

## 10. Category Electrics

### 10.1. Consumption

#### 10.1.1. Purpose (What can it be used for? What can it not be used for?)

The program is part of category 5 – electrics. Operating a pump, a blower, a fan respectively an engine in general or a complete plant with respect to the operation time means a consumption of energy according to the nominal power rate in the first. By this at least it means also a consumption of money - operation time means operation costs. Sometimes it is needful to determine the costs that result directly out of the operating time. By the way for the total operation costs further compounds like maintenance and spare part costs have to be evaluated as well, of course.

If the nominal active power rate of the operated engine is multiplied by the operation time, it results the theoretical consumed energy. The unit results usually in kilowatt by hours [kWh] which is multiple of the unit kilo-Joule [kJ] based on the fact that 1 Watt is equal to 1 Joule per second. If the consumed energy is multiplied by the costs per kilowatt by hour, the costs that result directly out of the operation time can be calculated. It is quite trivial, but often useful for cost economic efficiency evaluations. This is why this small calculation is included in the program collection.

Either power rate or operation time or total costs, respectively the total energy, can be chosen as resulting variable. It is like executing an internal conversion of the equation. As an option the currency can be selected by land according to the status of 2015. Be aware that the value for the costs per unit has to be adapted also according to this.

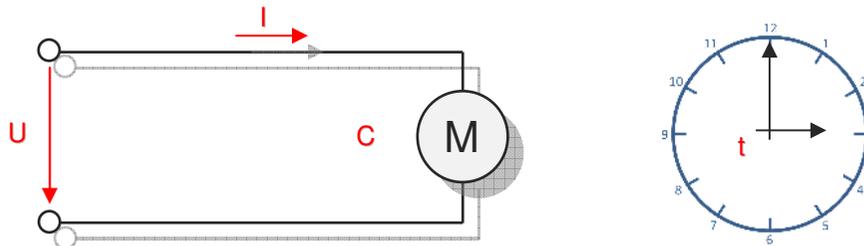


Figure 106: sketch consumption

## 10.1.2. Variables (What are the input and output values? What are their limits?)

### **power rate**

It is the active power rate of the aggregate that is operated.

The variable type is Input or Output.  
The unit is kilowatt [kW].  
The minimum limit is 0.0001.  
The maximum limit is 9999999999.  
The replacement value is 100.  
The number of digits is 10.

### **cost per unit**

It is the actual price that has to be paid per energy unit. In this case the energy unit is kilowatt by hour [kWh]. For this variable different currencies are provided by land. The default selection is Germany / EUR.

The variable type is Input.  
The unit is kilowatt [kWh / EUR].  
The minimum limit is 0.0001.  
The maximum limit is 9999999999.  
The replacement value is 100.  
The number of digits is 10.

### **operation time**

It is the time that the aggregate is in operation.

The variable type is Input or Output.  
The unit is seconds [s].  
The minimum limit is 0.0001.  
The maximum limit is 9999999999.  
The replacement value is 100.  
The number of digits is 10.

### **total energy**

It is the total energy that has been consumed after operating the aggregate for the given operation time.

The variable type is Input or Output.  
The unit is kilowatt by hours [kWh].  
There is no defined minimum limit for output variables.  
There is no defined maximum limit for output variables.  
There is no defined replacement value for output variables.  
There is no defined number of digits for output variables.

## **total cost**

It is total price that has to be paid for the consumption of the total corresponding energy.

The variable type is Input.

The unit is kilowatt [kW].

The minimum limit is 0.0001.

The maximum limit is 9999999999.

The replacement value is 100.

The number of digits is 10.

10.1.3. Operation (How can it be used? How to proceed?)

**Step 1:**  
**Select the variable to be calculated**  
By clicking on the corresponding *RadioButton* I can choose the variable to be calculated. It is like executing an internal conversion of the equation.

**Step 4:**  
**Calculate result**  
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

**Step 3:**  
**Fill the Input-TextBoxes**  
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

**Step 2:**  
**Select currency by land**  
I can select the currency by land (status 2015).

**Step 5:**  
**Check result**  
After clicking the Calculate-Button I can check the result.

**Step 6:**  
**Further actions**  
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

Figure 107: form consumption

## 10.2. Cross Section

### 10.2.1. Purpose (What can it be used for? What can it not be used for?)

The program is part of category 5 – electrics. For the electrical power supply of a motor, an engine, a plant or in general any electrical consumer a proper cable with a proper cross section has to be selected based on the installation set-up, the design criteria and the operation circumstances. Regarding this different factors have to be taken into consideration. Questions like the following are relevant.

<b>Routing:</b>	Is the cable routed inside an insulated wall? Is the cable routed on a wall made of wood or stone? Is the cable routed direct on a wall or in a not perforated cable tray? Is the cable routed inside an underground conduit or an underground cable trench? Is the cable routed with a distance to the wall in a perforated cable tray or in a cable ladder? Is the cable routing set-up installed horizontally or vertically?
<b>Cores:</b>	Are the installed cables single core cables or multi core cables?
<b>Cable Type:</b>	What is the type of the installed cable and its maximum core or insulation temperature?
<b>Distances:</b>	What are the distances to the surrounding equipment or to other cables?
<b>Ambient Circumstances:</b>	What is the ambient or underground temperature? What are the ambient or underground moisture conditions?
<b>Cable Arrangement:</b>	How many cables or circuits are additionally installed? What is the number of layers and how are the cables arranged to each other?
<b>Further Influences:</b>	Do oscillations or other influences occur, that have to be considered?
<b>Voltage Drop:</b>	What is the length of the cable and which value for the voltage drop according to the core current is acceptable? What is the proper cross section for the cable routing according to the mentioned circumstances?

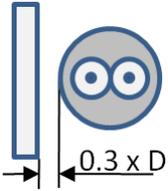
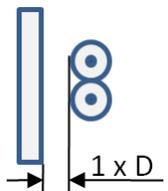
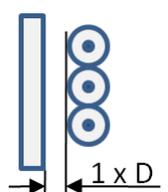
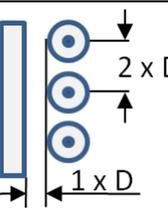
In the first the type of cable routing has to be defined. According to the rules the routing is divided up into seven different types. These are provided for selection. Each routing type has a number of sub-types that can be selected according to the used installation case (also refer to the sketch in the left top of the form).

- Type A:** single core conductors or multi core cables inside an insulated wall.  
+ single core conductors in conduit (A1)  
+ multi core cables in conduit (A2)
- Type B:** single core conductors or multi core cables on a wall made of wood or stone.  
+ single core conductors in conduit (B1)  
+ multi core cables in conduit (B2)
- Type C:** single or multi core cables direct on a wall or in a not perforated cable tray.  
+ direct on the wall (C1)  
+ in a not perforated cable tray (C2)
- Type D:** single or multi core cables inside an underground conduit or an underground cable trench.  
+ multi core cables (D1)  
+ single core cables (D2)
- Type E:** multi core cables with a distance of minimum  $0.3 \times D$  to the wall in a perforated cable tray.  
+ two core cables (E1)  
+ three core cables (E2)
- Type F:** single core cables with a distance of minimum  $1 \times D$  to the wall in a perforated cable tray.  
+ two single cores in a row (F1)  
+ three single cores in a triangle order (F2)  
+ three single cores in a row (F3)
- Type G:** single core conductors in a row installed on insulators with safety distances (to each and  $1 \times D$  to the wall).  
+ three single cores horizontal (G1)  
+ three single cores vertical (G2)

<p><u>Type A:</u> single core conductors or multi core cables inside an insulated wall</p>		<p>(A1) single core conductors in conduit</p>
<p><u>Type B:</u> single core conductors or multi core cables on a wall made of wood or stone</p>		<p>(B1) single core conductors in conduit</p>
<p><u>Type C:</u> single or multi core cables direct on a wall or in a not perforated cable tray</p>		<p>(C1) direct on the wall</p>
<p><u>Type D:</u> single or multi core cables inside an underground conduit or an underground cable trench</p>		<p>(D1) multi core cables</p>

<p><u>Type A:</u> single core conductors or multi core cables inside an insulated wall</p>		<p>(A2) multi core cables in conduit</p>
<p><u>Type B:</u> single core conductors or multi core cables on a wall made of wood or stone</p>		<p>(B2) multi core cables in conduit</p>
<p><u>Type C:</u> single or multi core cables direct on a wall or in a not perforated cable tray</p>		<p>(C2) in a not perforated cable tray</p>
<p><u>Type D:</u> single or multi core cables inside an underground conduit or an underground cable trench</p>		<p>(D2) single core cables</p>

Figure 108: sketches cross section Type A - D

<p><u>Type E:</u> multi core cables with a distance of minimum <math>0.3 \times D</math> to the wall in a perforated cable tray</p>		<p>(E1) two core cables</p>
<p><u>Type F:</u> single core cables with a distance of minimum <math>1 \times D</math> to the wall in a perforated cable tray</p>		<p>(F1) two single cores in a row</p>
<p><u>Type F:</u> single core cables with a distance of minimum <math>1 \times D</math> to the wall in a perforated cable tray</p>		<p>(F3) three single cores in a row</p>
<p><u>Type G:</u> single core conductors in a row installed on insulators with safety distances (to each and <math>1 \times D</math> to the wall)</p>		<p>(G2) three single cores vertical</p>

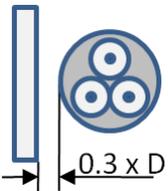
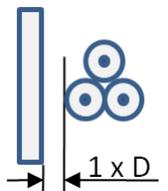
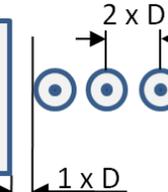
<p><u>Type E:</u> multi core cables with a distance of minimum <math>0.3 \times D</math> to the wall in a perforated cable tray</p>		<p>(E2) three core cables</p>
<p><u>Type F:</u> single core cables with a distance of minimum <math>1 \times D</math> to the wall in a perforated cable tray</p>		<p>(F2) three single cores in a triangle order</p>
<p><u>Type G:</u> single core conductors in a row installed on insulators with safety distances (to each and <math>1 \times D</math> to the wall)</p>		<p>(G1) three single cores horizontal</p>

Figure 109: sketches cross section Type E - G

Regarding the cable type the program provides a selection of different cables. Anyhow for the final installation it is mandatory that the selected cable type, especially the insulation and the cross section is proper for the use case (e.g. underground cable for an underground installation). In the first the cable selection is relevant in regard to the maximum allowed insulation or core temperature of the cable, which can be a parameter for the further calculations and table values.

After selecting the type of routing, the sub-type and the cable type the relation between nominal current and cross section is displayed in a corresponding list. Therefore two possibilities are provided. One: select the nominal current as input variable and get the corresponding cross section as result. Two: select the cross section as input variable and get the corresponding nominal current as result. Be aware that these table values are the base values. Depending on the ambient and routing circumstances, the current has to be adapted by calculation. This has to be done by considering the factors k1 to k5 in the first and finally taking also the voltage drop into consideration that is caused by the cable resistance (depending on the cable length, the core material and the core cross section).

In the following an overview of the single factors with their purpose and their relevance for the different routing types is shown.

- Factor k1:**
- + considers the ambient temperature.
  - + is relevant for all types and sub-types of routing except Type D.
- Factor k2:**
- + considers the underground temperature.
  - + is usually relevant only for routing type D including all its sub-types.
- Factor k3:**
- + considers the underground moisture circumstances.
  - + is usually relevant only for routing type D including all its sub-types
- Factor k4:**
- + considers the number of cables, the layers, the types of cable routing.
  - + is relevant for all sub-types of routing.
- Factor k5:**
- + considers oscillations and other influences.
  - + can be relevant for all types and all sub-types of routing.
- Factor kx:**
- + considers all the previous mentioned factors (k1 to k5) by multiplication.
  - + is at least relevant for all types and all sub-types of routing regarding the voltage drop calculations.

Following up the single purposes and the use cases for the different factors k1 to k5 with their possible and provided selections are explained in more details.

**Factor k1:**

The factor k1 considers the ambient temperature for cables with contact to the air. The nominal tables for current and cross section presuppose an ambient temperature of 30°C. In case if the actual ambient temperature differs from this value, the selection can be changed accordingly.

	<p>max. 14 Items</p>	<p>Selections are provided for 8, 10 or 14 items depending on the maximum allowed cable temperature. There are 3 ranges defined: 60°C, 70°C and 90°C. The ranges depend on the selected cable type. The following selections are provided: 10°C, 15°C, 20°C, 25°C, 35°C, 40°C, 45°C, 50°C, 55°C, 60°C, 65°C, 70°C, 75°C and 80°C. The corresponding values for k1 are shown accordingly. There is a limit of 10°C to be respected to the maximum allowed cable temperature.</p>	<p>Type A Type B Type C Type E Type F Type G</p>
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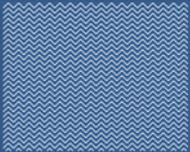
**Factor k2:**

The factor k2 considers the ambient temperature for cables routed in the earth or ground. The nominal tables for current and cross section presuppose an ambient temperature of 20°C. In case if the actual ambient temperature differs from this value, the selection can be changed accordingly.

	<p>max. 14 Items</p>	<p>Selections are provided for 8, 10 or 14 items depending on the maximum allowed cable temperature. There are 3 ranges defined: 60°C, 70°C and 90°C. The ranges depend on the selected cable type. The following selections are provided: 10°C, 15°C, 25°C, 30°C, 35°C, 40°C, 45°C, 50°C, 55°C, 60°C, 65°C, 70°C, 75°C and 80°C. The corresponding values for k2 result accordingly. There is a limit of 10°C to be respected to the maximum allowed cable temperature.</p>	<p>Type D</p>
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**Factor k3:**

The factor k3 considers the earth or ground conditions for cables routed in the earth or ground. The nominal tables for current and cross section presuppose a dry floor. In case if actual or permanent circumstances differ from this, the selection can be changed accordingly.

	-		<p>5 Items</p>	<p>Selections are provided for different ground consistencies and conditions There are 5 conditions defined: flooded ground, wet ground, moist ground, dry ground, very dry ground. The corresponding values for k3 result accordingly.</p>	<p>Type D</p>
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**Factor k4:**

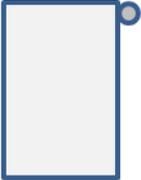
The factor k4 considers the amount of cables or circuits in combination with the arrangement of the cables and the cable trays or cable ladders. The nominal tables for current and cross section presuppose one cable or circuit in a usual cable tray. In case if the actual circumstances differ from this value, the selection can be changed accordingly. Regarding the factor k4 there are many different selections possible and provided. These selections are divided up into 12 different blocks. Each type has its own combination of blocks as provided selections.

- + Block 1 considers the cumulation of cables with multiple layers in a conduit.
- + Block 2 considers the cumulation of cables in one line (single layer) on a wall made of stone or wood.
- + Block 3 considers the cumulation of circuits in one line (single layer) with no space between the cables.
- + Block 4 considers the cumulation of circuits in one line (single layer) with different spaces between the cables.
- + Block 5 considers the cumulation of cables in one line (single layer) in horizontally installed cable trays.
- + Block 6 considers the cumulation of cables in one line (single layer) in vertically installed cable trays.
- + Block 7 considers the cumulation of cables in one line (single layer) in horizontally installed cable ladders.
- + Block 8 considers the cumulation of cables in triangle order in horizontally installed cable trays.
- + Block 9 considers the cumulation of cables in triangle order in vertically installed cable trays.
- + Block 10 considers the cumulation of cables in triangle order in horizontally installed cable ladders.
- + Block 11 considers the cumulation of cables installed in horizontal order with min. distances to the wall and to the closest cable.
- + Block 12 considers the cumulation of cables installed in vertical order with min. distances to the wall and to the closest cable.

