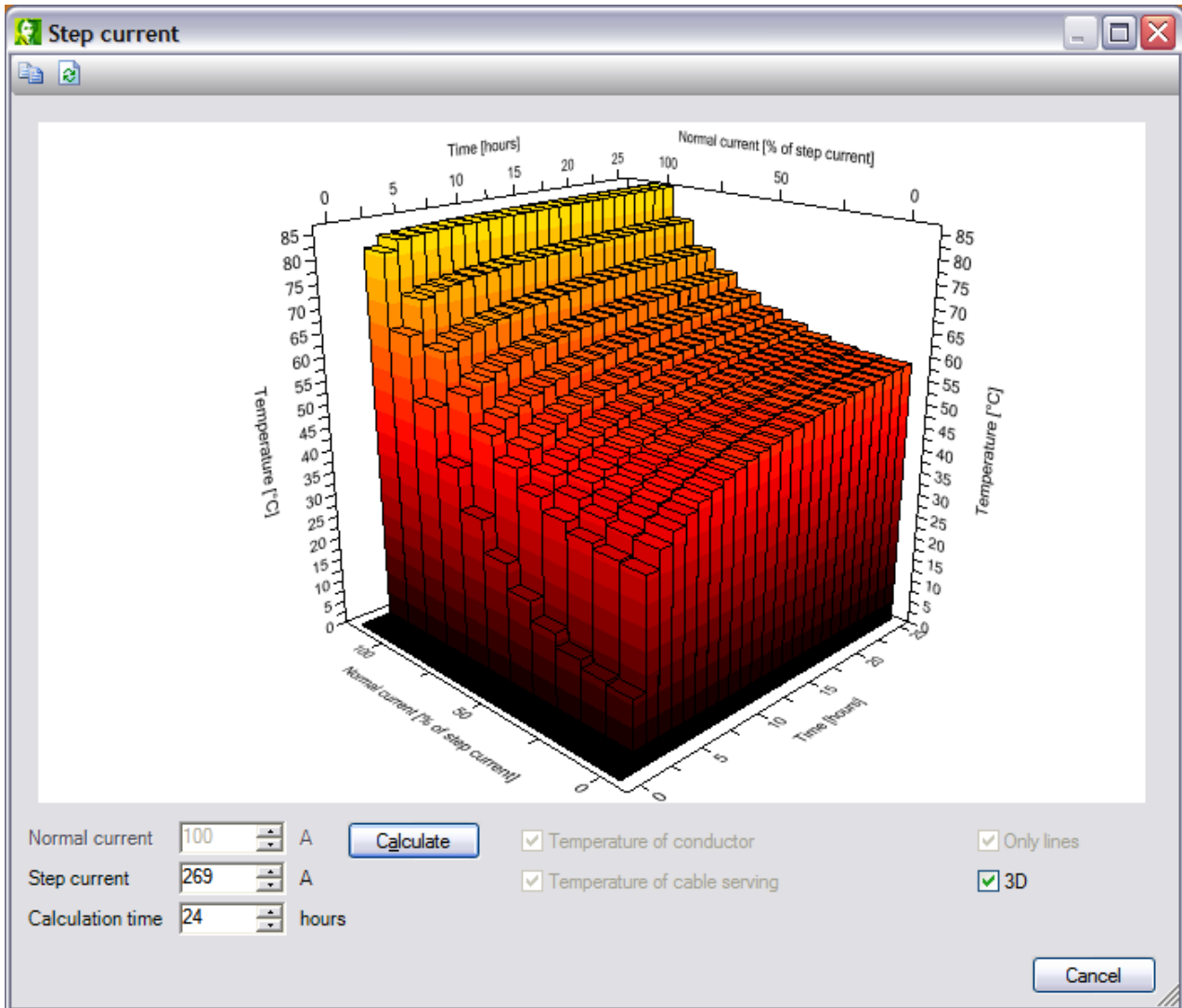
4.3.5.5.7 Maximum load

The IEC 60853 describes an "Emergency Load" calculation, to calculate the maximum step load during a given time period. The calculation is based on the dynamic temperature change after a step increase of the cable load current. The calculation is enabled for configurations with one circuit of multiple equally loaded identical circuits.

Normal current
This value indicates the cable current before the "Emergency Load" step increase. The higher the normal current, the lower the emergency load current can be.

Calculation time
This value indicates the total simulation time.

Result

Result of the calculation is a graph, presenting the maximum emergency current as function of the duration of the emergency current.
The example below shows that, with a normal load of 100 A, the maximum emergency current during 8 hours is 357 A. After this period, the maximum current should not exceed the maximum stationary value.

3D
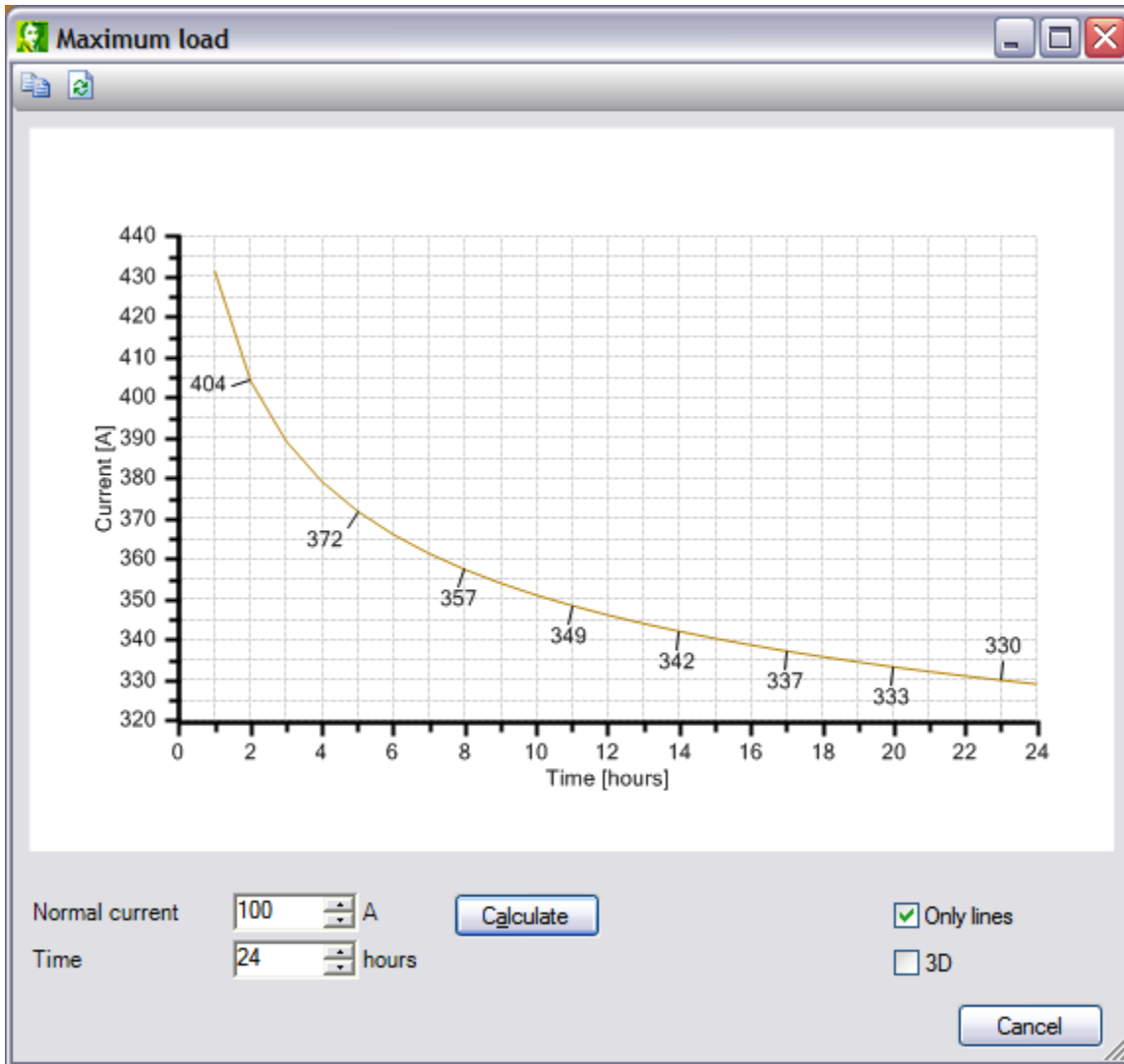
In a three-dimensional graph the maximum emergency durations are presented for values of the normal load, varying in 10% steps from 0 to 100% of the maximum stationary current.

The example below shows the results for a circuit with a step current of 269 A. A normal load of 0% of the maximum stationary current results in a high graph. A normal load of 100% of the maximum stationary current results in a low graph. The fourth curve, with a 40% normal load, almost matches the previous example with a 100 A normal load.
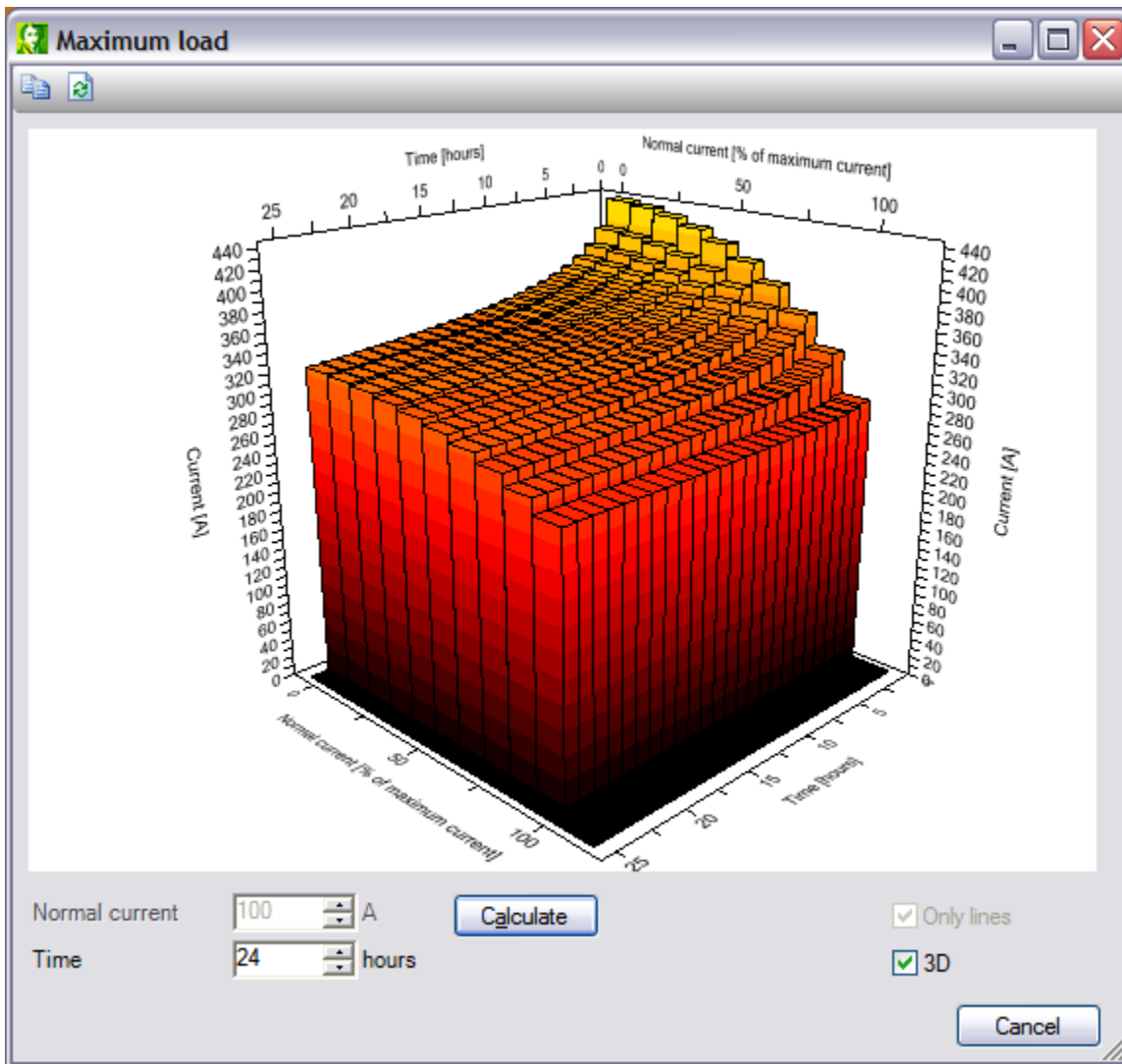
4.3.5.5.8 Sensitivity analysis

The sensitivity analysis evaluates the maximum stationary current for variations of depth (L), specific thermal
resistance of the environment (G) and external thermal resistance (T4) of the circuit.
The analysis is only enabled for one selected buried circuit (not in a duct bank).

The sensitivity analysis calculates the maximum stationary current for varying parameters:
• Depth, varied from 0,3*L to 2*L, where L is the specified depth of lay
• G-value: varied from 0,5*G to 2,5*G, where G is the specific thermal resistance of the soil
• T4-value: varied from 0,5*T4 to 2*T4, where T4 is the thermal resistance of the soil.

