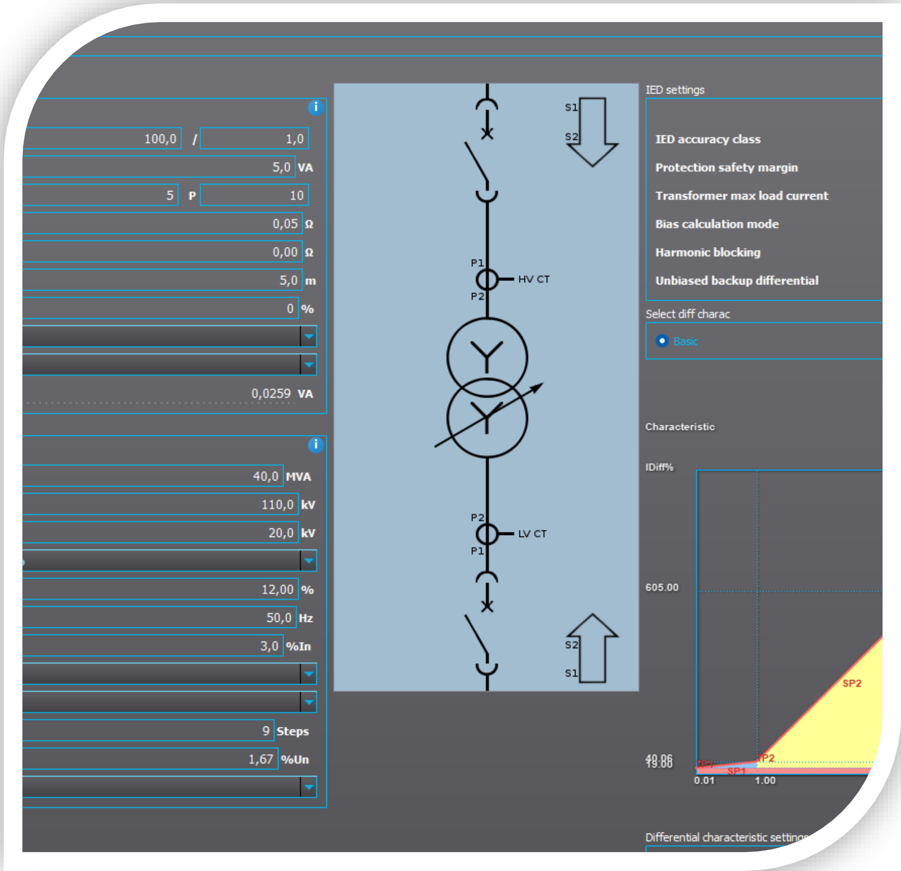
Transformer Wizard

Instruction booklet



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Instruction booklet

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Changes	- The first revision of the booklet
Revision	**1.1**
Date	25 April 2023
Changes	- Updated the booklet visually. - Added the internal document ID. - Updated the document title to be consistent with other Wizard instruction booklets. - Added a cover image. - Updated the disclaimer and moved it to its own page. - Added the setting parameters, their ranges, default values, and the content in the wizard's built-in user manual (Chapter 5). - Updated and expanded the text where necessary in general. - Updated the images and added new ones where necessary.

DISCLAIMER

Please read these instructions carefully before using the equipment or taking any other action with respect to the equipment. Only trained and qualified persons are allowed to perform installation, operation, service, or maintenance of the equipment. Such qualified persons have the responsibility to take all appropriate measures (such as the use of authentication, encryption, and anti-virus programs, safe switching programs, etc.) necessary to ensure a safe and secure environment and the usability of the equipment. The warranty granted to the equipment remains in force only provided that the instructions contained in this document have been strictly complied with.

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1 Introduction

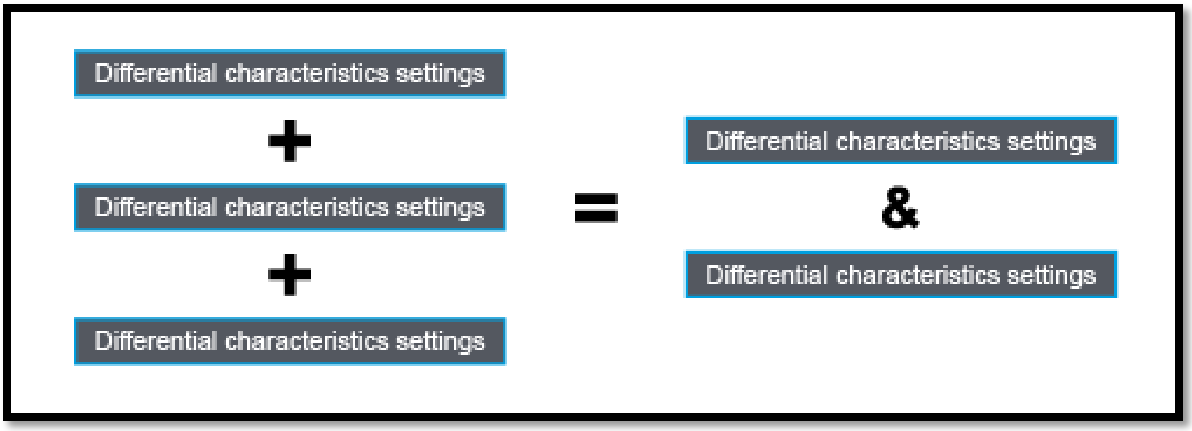
The Transformer Wizard is an advanced setting tool integrated into the AQtivate 200 setting and configuration tool. The Wizard can be used to generate settings to Arcteq's transformer protection relays (for example, AQ-T215 and AQ-T257A). A variety of transformer-related information, such as CT specifications and the wiring, is the basis that the Wizard uses to build suitable setting parameters to your relay.

Using the Transformer Wizard offers various benefits:

- It is easy to install and easy to use.
- It has a built-in user manual in AQtivate 200.
- It makes it easy for you to write differential and restricted earth fault setting to your relay.
- It presents direct feedback from the installation.

The basic function of the Transformer Wizard is to calculate certain output results based on given input values. It combines data from name plate values, current transformer (CT) specifications and certain relay setting parameters, and calculates differential characteristic settings and CT saturation limits (*Figure 1-1*).

Figure 1-1. The basic principle of the Transformer Wizard.



If you prefer to calculate the differential and restricted earth fault settings yourself, please refer to the document titled "CT selection for Arcteq relays" and its accompanying Excel file ("Calculations for high-impedance differential protection"). Both are located on our website at arcteq.fi/documents-and-software, and can be found under *Resources* in the "AQ 200 series" section.