**Block 1** considers the cumulation of cables with multiple layers in a conduit.

 <span style="margin: 0 10px;">-</span> 	<p>12 Items</p>	<p>Selections are provided for 1 to 20 cables (multi layer) routed in a conduit. 12 items are selectable. The following selections are provided: 1, 2, 3, 4, 5, 6, 7, 8, 9, 12, 16 and 20 cables. The corresponding values for k4 result accordingly.</p>	<p>Type A Type B Type C Type D</p>
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**Block 2** considers the cumulation of cables in one line (single layer) on a wall made of stone or wood.

 <span style="margin: 0 10px;">-</span> 	<p>2 x 9 Items</p>	<p>Selections are provided for 1 to 9 cables in one line (single layer) installed on a stone wall or on a wooden wall. 18 items are selectable (9 for a wooden wall and 9 for a stone wall). The corresponding values for k4 result accordingly.</p>	<p>Type C</p>
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**Block 3** considers the cumulation of circuits in one line (single layer) with no space between the cables.

 <span style="margin: 0 10px;">-</span> 	<p>5 Items</p>	<p>Selections are provided for 2 - 6 circuits routed in a cable conduit with no space in between the cables respectively the circuit conductors. The following selections are provided: 2, 3, 4, 5 and 6 circuits. The corresponding values for k4 result accordingly.</p>	<p>Type D</p>
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**Block 4** considers the cumulation of circuits in one line (single layer) with different spaces between the cables.

	<p>4 x 5 Items</p>	<p>Selections are provided for 2 to 6 circuits routed in a cable conduit with different spaces in between the cables respectively the circuit conductors. Regarding the circuits the following selections are provided: 2, 3, 4, 5 and 6 circuits. Regarding the spaces in between the circuits there is a choice for 4 different measures. These are: one cable diameter (<math>s \geq D</math>), <math>s \geq 0.125</math> m, <math>s \geq 0.25</math> and <math>s \geq 0.5</math> m space. The corresponding values for k4 result accordingly.</p>	<p>Type D</p>
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**Block 5** considers the cumulation of cables in one line (single layer) in horizontally installed cable trays.

	<p>9 Items</p>	<p>Selections are provided for 1 to 3 cables arranged in one line (single layer), routed in 1 to 3 horizontally installed cable trays. 9 items are selectable (3 cables by 3 trays). The cable trays are supposed to be perforated cable trays. The corresponding values for k4 result accordingly.</p>	<p>Type E Type F</p>
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**Block 6** considers the cumulation of cables in one line (single layer) in vertically installed cable trays.

	<p>4 Items</p>	<p>Selections are provided for 1 or 2 cables arranged in one line (single layer), routed in 1 or 2 vertically installed cable trays. 4 items are selectable (2 cables by 2 trays). The cable trays are supposed to be perforated cable trays. The corresponding values for k4 result accordingly.</p>	<p>Type E Type F</p>
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**Block 7** considers the cumulation of cables in one line (single layer) in horizontally installed cable ladders.

	<p>9 Items</p>	<p>Selections are provided for 1 to 3 cables arranged in one line (single layer), routed in 1 to 3 horizontally installed cable ladders. 9 items are selectable (3 cables by 3 ladders). The corresponding values for k4 result accordingly.</p>	<p>Type E Type F</p>
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**Block 8** considers the cumulation of cables in triangle order in horizontally installed cable trays.

	<p>9 Items</p>	<p>Selections are provided for 1 to 3 cables arranged in triangle order, routed in 1 to 3 horizontally installed cable trays. 9 items are selectable (3 cables by 3 trays). The cable trays are supposed to be perforated cable trays. The corresponding values for k4 result accordingly.</p>	<p>Type E Type F</p>
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**Block 9** considers the cumulation of cables in triangle order in vertically installed cable trays.

	<p>6 Items</p>	<p>Selections are provided for 1 to 3 cables arranged in triangle order, routed in 1 or 2 vertically installed cable trays. 6 items are selectable (3 cables by 2 trays). The cable trays are supposed to be perforated cable trays. The corresponding values for k4 result accordingly.</p>	<p>Type E Type F</p>
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**Block 10** considers the cumulation of cables in triangle order in horizontally installed cable ladders.

	<p>9 Items</p>	<p>Selections are provided for 1 to 3 cables arranged in triangle order, routed in 1 to 3 horizontally installed cable ladders. 9 items are selectable (3 cables by 3 ladders). The corresponding values for k4 result accordingly.</p>	<p>Type E Type F</p>
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**Block 11** considers the cumulation of cables installed in horizontal order with min. distances to the wall and to the closest cable.

	<p>3 Items</p>	<p>Selections are provided for 1 to 3 or more cables installed in horizontal order with minimum distances (1 x D) to the wall and (2 x D) to the closest cable. 3 items are selectable. These are: 1, 2 and 3 or more cables. The corresponding values for k4 result accordingly.</p>	<p>Type G</p>
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**Block 12** considers the cumulation of cables installed in vertical order with min. distances to the wall and to the closest cable.

	<p>3 Items</p>	<p>Selections are provided for 1 to 3 or more cables installed in vertical order with minimum distances (1 x D) to the wall and (2 x D) to the closest cable. 3 items are selectable. These are: 1, 2 and 3 or more cables. The corresponding values for k4 result accordingly.</p>	<p>Type G</p>
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**Factor k5:**

The factor k5 considers effects like oscillations and other, similar influences. The nominal tables for current and cross section do not presuppose a value regarding this. If the effects should be disregarded, the value for the factor can be set to 1.00. The factor to be considered for oscillation effects is in general based on the expected value for the harmonic current of the third order in relation to the total phase current as a percentage value. If this is in a range below 15% a factor of 1 can be assumed. In a range from 15% to 33% a factor of 0.86 should be sufficient. In case if the value exceeds the 33% it can be expected that a bigger cross section for neutral conductor is required than for the phases. Additional considerations have to be done in this case.

	<p>no Items</p>	<p>For the factor k5 there are no selections provided. A value can be entered manually. The range for this value is 0.1 to 1.85. Due to the fact, that the value for the factor can be entered also other influences can be taken into consideration hereby. Be aware that the factor k5 is usually <math>\geq 1</math>.</p>	<p>all Types</p>
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**Factor kx:**

The factor kx results from the multiplication of all activated factors (k1 to k5). If a factor is not activated, it will be calculated internally with a value of 1.00. The factor kx equals k1 by k2 by k3 by k4 by k5. Usually not all factors are relevant for all types and sub-types of cable routing. For a small overview regarding this refer to the table on the left side.

$k_x = k_1 \times k_2 \times k_3 \times k_4 \times k_5$	<p>no Items</p>	<p>For the factor kx there are no selections provided. A value can be entered manually. The factor kx equals k1 by k2 by k3 by k4 by k5.</p>	<p>all Types</p>
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The single internal steps for the determination of the selected values are as follows:

- Step 1:** Select the cable routing type according to the installation set-up and the in advance planned cable to be used.
- Step 2:** Select the cable routing sub-type according to the installation set-up and the in advance planned cable to be used.
- Step 3:** Select the cable type (insulation). Anyhow for the final installation it is mandatory that the selected cable type, especially the insulation and the cross section is proper for the use case.
- Step 4:** Consider the factors  $k_1$  to  $k_5$ , respectively the resulting factor  $k_x$ , so far they are required for the planned use case.
- Step 5:** Consider the voltage drop. The base table and the total factor will be considered according to the routing type including the carried out adjustments and the entered data. The minimum allowed cross section will be considered automatically in case if the calculation results a lower value.

For the voltage drop calculations there is a selection provided for a one phase or a three phase system. Power rate, voltage or current can be selected as output variable in the upper part of the form. The residual two variables are input variables. The nominal current is relevant for the further calculations. In case if this is not known, it can be calculated as result, if the corresponding *RadioButton* is selected. For the percentage of the voltage drop the supply voltage is relevant. In case if this is not known, it can be calculated as result, if the corresponding *RadioButton* is selected.

Voltage drop (as a percentage value of the supply voltage), cable length and cross section can be selected as output variable in the lower part of the form. The residual two variables are input variables. The factor will be transferred according to the adjusted cable routing type. Therefore a selection is provided on the right side in the top of the form. The current will be adapted according to the corresponding factors and the new relevant value will be displayed in the lower part of the form. The new current and the voltage drop are the relevant values for the determination of the cross section.

The base table and the total factor will be considered according to the routing type including the carried out adjustments and entered data. The minimum allowed cross section will be considered automatically in case if the calculation results a lower value. Be aware that the determined cross section can be, especially with respect to the cable length, a multiple of the base value and much more than expected.

## 10.2.2. Variables (What are the input and output values? What are their limits?)

### current

It is the nominal current that is corresponding to the nominal cross section. The value from the list selection is a base value that is in coherence to the type and the sub-type of cable routing. Additionally the factors are important (k1, k2, k3, k4, k5). Multiplying all the five factors results the factor kx. For long cables it is mandatory, that the voltage drop is also taken into consideration.

The variable type is Input or Output.  
The unit is ampere [A].  
The minimum limit is 3.  
The maximum limit is 1454.  
The variable has no replacement value.  
The number of digits is 4.

### Tmax

It is the maximum allowed respectively the maximum recommended temperature at the cores of the cable. Tmax is depending on the selected cable type. The following values are possible 40°C, 60°C, 70°C, 90°C, 105°C.

The variable type is Output by selection.  
The unit is degree Celsius [°C].  
The minimum limit is 40.  
The maximum limit is 105.  
The variable has no replacement value.  
The number of digits is 3.

### cross section

It is the nominal cross section that is corresponding to the nominal current. The value from the list selection is a base value that is in coherence to the type and the sub-type of cable routing. Additionally the factors are important (k1, k2, k3, k4, k5). Multiplying all the five factors results the factor kx. For long cables it is mandatory, that the voltage drop is also taken into consideration.

The variable type is Input or Output.  
The unit is millimeter square [mm<sup>2</sup>].  
The minimum limit is 0.5.  
The maximum limit is 630.  
The variable has no replacement value.  
The number of digits is 3.

### factor k1

The factor k1 considers the ambient temperature for cables with contact to the air. The nominal tables for current and cross section presuppose an ambient temperature of 30°C. In case if the actual ambient temperature differs from this value, the selection can be changed accordingly.

The variable type is Factor.  
The variable has no unit [-].  
The minimum limit is 0.32.  
The maximum limit is 1.22.  
The replacement value is 1.00.  
The number of digits is 5.

## **factor k2**

The factor k2 considers the ambient temperature for cables routed in the earth or ground. The nominal tables for current and cross section presuppose an ambient temperature of 20°C. In case if the actual ambient temperature differs from this value, the selection can be changed accordingly.

The variable type is Factor.  
The variable has no unit [-].  
The minimum limit is 0.38.  
The maximum limit is 1.10.  
The replacement value is 1.00.  
The number of digits is 5.

## **factor k4**

The factor k4 considers the amount of cables or circuits in combination with the arrangement of the cables and the cable trays. The nominal tables for current and cross section presuppose one cable or circuit in a usual cable tray. In case if the actual circumstances differ from this value, the selection can be changed accordingly.

The variable type is Factor.  
The variable has no unit [-].  
The minimum limit is 0.38.  
The maximum limit is 1.00.  
The replacement value is 1.00.  
The number of digits is 5.

## **factor k3**

The factor k3 considers the earth or ground conditions for cables routed in the earth or ground. The nominal tables for current and cross section presuppose a dry floor. In case if actual or permanent circumstances differ from this, the selection can be changed accordingly.

The variable type is Factor.  
The variable has no unit [-].  
The minimum limit is 0.86.  
The maximum limit is 1.21.  
The replacement value is 1.00.  
The number of digits is 5.

## **factor k5**

The factor k5 considers effects like oscillations and other, similar influences. The nominal tables for current and cross section do not presuppose a value regarding this. If the effects should be disregarded, the value for the factor can be set to 1.00. 0.86 can be assumed if the expected value for the harmonic current of the third order in relation to the total phase current as a percentage value does not increase 33%.

The variable type is Factor.  
The variable has no unit [-].  
The minimum limit is 0.1.  
The maximum limit is 1.85.  
The replacement value is 0.86.  
The number of digits is 5.

## **factor kx**

The factor kx results from the multiplication of all activated factors (k1 to k5). If a factor is not activated, it will be calculated internally with a value of 1.00. The factor kx equals k1 by k2 by k3 by k4 by k5. Usually not all factors are relevant for all types and sub-types of cable routing. For a small overview regarding this refer to the table on the left side.

The variable type is Factor.

The variable has no unit [-].

There is no defined minimum limit for output variables.

There is no defined maximum limit for output variables.

There is no defined replacement value for output variables.

There is no defined number of digits for output variables.

## **voltage**

It is the power supply voltage for the relevant cable.

The variable type is Input or Output.

The unit is volt [V].

The minimum limit is 0.1.

The maximum limit is 99999.

The replacement value is 1.

The number of digits is 5.

In the following an overview with the relevance of the factors for the different routing types is shown.

**k1:** relevant for all types and sub-types of routing except Type D.

**k2:** usually relevant only for routing type D including all its sub-types.

**k3:** usually relevant only for routing type D including all its sub-types.

**k4:** relevant for all types and all sub-types of routing.

**k5:** relevant for all types and all sub-types of routing.

## **power rate**

It is the active power rate of the aggregate that is operated.

The variable type is Input or Output.

The unit is kilowatt [kW].

The minimum limit is 0.0001.

The maximum limit is 99999.

The replacement value is 1.

The number of digits is 5.

## **spec. cos phi**

It is the average specified power factor of all the operated devices.

The variable type is Input.  
The variable has no unit [-].  
The minimum limit is 0.50.  
The maximum limit is 1.00.  
The replacement value is 0.85.  
The number of digits is 5.

## **eff. voltage drop**

It is the voltage drop that occurs for the cable at the actual operating circumstances. It depends on the cable length, the core material, the current and the cross section. The voltage drop is given as a percentage value of the supply voltage.

The variable type is Input or Output.  
The unit is volt [V].  
The minimum limit is 0.1.  
The maximum limit is 99999.  
The replacement value is 1.  
The number of digits is 5.

## **current**

It is the nominal current that occurs while operating the connected system with the specified power rate and the specified supply voltage.

The variable type is Input or Output.  
The unit is ampere [A].  
The minimum limit is 0.1.  
The maximum limit is 99999.  
The replacement value is 1.  
The number of digits is 5.

## **cable length**

It is the length of the cable that is used for the power supply cable. Cable length, core material, core cross section and temperature are the main parameters for the electrical resistance of the cable.

The variable type is Input or Output.  
The unit is seconds [m].  
The minimum limit is 0.1.  
The maximum limit is 99999.  
The replacement value is 1.  
The number of digits is 5.

**factor**

It is the factor  $k_x$  for the selected type of cable routing. By selecting a routing type from the *ComboBox*, the corresponding value for  $k_x$  is transferred from the *TabPage* accordingly.

The variable type is Factor.

The variable has no unit [-].

There is no defined minimum limit for output variables.

There is no defined maximum limit for output variables.

There is no defined replacement value for output variables.