When two circuits cross each other, the value of 0 A will be presented as result.
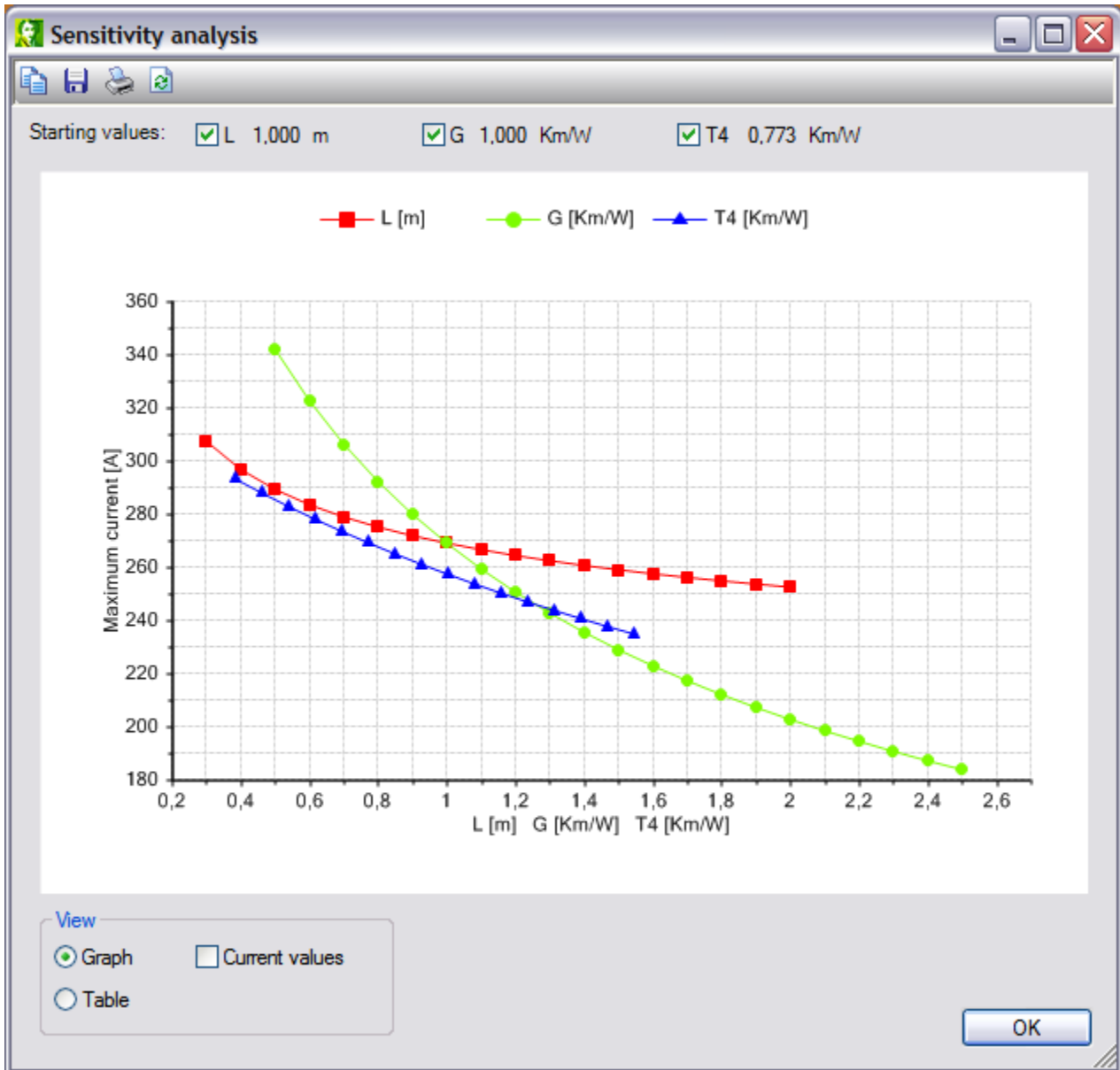
All results can also be presented in a table:
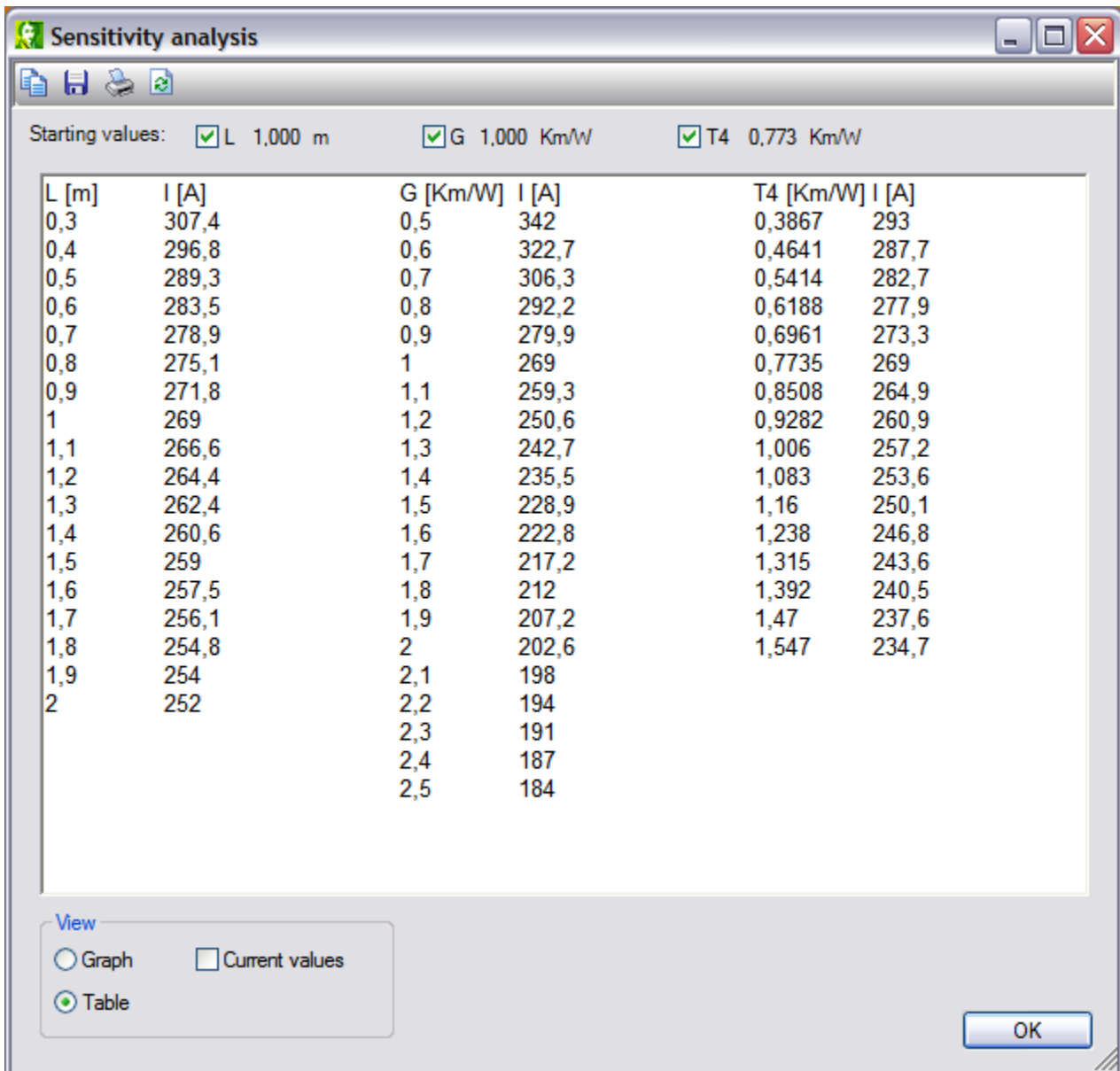
4.3.5.6   Results

All results are presented immediately in the graphic worksheet. More information can be obtained from the details, by choosing **Results | General**. Some results can also be exported to a CSV-file.

4.3.5.6.1 General
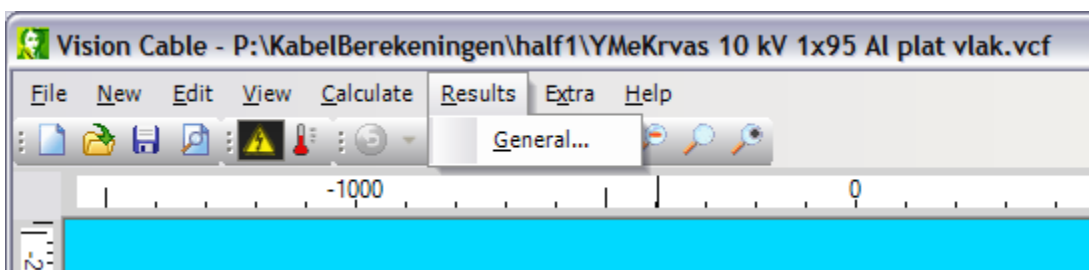
The **Results | General** function presents detail information of:

- Cable construction:
  - conductor
  - isolation
  - screen
  - bedding
  - armour
  - serving
- Installation:
  - duct
  - duct bank
- Circuit:
  - cable type
  - configuration parameters
  - maximum stationary current
- Temperature image:
  - conductor
  - screen
  - armour
  - serving
  - duct
- Electrical data:
  - resistances
  - capacity
  - induction, reactance
- Losses:
  - conductor
  - screen
  - armour
- Thermal resistances:
  - isolation
  - bedding
  - serving
  - environment

Result

Cable construction
Installation
Circuit
Temperatures
Electrical data
Losses
Thermal parameters

Vision Cable Version 1.4.0
P:\KabelBerekeningen\half1\YMeKrvas 10 kV 1x95 Al plat vlak.vcf
14-5-2008 12:46:18

Cable construction:				Circuit:		
Conductor:				Cable type	:	YMeKrvas 6/10 kV 1x 95 Al
Cond. cross-section	:	95 mm²		Rated voltage	:	10392 V
Nr of conductors	:	1		U0 (phase-to-ground)	:	6000 V
Config,type,material	:	Round,Solid,Al		Frequency	:	50 Hz
Diameter	:	10,7 mm		Depth of lay	:	1000 mm
Screen material	:	Copper Tape		Axial sep. cables	:	62 mm
Diam. cond. screen	:	11,9 mm		Lay	:	ground, no drying
				Configuration	:	flat formation
Isolation:				Bonding	:	single point
Material	:	XLPE unfilled		Temp. of environment	:	15 °C
Diam. isolation	:	23 mm		Thermal res. ground	:	1 Km/W
Diam. core-screen	:	24 mm		Current at 90°C cond. temp	:	269 A
Diam. cores	:	0 mm				
				Temperatures:		
Screen:				Conductor	:	90 °C
Material	:	Copper		Sheath	:	76,6 °C
Cable type	:	Separate		Arm	:	74,7 °C
Conducting surface	:	1 mm²		Cable serving	:	70,5 °C
Diameter	:	24 mm				
Thickness	:	0,01 mm		**Electrical data:**		
				Rdc at 20°C	:	0,32 Ohm/km
Bedding:				Rdc (operating temp)	:	0,4103 Ohm/km
Material	:	Rubber		Rac (operating temp)	:	0,4105 Ohm/km
Diameter	:	26 mm		skin effect (ks)	:	1
				skin effect factor (ys)	:	0,0005001
Arm:				proximity effect (kp)	:	1
Material	:	Copper		proximity effect factor (yp)	:	6,512e-05
Configuration	:	Separate		Rs (sheath)	:	1,004 Ohm/km
Type	:	Wire		Ra (arm)	:	1,055 Ohm/km
Lay of wires	:	Longitudinal lay		Capacity	:	0,2156 µF/km
Internal diameter	:	23 mm		Induction	:	0,5862 mH/km
External diameter	:	24 mm		Reactance	:	0,1842 Ohm/km
Conducting surface	:	20 mm²				
Wire thickness	:	0,7 mm		**Losses:**		
Nr of wires	:	51		Conductor	:	29,38 W/m
				Lambda1R	:	0,0001319
Cable serving:				Lambda1S	:	0,0005274
Material	:	PE		Lambda1T	:	0,0001319
Diameter	:	31 mm				
				Thermal parameters:		
				T1	:	0,4495 Km/W
				T2	:	0,0637 Km/W
				T3	:	0,1426 Km/W
				T4	:	0,7735, 0,7735, 0,7735 Km/W

4.3.5.6.2 Export

The detail results can be exported to a CSV-file, using the fourth speedbutton.
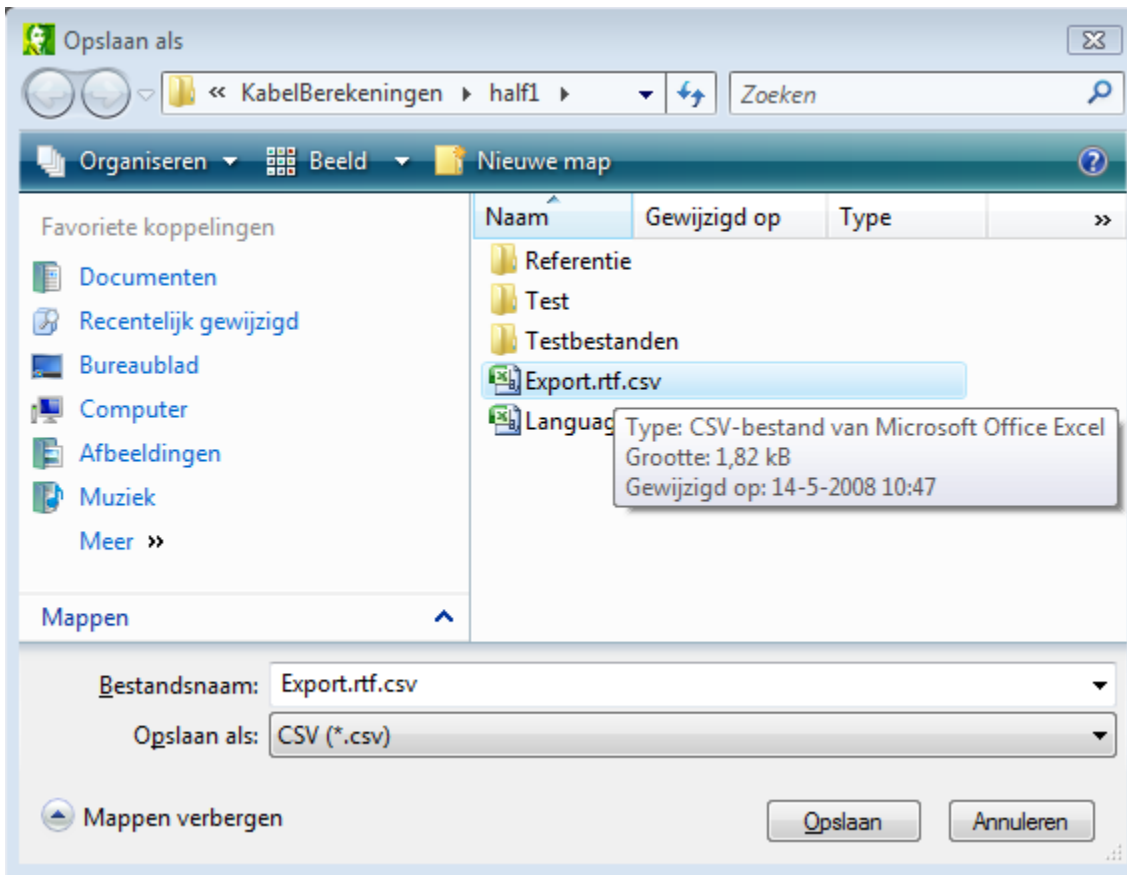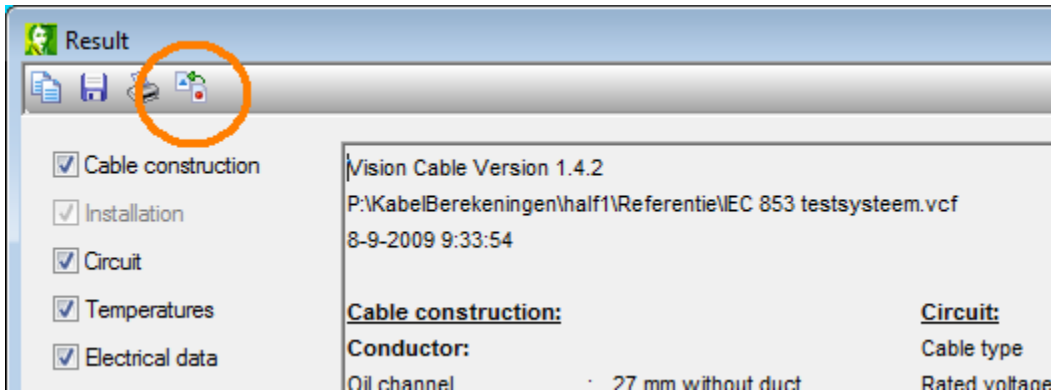
4.3.5.7 Extra
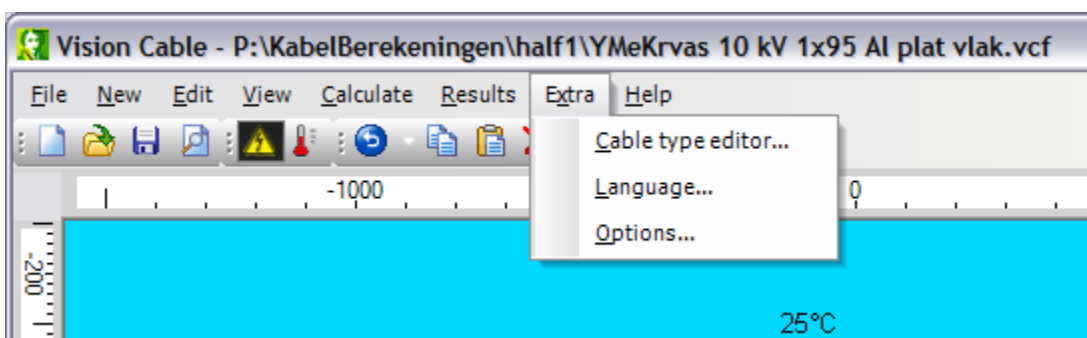
The Extra-menu contains tools and options.