2 GETTING STARTED

2.1 Requirements

In order to download and upload configurations into and from your device, you first need to establish communication with it. This requires that you have a standard RJ-45 cable as well as at least one (1) free Ethernet port in your PC. Please make sure that your firewall and anti-virus protection programs allow AQtivate 200 to connect to the PC and freely use its Ethernet ports.

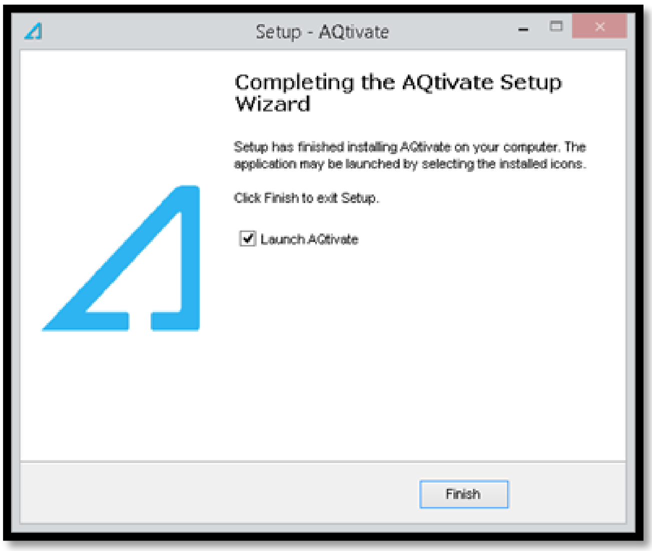
2.2 Installing the AQtivate 200 software suite

First, download the latest software installation file for AQtivate 200 from our website at arcteq.fi/documents-and-software, from the "Software" section. The software suite is free of charge. Please note that downloading requires that you log in to the Arcteq website. If you do not have a username to log in, you can create one at the top-right corner of our website. This is also free of charge.

When you have downloaded the installation files, launch the AQtivate Offline Installer .exe file (please note that this requires you to have administrator rights to the PC). First, the installer asks you to select the language that you would like to use during the installation process. Next, follow the step-by-step instructions provided by the AQtivate Setup Wizard to finish installing the software (*Figure 2–2*): select a destination for the software, select a place for the program's shortcuts, choose whether you want a desktop icon, and finally start the installation process by clicking **Install**.

When AQtivate 200 has been successfully installed, a pop-up window (*Figure 2-1*) will appear to prompt you to finish the installation process by clicking the **Finish** button in the window.

Figure 2-1. Finishing the AQtivate 200 installation process.

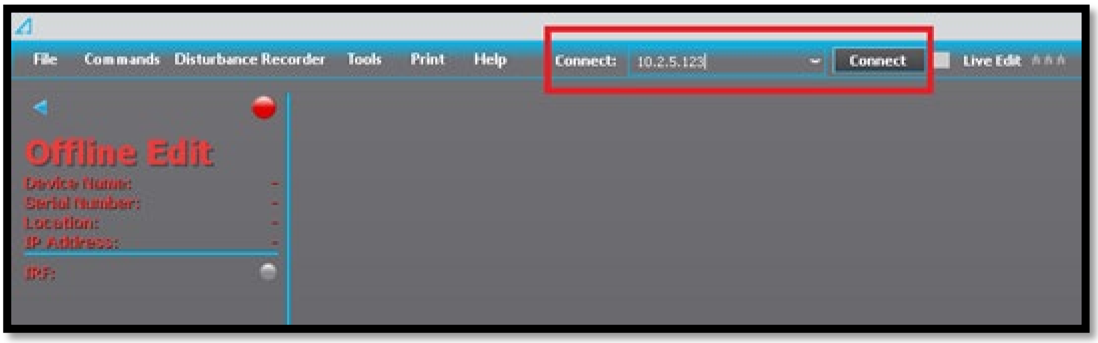


Please note that the installation process may be halted by your cybersecurity protections! If they detect the software suite, select to allow the connection to the PC. You may also manually whitelist AQtivate 200 on a list of programs allowed to have a connection to the PC.

3 CONNECTING TO A DEVICE

You can establish a connection between AQtivate 200 and your device by typing the relay's IP address to the Connect field at the top of the AQtivate 200 window (*Figure 3-1*) and then clicking **Connect**.

Figure 3-1. Connecting AQtivate 200 to a relay.



You do not have to be connected to a device in order to use the Transformer Wizard as it can also be used offline. You can store and open any project at any time. However, when you want to write your settings to the relay, you must have a connection between AQtivate 200 and your device.

> ⚠ Please note that establishing a connection to your protection device with the AQtivate 200 setting tool requires that the following ports must be open: 20, 21, and 1551. If the software cannot connect to your device, please check the settings in your firewall and anti-virus software suites.

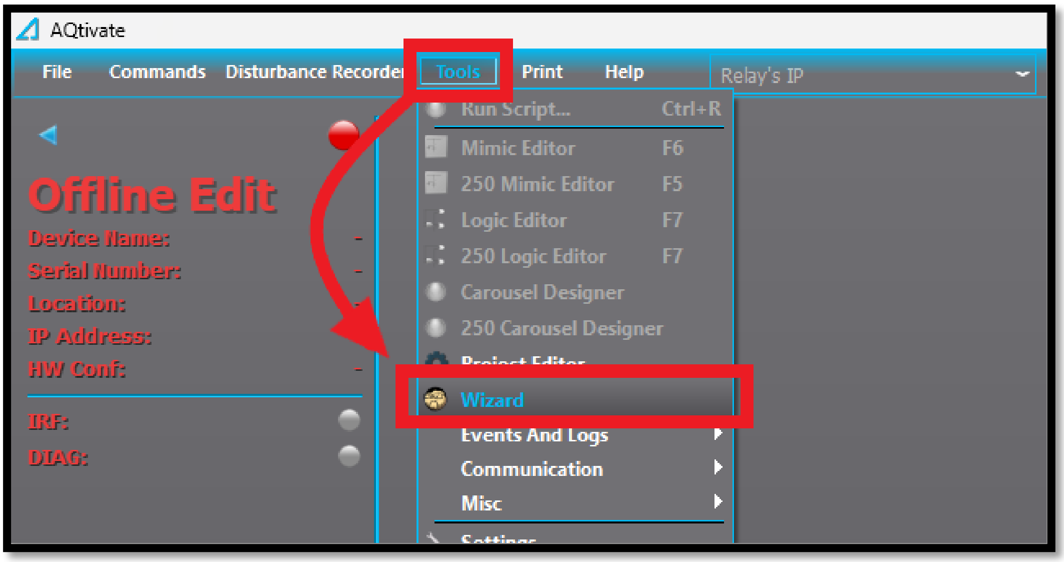
> ⚠ Each Arcteq protection relay is equipped with two (2) RJ-45 ports: one is at the front of the device, the other at the back. Both can be used to connect the relay to AQtivate 200. Please note that only the back port can be used for upgrading the device's firmware and for communication protocols. For more information on the ports, please refer to Chapter 3.3 in the AQtivate 200 instruction manual!