There is no defined number of digits for output variables.

**rnd cross section**

It is the math rounded cross section. For the design criteria the calculated cross section has to be rounded up. Therefore two circumstances are taken into consideration. One: the cross section after rounding up has to be available. Two: the cross section after rounding up has to be permitted for the determined current according to the actual rules.

The variable type is Input or Output.

The unit is millimeter square [mm<sup>2</sup>].

The minimum limit is 0.5.

The maximum limit is 630.

The replacement value is 1.

The number of digits is 5.

**current'**

It is the value that results by dividing the current with the factor. This value is displayed just for information purpose. At least it is the base value for the determination of the cross section according to the internally used tables.

The variable type is Output.

The unit is ampere [A].

There is no defined minimum limit for output variables.

There is no defined maximum limit for output variables.

There is no defined replacement value for output variables.

There is no defined number of digits for output variables.

**cal cross section**

It is the calculated cross section. Therefore the calculated result for the cross section is shown. This value is for further evaluation purposes, only. For the design criteria it has to be rounded up. Therefore two circumstances are taken into consideration. One: the cross section after rounding up has to be available. Two: the cross section after rounding up has to be permitted for the determined current according to the actual rules.

The variable type is Input or Output.

The unit is millimeter square [mm<sup>2</sup>].

The minimum limit is 0.1.

The maximum limit is 99999.

The replacement value is 1.

The number of digits is 5.

10.2.3. Operation (How can it be used? How to proceed?)

**Step 1:**  
**Select the cable type**  
 I can select the type of cable that has to be taken into consideration. Therefore seven different types are provided. There are two possibilities for the selection: by button or by *TabPage*.

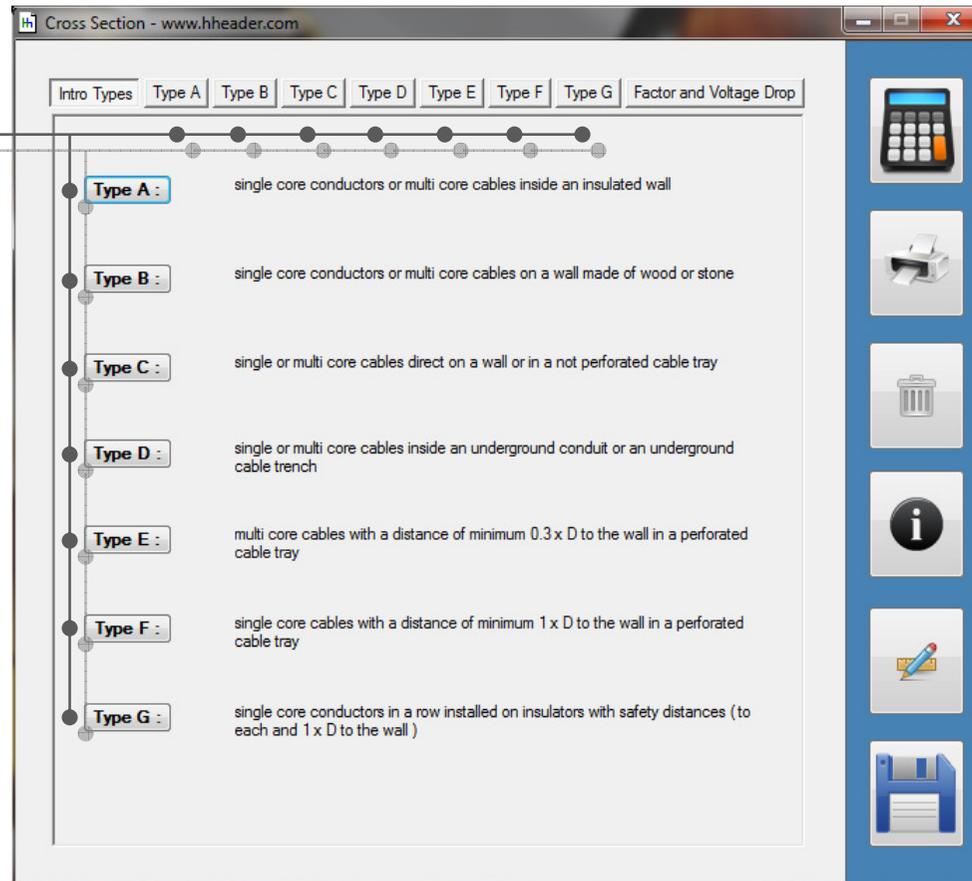


Figure 110: form cross section –intro types

**Step 8:**  
**Calculate result**  
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

**Step 5:**  
**Activate the factors**  
I can activate the factors that should be considered.

**Step 1: (option)**  
**Select input and output variable**  
I can select the input and output variable for the basic table.

**Step 2: (option)**  
**Select values for the basic table**  
The basic table shows the coherence between current and cross-section according to the selected cable routing type, sub-type and cable type.

**Step 9:**  
**Check result**  
After clicking the Calculate-Button I can check the result.

**Step 10:**  
**Further actions**  
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once. I should take the total factor and the voltage drop into consideration.

**Step 3:**  
**Select the cable routing sub-type**  
I can select the cable routing sub-type according to the used cable routing.

**Step 4:**  
**Select the cable type**  
I can select the cable type according to the used cable.

**Step 6:**  
**Select the conditions for the factors**  
I can select the conditions for the four factors.

**Step 7:**  
**Fill the Input-TextBoxes**  
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

Figure 111: form cross section – Type D

**Step 6:**  
**Calculate result**  
 After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

**Step 3:**  
**Select the variable to be calculated**  
 By clicking on the corresponding *RadioButton* I can choose the variable to be calculated. It is like executing an internal conversion of the equation.

**Step 4:**  
**Fill the Input-TextBoxes**  
 I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

**Step 7:**  
**Check result**  
 After clicking the Calculate-Button I can check the result.

**Step 8:**  
**Further actions**  
 After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

**Step 1:**  
**Select the number of phases**  
 I can select if the system has one phase or three phases.

**Step 2:**  
**Select the cable routing type**  
 I select the cable routing type. The factor will be transferred from the corresponding *TabPage*.

**Step 5:**  
**Enter the number of decimal places**  
 I enter the number of decimal places for the variables. It is valid only if the corresponding variable is selected as output. The input variables can get more or less decimal numbers according to the number of digits.

Figure 112: form cross section – factor and voltage drop

**10.3. Intrinsic Safety**

**10.3.1. Purpose (What can it be used for? What can it not be used for?)**

The program is part of category 5 – electrics. If there is a probability for the occurrence of an explosive atmosphere on site, special installation equipment can be required in order to avoid the risk of a spark that has enough energy to cause an ignition of the explosive atmosphere. In general explosion protection is divided up in three different parts. There is the primary explosion protection, where provisions are taken in order to avoid the occurrence of an explosive atmosphere at all. Then there is the secondary explosion protection, where provisions are taken in order to avoid the occurrence of an ignition source. And finally there is the tertiary explosion protection, where provisions are taken in order to avoid damages and harmful situations in case of an explosion. This program provides calculations for the secondary explosion protection, especially for the installed measurements. Therefore it is according to the rules required to install intrinsic safe circuits. These circuits consist of a transformer, a cable and a sensor. These compounds have to fit to each other, properly. The program provides the corresponding calculations that are required to evaluate if the circuit is intrinsic safe or not. The proof of intrinsic safety is required for the documentation of plants or the parts of the plants that are operated in areas where an explosive atmosphere can occur. For the documentation it is important to note the correct designation, the certification and the classification of the transformer and the sensor. By these information can be determined, if the device is proper for the ambient conditions (EX-ZONE) or not.

For the calculations the values for the capacitance (C), the inductance (L), the current (I), the voltage (U) and the power rate (P) are relevant. The nominal values must be given on the device housing or in the device documentation. The devices in this case are the transformers and the sensors. For the cable the specific capacitance and the specific inductance in relation to a defined cable length are relevant. To determine the capacitance and the inductance of the cable the specific values have to be multiplied by the real cable length. It is obvious that the cable has to be approved for the use case. The maximum allowed voltage and current have to be greater than the maximum values that can occur for the transformer and the sensor. Usually this is the case, if the cable is approved and has a core cross section of 0.5mm<sup>2</sup> or greater, because the electric signals for the measurements are normally far beyond the cable parameters.

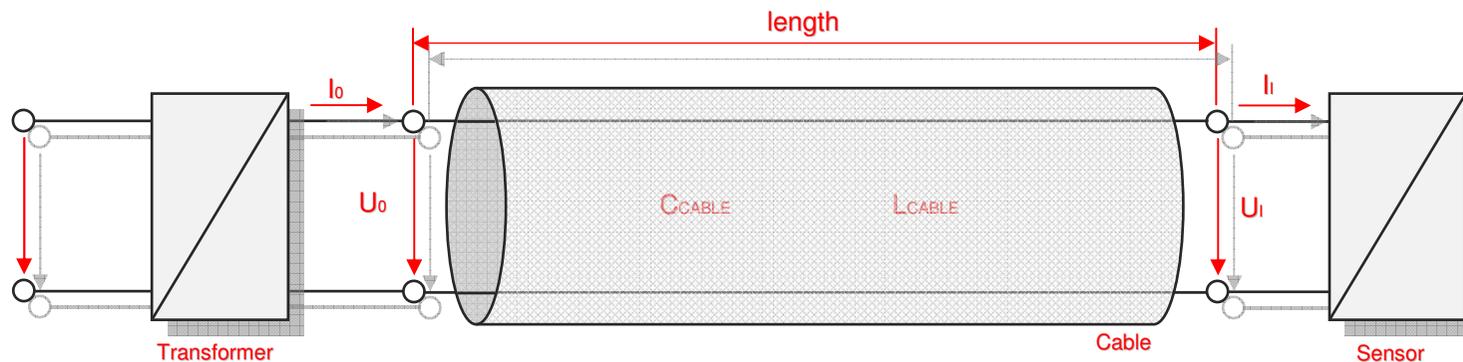


Figure 113: sketch intrinsic safety

For a successful proof of intrinsic safety the following circumstances have to be fulfilled:

- The capacitance of the transformer has to be greater than the summed up capacitance of the sensor and the cable.
- The inductance of the transformer has to be greater than the summed up inductance of the sensor and the cable.
- The withstand voltage of the cable has to be greater than the maximum output voltage of the transformer.
- The withstand voltage of the sensor has to be greater than the maximum output voltage of the transformer.
- The maximum allowed current for the cable has to be greater than the maximum output current of the transformer.
- The maximum allowed current for the sensor has to be greater than the maximum output current of the transformer.
- The maximum allowed power rate for the cable has to be greater than the maximum output power rate of the transformer.
- The maximum allowed power rate for the sensor has to be greater than the maximum output power rate of the transformer.

For the proof of capacitance (C), inductance (L), voltage (U), current (I) and power rate (P) there is an indication for each, showing the state of proof by color. Therefore green means the point is ok, red means it has failed. Finally there is an additional indication for the complete proof of intrinsic safety (S). If this indication shows green, the circuit is intrinsic safe due to the considerations, if the indications shows red, the circuit is not safe and the installation is not proper for the use case. In this case the installation set-up has to be adapted, accordingly.

The program provides three different *TabPage*s for the documentation and the proof of the intrinsic safety for the circuits.

The first *TabPage* is a database for different transformers. Therefore twelve different types of transformers can be entered. It is possible to save different sets in different files. Be aware that there is no need to enter the same type of transformer more than once, because on the *TabPage* with the calculations and evaluations the transformer can be selected from the database for each circuit, separately.

Each data set for the transformer includes the following information and values:

- the designation for the transformer type as an undefined text variable of 26 characters (e.g. manufacturers device name),
- the certification for the transformer type as an undefined text variable of 26 characters (according to the device certificate),
- the classification for the transformer type as an undefined text variable of 26 characters (according to the device certificate),
- the voltage (U0) that is relevant for the intrinsic safety according to the device certificate,
- the current (I0) that is relevant for the intrinsic safety according to the device certificate,
- the power rate (P0) that is relevant for the intrinsic safety according to the device certificate,
- the capacitance (C0) that is relevant for the intrinsic safety according to the device certificate,
- the inductance (L0) that is relevant for the intrinsic safety according to the device certificate.

The second *TabPage* is a database for different sensors. Therefore twelve different types of sensors can be entered. It is possible to save different sets in different files. Be aware that there is no need to enter the same type of sensor more than once, because on the *TabPage* with the calculations and evaluations the sensor can be selected from the database for each circuit, separately.

Each data set for the sensor includes the following information and values:

- designation for the sensor type as an undefined text variable of 26 characters (e.g. manufacturers device name),
- certification for the sensor type as an undefined text variable of 26 characters (according to the device certificate),
- classification for the sensor type as an undefined text variable of 26 characters (according to the device certificate),
- the voltage (Ui) that is relevant for the intrinsic safety according to the device certificate,
- the current (Ii) that is relevant for the intrinsic safety according to the device certificate,
- power rate (Pi) that is relevant for the intrinsic safety according to the device certificate,
- the capacitance (Ci) that is relevant for the intrinsic safety according to the device certificate,
- the inductance (Li) that is relevant for the intrinsic safety according to the device certificate.

The third *TabPage* is for defining and evaluation of the circuit. Regarding this calculations for twelve circuits at once are provided. It is possible to save different sets in different files. Be aware that there is no need to enter the same circuit more than once, if transformer, sensor and cable length are equal. For each circuit a transformer from the transformer database (first *TabPage*) and a sensor from the sensor database (second *TabPage*) have to be selected. Further it is required to enter the cable length. This has to be done according to the installation set-up on site. The specific capacitance and the specific inductance depend on the cable type. In case if these data are not available, the presetting of 120 nF / km for the specific capacitance and 0.7 mH / km for the specific inductance can usually be assumed as proper values. The specific values for the capacitance and the inductance are multiplied by the cable length. Further the proof of intrinsic safety is done. The results are shown accordingly after clicking the calculate button.

Regarding the proof of intrinsic safety there are principally the following cases:

- the result (S) will be only OK, if all of the single parameters (C, L, U, I, P) are also OK,
- the result (S) will be not OK, if even one of the single parameters (C, L, U, I, P) is not OK.

Be aware that there are no safety differences considered!

The circuits that should be included in the calculation have to be activated by clicking the corresponding *CheckBox* on the left side of the form. Regarding the printout it is only possible to print the data for one row at a time. The row to be printed has to be selected via the corresponding *RadioButton* on the right side of the form.

## 10.3.2. Variables (What are the input and output values? What are their limits?)

### voltage

It is the nominal, respectively the maximum allowed power supply voltage for the relevant device. Each circuit is divided up into three parts: the transformer as isolating amplifier, the connected sensor and the cable in between both. It is mandatory, that all compounds have to be selected properly for the existing use case.

The variable type is Input.

The unit is volt [V].

The minimum limit is 0.

The maximum limit is 999999.

The replacement value is 100.

The number of digits is 6.

### power rate

It is the nominal, respectively the maximum allowed power rate for the relevant device. Each circuit is divided up into three parts: the transformer as isolating amplifier, the connected sensor and the cable in between both. It is mandatory, that all compounds have to be selected properly for the existing use case.

The variable type is Input.

The unit is milliwatt [mW].

The minimum limit is 0.

The maximum limit is 999999.

The replacement value is 100.

The number of digits is 6.

### current

It is the nominal, respectively the maximum allowed current for the relevant device. Each circuit is divided up into three parts: the transformer as isolating amplifier, the connected sensor and the cable in between both. It is mandatory, that all compounds have to be selected properly for the existing use case.