Cable type editor
The cable type editor manages the cable type data. Cables can be added and modified. See: Cable type editor 47.

Language
Switching languages. See: Language 55.

Options
General settings for Vision *Cable analysis*. See: Options 55.

4.3.5.7.1 Cable type editor

The cable type editor manages the cable type data. Cables can be added and modified.

In the upper left corner in the form a cable can be selected from the database.

Filter for the voltage level:
The voltage levels are line voltages, however, in the cable type database, the phase voltage is stored.
Some PILC cables have a higher phase voltage (8/10 and 10/10 kV), so these cables will be in a higher voltage range.

Cable type
A selected cable type can be modified. Also a new cable type can be added.

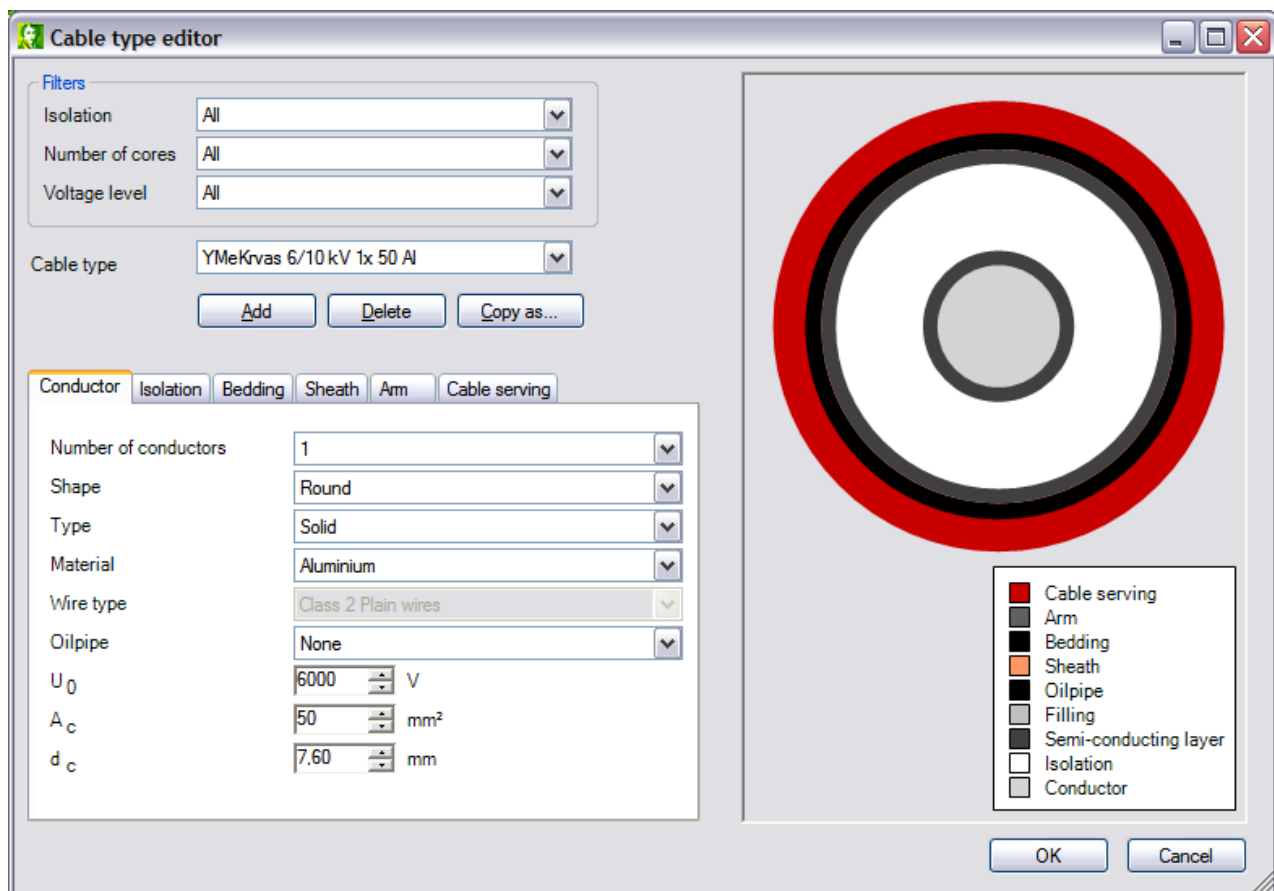| Kabeltype editor	Description	Values
Number of conductors	Number of conductors in the cable	1,3
Shape	Conductor cross-sectional shape	round, sector, oval
Type	Conductor type	solid, stranded, compact, milliken
Material	Conductor material	copper, aluminium
Oil pipe	Type of oil channel in/near conductor	internal, external, ductless
Isolation material	Isolation material	paper olie filled, paper mass impregnated, rubber, butyl rubber, EPR, PVC, PE, XLPE filled, XLPE unfilled, PPL, bitumen / jute, polychloroprene, paper oil pressure, paper mass impregnated internal gas pressure, papier pre-impregnated internal gas pressure, paper external gas pressure
Screen material	Conductor / Isolation screen	aluminium tape, copper tape, metalized paper, metaal tape, XLPE semiconductive layer
Screen	Afscherming van de kabel	lood, staal, brons, roestvast staal, aluminium, koper
Sheath/Cable type	Sheath	separate, common, belted, SL-type, corrugated, pipe-type
Bedding material	Bedding between sheath and armour	paper oil filled, paper mass impregnated, rubber, butyl rubber, EPR, PVC, PE, XLPE filled, XLPE unfilled, PPL, bitumen / jute, polychloroprene, paper oil pressure, paper mass impregnated internal gas pressure, paper pre-impregnated internal gas pressure, paper external gas pressure
Arm material	Armour material	load, steel, bronze, stainless steel, aluminium, copper
Arm configuration	Armour configuration	separate, common
Arm type	Armour type	tape, wire, mixed
Lay of wire tapes	Lay of armour wires and tapes	long, 54 degrees, short, 2 or more layers wound up
Serving material	Serving material	rubber, PVC, PE, bitumen / jute

The next table summarizes the construction parameters.

| Kabeltype editor	Description
U_0	Rated cable voltage phase to ground (V)
A_c	Conductor cross-sectional area (mm2)
d_c	Round conductor diameter (mm)
d_i	Oil channel diameter (mm)
d_{cM}	Oval conductor largest diameter (mm)
d_{cm}	Oval conductor smallest diameter (mm)
t_1	Isolation thickness (mm)
δ_1	Conductor screen thickness (mm)
A_s	Sheath cross-sectional area (mm2)
D_s	Sheath external diameter (mm)
D_{oc}	Corrugated sheath external crest diameter (mm)
D_{ot}	Corrugated sheath external through diameter (mm)
d_M	Oval conductor major diameter of screen or sheath (mm)
d_m	Oval conductor minor diameter of screen or sheath (mm)
t_s	Sheath thickness (mm)
t_2	Bedding thickness (mm)
d_{Ai}	Armour internal diameter (mm)
d_A	Armour external diameter (mm)
d_{AM}	Oval conductor separate armour major diameter (pipe-type cable) (mm)
d_{Am}	Oval conductor separate armour minor diameter (pipe-type cable) (mm)
d_f	Armour wires diameter (mm)
A	Armour cross-sectional area (mm2)
n_1	Number or armour wires
D_d	Pipe-type cable internal pipe diameter (mm)
D_o	Pipe-type cable external pipe diameter (mm)
D_e	Cable external diameter (mm)
D_{oga}	Diameter over laid up cores (mm)

Examples of three common cable types:
- single-core XLPE cable with aluminium conductor [49]
- three-core XLPE cable with copper conductor [51]
- three-core PILC cable with copper conductor [53]

4.3.5.7.1.1 Example single-conductor XLPE cable

Construction

The example concerns a 1x95 mm2 Al 10 kV XLPE cable.
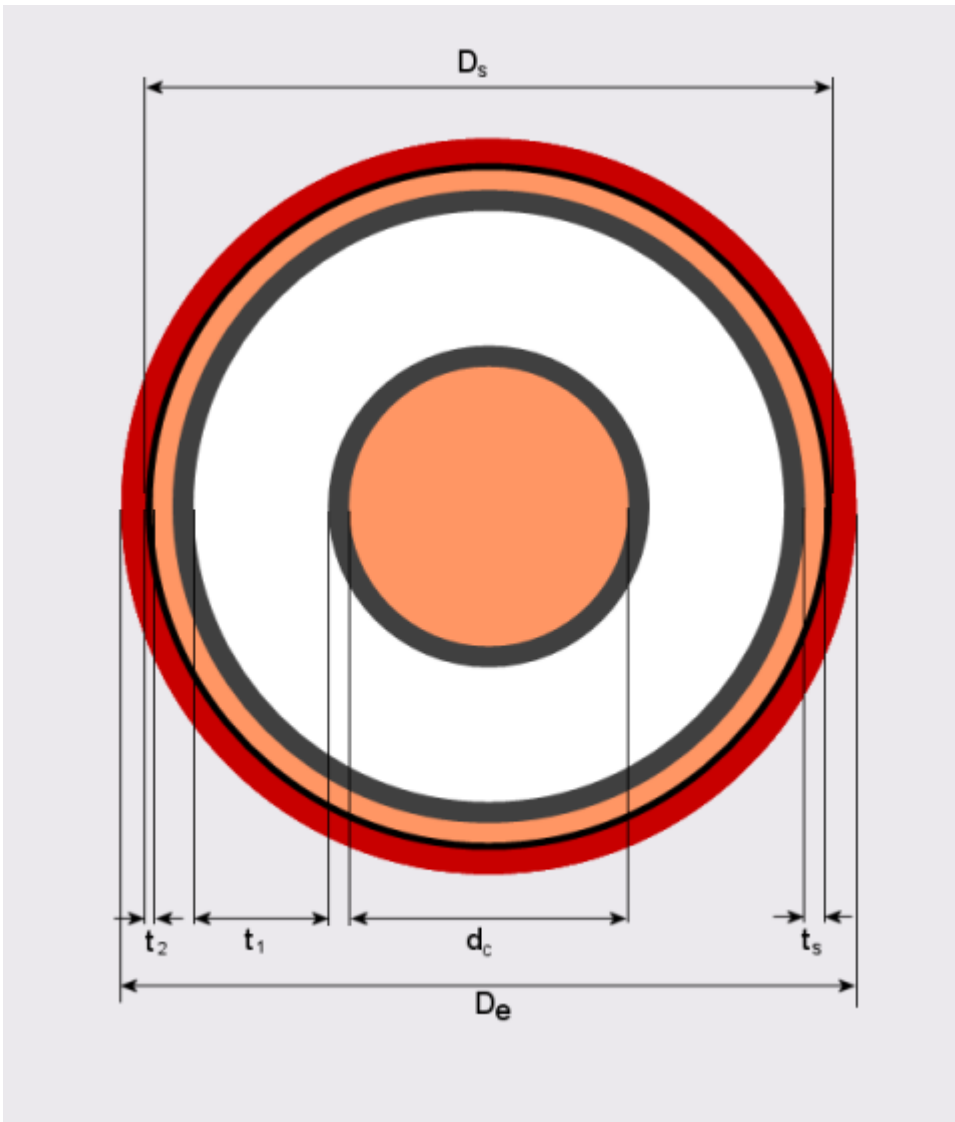
Conductor:
Number of conductors	1
Shape	Round
Type	Solid
Material	Aluminium
Oil channel	None

Isolation material:
Isolation material	XLPE unfilled
Conductor/isolation screen	XLPE semi-conductive layer

Sheath:
Sheath material	Copper
Sheath/cable type	Separate

Bedding:
Bedding material	Rubber

Armour:
Armour material	None
Armour configuration	None
Armour type	None

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Lay of wire tapes   None

Cable serving:
Cable serving material   PE

Next, specify the construction data for this 1x95 mm2 Al cable.
- Start from the outside: cable serving diameter (D_e=31 mm). This defines the size of the graphical construction presentation.
- Enter the conductor data: rated voltage (U_o=6000 V) and the conductor cross-sectional area (A_c=95 mm^2).
- Enter the conductor diameter (d_c=10.7 mm). Now the conductor is presented in the graph.
- Enter the isolation thickness (t_1=3.4 mm).
- Enter the sheath external diameter (D_s=24.5 mm) and the sheath thickness (t_s=0.33 mm). The sheath is now visible in the graph. Calculate or enter the sheat cross-sectional area (A_s =25 mm^2).
- Enter the bedding thickness (t_2=1 mm).