4 Basic operations

4.1 Opening the Transformer Wizard

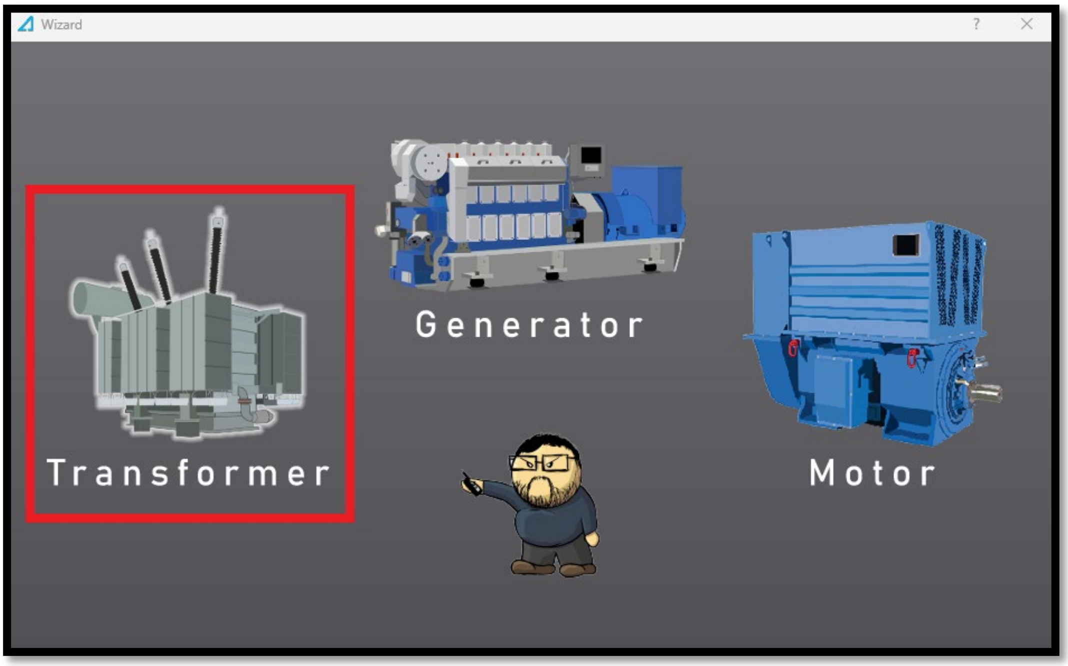
You can open the Transformer Wizard tool from the AQtivate 200 software. Open the *Tools* menu on the software's main toolbar and select "Wizard" (*Figure 4-1*).

Figure 4-1. Opening the Wizard selection window.



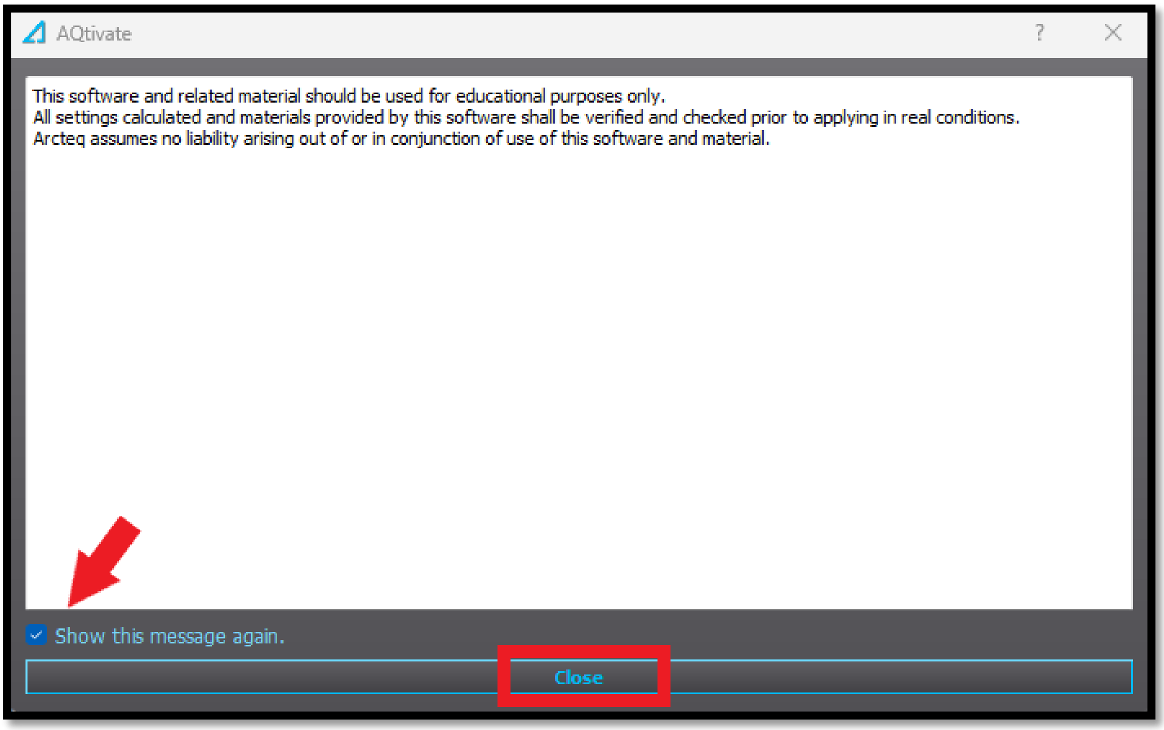
This opens the wizard selection window, allowing you to choose which integrated wizard tool you want to use. For the Transformer Wizard, select "Transformer" (*Figure 4-2*).

Figure 4-2. Selecting the Transformer Wizard.



Before you can access the Wizard itself, you need to acknowledge the disclaimer pop-up window (*Figure 4-3*) by clicking the **Close** button. You can also choose whether the disclaimer message will be shown in the future when you open the Wizard by tapping or untapping the checkbox titled "Show this message again".