The variable type is Input.

The unit is milliampere [mA].

The minimum limit is 0.

The maximum limit is 999999.

The replacement value is 100.

The number of digits is 6.

### eff. length

It is the total length of the effectively installed cable for the corresponding circuit. Each circuit is divided up into three parts: the transformer as isolating amplifier, the connected sensor and the cable in between both. It is mandatory, that all compounds have to be selected properly for the existing use case.

The variable type is Input.

The unit is meter [m].

The minimum limit is 0.5.

The maximum limit is 9999.

The replacement value is 10.

The number of digits is 6.

## **spec. capa.**

It is the specific capacitance for the installed cable. The specific capacitance is a measure for the capacitance value per kilometer. Each circuit is divided up into three parts: the transformer as isolating amplifier, the connected sensor and the cable in between both. It is mandatory, that all compounds have to be selected properly for the existing use case.

The variable type is Input.  
The unit is nano-Farad per kilometer [nF / km].  
The minimum limit is 0.0001.  
The maximum limit is 99999.  
The replacement value is 100.  
The number of digits is 6.

## **capacitance**

It is the nominal, respectively the maximum allowed capacitance for the relevant device. Each circuit is divided up into three parts: the transformer as isolating amplifier, the connected sensor and the cable in between both. It is mandatory, that all compounds have to be selected properly for the existing use case.

The variable type is Input or Output.  
The unit is nano-Farad [nF].  
The minimum limit is 0.  
The maximum limit is 999999.  
The replacement value is 100.  
The number of digits is 6.

## **spec. ind.**

It is the specific inductance for the installed cable. The specific inductance is a measure for the inductance value per kilometer. Each circuit is divided up into three parts: the transformer as isolating amplifier, the connected sensor and the cable in between both. It is mandatory, that all compounds have to be selected properly for the existing use case.

The variable type is Input.  
The unit is milli-Henry per kilometer [mH / km].  
The minimum limit is 0.0001.  
The maximum limit is 99999.  
The replacement value is 100.  
The number of digits is 6.

## **inductance**

It is the nominal, respectively the maximum allowed inductance for the relevant device. Each circuit is divided up into three parts: the transformer as isolating amplifier, the connected sensor and the cable in between both. It is mandatory, that all compounds have to be selected properly for the existing use case.

The variable type is Input or Output.  
The unit is milli-Henry [mH].  
The minimum limit is 0.  
The maximum limit is 999999.  
The replacement value is 100.  
The number of digits is 6.

10.3.3. Operation (How can it be used? How to proceed?)

**Step 1:**  
Fill the Input-  
TextBoxes for the  
Transformers

I enter the values for the input variables. I should respect the variable limits and take care that the entered values for voltage, current, power rate, capacitance and inductance are numeric. The values are usually given on the transformer housing or in the equipment documents. Designation, certification and classification can be string variables. They are for information purpose. Twelve different transformer types are possible.

The screenshot shows a software window titled 'Intrinsic Safety - www.hheader.com'. It has three tabs: 'Transformers', 'Sensors', and 'Cables and Evaluation'. The 'Transformers' tab is active, displaying a table with 12 rows of transformer data. The table columns are: designation, certification, classification, voltage (V), current (mA), power rate (mW), capacitance (nF), and inductance (mH). Below the table is a toolbar with icons for a calculator, TRANS, SENS, CABLE, a trash can, an information icon, a pencil, a double-headed arrow, another trash can, and three save icons labeled TRANS, SENS, and CABLE.

designation	certification	classification	voltage V	current mA	power rate mW	capacitance nF	inductance mH
Transformer 01 Type XY 01	PTB XY ATEX ????	Ex II (1) GD EEx [ja Ga] IIC ??°C	25.2	93	587	107	2
Transformer 02 Type XY 02	PTB XY ATEX ????	Ex II (1) GD EEx [ja Ga] IIC ??°C	28	93	650	83	4.11
Transformer 03 Type XY 03	PTB XY ATEX ????	Ex II (1) GD EEx [ja Ga] IIC ??°C	30.4	94.24	720	64	4
Transformer 04 Type XY 04	PTB XY ATEX ????	Ex II (1) GD EEx [ja Ga] IIC ??°C	28	93	650	65	16.44
Transformer 05 Type XY 05	PTB XY ATEX ????	Ex II (1) GD EEx [ja Ga] IIC ??°C	27.3	87.6	597	86	5.2
Transformer 06 Type XY 06	PTB XY ATEX ????	Ex II (1) GD EEx [ja Ga] IIC ??°C	10.5	13	34	2.41	210
Transformer 07 Type XY 07	PTB XY ATEX ????	Ex II (1) GD EEx [ja Ga] IIC ??°C	10.6	19.1	51	2.32	97
Transformer 08 Type XY 08	PTB XY ATEX ????	Ex II (1) GD EEx [ja Ga] IIC ??°C	7.2	3	5.4	13500	1000
Transformer 09 Type XY 09	PTB XY ATEX ????	Ex II (1) GD EEx [ja Ga] IIC ??°C	21	75	660	178	6.7
Transformer 10 Type XY 10	PTB XY ATEX ????	Ex II (1) GD EEx [ja Ga] IIC ??°C	6	15	39	990	5
Transformer 11 Type XY 11	PTB XY ATEX ????	Ex II (1) GD EEx [ja Ga] IIC ??°C	23.1	100	580	140	4
Transformer 12 Type XY 12	PTB XY ATEX ????	Ex II (1) GD EEx [ja Ga] IIC ??°C	21	100	660	178	4

**Step 9:**  
Further actions  
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the TextBoxes at once.

Figure 114: form intrinsic safety - transformers

**Step 2:**  
**Fill the Input-TextBoxes for the Sensors**  
 I enter the values for the input variables. I should respect the variable limits and take care that the entered values for voltage, current, power rate, capacitance and inductance are numeric. The values are usually given on the sensor housing or in the equipment documents. Designation, certification and classification can be string variables. They are for information purpose. Twelve different sensor types are possible.

	designation	certification	classification	voltage V	current mA	power rate mW	capacitance nF	inductance mH
1.)	Sensor 01 Type XY 01	PTB XY ATEX ????	Ex II 1 G EEx ia IIC / IIB T?	30	100	750	6	0.4
2.)	Sensor 02 Type XY 02	PTB XY ATEX ????	Ex II 1 G EEx ia IIC / IIB T?	30	100	1000	22	0
3.)	Sensor 03 Type XY 03	PTB XY ATEX ????	Ex II 1 G EEx ia IIC / IIB T?	30	150	1000	10	0
4.)	Sensor 04 Type XY 04	PTB XY ATEX ????	Ex II 1 G EEx ia IIC / IIB T?	24	50	250	0	0
5.)	Sensor 05 Type XY 05	PTB XY ATEX ????	Ex II 1 G EEx ia IIC / IIB T?	30	120	800	6.2	0.11
6.)	Sensor 06 Type XY 06	PTB XY ATEX ????	Ex II 1 G EEx ia IIC / IIB T?	30	100	750	6	0.4
7.)	Sensor 07 Type XY 07	PTB XY ATEX ????	Ex II 1 G EEx ia IIC / IIB T?	7.2	15	27	0	0
8.)	Sensor 08 Type XY 08	PTB XY ATEX ????	Ex II 1 G EEx ia IIC / IIB T?	30	160	1000	10	0
9.)	Sensor 09 Type XY 09	PTB XY ATEX ????	Ex II 1 G EEx ia IIC / IIB T?	30	160	1000	0	0
10.)	Sensor 10 Type XY 10	PTB XY ATEX ????	Ex II 1 G EEx ia IIC / IIB T?	33	150	1000	0	0.024
11.)	Sensor 11 Type XY 11	PTB XY ATEX ????	Ex II 1 G EEx ia IIC / IIB T?	30	150	1000	12	0.024
12.)	Sensor 12 Type XY 12	PTB XY ATEX ????	Ex II 1 G EEx ia IIC / IIB T?	28	150	970	18	0.5

**Step 3:**  
**Select the rows to be calculated**  
 By clicking on the corresponding *CheckBox* I can select all the rows that should be included in the calculation. Via the *CheckBox* "all" all the twelve rows can be selected or deselected.

SENS CABLE

Figure 115: form intrinsic safety - sensors

**Step 4:**  
**Select the used transformer and sensor**  
I can select the used transformer and the corresponding used sensor for each row. The selection is according to the entered transformer and sensor types on the previous *TabPage*s.

**Step 5:**  
**Fill the Input-TextBoxes**  
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric. The values refer to the cable specification.

**Step 7:**  
**Check results**  
After clicking the Calculate-Button I can check the results. The evaluation of the compound combination is indicated by color. A green indication means the parameter is proper, a red indication means the parameter is not proper. At least the evaluation is proper, if all indicators are green. Even one red indication means the installation is not proper and has to be changed.

**Step 6:**  
**Calculate result**  
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

**Step 8:**  
**Select the row to be printed**  
I can select the row that should be printed in case if the corresponding *ToolStripButton* is clicked. Only one row can be printed at once.

**Step 7:**  
**Check results**  
After clicking the Calculate-Button I can check the results. The evaluation of the compound combination is indicated by color. A green indication means the parameter is proper, a red indication means the parameter is not proper. At least the evaluation is proper, if all indicators are green. Even one red indication means the installation is not proper and has to be changed.

Figure 116: form intrinsic safety – cables and evaluation

## 10.4. Measure Range

### 10.4.1. Purpose (What can it be used for? What can it not be used for?)

The program is part of category 5 – electrics. Fully or even partly automated plants nowadays have generally different sensors for measuring and control purposes. Thereby a physical value is measured with help of an electrical sensor and a corresponding signal transmitter. Principally the physical value is converted into an electrical signal by the sensor. The transmitter again converts the sensor signal into a linear standard signal that can be handled by a programmable logic controller. The signal is defined by a minimum value and a maximum value. The difference between these values is the range. Sometimes the minimum signal is greater than zero. This is called offset zero or live-zero. The advantage is that a wire break or a defective sensor can be detected instantly, because there has to be a signal above zero, even if the physical value is below the defined range.

In the following signals are defined as standard signals, which are divided up into voltage- and current signals.

#### Current signals according to the German rule DIN IEC 60381-1:

- 0 mA ... 20 mA,
- 4 mA ... 20 mA.

#### Commonly occurring voltage signal for microcontrollers:

- -5 V ... +5 V.

#### Voltage signals according to the German rule DIN IEC 60381-2:

- 0 V ... 5 V,
- 0 V ... 10 V,
- 1 V ... 5 V,
- 2 V ... 10 V,
- -10 V ... +10 V.

The program provides calculations for the corresponding conversions of a physical value into one of the mentioned standard signals. Therefore one of the signal types can be selected. The unit for the physical value can be entered as an undefined text variable. Further the range for the physical value has to be defined by the minimum and the maximum value, which are input variables. Either the physical value or the signal value can be selected as output variable. In each case the residual variable is the input variable. The slope of the mathematic function and the intercept with the y-axis are also calculated. The y-axis is provided for the electrical signal and the x-axis is provided for the physical value. According to the selected signal type the corresponding graph for the mathematic function is shown in the diagram window. It is a simple graph just for overview purposes. It is possible to scroll the graph left, right, up and down as well as to zoom in and out.

The sketch below shows the different signal types as a graph in a diagram. Hereby the electrical signal is dedicated to the y-axis and the physical value is dedicated to the x-axis. For the example shown in the diagram the physical value is supposed to be a temperature value measured by a sensor with a range from -30°C to 70°C. The ranges for the y-axis are according to the signal type.

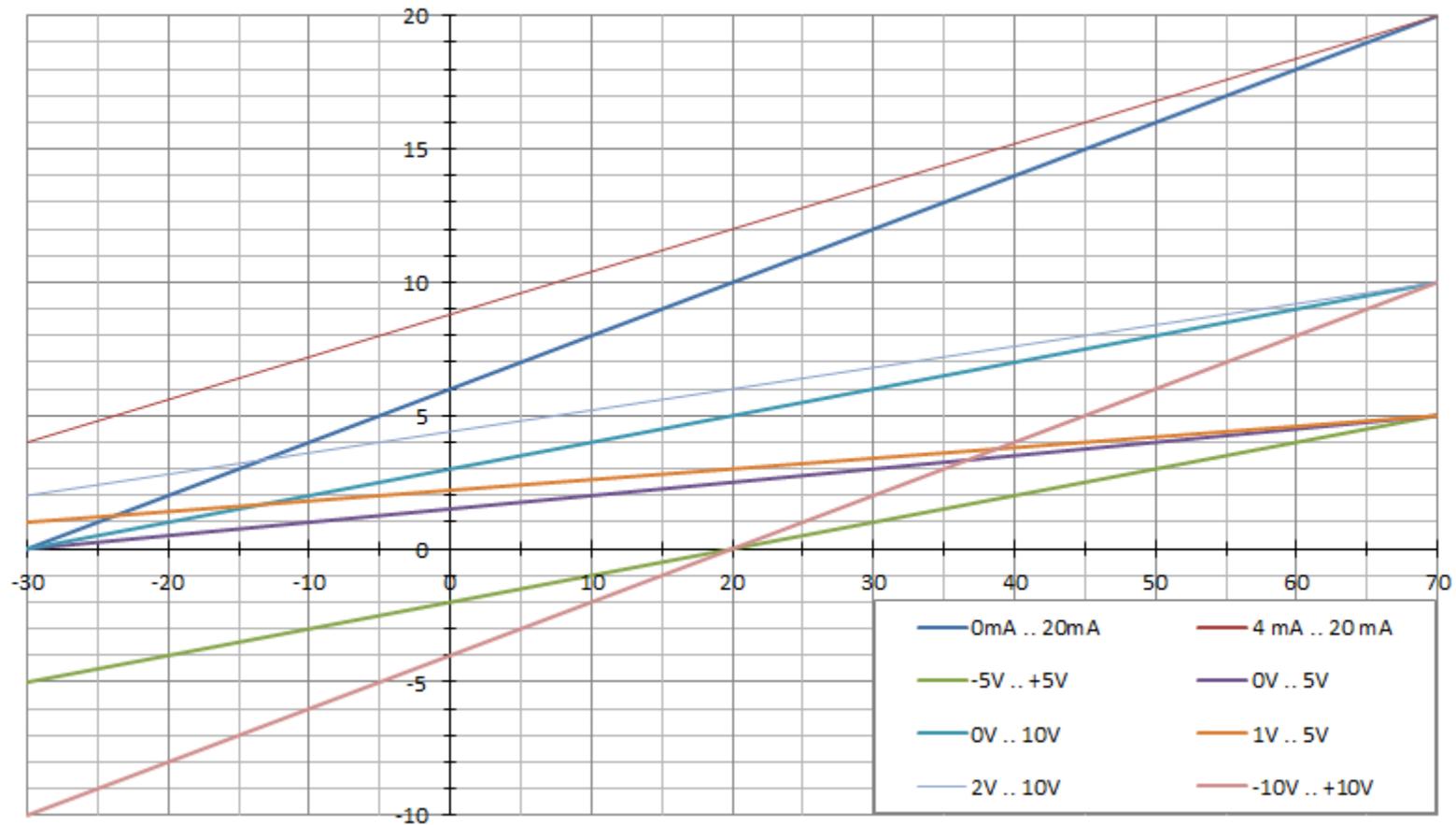


Figure 117: sketch measure range

#### 10.4.2. Variables (What are the input and output values? What are their limits?)

##### **signal low value (range for signal: left side)**

It is the specified low value for the electric signal. For the electric signal there are the different main standards provided for selection. These are 0 to 20 mA, 4 to 20 mA, 0 to 5 V, 1 to 5 V, 0 to 10 V, 2 to 10 V, -10 to 10 V and -5 to 5 V. Both, the spec. signal low and high value will be set according to the selection.