In the construction the conductor screen and isolation screen are calculated as follows:
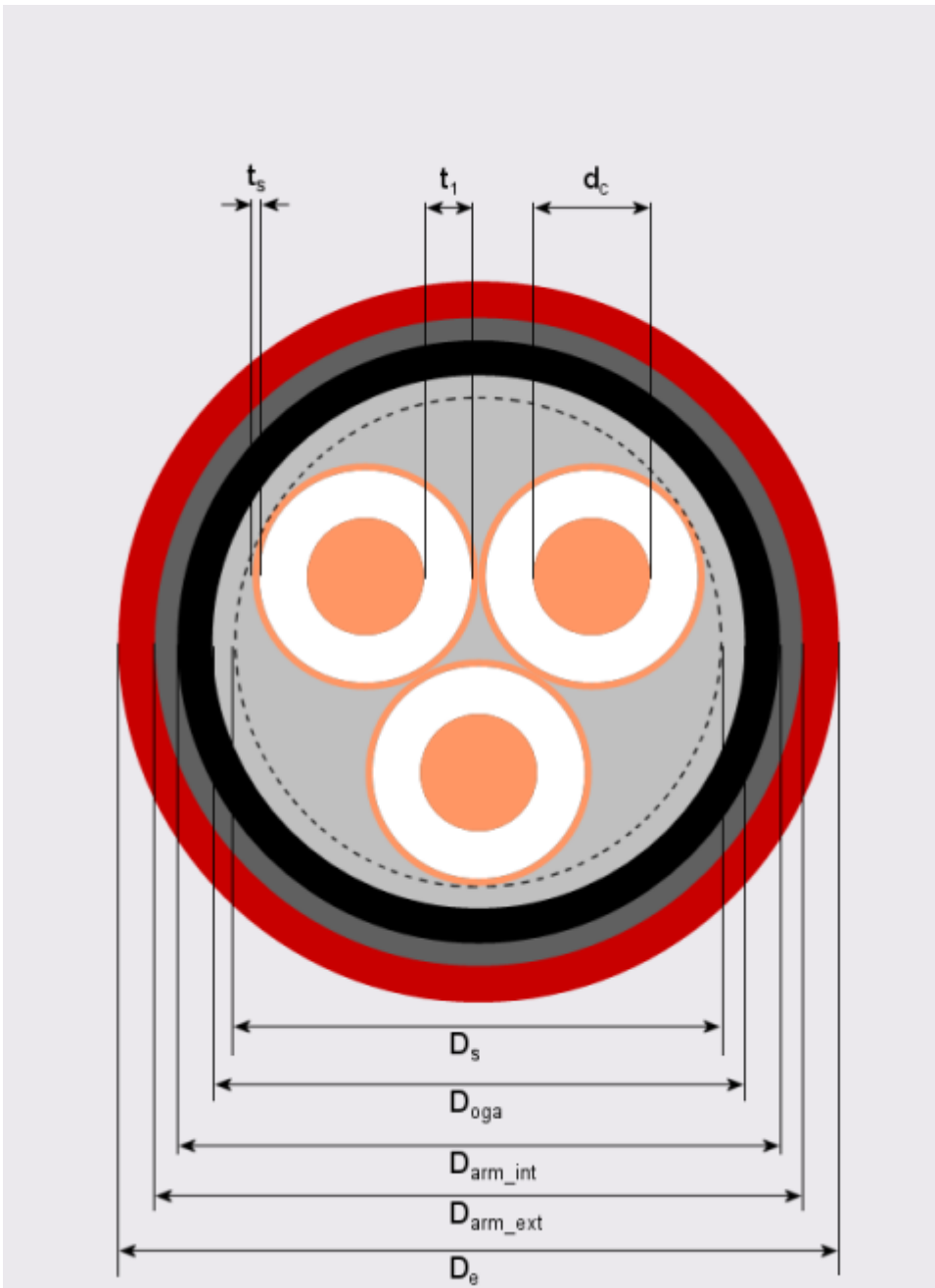$$t_{screen} = [D_s - (d_c + 2\,t_1 + 2\,t_s)] / 4$$

In the construction the serving thickness (t_e) is calculated as follows:
$$t_e = [D_e - d_A] / 2$$

4.3.5.7.1.2 Example three-conductor XLPE cable

Construction

The example concerns a 3x95 mm2 Cu 10 kV XLPE cable.

Conductor:

Number of conductors	3
Shape	Round
Type	Stranded
Material	Copper
Oil channel	None

Isolation material:

Isolation material	XLPE unfilled
Conductor/isolation screen	XLPE semi-conductive layer

Sheath:

Sheath material	Copper
Sheath/cable type	SL

Bedding:
Bedding material   PVC

Armour:
Armour material   Steel
Armour configuration   Common
Armour type   Wire
Lay of wire tapes   Longitudinal lay

Cable serving:
Cable serving material   PVC

Next, specify the construction data for this 3x95 mm2 Cu cable.
- Start from the outside: cable serving diameter (D_e=65 mm). This defines the size of the graphical construction presentation.
- Enter the armour data: number of wires (n_1=69), armour wire diameter (d_f=2.5 mm), external armour diameter (d_A=60 mm) and internal armour diameter (d_{Ai}=55 mm).
- Enter the conductor data: rated voltage (U_o=6000 V) and the conductor cross-sectional area (A_c=95 mm^2).
- Enter the conductor diameter (d_c=11.7 mm). Now the conductors are presented in the graph.
- Enter the isolation thickness (t_1=3.4 mm).
- Enter the sheath external diameter (D_s=22.5 mm) and the sheath thickness (t_s=0.1 mm). The sheath is now visible in the graph. Calculate or enter the sheath cross-sectional area (A_s =7 mm^2).
- Enter the bedding thickness (t_2=3.5 mm).
- Enter the diameter over laid up cores (D_{oga}=51 mm).

In the construction the conductor screen and isolation screen are calculated as follows:
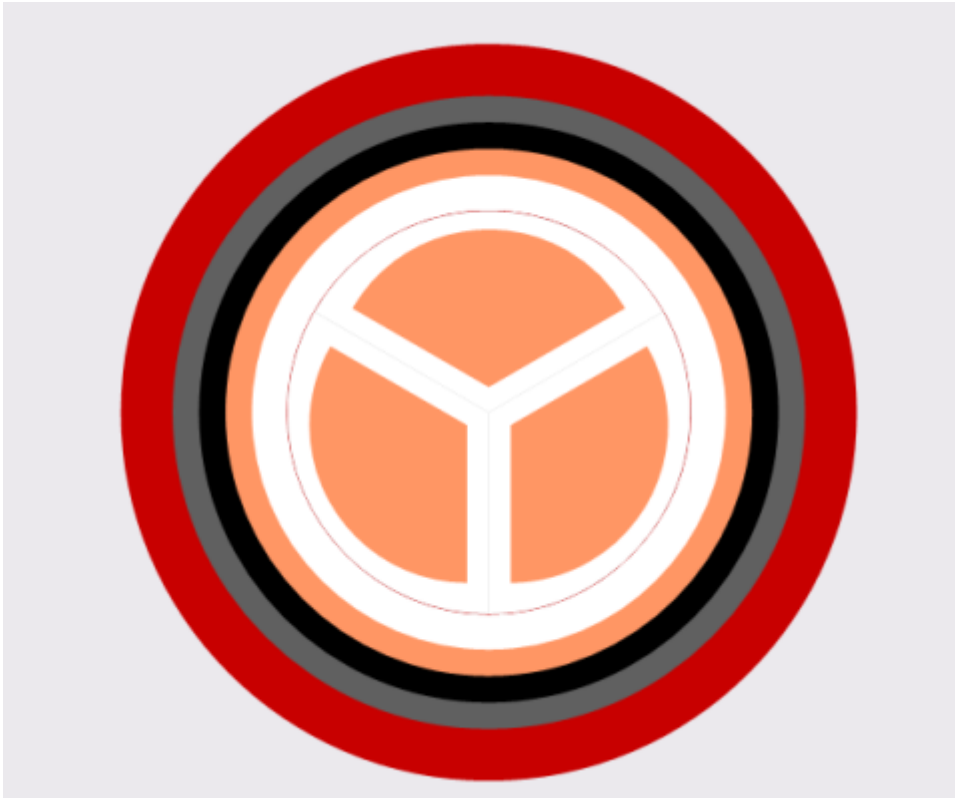$$t_{screen} = [D_s - (d_c + 2 \, t_1 + 2 \, t_s)] / 4$$

In the construction the serving thickness (t_e) is calculated as follows:
$$t_e = [D_e - d_A] / 2$$

4.3.5.7.1.3 Example three-conductor PILC cable

Construction

The example concerns a 3x95 mm2 Cu 8/10 kV PILC cable with lead sheath and steel tape armour.

Conductor:
Number of conductors   3
Shape   Sector
Type   Stranded
Material   Copper
Oil channel   None

Isolation material:
Isolation material   Paper, mass impregnated
Conductor/isolation screen Metalized paper

Sheath:
Sheath material   Lead
Sheath/cable type   Belted

Bedding:
Bedding material   Paper, mass impregnated

Armour:
Armour material   Steel
Armour configuration   Common
Armour type   Tape
Lay of wire tapes   2 or more layers wound up

Cable serving:
Cable serving material   Bitumen / Jute

Next, specify the construction data for this 3x95 mm2 Cu cable.
- Start from the outside: cable serving diameter (D_e=54 mm). This defines the size of the graphical construction presentation.
- Enter the armour data: external armour diameter (d_A=50 mm) and internal armour diameter (d_{Ai}=45.5 mm).

Calculate or enter the armour cross-sectional area (A=200 mm^2)
- Enter the conductor data: rated voltage (U$_o$=8000 V) and the conductor cross-sectional area (A$_c$=95 mm^2).
- Enter the conductor diameter (d$_c$=11.7 mm). Now the conductors are presented in the graph.
- Enter the diameter over laid up cores (D$_{oga}$=32 mm).
- Enter the isolation thickness (t$_1$=3.9 mm).
- Enter the sheath external diameter (D$_s$=40 mm) and the sheath thickness (t$_s$=2 mm). The sheath is now visible in the graph. Calculate or enter the sheath cross-sectional area (A$_s$ =238.76 mm^2).
- Enter the bedding thickness (t$_2$=2.75 mm).

The quotient of conductor isolation and belt isolation is determined from the diameter over the laid up cores (D$_{oga}$).

In the construction the serving thickness (t$_e$) is calculated as follows:

$$t_e = [D_e - d_A] / 2$$

4.3.5.7.2 Langauge

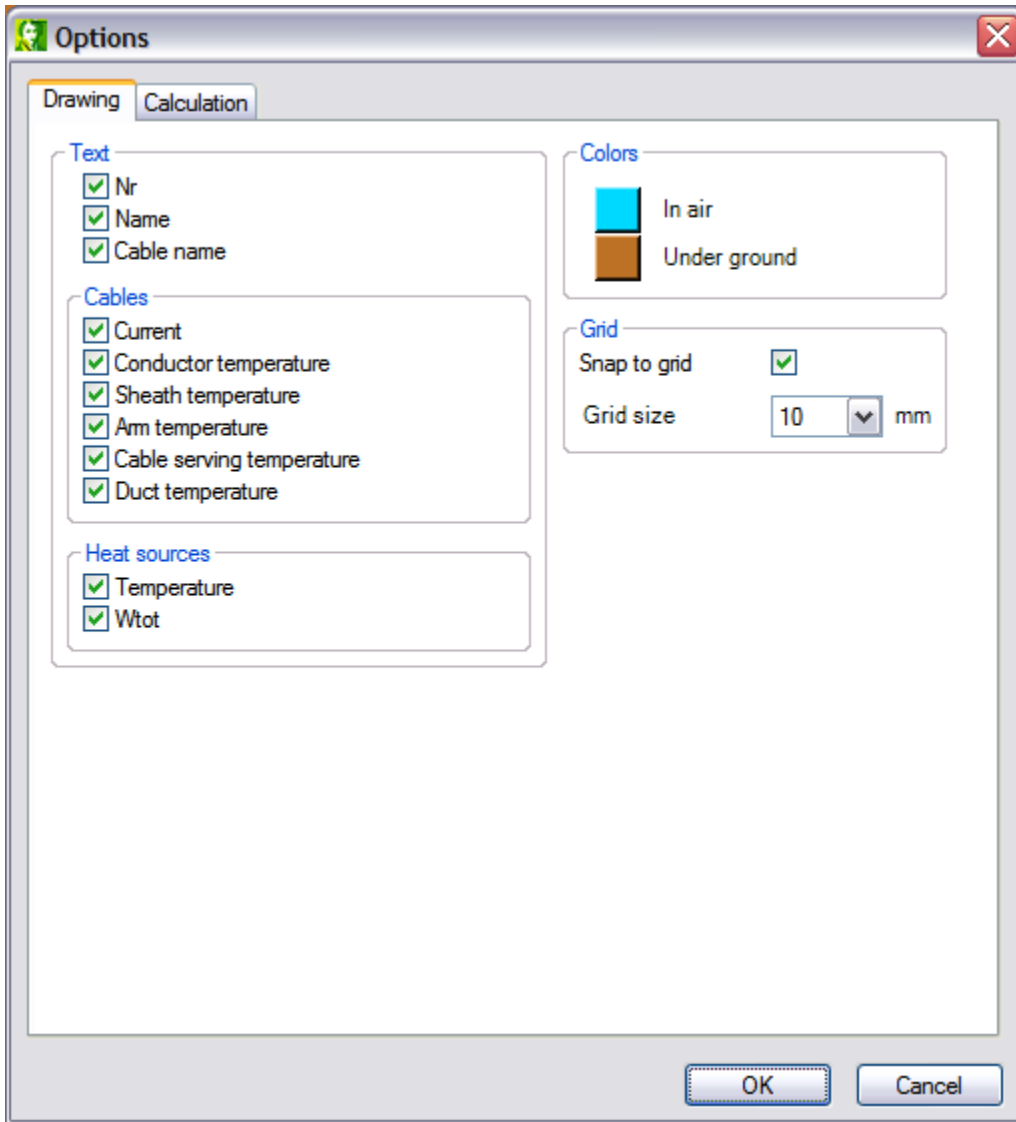The language setting concerns all menus and dialogues. The program does not need to be restarted.