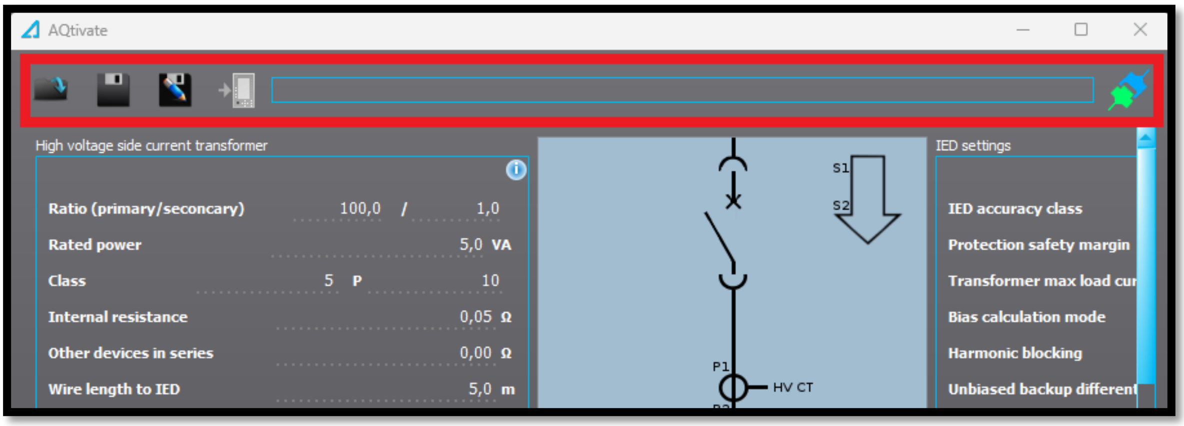
Figure 4-3. The Disclaimer pop-up window.



4.2 Toolbar buttons

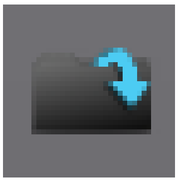
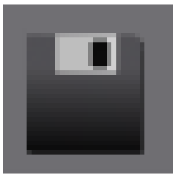
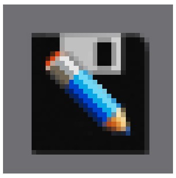
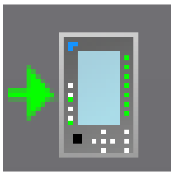
The Transformer Wizard window's default view includes a toolbar at the top of the window (*Figure 4-4*).

Figure 4-4. The main toolbar.



The buttons in the toolbar are explained in *Table 1* below.

Table 1. The toolbar buttons and their descriptions.

Toolbar icon	Name	Description
	Open	Open an existing wizard file (*.aqwz).
	Save	Save changes.
	Save as…	Save a wizard file (*.aqwz) to the selected location under the selected name.
	Write into relay	Write the calculated values of the Wizard into the connected relay. **If you are <u>not</u> connected to a relay, this icon is colored in grayscale!**
	Connect	Connect to a relay.
	Disconnect	Disconnect from the connected relay.

4.3 Visualizations for application settings and the differential characteristic

The Transformer Wizard has a separate schematic view (*Figure 4-5*, below on the left) at the center of the Transformer Wizard window. It follows the application settings, and makes it easier for you to get a fuller picture of your transformer protection.

Figure 4-5. Schematic view.

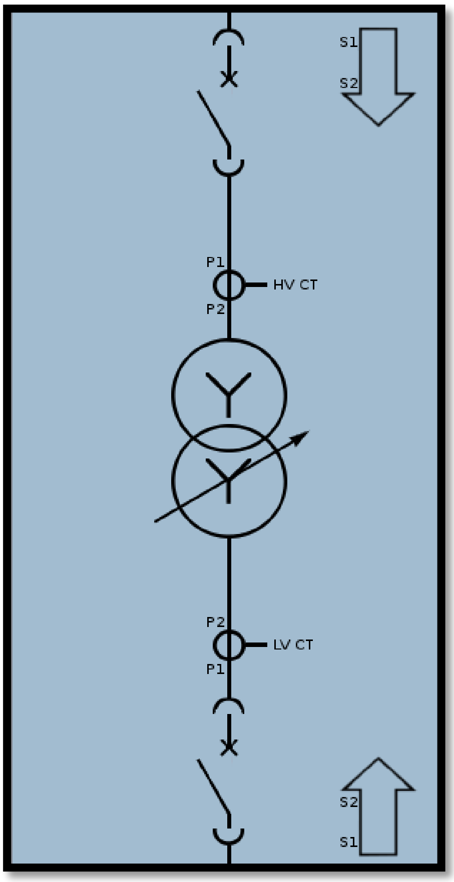
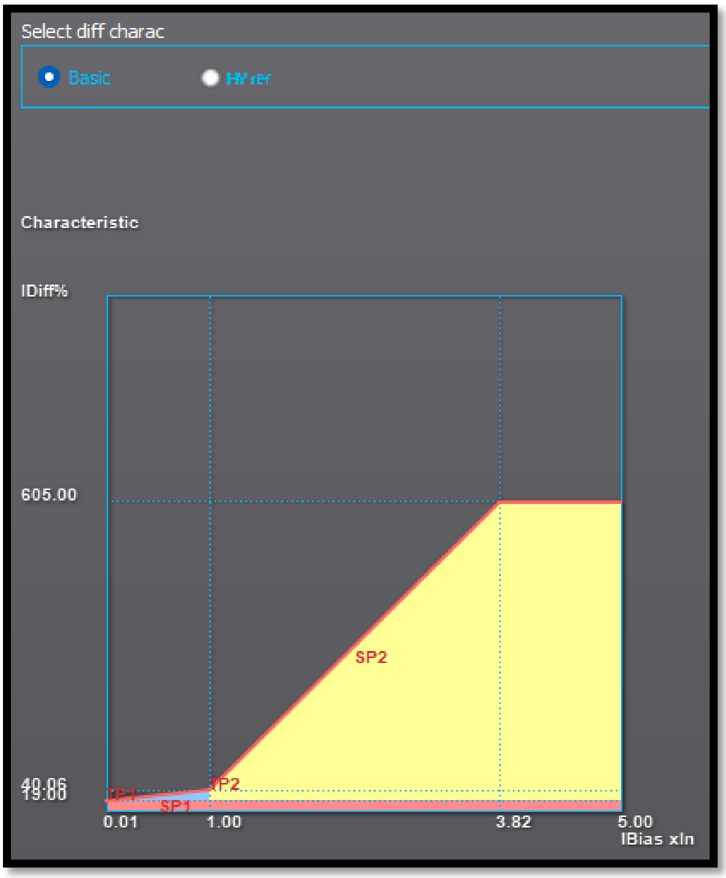


Figure 4-6. Differential characteristic curve view.



The Wizard also includes a visualization for the differential characteristic curve (*Figure 4-6*, above on the right). You can toggle between the basic differential characteristic and the restricted earth fault characteristic (REF1 and REF2).