The variable type is Input.  
The unit is volt [V] or milliampere [mA].  
The minimum limit is depending on the selection.  
The maximum limit is depending on the selection.  
The replacement value is 10.  
The number of digits is 5.

##### **unit low value (range for signal: left side)**

It is the effective low value for the entered measuring unit. The unit can be entered as a text variable. The unit low value will be the minimum limit for the specified unit value.

The variable type is Input.  
The variable has no fix unit [?], it can be entered.  
The minimum limit is -9999.  
The maximum limit is 9999.  
The replacement value is 10.  
The number of digits is 5.

##### **signal high value (range for signal: right side)**

It is the specified high value for the electric signal. For the electric signal there are the different main standards provided for selection. These are 0 to 20 mA, 4 to 20 mA, 0 to 5 V, 1 to 5 V, 0 to 10 V, 2 to 10 V, -10 to 10 V and -5 to 5 V. Both, the spec. signal low and high value will be set according to the selection.

The variable type is Input.  
The unit is volt [V] or milliampere [mA].  
The minimum limit is depending on the selection.  
The maximum limit is depending on the selection.  
The replacement value is 10.  
The number of digits is 5.

##### **unit high value (range for signal: right side)**

It is the effective high value for the entered measuring unit. The unit can be entered as a text variable. The unit high value will be the maximum limit for the specified unit value.

The variable type is Input.  
The variable has no fix unit [?], it can be entered.  
The minimum limit is -9999.  
The maximum limit is 9999.  
The replacement value is 10.  
The number of digits is 5.

## **slope**

It is the slope that is resulting from the selected values for the electric signal range and the entered values for the measuring unit range. The slope is calculated by the difference of high and low value for the electric signal divided by the difference of high and low value for the measuring unit.

The variable type is Output.  
The unit is volt per unit [V / unit] or milliampere per unit [mA / unit].  
There is no defined minimum limit for output variables.  
There is no defined maximum limit for output variables.  
There is no defined replacement value for output variables.  
There is no defined number of digits for output variables.

## **eff. unit value**

It is effective value for the measuring unit. Either a value for the measuring unit is given and the corresponding signal value is calculated or a value for the signal is given and the corresponding unit value is calculated.

The variable type is Input or Output.  
The variable has no fix unit [?], it can be entered.  
The minimum limit is equal to the unit low value.  
The maximum limit is equal to the unit high value.  
The replacement value is 10.  
The number of digits is 5.

## **intercept**

It is the intercept of the graph and the y-axis. The standard electric signal is a linearization of the measured unit in between the defined ranges. However the signal is defined, the linear graph will get either regularly or by extrapolation in contact with the y-axis.

The variable type is Output.  
The unit is volt [V] or milliampere [mA].  
There is no defined minimum limit for output variables.  
There is no defined maximum limit for output variables.  
There is no defined replacement value for output variables.  
There is no defined number of digits for output variables.

## **spec. signal value**

It is specified value for the electrical signal. Either a value for the measuring unit is given and the corresponding signal value is calculated or a value for the signal is given and the corresponding unit value is calculated.

The variable type is Input or Output.  
The unit is volt [V] or milliampere [mA].  
The minimum limit is depending on the selection.  
The maximum limit is depending on the selection.  
The replacement value is 10.  
The number of digits is 5.

10.4.3. Operation (How can it be used? How to proceed?)

**Step 1:**  
**Select the signal type**  
I can select the type of measuring signal that is relevant for the calculations. There are five different standard signals provided which are used for analog PLC-inputs.

**Step 3:**  
**Fill the Input-TextBoxes**  
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

**Step 4:**  
**Select the variable to be calculated**  
By clicking on the corresponding *RadioButton* I can choose the variable to be calculated. It is like executing an internal conversion of the equation.

**Step 6:**  
**Calculate result**  
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

The screenshot shows the 'Measure Range' software window. At the top, there are two input ranges: 'range for signal' (4 to 20 mA) and 'range for unit' (-30 to 70 °C). Below these is a graph with a red line representing a linear relationship. At the bottom, there are several input fields for 'slope' (0.16), 'intercept' (8.80), and 'eff. unit value' (5.7), each with a unit selector. There are also 'spec. signal value' fields (9.71) and a 'Calculate' button. A toolbar at the very bottom contains icons for calculator, printer, trash, info, and save.

**Step 2:**  
**Enter unit for variable**  
I can enter the unit for the measured variable. The format for this unit is string. There are no plausibility checks provided for this entry.

**Step 7:**  
**Check result**  
After clicking the Calculate-Button I can check the result.

**Step 5:**  
**Enter the number of decimal places**  
I enter the number of decimal places for the variables. It is valid only if the corresponding variable is selected as output. The input variables can get more or less decimal numbers according to the number of digits.

**Step 8:**  
**Further actions**  
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

Figure 118: form measure range

**10.5. Power Rates**

**10.5.1. Purpose (What can it be used for? What can it not be used for?)**

The program is part of category 5 – electrics. Energy cannot get lost - energy can be converted from one kind to another kind. There are many different kinds of energy. Energy can appear, can be stored and can be converted. The law of conservation of energy is a powerful tool to evaluate technical or process circumstances. In every case we must be aware that the energy can never be converted from one kind to another to hundred percent. Parts of the energy will convert into other kinds, too. This is what we call losses, but the energy is only lost in reference to the considered process. In many cases these losses are converted into thermal energy. The energy input minus the energy losses is the energy output. The energy output in relation to the energy input is the efficiency rate, which is an important measure to be taken into consideration for the law of conservation of energy.

The program provides calculations for the operation of a pump, a fan or a blower, where at least the electrical supply power rate is divided up in the first, then converted into a mechanical power rate at the shaft of the stator and finally occurs as a power rate of a moving fluid at a certain pressure. Therefore the losses of power rate have to be considered as the efficiencies of the single stages. The losses for each stage are visualized with the help of small battery figures in the lower part of the form for overview purposes. Be aware that all the losses are displayed in relation to the electrical apparent input power rate!

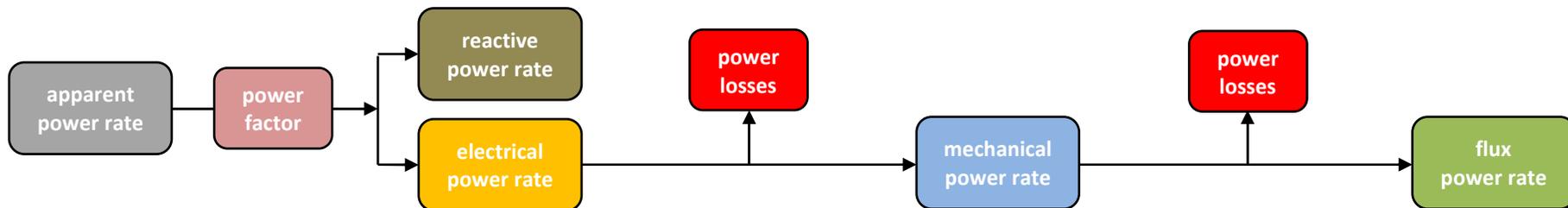


Figure 119: sketch power rate

**Stage 1:  
electrical power rates**

The electrical power rates apparent power rate, reactive power rate and active power rate are defined by the voltage, the current and the power factor. Further it is important, if a 1-phase or a 3-phase system is available for the power supply. Active power rate, voltage or current can be selected as output variable. The residual two are input variables. Apparent power rate and reactive power rate are calculated values. The specified power factor is an input variable.

**Stage 2:  
mechanical power rate**

The mechanical power rate is defined by the rotation frequency and the torque of the motor shaft. The conversion of the active power rate into the mechanical power rate can only take place in coherence with power losses. The active power rate, the rotation frequency or the torque can be selected as output variable. The residual two are input variables. The mechanical power rate is calculated by the input value of the efficiency and the active power rate.

**Stage 3:  
flux power rate**

The flux power rate is defined by the operation pressure and the flow rate. The mechanical power rate, the pressure or the flow rate can be selected as output variable. The residual two are input variables. The flux power rate is calculated by the input value of the efficiency and the mechanical power rate. Operating a pump, a blower, a fan or any other device with the shaft power, will cause losses, which means that the efficiency has to be considered.

For each stage (electrical, mechanical and flux) there is a transfer button provided. If this is clicked, the calculation for the corresponding stage will be carried out accordingly in the first. After this the value for the power rate will be transferred into the residual two stages and the calculations for these stages will be done automatically, so that the transitions are in coherence.

For information: after performing any of the Transfer-Buttons the following variable selections will be carried out automatically.

One: the current will be selected as an output variable for the electrical stage.

Two: the torque will be selected as an output variable for the mechanical stage.

Three: the flow rate will be selected as an output variable for the flux stage.

## 10.5.2. Variables (What are the input and output values? What are their limits?)

### **active power rate**

It is the active power rate which is available for the use case. The apparent power rate results from the vector addition of active power rate and reactive power rate.

The variable type is Input or Output.  
The unit is kilowatt [kW].  
The minimum limit is 0.0001.  
The maximum limit is 99999999.  
The replacement value is 100.  
The number of digits is 8.

### **apparent power rate**

It is the apparent power rate which is present due to the active and reactive loads. The apparent power rate results from the vector addition of active power rate and reactive power rate.

The variable type is Output.  
The unit is kilowatt [kvar].  
There is no defined minimum limit for output variables.  
There is no defined maximum limit for output variables.  
There is no defined replacement value for output variables.  
There is no defined number of digits for output variables.

### **reactive power rate**

It is the reactive power rate which is present in the network due to the reactive loads. The apparent power rate results from the vector addition of active power rate and reactive power rate.

The variable type is Output.  
The unit is kilowatt [kVA].  
There is no defined minimum limit for output variables.  
There is no defined maximum limit for output variables.  
There is no defined replacement value for output variables.  
There is no defined number of digits for output variables.

### **voltage**

It is the power supply voltage of the aggregate that is focus for the calculations. Voltage, current, the power factor and the type of the phase system are relevant for the available power rates.

The variable type is Input or Output.  
The unit is volt [V].  
The minimum limit is 0.0001.  
The maximum limit is 99999999.  
The replacement value is 100.  
The number of digits is 8.

## **current**

It is the actual operating current of the aggregate that is focus for the calculations. Voltage, current, the power factor and the type of the phase system are relevant for the available power rates.

The variable type is Input or Output.  
The unit is ampere [A].  
The minimum limit is 0.0001.  
The maximum limit is 99999999.  
The replacement value is 100.  
The number of digits is 8.

## **mech. power rate**

It is the mechanical power rate of the aggregate that is focus for the calculations. The mechanical power rate of an aggregate that rotates results from the torque and the rotation frequency. The mechanical power rate is due to the losses practically less than the active power rate. A measure for this is the efficiency.

The variable type is Input or Output.  
The unit is kilowatt [kW].  
The minimum limit is 0.0001.  
The maximum limit is 99999999.  
The replacement value is 100.  
The number of digits is 8.

## **spec. power factor**

It is the specified power factor of the aggregate that is focus for the calculations. Voltage, current, the power factor and the type of the phase system are relevant for the available power rates.

The variable type is Input.  
The variable has no unit [-].  
The minimum limit is 0.5.  
The maximum limit is 1.  
The replacement value is 0.85.  
The number of digits is 8.

## **rotation**

It is the actual rotation respectively the operation rotation frequency of the aggregate. The mechanical power rate of an aggregate that rotates results from the torque and the rotation frequency.

The variable type is Input or Output.  
The unit is one over minute [1 / min].  
The minimum limit is 0.0001.  
The maximum limit is 99999999.  
The replacement value is 100.  
The number of digits is 8.

## **torque**

It is the actual torque respectively the operation torque of the aggregate. The mechanical power rate of an aggregate that rotates results from the torque and the rotation frequency.

The variable type is Input or Output.  
The unit is Newton by meter [Nm].  
The minimum limit is 0.0001.  
The maximum limit is 99999999.  
The replacement value is 100.  
The number of digits is 8.

## **flux power rate**

It is the power rate of the flux respectively the fluid flow that is produced by the operated pump or fan. The flux power rate results from the flow rate and the differential pressure of the fluid. Due to the losses in practice the flux power rate (output) is always less than the mechanical power rate (input). A measure for this is the efficiency.

The variable type is Input or Output.  
The unit is kilowatt [kW].  
The minimum limit is 0.0001.  
The maximum limit is 99999999.  
The replacement value is 100.  
The number of digits is 8.

## **efficiency (mech)**

It is the efficiency of the aggregate that is focus for the calculations. Due to the losses in practice the output power rate is always less than the input power rate. A measure for this is the efficiency.

The variable type is Input.  
The unit is percent [%].  
The minimum limit is 15.  
The maximum limit is 100.  
The replacement value is 50.  
The number of digits is 8.

## **diff. pressure**

It is the differential pressure of the flux respectively the fluid flow that is produced by the operated pump or fan. The flux power rate results from the flow rate and the differential pressure of the fluid. Due to the losses in practice the flux power rate (output) is always less than the mechanical power rate (input). A measure for this is the efficiency.

The variable type is Input or Output.  
The unit is bar [bar].  
The minimum limit is 0.001.  
The maximum limit is 999.  
The replacement value is 2.  
The number of digits is 8.

**flow rate**

It is the flow rate for the fluid that is moved by the operated pump or fan. The flux power rate results from the flow rate and the differential pressure. Due to the losses in practice the flux power rate (output) is always less than the mechanical power rate (input). A measure for this is the efficiency.

The variable type is Input or Output.  
The unit is bar [bar].  
The minimum limit is 0.0001.  
The maximum limit is 99999999.  
The replacement value is 100.  
The number of digits is 8.

**efficiency (flux)**

It is the efficiency of the aggregate that is focus for the calculations. Due to the losses in practice the output power rate is always less than the input power rate. A measure for this is the efficiency.

The variable type is Input.  
The unit is percent [%].  
The minimum limit is 15.  
The maximum limit is 100.  
The replacement value is 50.  
The number of digits is 8.

The power rate of the moving fluid is at least the product that results by multiplying the values of differential pressure and flow rate. Thereby the fluid pressure consists of three different pressure compounds. These are static pressure, dynamic pressure and the pressure drop caused by frictional losses. The total system pressure is the sum of the three pressure compounds.

The on-site measured pressure value always includes all the three compounds. The law where the power rate of the fluid system is equal to the product of differential pressure and flow rate, is in the first relevant for fluids that can be assumed as incompressible. This means in the first liquids which are transferred e.g. by pumps. Considering the general group / family of work machines there are two other kinds relevant. These are fans and compressors. Regarding the fans the fluid (gas) can be assumed as incompressible in case if the pressure difference is low and in order to carry out a rough evaluation of the circumstances in practice. For both (fans and compressors) the isentropic factor has to be taken into consideration. Further and especially for the compressors the corresponding temperature values are also important.

Keep in mind that the fluid density is already included in the pressure value. A simple fluid transfer machine cannot build up a high pressure with a low density fluid. Due to this the program can be used for rough evaluation purposes regarding pumps and also for fans, as long as the pressure difference is low in reference to one bar. The program cannot be used for compressors, where the pressure difference is principally high and temperature changes occur.