4.3.5.7.3 Options

Drawing
The worksheet output format can be modified using this form. Colours can be set and a grid for vertical alignment can be defined.
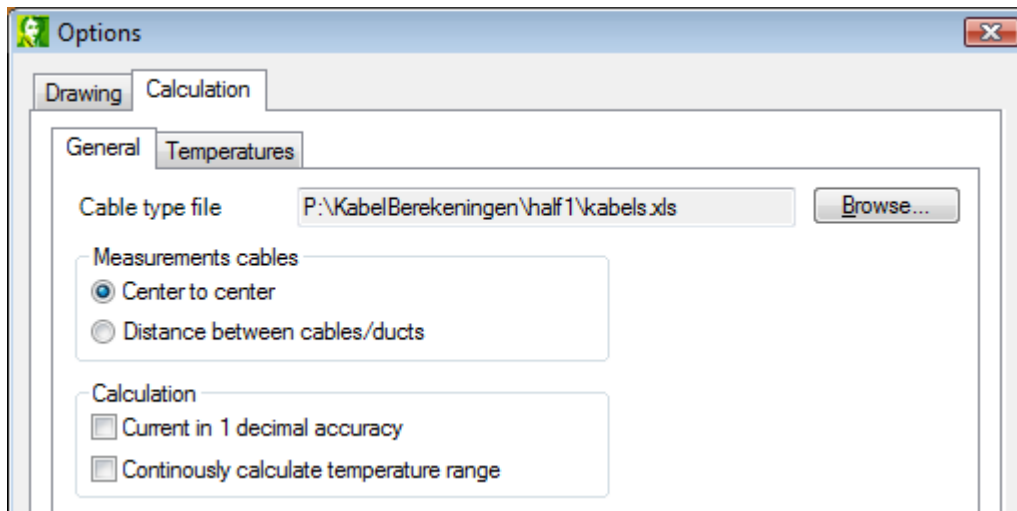
Calculation, General

This form defines:
- location of cable type file
- definition of cable distance measurement
- precision of output details
- advanced calculation

The 'advanced calculation' gives access to some enhanced functions that are not described in the IEC 60287 and 60853 standards. Modification of this checkbox is enabled in an empty worksheet only.

Calculation, Temperatures

This form defines the maximum conductor temperatures, for various isolation materials. The 'default' button restores all values to their default settings.
This form also defines the default values for ground and air temperatures.

5 IEC Background information

The calculation method is based on the international standards IEC 60228, IEC 60287 and IEC 60853.

The parts that are most important to the implementation od the method are:
- IEC 60228: resistances of conductors
- IEC 60287-1-1: continuous current rating and losses
- IEC 60287-2-1: thermal resistances
- IEC 60853-2: cyclic & emerging current for all cables.

The IEC 60287 standard is the basic for all calculations, describing the cable losses and thermal resistances calculations. It also describes the overall maximum current calculation.

The IEC 60853 standard describes the dynamic behaviour of the cable and the environment. The part that is used, describes the larger cables, and therefore is applicable to cables of all sizes.
The method calculates the cyclic load 73 behaviour and the emergency load 15 behaviour.

The IEC 60228 standard us used to determine the standard DC resistances of conductors, to be used in IEC 60287.

5.1 Cable model

The standard describes the use of most common cable types, from XLPE, oil pressure, mass-impregnated to pipe type cables. The standard describes one, two and three core cables. In Vision *Cable analysis* the two core cables are not implemented. According to the standard four core LV cables can be treated as three core cables.

The cable model distinguishes:
- Cable construction 59
- Cable Losses 62
- Thermal resistances 62
- Calculation model 63
- Temperature scheme 64

5.1.1 Cable construction

The cable construction describes the cable from layer to layer. Each cable has been constructed from conductor, screen, isolation, screen, sheath, armour to serving. The multi-core cable is constructed by binding the cores, from conductor to isolation screen or sheath, together and applying a common sheath, armour and serving. This documentation describes the construction of three commonly used cables.

Single-core XLPE cable
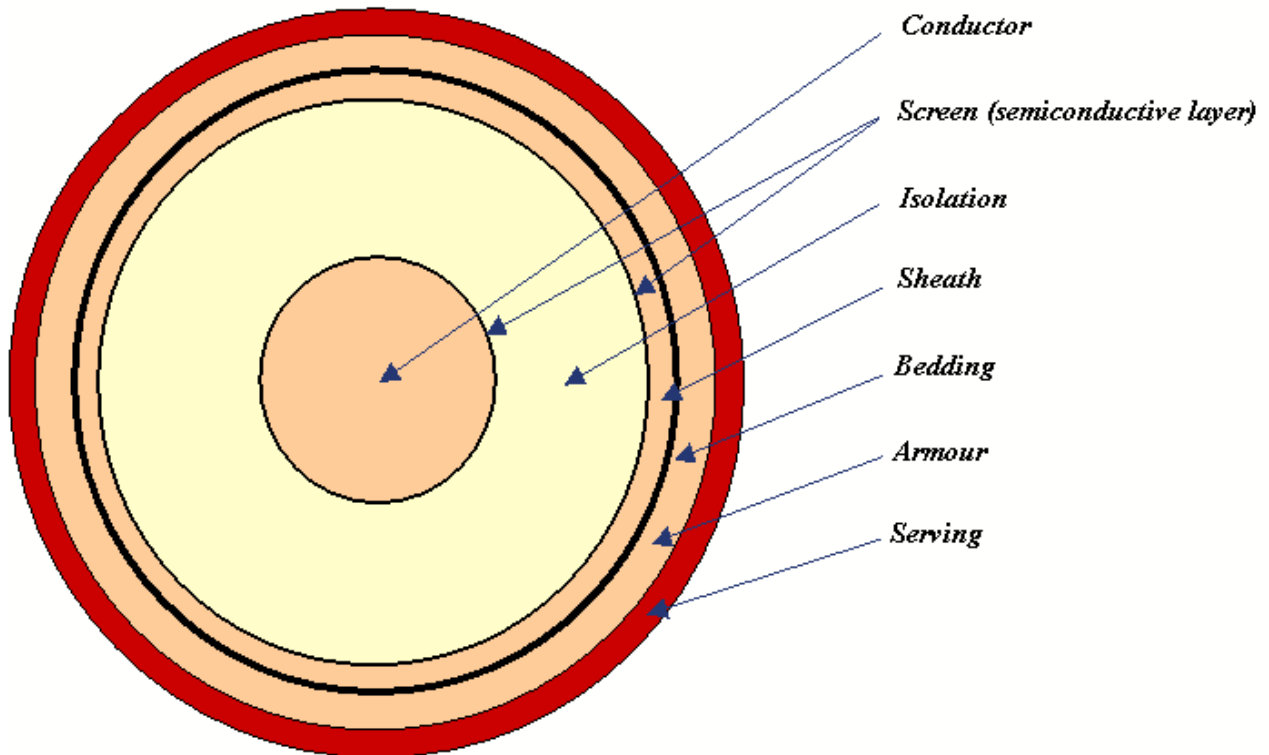
The construction is as follows:
- Copper or aluminium conductor; solid or stranded.
- Conductor screen, creating a homogeneous electric field at the conductor-side of the isolation.
- Isolation material; XLPE.
- Isolation screen, creating a homogeneous electric field at the outside of the isolation.
- Sheath, closing the electric field from the conductor.
- Armour, optional reinforcement. A bedding layer separates the armour from the sheath.
- Serving, protecting the cable from outside influences.
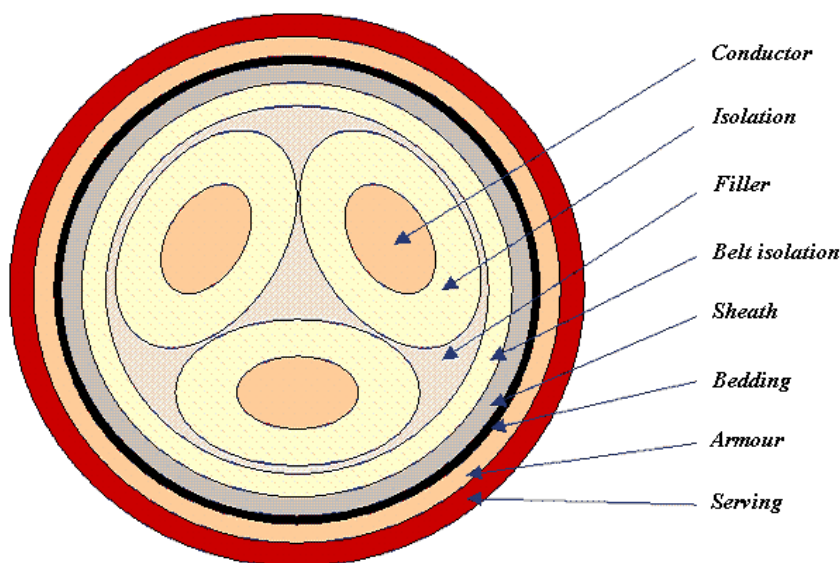
Three-core XLPE cable
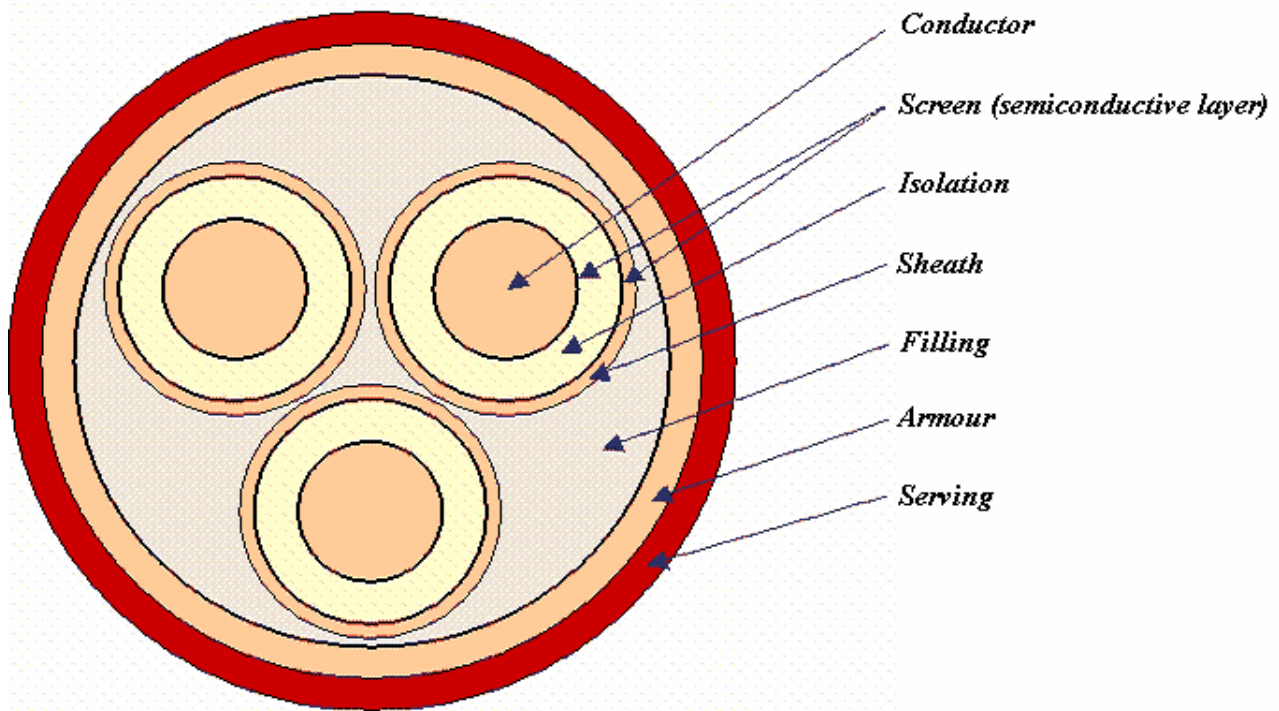
The construction is as follows:
- Each core consist of: conductor, conductor screen, isolation, isolation screen, sheath (optional).
- Three cores are bound together, surrounded by filler material.
- Next layer is armour, sometimes combined with copper wires for return current.
- Serving.

The cores can be round, oval or sector shaped. Most multi-core LV cables have sector shaped cores.

Three-core PILC cable

The construction is as follows:

- Conductors with mass-impregnated paper isolation
- Three cores surrounded by a common belt isolation.
- Common lead sheath.
- Armour of steel tape.

5.1.2   Cable losses

The cable losses originate from conductor, isolation, sheath and armour:

Conductor losses
The conductor losses are equal to I^2R. The resistance depends on the conductor material, proximity effect, skin effect and temperature.

Isolation losses
Dielectric losses originate in the isolation. The losses depend on the isolation material and the voltage. These losses are neglected for LV and MV cables.

Sheath losses
The losses in the sheaths originate from eddy currents and circulating currents. The circulating currents depend on the way the sheaths are bonded.

Armour losses
Most losses in the armour are eddy current losses, but sometimes also circulating losses.