5 SETTING PARAMETERS

5.1 Parameters for the HV and LV sides of the current transformer

Table 2. Setting parameters for the HV and LV sides of the current transformer.

Name	Range	Default
Ratio (primary/secondary)	1.0…25,000.0 (primary) 0.2…10.0 (secondary)	100.0/1.0
Rated power	1.0…50.0 VA	5.0 VA
Class	1…20 P 1…50	5P10
Internal resistance	0.01…50.00 Ω	0.05 Ω
Other devices in series	0.00…50.00 Ω	0.00 Ω
Wire length to IED	1.0…500.0 m	5.0 m
% of wiring is 6w	0…100 %	0 %
Wire type	1: Manually set 2: Copper 75 °C	2: Copper 75 °C
Wire resistance	0.00001…1.00000 Ω/m	0.01350 Ω/m
Wire cross section	1: 1.5 mm^2 2: 2.5 mm^2 3: 4.0 mm^2 4: 6.0 mm^2	3: 4.0 mm^2
Total burden	–	–

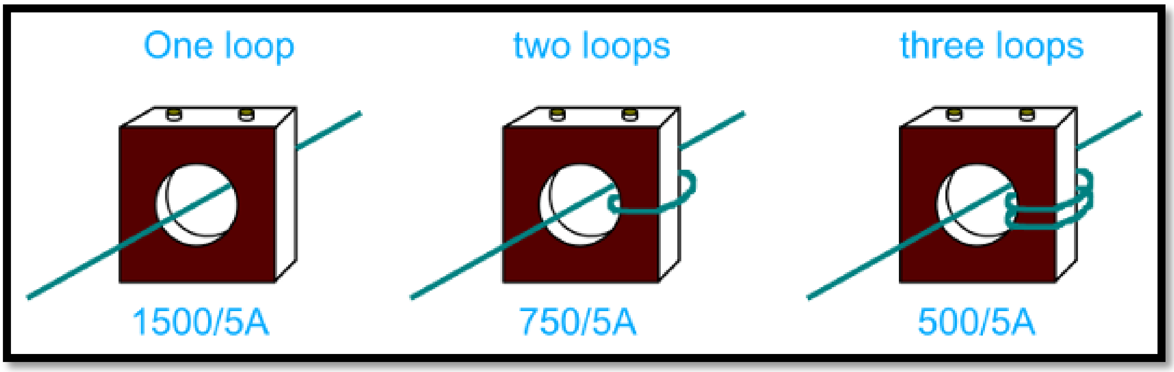
5.1.1 Ratio (primary/secondary)

Under normal operation, the secondary current of a current transformer is proportional to its primary current. For example, a CT with the ratio "3 000/1 A" has a 3 000 A primary (input) current and a 1 A secondary (output) current. Mechanically speaking the secondary has 3 000 turns of copper winding wire around the steel core, and the CT is said to have a 3 000:1 proportional ratio.

Similarly, a CT with the ratio "3 000/5 A" has a 3 000 A primary with a 5 A secondary. However, as the ratio is proportional, this CT only has 600 turns of winding wire around the core and therefore has a proportional ratio of 600:1.

In *Figure 5-1*, you can see how a CT with the ratio of 1 500/5 A can be converted to a CT with the ratio 750/5 A by passing the primary conductor through its interior window twice. With three loops the ratio becomes 500/5 A.

Figure 5-1. Example of CT primary turns ratio.



The rated primary current of a CT should be equal to or greater than the nominal load current (aka. service current) of the protected transformer. For example, if the nominal current on the transformer's LV side is 1 157 A, the CT should at minimum have a rated primary current of 1 200 A. You can calculate the transformer nominal secondary current with Equation (1):

$$I_n = \frac{S_n}{\sqrt{3} \times U_n} \tag{1}$$

The CT's rated secondary current, on the other hand, should be selected according to the application. As a general rule, the rated secondary current can be 5 A in local situations (that is , the CT is close to the protection device), whereas in remote situations a value of 1 A should be considered. You can use 5 A rated secondary current in remote situations as well. However, in order to keep the burden low and to avoid CT saturation, you must either increase the line's cross-section or increase the transformer's size (please refer to the description for the "Rated power" parameter for more information). In normal conditions a low secondary current (1 A or 2 A) is preferred when dealing with transformer differential protection.

5.1.2 Rated power

The apparent power of the secondary circuit is expressed in volt-amperes, at the rated secondary current and at a specific power factor (the value of which is 0.8 for nearly all standards). When the limit of the nominal apparent power is exceeded, the CT saturates too early and causes the CT to fall outside its accuracy specifications. This may influence protection functions in a negative way, especially the differential algorithm during large through faults.

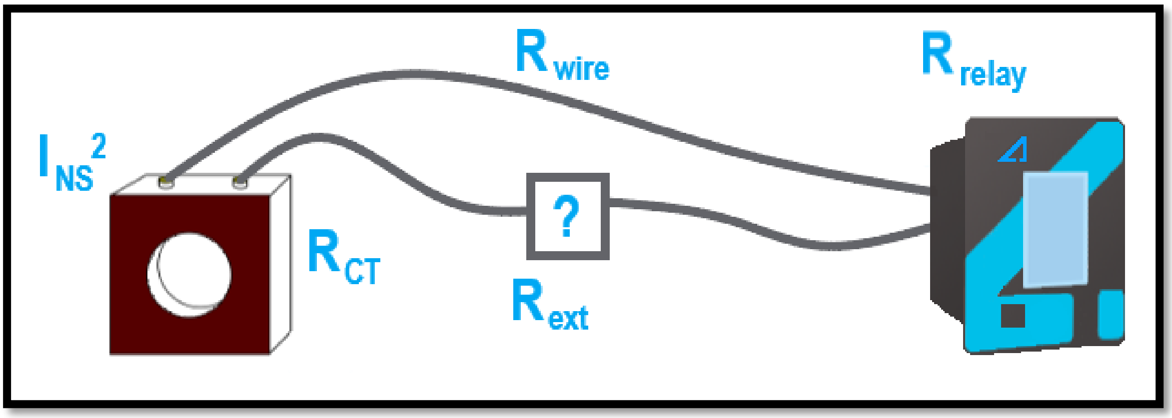
In a CT metering circuit, the impedance presented to the CT's secondary winding is the CT's secondary load (or, the burden). This burden is mostly resistive and is mainly caused by the combination of the CT secondary and the resistance from the wiring in the metering circuit. The smaller this combined resistance is, the better the CT can operate. Ideally, a small burden has a short distance between the CT and the measuring device (the protection relay), and the wire connecting the two has a large cross-section. Additionally, since the burden in related to the square of the current, having a CT secondary nominal of 1 A results in a notably different burden (1^2 = 1 A) than when the CT secondary nominal is 5 A (5^2 = 25 A).