10.5.3. Operation (How can it be used? How to proceed?)

**Step 1:**  
**Select the number of phases**  
I can select the number of phases for the electrical supply system.

**Step 2:**  
**Select the variable to be calculated**  
By clicking on the corresponding *RadioButton* I can choose the variable to be calculated. It is like executing an internal conversion of the equation.

**Step 3:**  
**Fill the Input-TextBoxes**  
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

The screenshot shows a software interface titled 'Power Rates - www.hheader.com'. It is divided into three main sections: 'electrical', 'mechanical', and 'flux'. Each section has several input fields and radio buttons. Below the input fields are three columns of gauges showing calculated values and percentages. At the bottom, there are three sets of utility icons including a calculator, printer, trash, and information icon.

Section	Variable	Value	Unit
electrical	1 or 3 - phase system	3 - phases	-
	active power rate	9.5	kW
	apparent power rate	10.7	kVA
	reactive power rate	4.9	kvar
mechanical	active power rate	9.5	kW
	mech. power rate	6.4	kW
	rotation	2920	1 / min
	torque	20.9	Nm
flux	mech. power rate	6.4	kW
	flux power rate	3.5	kW
	diff. pressure	4	bar
	flow rate	31.7	m <sup>3</sup> / h
Gauges (Electrical)	apparent power rate	100%	-
	active power rate	89%	-
Gauges (Mechanical)	active power rate	89%	-
	mech. power rate	60%	-
Gauges (Flux)	mech. power rate	60%	-
	flux power rate	33%	-

**Step 6:**  
**Check result**  
After clicking the Calculate-Button I can check the result.

Figure 120: form power rates

**Step 4: Calculate result**  
 After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

The screenshot shows a software interface titled "Power Rates - www.hheader.com" with three main sections: electrical, mechanical, and flux. Each section has input fields for various parameters and corresponding calculated values. Below the input fields are progress bars and percentage indicators for different power rates and losses.

Section	Parameter	Value	Unit
electrical	1 or 3 - phase system	3 - phases	-
	active power rate	9.5	kW
	apparent power rate	10.7	kVA
mechanical	active power rate	9.5	kW
	mech. power rate	6.4	kW
	efficiency	67	%
flux	mech. power rate	6.4	kW
	flux power rate	3.5	kW
	efficiency	55	%

**Step 5: Transfer**  
 After the calculation clicking one of the transfer buttons will execute a calculation for all three subjects. The basis values depend on the corresponding transfer button.

**Step 7: Further actions**  
 After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the TextBoxes at once.

Figure 121: form power rates

## 10.6. Electrical Resistance –Resistance

### 10.6.1. Purpose (What can it be used for? What can it not be used for?)

The program is part of category 5 – electrics. The electrical resistance is not only in theory but also on site an important value. Resistance calculations can be used to check, if a cable is still in a proper condition or not, for example. The program provides calculations regarding this subject.

For the resistance of a core in the first the core material, the cross section of the core and the length of the core are relevant. In practice on site usually the length of the cable is known or can be determined. Keep in mind that for single loop circuits the core length is usually equal the cable length by two.

The properties of the core material regarding the electrical resistance are considered by the specific resistivity. A selection of useful core materials is provided, which gives back the specific resistivity of the selected material. The value can be transferred from the list as input variable for the calculation by the transfer button or it can be entered directly. The specific resistivity is an input variable. Core length, core cross section or resistance can be selected as output variable. The residual two are input variables.

The resistance is calculated by multiplying the specific resistivity by the core length divided by the cross section. The calculations refer to a temperature of 20°C. In case if the temperature should be considered, further calculations are required. These are provided on the second *TabPage*.

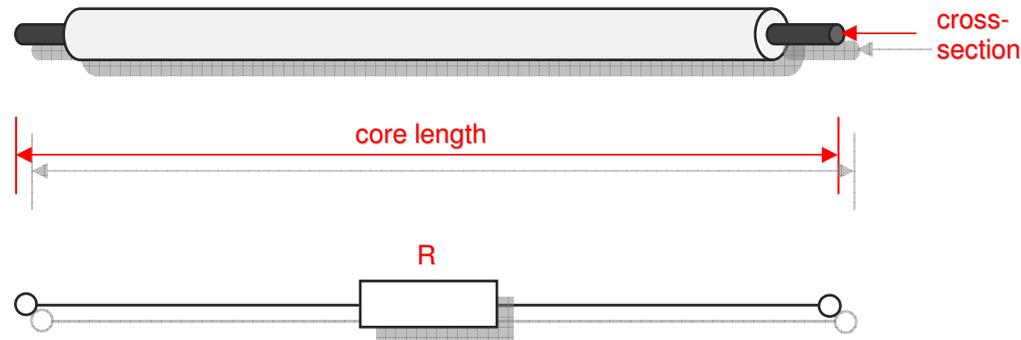


Figure 122: sketch electrical resistance – resistance

## 10.6.2. Variables (What are the input and output values? What are their limits?)

### core length

It is the total length of the core that is focus for the calculations. Keep in mind that for single loop circuits the core length is usually equal the cable length by two.

The variable type is Input or Output.  
The unit is meter [m].  
The minimum limit is 0.0001.  
The maximum limit is 99999999.  
The replacement value is 10.  
The number of digits is 8.

### spec. resistivity

It is the specific resistivity of the core material. It defines the electrical resistance of a material based on a cross section of one millimeter square and a length of one meter.

The variable type is Input.  
The unit is Ohm by millimeter square per meter [Ohm mm<sup>2</sup> / m].  
The minimum limit is -0.0004.  
The maximum limit is 40.  
The replacement value is 0.0039.  
The number of digits is 8.

### cross section

It is the cross section of one cable core. Keep in mind that for single loop circuits the core length is usually equal the cable length by two.

The variable type is Input or Output.  
The unit is millimeter square [mm<sup>2</sup>].  
The minimum limit is 0.0001.  
The maximum limit is 99999999.  
The replacement value is 10.  
The number of digits is 8.

### resistance at 20°C

It is the calculated electrical resistance for the core at a temperature of 20°C. Keep in mind that for single loop circuits the core length is usually equal the cable length by two. If the temperature is below or above 20°C, further calculations are required.

The variable type is Input or Output.  
The unit is Ohm [Ohm].  
The minimum limit is 0.0001.  
The maximum limit is 99999999.  
The replacement value is 10.  
The number of digits is 8.

10.6.3. Operation (How can it be used? How to proceed?)

**Step 4:**  
**Enter the number of decimal places**  
I enter the number of decimal places for the variables. It is valid only if the corresponding variable is selected as output. The input variables can get more or less decimal numbers according to the number of digits.

**Step 2:**  
**Select the variable to be calculated**  
By clicking on the corresponding *RadioButton* I can choose the variable to be calculated. It is like executing an internal conversion of the equation.

**Step 3:**  
**Fill the Input-TextBoxes**  
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

**Step 6:**  
**Check result**  
After clicking the Calculate-Button I can check the result.

**Step 5:**  
**Calculate result**  
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

**Step 7:**  
**Further actions**  
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

Figure 123: form electrical resistance – resistance

**Step 1 (option):**  
**Transfer spec. resistivity**  
After selecting a material I can transfer the value for the specific resistivity.

## 10.7. Electrical Resistance –Temp. Resistance

### 10.7.1. Purpose (What can it be used for? What can it not be used for?)

The program is part of category 5 – electrics. The electrical resistance is not only in theory but also on site an important value. Resistance calculations can be used to check, if a cable is still in a proper condition or not, for example. The program provides calculations regarding this subject.

For the resistance of a cable in the first the core material, the cross section of the core and the length of the core are relevant. In practice on site usually the length of the cable is known or can be determined. In most cases the current has to go through the core to the operated device and its way back. This is why the relevant core length is equal cable length multiplied by two. The resistance is calculated by multiplying the specific resistivity by the core length divided by the cross section. These calculations refer to a temperature of 20°C. In case if the temperature should be considered, further calculations are required.

To consider the temperature taking influence on the electrical resistance the resistance at 20°C has to be known. This can be calculated on the previous *TabPage*. Further the temperature coefficient for the used core material is important. By the way, the temperature coefficient is not constant. For temperatures up to 100°C the calculations with the linear alpha-coefficient which is displayed in the list and used for the calculations, can be assumed as exactly enough. Anyhow regarding practical calculations for cables the provided temperature range from -50°C to 95°C is sufficient, because normally the temperature of the cable core should not exceed 90°C. Just for information purpose in general it is mentioned, that for temperatures above 100°C the square based beta-coefficient should to be also considered.

A selection of useful core materials is provided, which gives back the specific temperature coefficient (linear alpha-coefficient) of the selected material. The value can be transferred from the list as input variable for the calculation by the transfer button or it can be entered directly. The specific temperature coefficient is an input variable. The resistance at 20°C, the temperature or the resistance at the given temperature can be selected as output variable. The residual two are input variables.

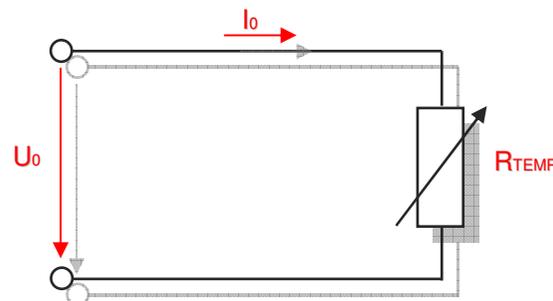


Figure 124: sketch electrical resistance – temp. resistance

## 10.7.2. Variables (What are the input and output values? What are their limits?)

### resistance at 20°C

It is the calculated electrical resistance for the cable cores at a temperature of 20°C.

The variable type is Input or Output.  
The unit is Ohm [Ohm].  
The minimum limit is 0.0001.  
The maximum limit is 99999999.  
The replacement value is 10.  
The number of digits is 8.

### spec. temperature coefficient

It is the specific temperature coefficient for the core material. The electrical resistance of the core material will change with respect to the temperature. The specific temperature coefficient is a measure for this behavior.

The variable type is Input.  
The unit is one over Kelvin [ $1 / K$ ].  
The minimum limit is -0.0004.  
The maximum limit is 40.  
The replacement value is 0.0039.  
The number of digits is 8.

### temperature

It is the actual temperature at the cores of the cable which is relevant for the calculations. In case if the ambient temperature is not constant, the maximum temperature that can be assumed as possible should be taken into consideration.

The variable type is Input or Output.  
The unit is degree Celsius [°C].  
The minimum limit is -200.  
The maximum limit is 1400.  
The replacement value is 20.  
The number of digits is 8.

### resistance at T

It is the calculated electrical resistance for the cable cores at a given temperature.

The variable type is Input or Output.  
The unit is Ohm [Ohm].  
The minimum limit is 0.0001.  
The maximum limit is 99999999.  
The replacement value is 10.  
The number of digits is 8.

10.7.3. Operation (How can it be used? How to proceed?)

**Step 4:**  
**Enter the number of decimal places**  
I enter the number of decimal places for the variables. It is valid only if the corresponding variable is selected as output. The input variables can get more or less decimal numbers according to the number of digits.

**Step 2:**  
**Select the variable to be calculated**  
By clicking on the corresponding *RadioButton* I can choose the variable to be calculated. It is like executing an internal conversion of the equation.

**Step 3:**  
**Fill the Input-TextBoxes**  
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

**Step 6:**  
**Check result**  
After clicking the Calculate-Button I can check the result.

**Step 5:**  
**Calculate result**  
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

**Step 7:**  
**Further actions**  
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

Figure 125: form electrical resistance – temp. resistance

**Step 1 (option):**  
**Transfer spec. temp. coefficient**  
After selecting a material I can transfer the value for the specific temperature coefficient.

## 10.8. Electrical Resistance – Voltage Drop

### 10.8.1. Purpose (What can it be used for? What can it not be used for?)

The program is part of category 5 – electrics. For the electrical power supply of a motor, an engine, a plant or in general any electrical consumer a proper cable with a proper cross section has to be selected due to the installation and operation circumstances. Regarding this different factors, design criteria and circumstances have to be taken into consideration. Especially for some kinds of devices as asynchronous motors for example, it is important to ensure a low voltage drop due to long supply cables, because the asynchronous motor works principally as a rotating transformer keeping the power rate constant. This will cause an increasing current due to the reduced supply voltage that is caused by the voltage drop occurring at the cable. The voltage drop has to be taken into consideration. It can be decreased by selecting a core cross section that is in a proper coherence with the cable length. The program provides calculations regarding this subject.

For the voltage drop calculations there is a selection provided for a one phase or a three phase system. Also different core materials can be selected. Power rate, voltage or current can be selected as output variable in the upper part of the form. The residual two variables are input variables. The nominal current is relevant for the further calculations. In case if this is not known, it can be calculated as result, if the corresponding *RadioButton* is selected. For the percentage of the voltage drop the supply voltage is relevant. In case if this is not known, it can be calculated as result, if the corresponding *RadioButton* is selected.

Voltage drop (as percentage of the supply voltage), cable length and cross section can be selected as output variable in the lower part of the form. The residual two variables are input variables. The current will be adapted according to the given factor and the new relevant value will be displayed in the lower part of the form. The new current and the voltage drop are the relevant values for the selection of the cross section. The cross section can be selected via a *ComboBox* in the lower part of the form. Be aware that the cross section has to be selected with respect to the current according to the actual rules! There is a minimum cross section defined depending on the cable type and the further cable routing circumstances. These detailed selections are provided in the program “Cross Section”, which is also part of category 5 - electrics. The maximum cross section for the provided choice is 630 mm<sup>2</sup>! The required cross section can be, especially with respect to the cable length, a multiple of the base value and much more than expected.

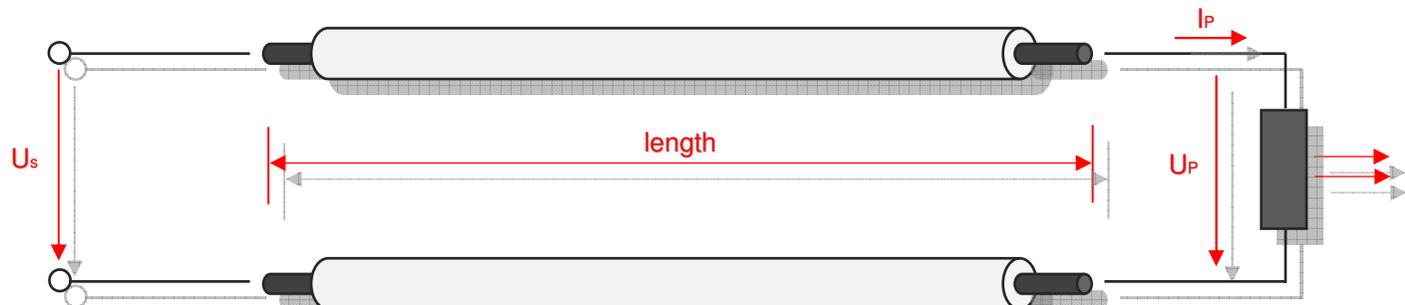


Figure 126: sketch electrical resistance – voltage drop

## 10.8.2. Variables (What are the input and output values? What are their limits?)

### voltage

It is the electrical voltage that is power supply for the operated device.