5.1.3   Thermal resistances

The conductor, sheath and armour thermal resistances are neglected. All non-metal materials, like isolation, bedding, serving and environment, have a non-negligible thermal resistance. Calculation of their values is prescribed by the IEC 60287 standard. The following thermal resistances are defined:
- T_1: isolation between conductor and sheath
- T_2: bedding between sheath and armour
- T_3: cable serving
- T_4: external thermal resistance

T_1
The thermal resistance of the isolation part includes the conductor screen and the isolation screen.

T_2
Also the thermal resistances of filler material is included. If there is no armour, the value of T_2 equals zero.

T_3
Cable serving.

T_4
The external thermal resistance represents the heat transfer towards the infinite environment.
- The heat transfer of a buried cable is by conduction. Neighbouring cables influence the temperature.
- In case of cables in air, the heat transfer is by radiation and convection. Besides air temperature, also solar radiation plays an important role.

5.1.4   Calculation model

Next figure illustrates the thermal losses sources and thermal paths for the heat transfer.
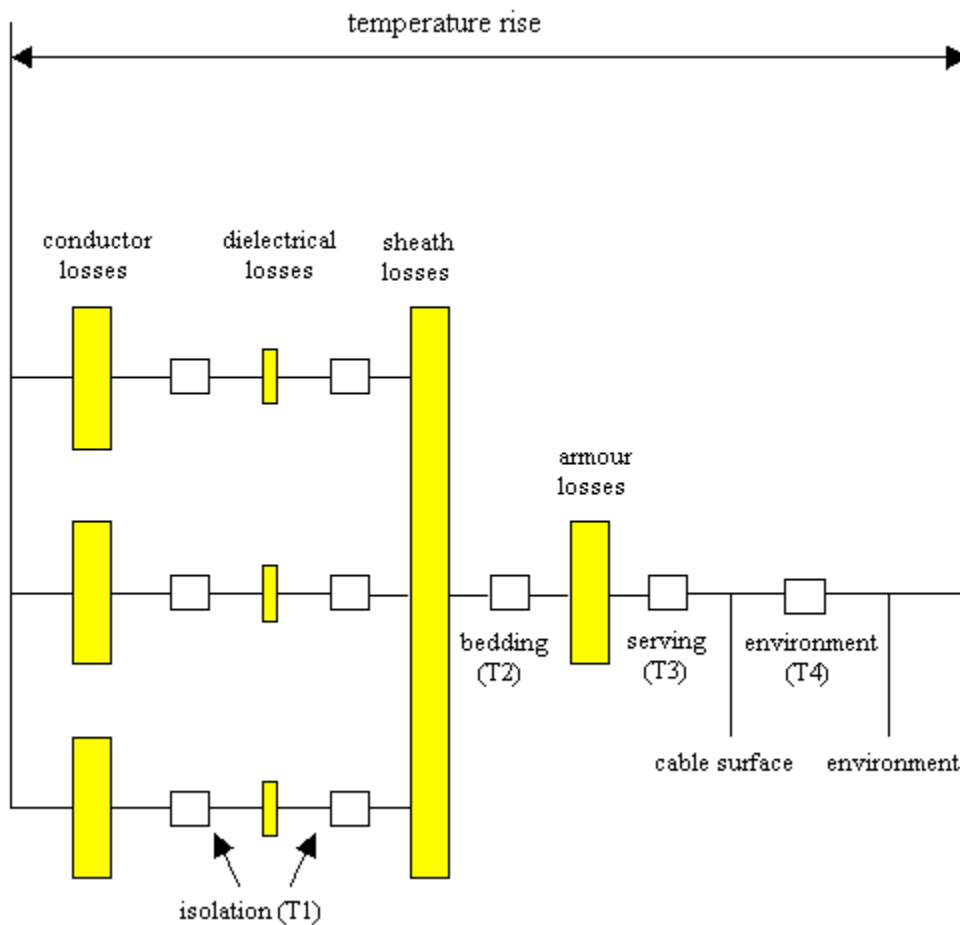
Losses sources:
- Conductor: Ohms losses (I^2R). Heat transfer through isolation, bedding, serving and environment.
- Isolation: capacitive/dielectric losses. Integration from conductor towards sheath yields the dielectric losses: mean value equals ½ W_d. Heat transfer through isolation, bedding, serving and environment.
- Neighbouring cables induce an emf in the cable sheath. If the sheaths are bonded at both sides of the cable, circulating currents can flow, resulting in losses. Additional losses are the eddy current losses. Heat transfer through bedding, serving and environment.
- Armour losses. Heat transfer through serving and environment.

The temperature calculation follows an electricity-analogous model.
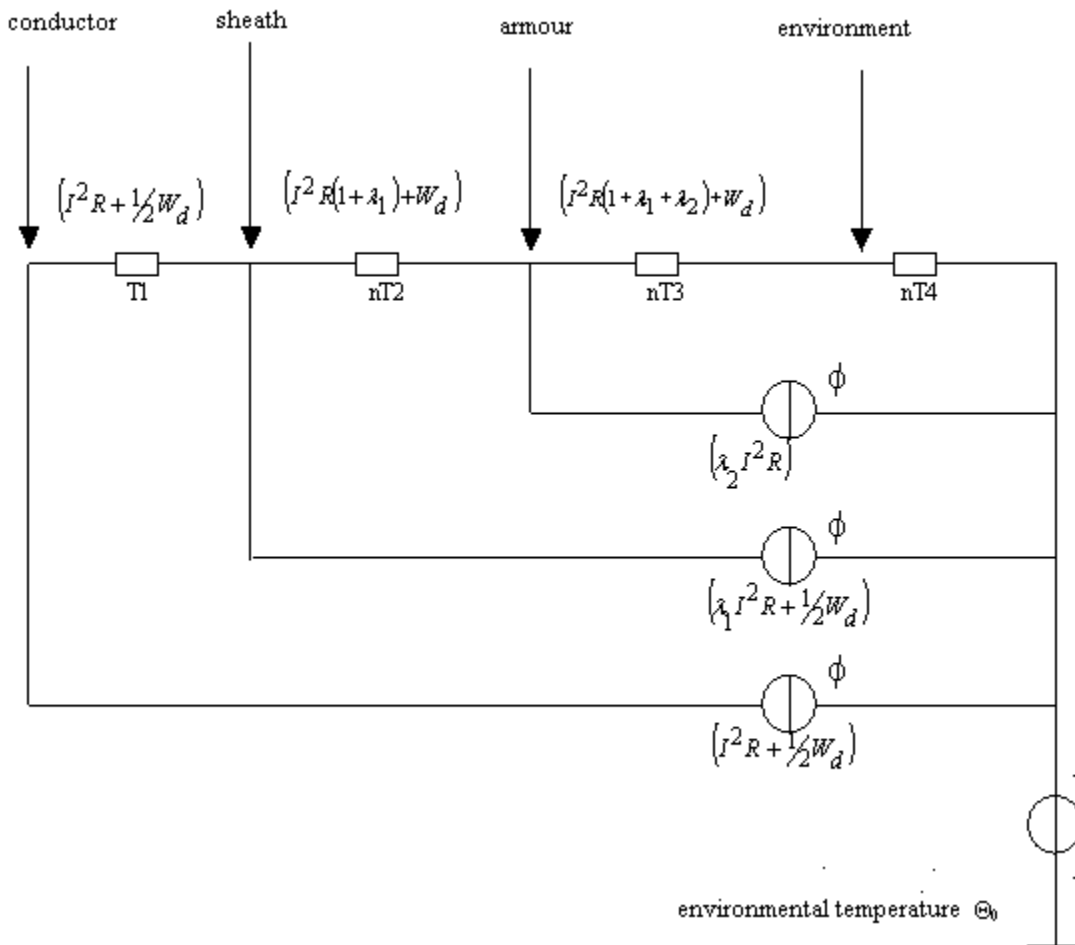
The electricity-analogous model is based on heat flow, thermal resistances and temperatures:

- The current sources are the heat flow form the conductor losses (I^2R) plus half the dielectric losses ($\frac{1}{2}$ W_d).
- The sheath losses are a factor λ_1 times the conductor losses I^2R. This heat flow, plus the heat flow from the conductor losses and the dielectric loss, flows through the bedding (T2). The variable n stands for the number of cores (1 or 3).
- The armour losses are a factor λ_2 times the conductor losses I^2R. This heat flow, plus the heat flow from the conductor losses, the dielectric loss and the sheath losses, flows through the serving (T3) and the environment (T4). The variable n stands for the number of cores (1 or 3).
- The environmental temperature has been represented by an analogous voltage source.
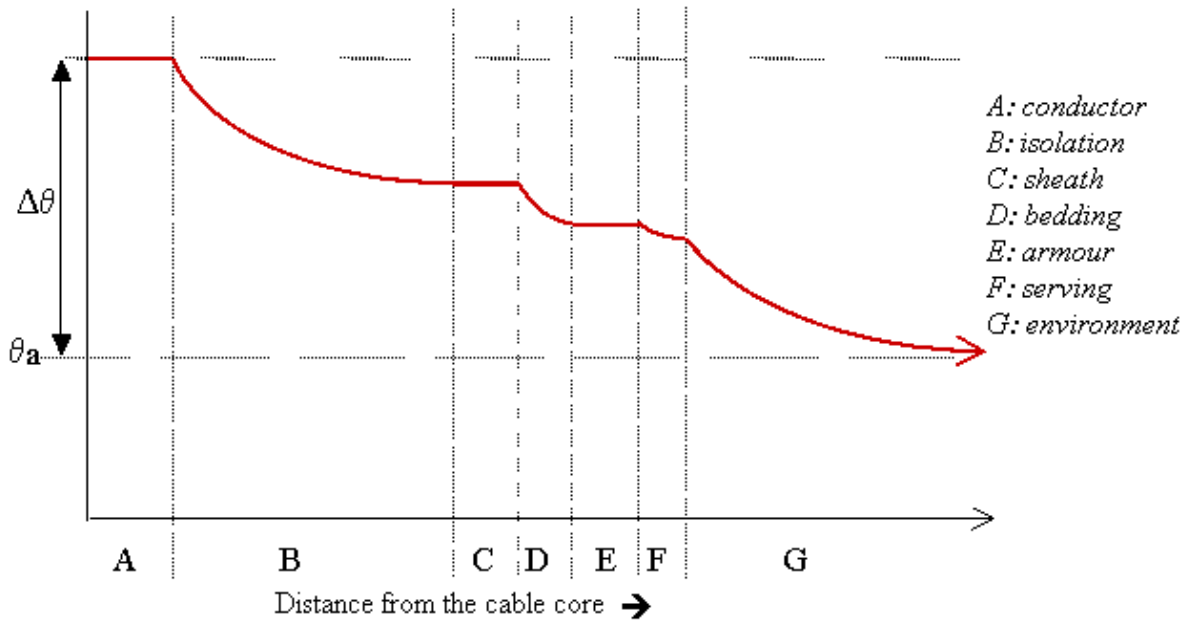
Elektricity model		Heat model	
Voltage U	[V]	Temperature rise $\Delta\theta$	[K]
Current I	[A]	Heat flow φ	[W/m]
Resistance R	[Ohm]	Thermal resistance T	[Km/W]

5.1.5   Temperature scheme

Next diagram illustrates the temperature scheme from cable conductor towards environment. The temperature inside all metallic parts remains constant, whereas the temperature inside all non-metallic parts change logarithmically.

A: conductor
B: isolation
C: sheath
D: bedding
E: armour
F: serving
G: environment

Distance from the cable core ➡

5.2 Calculation of continuous current rating

The continuous current causes the hottest cable of the circuit to have a maximum conductor temperature, so that the cable will not be damaged. The maximum conductor temperature is determined by the isolation material, according to the next table.

Isolation	Maximum conductor temperature (°C)
Paper, mass impregnated	50
Paper, oil pressure	85
Paper, internal/external gas pressure	75
XLPE, EPR, PPL	90
PE	70
PVC	55
Polychloroprene	70
Rubber	60
Butylrubber	85

The continuous cable rating depends on a large number of factors:
- cable construction (manufacturer)
- method of sheath bonding, especially for single-core cables in flat configuration
- depth of lay, cable spacing
- installation in air against to or far from a wall
- environmental conditions, like temperature, drying out of soil, solar radiation.

In the 'Environment [20]'-form, the frequency can be set for the entire configuration, being either 0, 50 or 60 Hz. If a value of 0 Hz has been chosen, the calculations will be made for a DC system.

Next factors will be described in detail:
- Cable types [66]
- Bonding [66]
- Environmental factors [66]
- Drying of ground [67]

- Installation under ground 68
- Installation free in air 67

5.2.1   Cable types

Single-core and three-core cables can be calculated. Their construction can be specified using the cable type editor 47.

The IEC standard describes the use of most common cable types, from XLPE, oil pressure, mass-impregnated to pipe type cables. The standard describes one, two and three core cables. In Vision *Cable analysis* the two core cables are not implemented. According to the standard four core LV cables can be treated as three core cables.

5.2.2   Bonding

Neighbouring cables induce an emf in the cable sheaths. Dependent on the bonding, circulating currents may flow. Next bonding methods have been implemented.

single side bonded

cross-bonded

both sides bonded

transposition
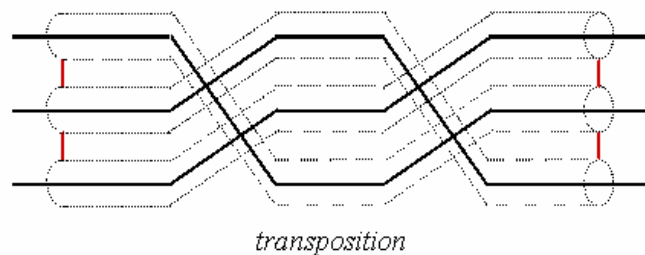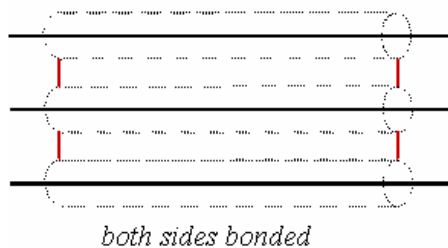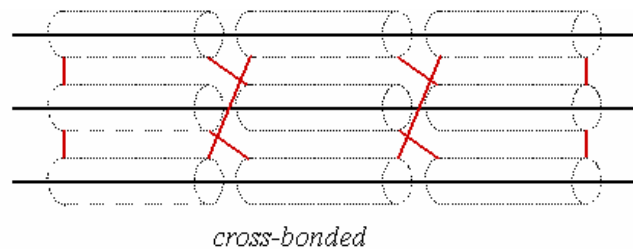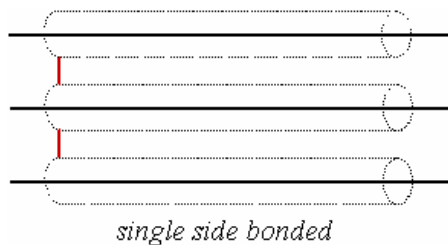
Single side bonded:
There will be no circulating currents. The induced emf will cause a voltage rise at the not bonded side.