According to IEC, the typical burden ratings for current transformers are the following: 1.5 VA, 3 VA, 5 VA, 10 VA, 15 VA, 20 VA, 30 VA, 40 VA, and 60 VA. ANSI/IEEE has a different rating system: B-0.1, B0.2, B-0.5, B-1.0, B-2.0, B-4.0 and B-8.0. A current transformer with a burden rating of B-2.0 has a metering circuit that can tolerate up to 0.2 Ω of impedance before its secondary accuracy falls outside its accuracy specification.

You can calculate the actual burden with Equation (2):

$$S_{actual} = I_{ns}^2 \times \left(R_{wire} + R_{relay}\right) \tag{2}$$

Figure 5-2. Actual burden.



5.1.3 Class

A current transformer's accuracy class is designated in the format "xPy". "x" refers to the highest permissible percentage of the composite error, and "y" refers to the CT's accuracy limit factor (ALF). The "P" in the middle stands for "protection", which in this case is the type of the CT.

Accuracy class tells you the CT's current error and its phase displacement at rated primary current. The ALF value, on the other hand, shows the multiple of the CT's rated primary current up to which the transformer is expected to keep within the so-called composite error requirements. Composite error is the deviation from an ideal CT, although it does consider the harmonics in the secondary current caused by non-linear magnetic conditions throughout the cycle at higher flux densities.

The standard composite error percentages are 5 and 10, whereas the standard accuracy limit factors are 5, 10, 15, 20, and 30. The IEC 61869-2 standard on the additional requirements for current transformers present the CT error limits for P protective current transformers, presented below in *Table 3*. For the limitations for other types of CTs (such as PR, PX, and TPZ), please refer to the standard.

Table 3. CT error limits according to IEC 61869-2.

Accuracy class	Ratio error at rated primary current	Phase displacement at rated primary current		Composite error at rated accuracy limit primary current
5P	±1 %	±60 minutes	±1.8 centiradians	5 %
10P	±3 %	–	–	10 %

The rated thermal short-circuit current is usually the short-circuit current of the installation, and its duration is assumed to be 1 s. All CTs must be able to withstand the maximum rated short-circuit current in the primary wiring until the malfunction induces a shutdown. The CT cannot overheat (thermal withstand) nor saturate (dynamic withstand). Additionally, in differential protection the protection device must trip massive in-zone faults, but at the same time it must not trip from major faults outside the protected area (= external faults). As CT saturation can cause the differential algorithm to trip during external faults, we can see that both the CT's burden as well as its maximum short-circuit capacity are highly relevant to having fully functioning protection.

You can calculate the maximum short-circuit current of the system using Equation (3):

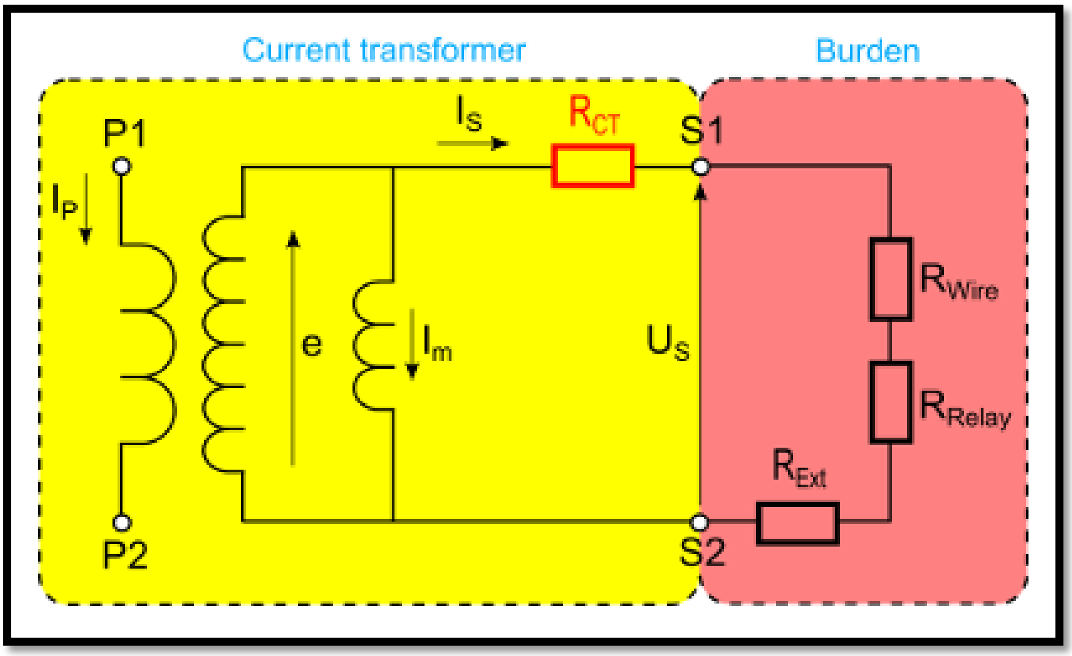
$$I_{3phSC} = \frac{U_n}{\sqrt{3} \times \left(\frac{U_n^2}{S_n} \times \frac{Z_{k\%}}{100\,\%} \right)} \qquad (3)$$

For example, if the maximum fault current of our transformer's HV side is 9 623 A and its nominal current is 1 157 A, we can calculate that our transformer must withstand a maximum short-circuit current of at least 8.32 × I_n. We can therefore say that a suitable CT for our transformer would have to have the accuracy class of xP10, as it can withstand ten times the nominal current without saturation at the rated burden.

5.1.4 Internal resistance

The internal resistance of a current transformer is not always included in the CT's name plate values. In these situations, the correct value should be asked directly from the manufacturer. However, if no better value is available, you should use the default value for CT internal resistance: 0.05 Ω. As the internal resistance of a current transformer directly affects the calculation of the CT saturation point, having a value as close to the CT's real internal resistance value is important.