The variable type is Input or Output.  
The unit is volt [V].  
The minimum limit is 0.0001.  
The maximum limit is 99999999.  
The replacement value is 10.  
The number of digits is 8.

### factor cos phi

It is the power factor that is specified for the operated device according to the actual use case.

The variable type is Input.  
The variable has no unit [-].  
The minimum limit is 0.5.  
The maximum limit is 1.  
The replacement value is 0.85.  
The number of digits is 8.

### power rate

It is the electrical power rate for the operated device that is focus for the calculations.

The variable type is Input or Output.  
The unit is kilowatt [kW].  
The minimum limit is 0.0001.  
The maximum limit is 99999999.  
The replacement value is 10.  
The number of digits is 8.

### current

It is the current for the operated device that is focus for the calculations according to the use case.

The variable type is Input or Output.  
The unit is ampere [A].  
The minimum limit is 0.0001.  
The maximum limit is 99999999.  
The replacement value is 10.  
The number of digits is 8.

## **eff. voltage drop**

It is the voltage drop that occurs for the according to the current and the cable resistance which results from the cable length and the cable cross section.

The variable type is Input or Output.  
The unit is percent [%].  
The minimum limit is 0.1.  
The maximum limit is 100.  
The replacement value is 50.  
The number of digits is 8.

## **factor**

It is a factor that considers all the different additional outer influences that can occur - for example the influence of the temperature or influences caused by other cables routed close to each other on a cable tray.

The variable type is Input.  
The variable has no unit [-].  
The minimum limit is 0.5.  
The maximum limit is 1.  
The replacement value is 0.85.  
The number of digits is 8.

## **cable length**

It is the total length of the cable from the power supply point to the operated field device. Because the current has to pass through one way to the device and also back, the double length of the cable is considered for the calculation of the resistance.

The variable type is Input or Output.  
The unit is meter [m].  
The minimum limit is 0.0001.  
The maximum limit is 99999999.  
The replacement value is 10.  
The number of digits is 8.

## **cross section**

It is the cross section of the cable. Because the current has to pass through one way to the device and also back, the double length of the cable is considered for the calculation of the resistance.

The variable type is Input or Output.  
The unit is millimeter square [mm<sup>2</sup>].  
The minimum limit is 0.0001.  
The maximum limit is 99999999.  
The replacement value is 10.  
The number of digits is 8.

10.8.3. Operation (How can it be used? How to proceed?)

**Step 1:**  
**Select the number of phases**  
I can select the number of phases for the electrical supply system.

**Step 2:**  
**Transfer spec. temp. coefficient**  
After selecting a material I can transfer the value for the specific temperature coefficient.

The screenshot shows a web-based application window titled 'Electrical Resistance - www.hheader.com'. It features several tabs: 'resistance', 'temp. resistance', 'voltage drop', 'ohms law', 'impedance', and 'testing bridge'. The 'voltage drop' tab is active. The interface includes a '1 or 3 - phase system' selector set to '1 - phase', a 'material' dropdown set to 'copper', and a grid of input fields with units and decimal place selectors. The 'current' field is selected with a radio button. A sidebar on the right contains icons for a calculator, printer, trash, information, notes, and a save button.

**Step 3:**  
**Select the variables to be calculated**  
By clicking on the corresponding *RadioButton* I can choose the variables to be calculated for the upper and lower part. It is like executing an internal conversion of the equation.

**Step 6:**  
**Calculate result**  
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

**Step 4:**  
**Fill the Input-TextBoxes**  
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

**Step 5:**  
**Enter the number of decimal places**  
I enter the number of decimal places for the variables. It is valid only if the corresponding variable is selected as output. The input variables can get more or less decimal numbers according to the number of digits.

**Step 7:**  
**Check result**  
After clicking the Calculate-Button I can check the result.

**Step 8:**  
**Further actions**  
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

Figure 127: form electrical resistance – voltage drop

**10.9. Electrical Resistance – OhmsLaw**

**10.9.1. Purpose (What can it be used for? What can it not be used for?)**

The program is part of category 5 – electrics. What can be the most popular and most often used (directly or not) equation in the field of electrical engineering? One candidate that has surely to be nominated for this is ohms law. Not only in theory and for training purposes it is important to be familiar with this, also on site it can help to evaluate actual circumstances and by this to determine possible causes of faults or dysfunctions. The cases need to be divided up according to the supply energy types as alternating current (AC) and direct current (DC). In case of an alternating current the number of phases is also important. The calculations can be used for example to determine if the resistance of the windings or the armature resistance of a motor is still proper or not. The resistance value can be assumed according to the given values for voltage and current, respectively by the given power rate and under taking the phases into consideration. Later the value can be compared with the measured resistance in order to evaluate the circumstances.

In the upper part of the form the base calculation takes place. Voltage, current or resistance can be selected as output variable. The residual two are input variables. The power rate is calculated by the given input values. For each variable, voltage, current, resistance and power rate, there are different selections provided for the units. In the first step the used supply energy as alternating current (AC) or direct current (DC) has to be selected. Therefore a *CheckBox* (consider AC) is provided on the left side in the middle of the form. If this is unchecked, the calculations for DC are activated. If the *CheckBox* (consider AC) is checked, the calculations for AC are activated. Further relevant variables appear in the lower part of the form. These are: power factor  $\cos \phi$ , active power rate, reactive power rate, real part and imaginary part of the resistance. A selection for the phase system appears also (1-phase or 3-phases are selectable). Whenever the item of the selection is changed, a pre-set value will be loaded for the voltage according to the selected number of phases. For the one phase system the pre-set value is 230V and for the three phase system the pre-set value is 400V. The calculations for the real part and the imaginary part are based on the given power factor, only. Therefore it is not differentiated, if the imaginary part is capacitive or inductive.

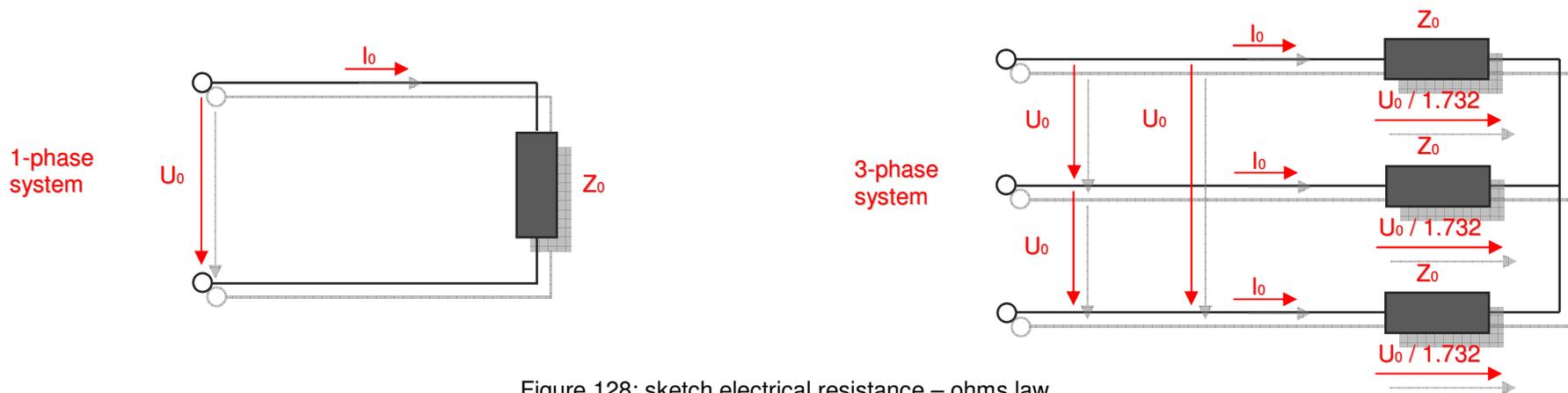


Figure 128: sketch electrical resistance – ohms law

## 10.9.2. Variables (What are the input and output values? What are their limits?)

### voltage

It is the electrical voltage that is power supply for the operated device. For the three-phase system the voltage is assumed to be the three-phase voltage which is equal the phase voltage multiplied by 1.732.

The variable type is Input or Output.

For this variable a selection of different units is provided:

- millivolt [mV],
- volt [V],
- kilovolt [kV].

The minimum limit is 0.0001.

The maximum limit is 99999999.

The replacement value is 10.

The number of digits is 8.

### current

It is the current for the operated device that is focus for the calculations according to the use case. For the three-phase system the current is assumed to be the phase current which occurs in each phase of the three-phase system.

The variable type is Input or Output.

For this variable a selection of different units is provided:

- milliamperere [mA],
- ampere [A],
- kiloampere [kA].

The minimum limit is 0.0001.

The maximum limit is 99999999.

The replacement value is 10.

The number of digits is 8.

## **resistance**

It is the calculated electrical resistance for the device that is focus for the calculations.

The variable type is Input or Output.

For this variable a selection of different units is provided:

- milliohm [mOhm],
- ohm [Ohm],
- kiloohm [kOhm],
- megaohm [MOhm].

The minimum limit is 0.0001.

The maximum limit is 99999999.

The replacement value is 10.

The number of digits is 8.

## **power rate**

It is the electrical power rate for the operated device that is focus for the calculations. It results from the multiplication of voltage and current. For an AC-system it is the apparent power rate.

The variable type is Input or Output.

For this variable a selection of different units is provided.

DC:

- milliwatt [mW],
- watt [W],
- kilowatt [kW],
- megawatt [MW].

AC:

- millivolt-ampere [mVA],
- volt-ampere [VA],
- kilovolt-ampere [kVA],
- megavolt-ampere [MVA].

The minimum limit is 0.0001.

The maximum limit is 99999999.

The replacement value is 10.

The number of digits is 8.

## **factor cos phi**

It is the power factor that is specified for the operated device according to the actual use case.

The variable type is Input.  
The variable has no unit [-].  
The minimum limit is 0.5.  
The maximum limit is 1.  
The replacement value is 0.85.  
The number of digits is 8.

## **reactive power rate**

It is the reactive power rate which is present in the network due to the reactive loads. The active power rate and the reactive power rate result the apparent power rate by vector addition.

The variable type is Output.  
The unit prefix is according to the selected power rate unit.  
The base unit is volt-ampere reactive watt [var].  
There is no defined minimum limit for output variables.  
There is no defined maximum limit for output variables.  
There is no defined replacement value for output variables.  
There is no defined number of digits for output variables.

## **active power rate**

It is the active power rate which is available for the use case. The active power rate and the reactive power rate result the apparent power rate by vector addition.

The variable type is Output.  
The unit prefix is according to the selected power rate unit.  
The base unit is watt [W].  
There is no defined minimum limit for output variables.  
There is no defined maximum limit for output variables.  
There is no defined replacement value for output variables.  
There is no defined number of digits for output variables.

## **real part**

It is the real part of the complex resistance which occurs for the AC-system.

The variable type is Output.

The unit prefix is according to the selected resistance unit.

The base unit is Ohm [Ohm].

There is no defined minimum limit for output variables.

There is no defined maximum limit for output variables.

There is no defined replacement value for output variables.

There is no defined number of digits for output variables.

## **imaginary part**

It is the imaginary part of the complex resistance which occurs for the AC-system.

The variable type is Output.

The unit prefix is according to the selected resistance unit.

The base unit is Ohm [Ohm].

There is no defined minimum limit for output variables.

There is no defined maximum limit for output variables.

There is no defined replacement value for output variables.

There is no defined number of digits for output variables.

10.9.3. Operation (How can it be used? How to proceed?)

**Step 6:**  
**Enter the number of decimal places**  
I enter the number of decimal places for the variables. It is valid only if the corresponding variable is selected as output. The input variables can get more or less decimal numbers according to the number of digits.

**Step 3:**  
**Select the variable to be calculated**  
By clicking on the corresponding *RadioButton* I can choose the variable to be calculated. It is like executing an internal conversion of the equation.

**Step 1:**  
**Consider AC**  
Select AC or DC calculation.

**Step 5:**  
**Fill the Input-TextBoxes**  
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

**Step 8:**  
**Check result**  
After clicking the Calculate-Button I can check the result.

Figure 129: form electrical resistance – ohms law

**Step 4:**  
**Units**  
There is a choice of different units for each variable.

**Step 7:**  
**Calculate result**  
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

**Step 9:**  
**Further actions**  
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

**Step 2:**  
**Select the number of phases**  
I can select the number of phases for the electrical supply system.

**10.10. Electrical Resistance – Impedance**

**10.10.1. Purpose (What can it be used for? What can it not be used for?)**

The program is part of category 5 – electrics. In real life we cannot find an absolute purely resistive resistance. Anyhow there will always be a combination of resistance, capacitance and inductance, which built up the complex impedance of a system. This can be caused directly by the related compounds or also indirectly for example by the installed constructions for cable routing (trays, conduits, trenches, railways for cables) or by other nearby installed cables or even by the cables (e.g. screens) themselves. For the indirectly build up impedances the capacitive and inductive party are mostly parasitic. Generally the impedance is built up for an alternating current system. Signals can be launched into a direct current system that is in range of an alternating system – power cables and cables for measurements should be separated as far as possible.

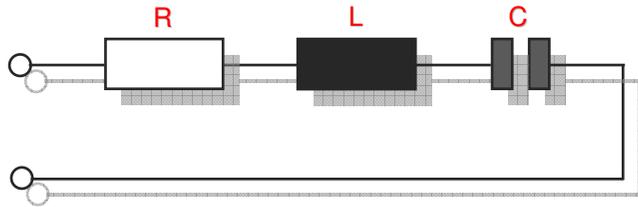
The program provides calculations for the impedance built up by the compounds resistance, capacitance and inductance. Therefore in the first stage, where one of each compound is considered, eight different combinations, which mean eight different circuits, are possible.

Those are:

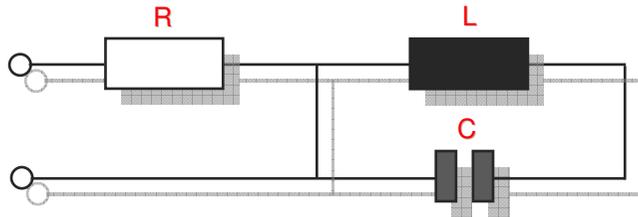
- |                                  |   |
|----------------------------------|---|
| Circuit 1: <b>R - L - C</b>      | The resistance R and the inductance L and the capacitance C are all in series.              |
| Circuit 2: <b>R - ( L    C )</b> | The resistance R is in series to the parallel connected inductance L and capacitance C.     |
| Circuit 3: <b>( R    L ) - C</b> | The parallel connected resistance R and inductance L are in series to the capacitance C.    |
| Circuit 4: <b>( R    C ) - L</b> | The parallel connected resistance R and capacitance C are in series to the inductance L.    |
| Circuit 5: <b>R    C    L</b>    | The resistance R and the inductance L and the capacitance C are all in parallel.            |
| Circuit 6: <b>( R - L )    C</b> | The series connected resistance R and inductance L are in parallel to the capacitance C.    |
| Circuit 7: <b>( R - C )    L</b> | The series connected resistance R and capacitance C are in parallel to the inductance L.    |
| Circuit 8: <b>R    ( L - C )</b> | The resistance R is in parallel to the series connected inductance L and the capacitance C. |

Note: “-“ means in series / “||” means in parallel / “(“ and “)” include the compounds.