Both sides bonded:
The induced emf will cause a circulating current to flow. The losses are not equal for all cables in flat formation.

Cross-bonding:
To eliminate circulating currents, the circuit will be divided in three sections of equal length, cross linking the sheaths at each section boundary.

Transposition:
Another way to reduce circulating currents is to change cable positions in three sections of equal length.

5.2.3   Environmental factors

The environmental temperature has a large influence on the continuous cable rating. The temperature of the air and the ground can be specified separately. Parallel cables and other heat sources may influence the cable and should therefore be modelled.

Installation in air:
- Cables subject to solar radiation
- Cables protected from solar radiation

Installation under ground:
- No drying out of soil
- Partial drying out of soil
- Drying out of soil has to be avoided

In air

Solar radiation heats the cable serving, limiting the current. The cables may be protected from solar radiation using a special construction.
In areas of hot climate the cables should not be installed in a closed housing. There will always be enough ventilation.

Under ground

A hot cable may cause drying out of soil, causing an irreversible change of thermal properties. Dried soil contains air that functions as a good heat isolator. Therefore drying out of soil should be avoided.

No drying out of soil:
If it is certain that the soil will not dry out, a high cable temperature can be sustained. A straightforward calculation method will be followed.

Avoid drying out of soil:
The serving temperature of cables will be limited to approximately 45 degrees Celsius.

Partial drying out of soil:
The calculation method follows a two-zone model, where the zone around the cable is dry. The boundary between the dry and wet zones is called the critical isotherm. Its temperature can be specified.

5.2.4 Drying of soil

Since the application of XLPE cables instead of PILC cables, the cable conductor temperatures are higher than before, causing higher cable serving temperatures with the danger of drying out of soil.

Examples:
- Very wet sand of constant moisture in groundwater has a specific thermal resistance G of 0.5 Km/W.
- Very wet clay, also in groundwater, has no constant moisture and therefore no constant specific thermal resistance. This is caused by the cable, causing the water to migrate. As a result the cable rating is lower than expected.

If it is known that the moisture in the soil decreases, it should be included in the calculation.

The IEC standard specifies values for the specific thermal resistance G for a number of countries. However, for each particular calculation the soil conditions for the complete cable route should be known and the calculation should be made for all expected hot spots.

5.2.5 Installation in air

The continuous cable rating of cables in air depends on the mounting. The cables can be positioned against a wall of free from it. The next figure shows the mounting positions as defined by the IEC standard. The definition of 'free from the wall' is determined by the cable diameter (D_e).

$\geq$ 0,3*D_e

a

$\geq$ 0,5*D_e

b

$\geq$ 0,05*D_e

c

$\geq D_e$

d

$\geq$ 0,5*D_e

D_e

e

f

g
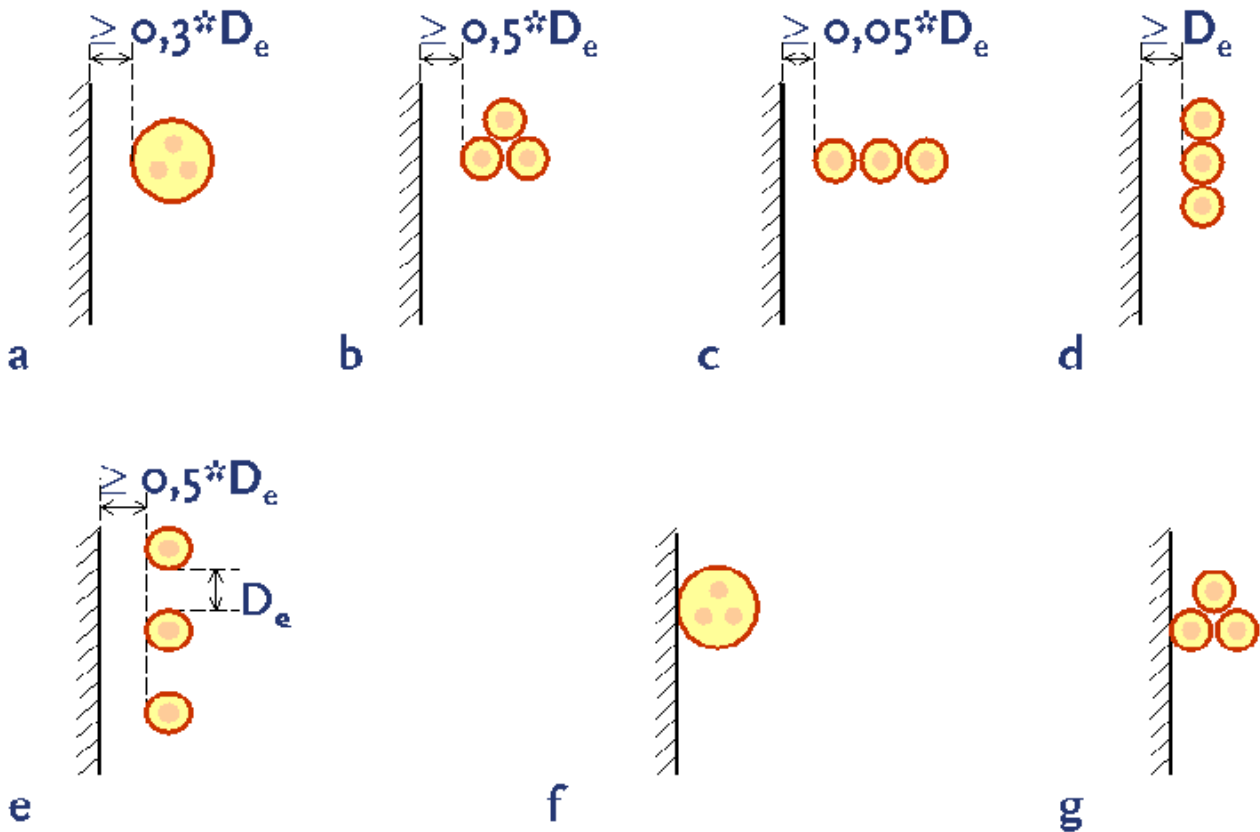
Cables free from the wall:
a : three-core cable
b : three single-core cables in trefoil
c : three single-core cables in flat formation, horizontal
d : three single-core cables in flat formation, vertical, touching
e : three single-core cables in flat formation, vertical, spaced

Cables touching the wall:
f : three-core cable
g: three single-core cables in trefoil

Cables can be protected from or exposed to solar radiation. Solar radiation heats the cable serving, reducing the cable rating.
The cables may be protected from solar radiation using a special construction.
In areas of hot climate the cables should not be installed in a closed housing. There will always be enough ventilation.

5.2.6   Installation under ground

Many configurations are possible under ground. Each configuration has its own calculation approach.

Depth

Three-core cable

Depth

Three single-core cables
(flat formation)

Depth

Three single-core cables
(trefoil)
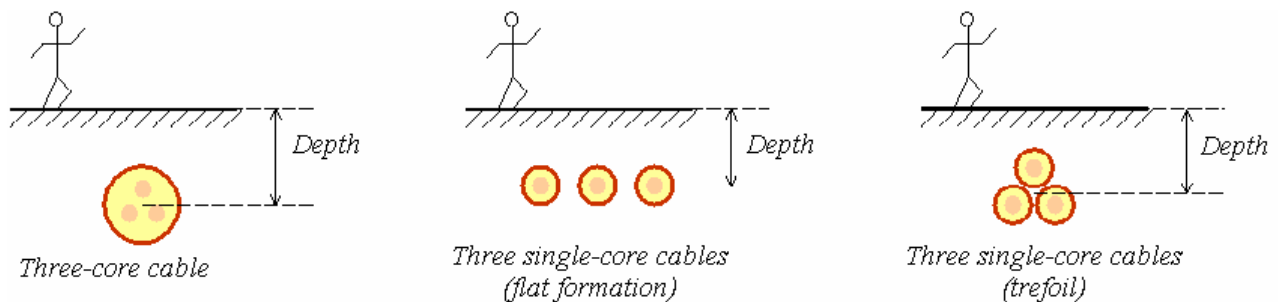
The cable rating is influenced by the depth of lay and the presence of other heat sources, like other circuits. Other heat sources should always be modelled.
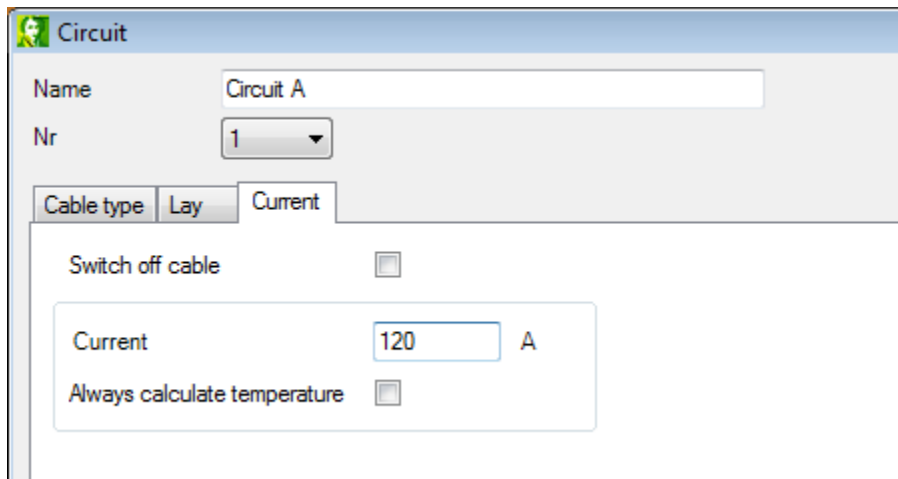
Multiple circuits

There are several approaches to calculate:
- each circuit its maximum current
- equally loaded identical circuits
- maximum current in a neighbouring circuit.

The default calculation is the maximum current for each circuit. If a parallel circuit is present, the same current should flow. In that case, the option 'equally loaded identical cables' can be chosen.

If the option 'Always calculate temperature' has been chosen, the current will be set to the specified value, enabling the user to focus on the maximum current of another circuit.

Other heat sources

A heat source can be parallel conduits for steam or hot fluids. A heat source is defined by:
- a fixed surface temperature or
- a fixed heat production.

See also: Heat source 28.

For underground configurations a temperature image 34 can be made visible.

5.3 Dynamic current calculation

The IEC 60287 standard calculates the continuous cable rating. For changing currents the IEC 60853 standard describes the behaviour for cyclic and emergency loads. Yhe standard uses a heat capacity model of the cable and its surrounding soil. The standard focuses on buried cables, since the time constants for cables in air are too short. This standard is not applicable for partial dried soil.

The cyclic load is a repetitive pattern of current values for a defined period, e.g. one day of 24 hours values. Using the cyclic pattern, its maximum current may be somewhat higher than the continuous cable rating.
The emergency load is a continuous current, larger than the rated value, that may flow during a limited time.

The IEC 60853 standard uses the basic parameters for losses and thermal resistances from the IEC 60287 standard.

Vision *Cable analysis* contains the next functions:
- calculation of the transient temperature response 71
- calculation of the maximum step current (emergency load) 72
- calculation of the cyclic current 73.

Method

The method uses a model of the cable, from conductor to serving, and a model of the environment. The individual responses will be summed to obtain the complete system response.
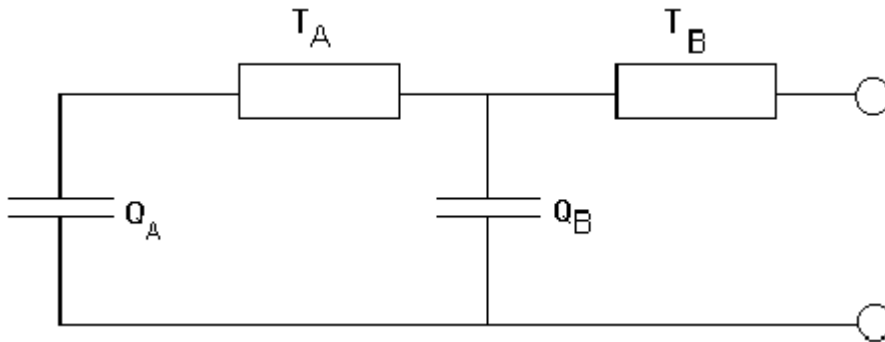
The dynamic cable temperature response after a step change of current depends on the combination of cable heat capacities and the thermal resistances of cable and environment.

For a short time response, the cable properties are of major influence. For longer time responses (longer than 6 hours) the environmental properties are of major influence. Therefore the model has been divided in two independent parts:

- one part from conductor to cable serving (Q_A and T_A) and
- one part for the environment (Q_B and T_B).

5.3.1   Transient temperarture response

The transient temperature response to a step change of current is the temperature rise, starting from a pre-change 'Normal current'.

Result is a graph, indicating the temperature response for the defined time period:

- orange line: conductor temperature
- green line: serving temperature
- red line: maximum allowed temperature

Example

Next example has been calculated for a 10 kV 1x95 Al XLPE cable in flat formation. Starting with a normal current of 100 A, the response has been calculated for a step change to 272 A. In 24 hours the conductor temperature rises from 24 to 62 degrees C. The serving temperature rises from 22 to 48 degrees C.