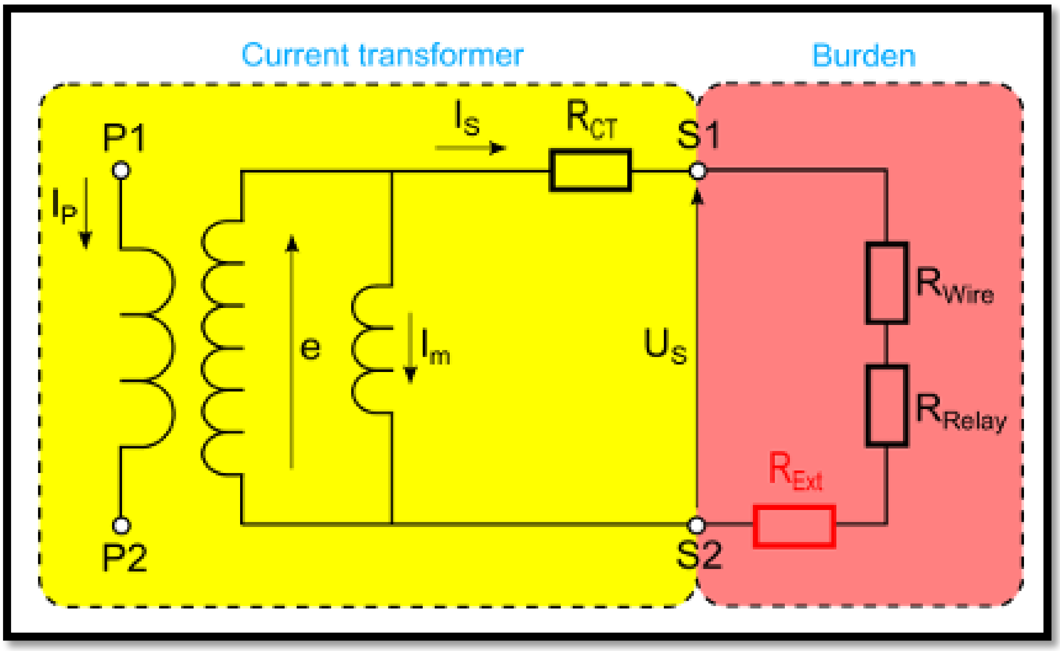
Figure 5-3. Internal resistance.



5.1.5 Other devices in series

You can have, for example, an external measuring equipment connected to the CT in series with the protection device. These add an external burden to the system, and it can have a major effect on the total burden. In order to calculate the total burden, you must know the total resistance of all external devices in the circuitry. If no external devices are connected, you can leave the parameter "Other devices in series" to its default value of 0 Ω.

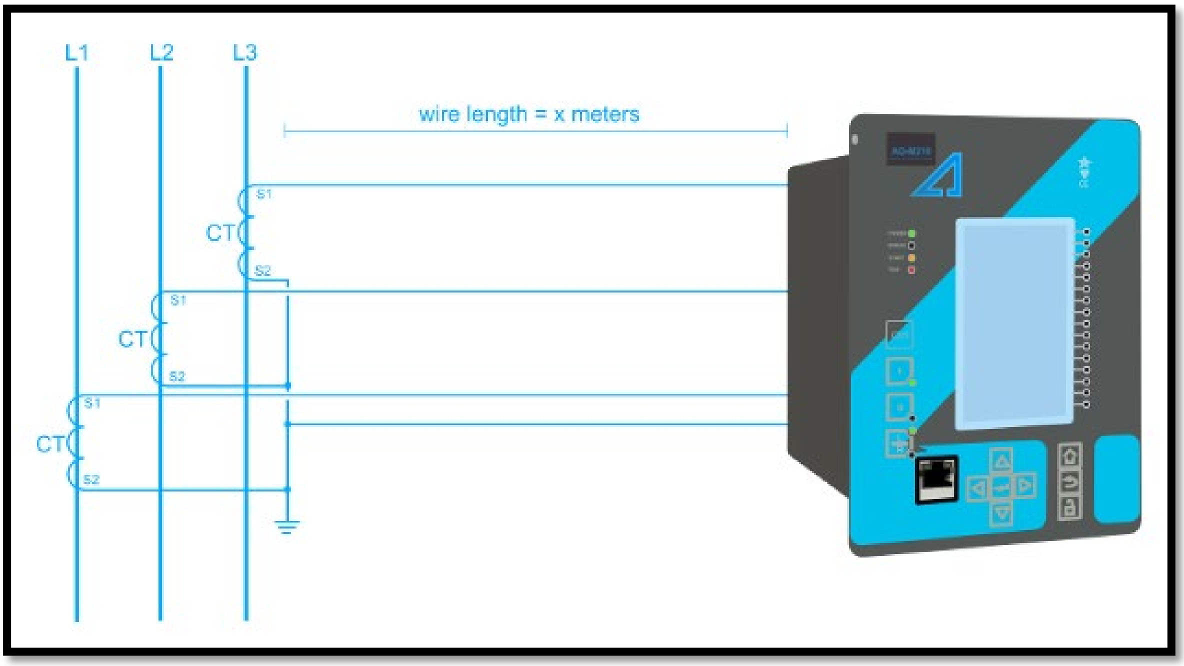
Figure 5-4. External burden.



5.1.6 Wire length to IED

The distance between the protection device and the current transformer has a remarkable effect on the total load of the measurement circuitry. Another major factor is the secondary load of the CT; please refer to the description for the "Rated power" parameter for more details. Please note that the value for the "Wire length to IED" parameter must be filled in meters!

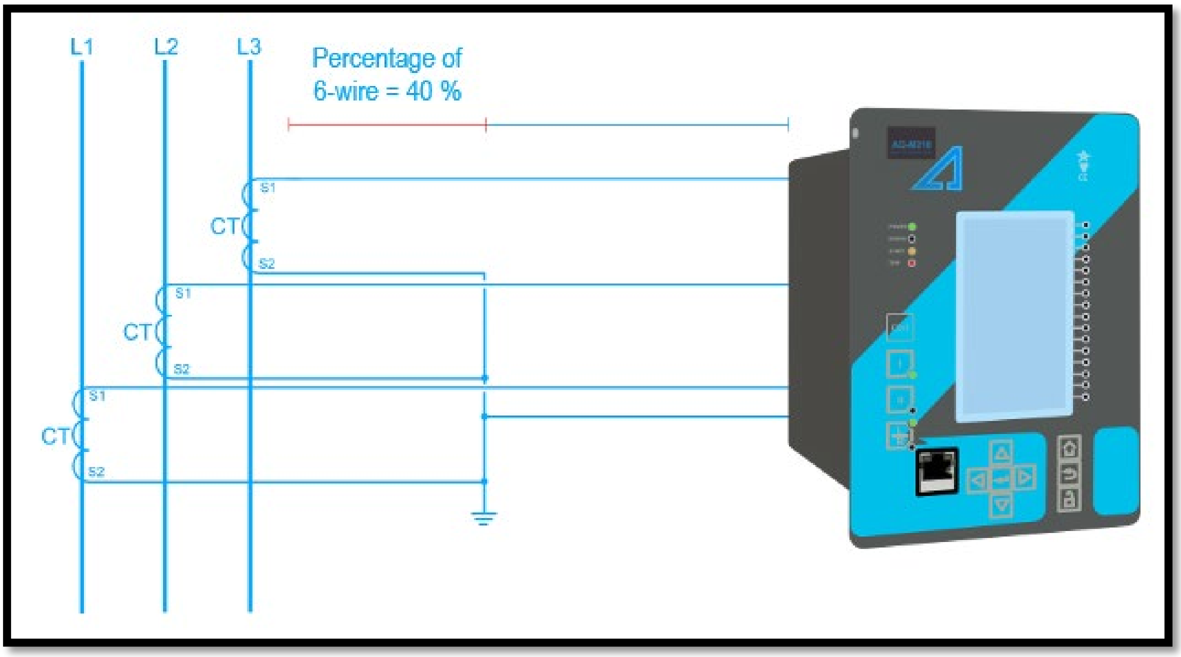
Figure 5-5. Wire length between the protection device and the CT.