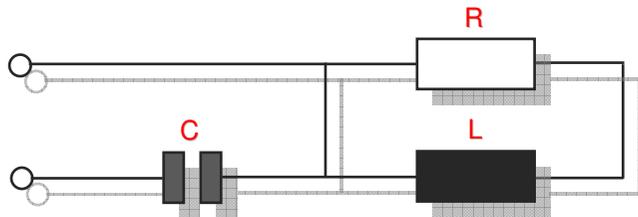
Circuit 1:  $R - L - C$ :



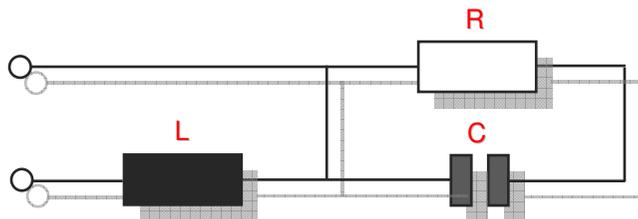
Circuit 2:  $R - (L \parallel C)$ :



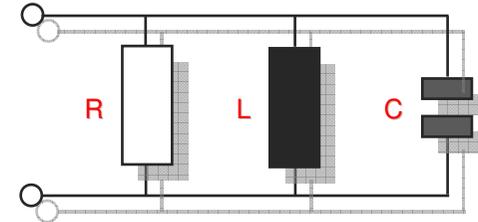
Circuit 3:  $(R \parallel L) - C$ :



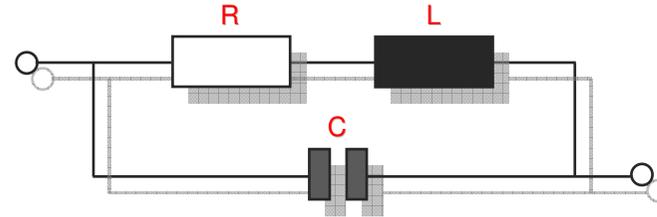
Circuit 4:  $(R \parallel C) - L$ :



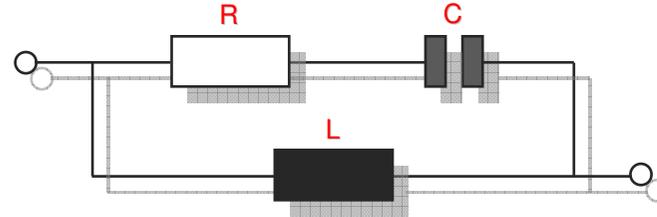
Circuit 5:  $R \parallel C \parallel L$ :



Circuit 6:  $(R - L) \parallel C$ :



Circuit 7:  $(R - C) \parallel L$ :



Circuit 8:  $R \parallel (L - C)$ :

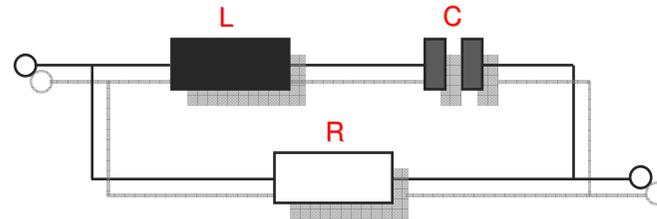


Figure 130: sketch electrical resistance – impedance

## 10.10.2. Variables (What are the input and output values? What are their limits?)

### resistance

It is the purely ohmic resistance of the selected circuit.

The variable type is Input or Output.

For this variable a selection of different units is provided:

- milliohm [mOhm],
- ohm [Ohm],
- kilohm [kOhm],
- megaohm [MOhm].

The minimum limit is 0.0001.

The maximum limit is 99999999.

The replacement value is 10.

The number of digits is 8.

### capacity

It is the capacity of the selected circuit.

The variable type is Input or Output.

For this variable a selection of different units is provided:

- nano-Farad [nF],
- micro-Farad [ $\mu$ F],
- milli-Farad [mF],
- Farad [F].

The minimum limit is 0.0001.

The maximum limit is 99999999.

The replacement value is 10.

The number of digits is 8.

## **inductivity**

It is the inductivity of the selected circuit.

The variable type is Input or Output.

For this variable a selection of different units is provided:

- nano-Henry [nH],
- micro-Henry [ $\mu$ H],
- milli-Henry [mH],
- Henry [H].

The minimum limit is 0.0001.

The maximum limit is 99999999.

The replacement value is 10.

The number of digits is 8.

## **real part**

It is the real part of the complex resistance that results for the selected circuit.

The variable type is Input or Output.

The unit is Ohm [Ohm].

There is no defined minimum limit for output variables.

There is no defined maximum limit for output variables.

There is no defined replacement value for output variables.

There is no defined number of digits for output variables.

## **imaginary part**

It is the imaginary part of the complex resistance that results for the selected circuit.

The variable type is Input or Output.

The unit is Ohm [Ohm].

There is no defined minimum limit for output variables.

There is no defined maximum limit for output variables.

There is no defined replacement value for output variables.

There is no defined number of digits for output variables.

## **impedance**

It is the calculated impedance that results from the vector addition of the determined real part and imaginary part.

The variable type is Output.

The unit is Ohm [Ohm].

There is no defined minimum limit for output variables.

There is no defined maximum limit for output variables.

There is no defined replacement value for output variables.

There is no defined number of digits for output variables.

## **power factor**

It is the power factor that is calculated for the selected circuit and the given values for resistance, capacity and inductivity.

The variable type is Input.

The variable has no unit [-].

There is no defined minimum limit for output variables.

There is no defined maximum limit for output variables.

There is no defined replacement value for output variables.

There is no defined number of digits for output variables.

10.10.3. Operation (How can it be used? How to proceed?)

**Step 4:**  
**Enter the number of decimal places**  
I enter the number of decimal places for the variables. It is valid only if the corresponding variable is selected as output. The input variables can get more or less decimal numbers according to the number of digits.

**Step 3:**  
**Fill the Input-TextBoxes**  
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric.

**Step 1:**  
**Select the type of circuit**  
I can select between the eight possible interconnections for the resistor, capacitor and inductor. The corresponding circuit is shown in the sketch above, accordingly.

**Step 6:**  
**Check result**  
After clicking the Calculate-Button I can check the result.

**Step 2:**  
**Units**  
There is a choice of different units for each variable.

**Step 5:**  
**Calculate result**  
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

**Step 7:**  
**Further actions**  
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

Figure 131: form electrical resistance – impedance

## 10.11. Electrical Resistance – Testing Bridge (bridge circuit)

### 10.11.1. Purpose (What can it be used for? What can it not be used for?)

The program is part of category 5 – electrics. The testing bridge is an important basic instrument for measuring purposes. It has many advantages and positive aspects. It has many different application and use cases. It can be built up easily. The expenses for the compounds are low. The compounds are easily available. By using potentiometers the bridge is adjustable and can be used for the simulation of different voltage signals or for power conversion.

The testing bridge provided in this program consists of four resistances. There are two branches in parallel to each other. Each branch has two resistances connected in series. The bridge voltage is measured in the middle between the two branches. Relevant is the relation between the resistances. If the relation between the series resistances is the same in both branches, the bridge is aligned and the bridge voltage is zero.

The supply voltage and the resistances are input values. For the input of the resistances there are two possibilities. The value can be entered directly or the value can be increased (+) or decreased (-) step by step. Therefore the step width can be defined. After increasing or decreasing the resistance value, a new calculation will be executed automatically (iteration). The voltages at the resistances and the bridge voltage are output variables. The current values for the branches and the total current, which is the sum-up of the branch currents, are also output variables. For all values there are corresponding unit selections provided.

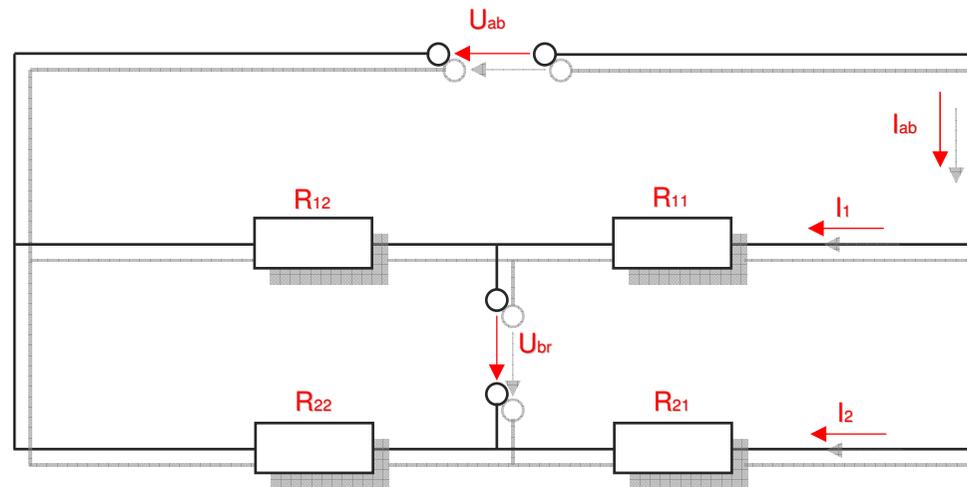


Figure 132: sketch electrical resistance – testing bridge

## 10.11.2. Variables (What are the input and output values? What are their limits?)

### Uab - voltage

It is the supply voltage for the testing bridge.

The variable type is Input.

For this variable a selection of different units is provided:

- millivolt [mV],
- volt [V],
- kilovolt [kV].

The minimum limit is 0.0001.

The maximum limit is 99999999.

The replacement value is 10.

The number of digits is 8.

### Iab - current

It is the total current for the testing bridge. It is the sum of the two branch currents I1 and I2.

The variable type is Output.

For this variable a selection of different units is provided:

- milliamperere [mA],
- ampere [A],
- kiloampere [kA].

There is no defined minimum limit for output variables.

There is no defined maximum limit for output variables.

There is no defined replacement value for output variables.

There is no defined number of digits for output variables.

## **I1 - current**

It is the current in branch one for the testing bridge. The current is passing through R11 and R12. Due to this the voltages U11 and U12 occur at the corresponding resistances R11 and R12.

The variable type is Output.

For this variable a selection of different units is provided:

- milliampere [mA],
- ampere [A],
- kiloampere [kA].

There is no defined minimum limit for output variables.

There is no defined maximum limit for output variables.

There is no defined replacement value for output variables.

There is no defined number of digits for output variables.

## **I2 - current**

It is the current in branch two for the testing bridge. The current is passing through R21 and R22. Due to this the voltages U21 and U22 occur at the corresponding resistances R21 and R22.

The variable type is Output.

For this variable a selection of different units is provided:

- milliampere [mA],
- ampere [A],
- kiloampere [kA].

There is no defined minimum limit for output variables.

There is no defined maximum limit for output variables.

There is no defined replacement value for output variables.

There is no defined number of digits for output variables.

## **R11 - resistance**

It is the electrical resistance R11 that is installed at the first position in branch one.

The variable type is Input.

For this variable a selection of different units is provided:

- milliohm [mOhm],
- ohm [Ohm],
- kilohm [kOhm],

The minimum limit is 0.0001.

The maximum limit is 99999999.

The replacement value is 10.

The number of digits is 8.

## **U11 - voltage**

It is the voltage that occurs at the resistance R11 due to the branch current I1.

The variable type is Output.

For this variable a selection of different units is provided:

- millivolt [mV],
- volt [V],
- kilovolt [kV].

There is no defined minimum limit for output variables.

There is no defined maximum limit for output variables.

There is no defined replacement value for output variables.

There is no defined number of digits for output variables.

## **R12 - resistance**

It is the electrical resistance R12 that is installed at the second position in branch one.

The variable type is Input.

For this variable a selection of different units is provided:

- milliohm [mOhm],
- ohm [Ohm],
- kilohm [kOhm],

The minimum limit is 0.0001.

The maximum limit is 99999999.

The replacement value is 10.

The number of digits is 8.

## **U12 - voltage**

It is the voltage that occurs at the resistance R12 due to the branch current I1.

The variable type is Output.

For this variable a selection of different units is provided:

- millivolt [mV],
- volt [V],
- kilovolt [kV].

There is no defined minimum limit for output variables.

There is no defined maximum limit for output variables.

There is no defined replacement value for output variables.

There is no defined number of digits for output variables.

## **R21 - resistance**

It is the electrical resistance R21 that is installed at the first position in branch two.

The variable type is Input.

For this variable a selection of different units is provided:

- milliohm [mOhm],
- ohm [Ohm],
- kilohm [kOhm],

The minimum limit is 0.0001.

The maximum limit is 99999999.

The replacement value is 10.

The number of digits is 8.

## **U21 - voltage**

It is the voltage that occurs at the resistance R21 due to the branch current I2.

The variable type is Output.

For this variable a selection of different units is provided:

- millivolt [mV],
- volt [V],
- kilovolt [kV].

There is no defined minimum limit for output variables.

There is no defined maximum limit for output variables.

There is no defined replacement value for output variables.

There is no defined number of digits for output variables.

## **R22 - resistance**

It is the electrical resistance R22 that is installed at the second position in branch two.

The variable type is Input.

For this variable a selection of different units is provided:

- milliohm [mOhm],
- ohm [Ohm],
- kilohm [kOhm],

The minimum limit is 0.0001.

The maximum limit is 99999999.

The replacement value is 10.

The number of digits is 8.

## **U22 - voltage**

It is the voltage that occurs at the resistance R22 due to the branch current I2.

The variable type is Output.

For this variable a selection of different units is provided:

- millivolt [mV],
- volt [V],
- kilovolt [kV].

There is no defined minimum limit for output variables.

There is no defined maximum limit for output variables.

There is no defined replacement value for output variables.

There is no defined number of digits for output variables.

## **Ubr - voltage**

It is the voltage that occurs at the bridge due to the voltages  $U_{11}$  and  $U_{21}$  at the resistances  $R_{11}$  and  $R_{21}$  respectively due to the voltages  $U_{12}$  and  $U_{22}$  at the resistances  $R_{12}$  and  $R_{22}$ .

The variable type is Output.

For this variable a selection of different units is provided:

- millivolt [mV],
- volt [V],
- kilovolt [kV].

There is no defined minimum limit for output variables.

There is no defined maximum limit for output variables.

There is no defined replacement value for output variables.

There is no defined number of digits for output variables.

10.11.3. Operation (How can it be used? How to proceed?)

**Step 3:**  
**Enter the number of decimal places**  
I enter the number of decimal places for the variables. It is valid only if the corresponding variable is selected as output. The input variables can get more or less decimal numbers according to the number of digits.

**Step 2:**  
**Fill the Input-TextBoxes**  
I enter the values for the input variables. I should respect the variable limits and take care that the entered values are numeric. For the resistors the value can be entered either directly or by step via the plus- (+) or minus (-) buttons. The step width can be defined in the corresponding *TextBox*. After increasing or decreasing the value, a new calculating will be executed automatically.

**Step 5:**  
**Check result**  
After clicking the Calculate-Button I can check the result.

**Step 1:**  
**Units**  
There is a choice of different units for each variable.

**Step 4:**  
**Calculate result**  
After I entered the input values I can calculate the result. Before the calculation starts, all the input values are checked by an internal routine. Whenever entered values decrease the corresponding min limits or increase the corresponding max limits or are not numeric there will be a message according to the fault. The values will be corrected automatically by the internal routine.

**Step 6:**  
**Further actions**  
After the calculation I can have the following options: Print Data, Erase Data, Program Information, Notes, Save or Restore Values. While printing a new calculation is done automatically. Clicking the Erase-Button will empty all the *TextBoxes* at once.

Figure 133: form electrical resistance – testing bridge