It can be seen that in the first few hours the conductor to serving temperature rises quickly, due to the cable properties. After 6 hours the conductor to serving temperature remains constant and only the environment properties determine the long period heating.
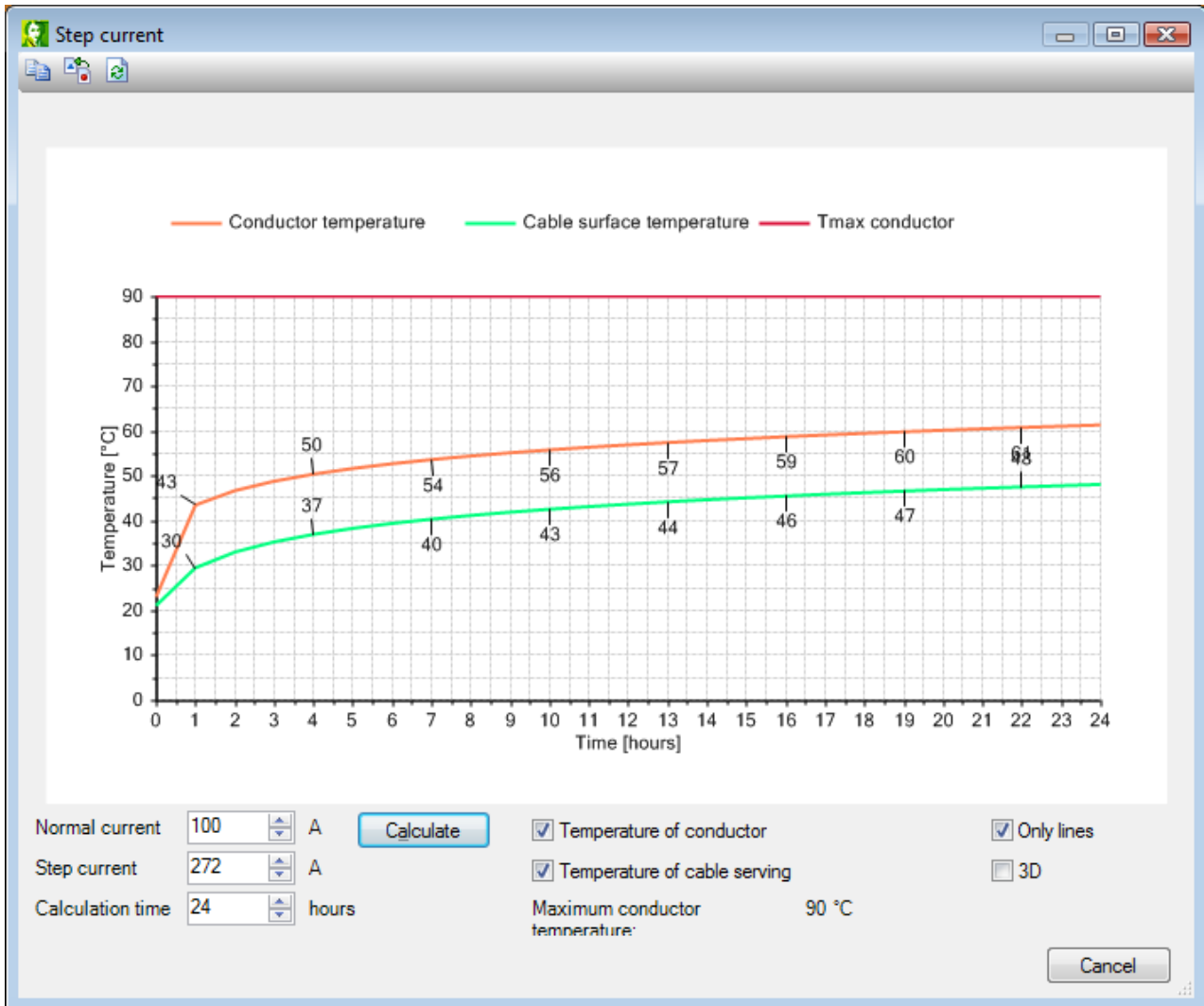
5.3.2 Maximum step current

The transient temperature response to a step change of current is the temperature rise, starting from a pre-change 'Normal current'. Using this response, an emergency current may flow during a limited time period. This function calculates the maximum emergency current for various durations.

The procedure starts with a continuous flowing current, the 'normal current' I_1. On time $t=0$ the current changes to I_2, the emergency current. The function calculates the maximum value of I_2 for specified duration t. The conductor temperature may not exceed its prescribed maximum value.

Example

Next example has been calculated for a 10 kV 1x95 Al XLPE cable in flat formation. Starting with a normal current of 100 A, the cable may carry 360 A during maximum 8 hours. After this duration, the current must be less tan or equal to the continuous cable rated current.
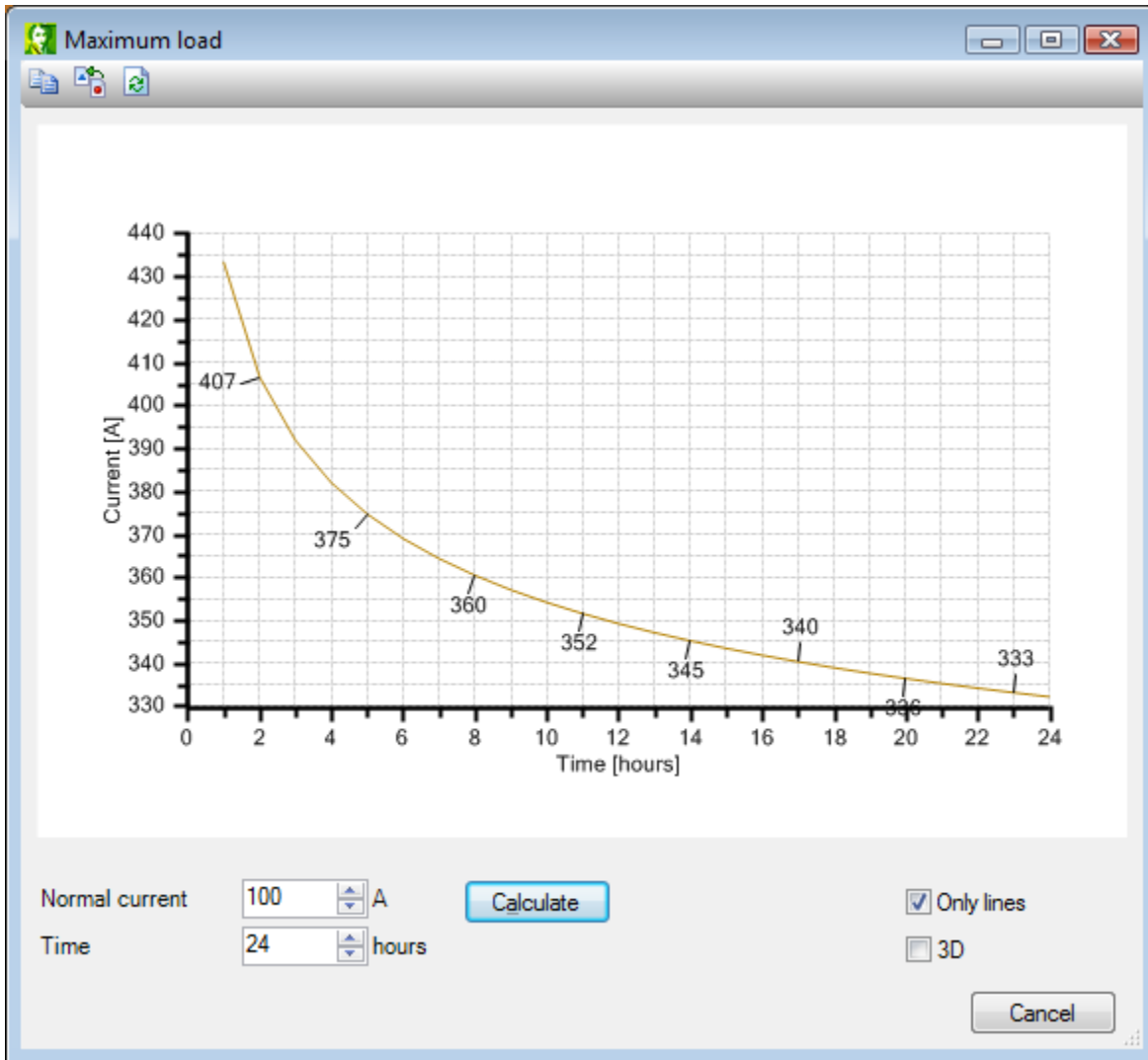
5.3.3   Cyclic current

During a daily cyclic varying load, with maximum value equal to the continuous cable rating, the cable temperature will not reach its maximum value. According to the IEC 60853 standard this allows the cyclic load peak to be somewhat higher than the rated value.

The cyclic factor M is a factor by which the continuous cable rating may be multiplied in order to obtain the peak value of the cyclic load. The factor M is only valid for the cyclic load curve that was used to calculate M.

Daily load cycle
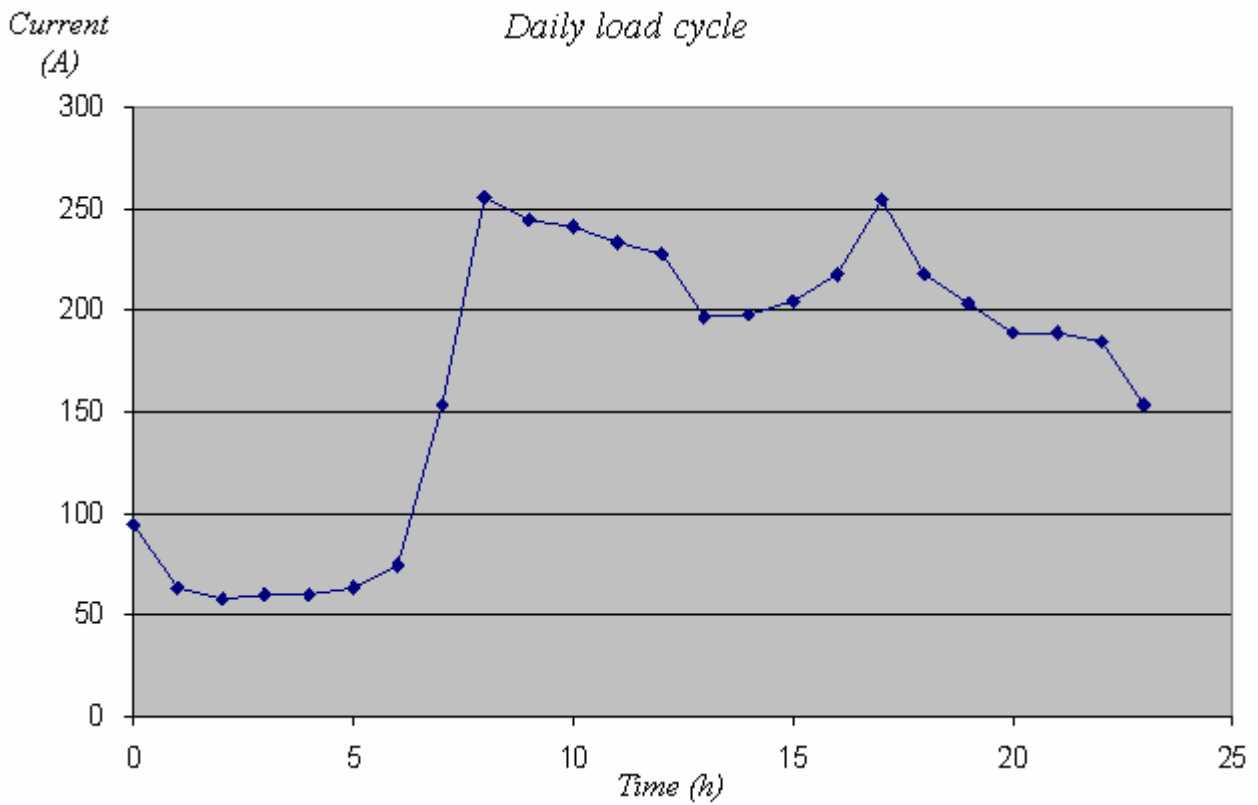
The load cycle above has to peaks, of approximately equal value, at t=8 h en at t=17 h. The critical temperature will be expected in the neighbourhood of these two points.

Example

Next example has been calculated for a 10 kV 1x95 Al XLPE cable in flat formation. The calculated conductor temperature for the original load cycle is presented with the red line and the serving temperature with the blue line. It can be seen that the maximum temperature is reached on t=17 h.
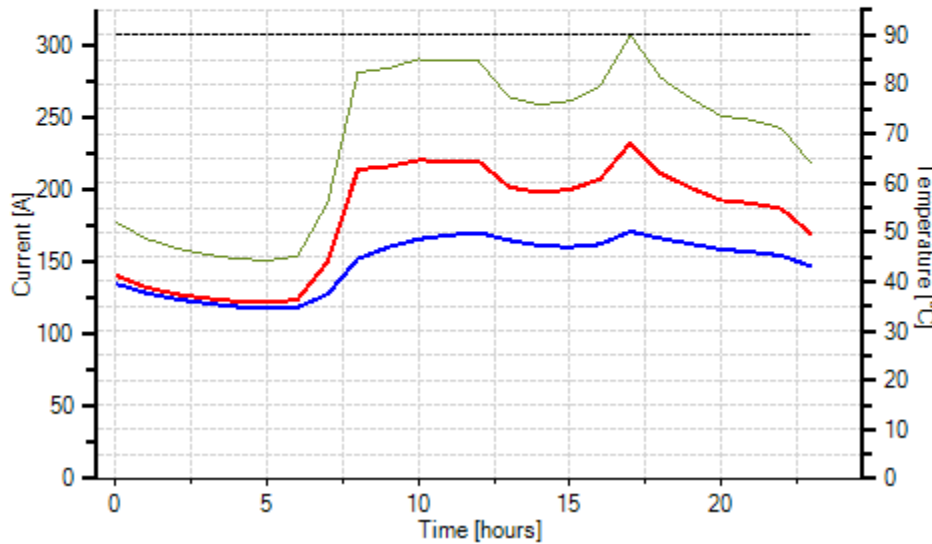
The calculated M factor is presented in the output form. In this example ist value is 1.188. This implies that the load cycle peak value may be equal to 1.188 times the continuous current rating (272 A for this cable). In this example the peak value may be equal to:

1,188 x 272 A = 323 A.

As a consequence, for the load cycle, having a peak value of 256 A, all values may be multiplied by:
323 / 256 = 1.264.
This value is presented as 'Maximum factor of cyclic load cycle'. The grey line in the graph indicates the conductor temperature for the maximum load cycle.

Next diagram shows the original load cycle (in blue) and the maximum load cycle (stacked in green). Overload will be presented in red bars.