5.1.7 % of wiring is 6w

The "% of wiring is 6w" parameter clarifies how large a percentage of the wiring between the protection device and the CT is wired using six wires instead of four. In practice, when the secondary of each CT is earthed at the terminal, this parameter is valued at 0 %.

Figure 5-6. Example of 6-wire percentage.



5.1.8 Wire type, wire cross section, and wire resistance

The length of the wire between the protection device and the CT is not the only thing that affects the total resistance (total burden) of the CT secondary. There are three other aspects in the wiring that must be considered: the wire's type, cross-section, and resistance.

The most commonly used material in medium-voltage application wiring is copper, which is why it has been set into the Wizard as the default. When you select the "Copper75°C" option, you only need to select the wire's cross-section from the "Wire cross section" dropdown menu as copper's value of resistance-per-meter has been programmed into the Wizard. You can choose from the following cross-section values: 1.5 mm^2, 2.5 mm^2, 4.0 mm^2, and 6.0 mm^2.

However, other materials (such as aluminum) can also be used in wiring, and you must therefore select "Manually set" as the wire type. This reveals the "Wire resistance" option, where you can type in the material's resistance-per-meter value. Please refer to *Table 4* for these values for copper and aluminum.

Table 4. Resistance values for copper and aluminum.

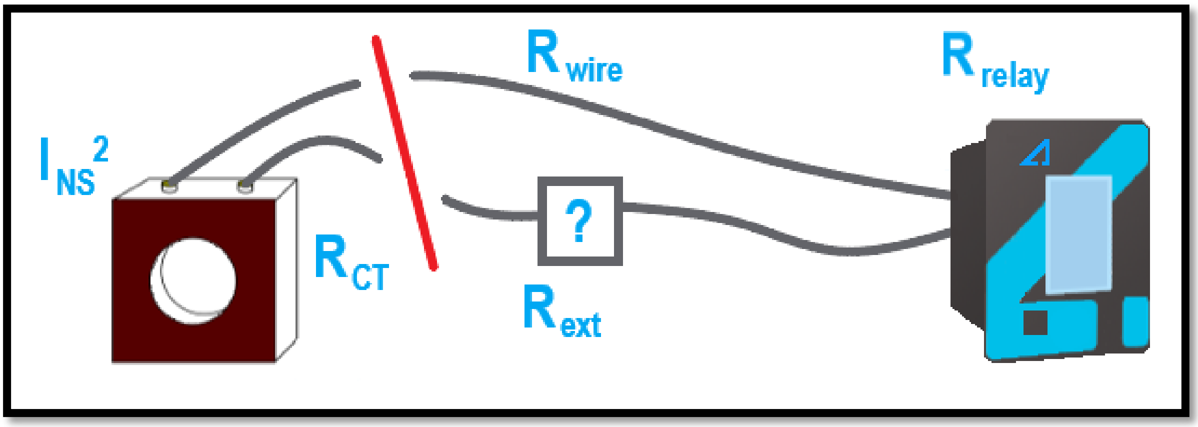
Material	Resistivity ρ (at 20 °C/68 °F/293 K)	Conductivity σ (at 20 °C/68 °F/293 K)	Temperature coefficient α
Copper	1.68×10^{-8} Ω·m	5.95×10^{7} (Ω·m)$^{-1}$	0.0068 (C°)$^{-1}$
Aluminum	2.65×10^{-8} Ω·m	3.77×10^{7} (Ω·m)$^{-1}$	0.00429 (C°)$^{-1}$

5.1.9 Total burden

The total burden (S_{actual}) affects the whole CT performance. It consists of the total resistance of the connected load: the resistance of the protection device's measurement circuit (R_{relay}), the resistance of the wiring (R_{wire}), and the resistance of all the external devices connected to the CT (R_{ext}). The total resistance is multiplied by the nominal secondary current squared to result in the total burden, as Equation (4) shows:

$$S_{actual} = I_{ns}^2 \times \left(R_{wire} + R_{relay} + R_{ext}\right) \quad (4)$$

Figure 5-7. Total burden.



5.2 Parameters for the transformer name plate values

Table 5. Setting parameters for the transformer name plate values.

Name	Range	Default
Transformer nominal power	0.1…500.0 MVA	40.0 MVA
HV side nominal voltage	0.1…500.0 kV	110.0 kV
LV side nominal voltage	0.1…500.0 kV	20.0 kV
HV/LV current transformer direction	1: Through trafo 2: Towards trafo	2: Towards trafo
Transformer Zk%	0.01…50.00 %	12.00 %
Transformer nominal frequency	7.0…75.0 Hz	50.0 Hz
Transformer magnetizing current	0.1… 50.0 %In	3.0 %In
Transformer vector group	1: Yy0 2: Yyn0 3: YNy0 4: YNyn0 5: Yy6 6: Yyn6	1: Yy0

Name	Range	Default
	7: YNy6 8: YNyn6 9: Yd1 10: YNd1 11: Yd7 12: YNd7 13: Yd11 14: YNd11 15: Yd5 16: YNd5 17: Dy1 18: Dyn1 19: Dy7 20: Dyn7 21: Dy11 22: Dyn11 23: Dy5 24: Dyn5 25: Dd0 26: Dd6	
Id0> (REF) HV side	1: Disabled 2: Enabled	1: Disabled
Id0> (REF) LV side	1: Disabled 2: Enabled	1: Disabled
Tap changer	1: No 2: LV side 3: HV side	2: LV side
Tap steps max (nom.to+/-)	1…20 steps	9 steps
Tap step effect	0.01…10.00 %Un	1.67 %Un
In-zone unit auxiliary transformer	1: No 2: Yes	1: No
Unit auxiliary transformer size	0.001…20.000 MVA	0.500 MVA

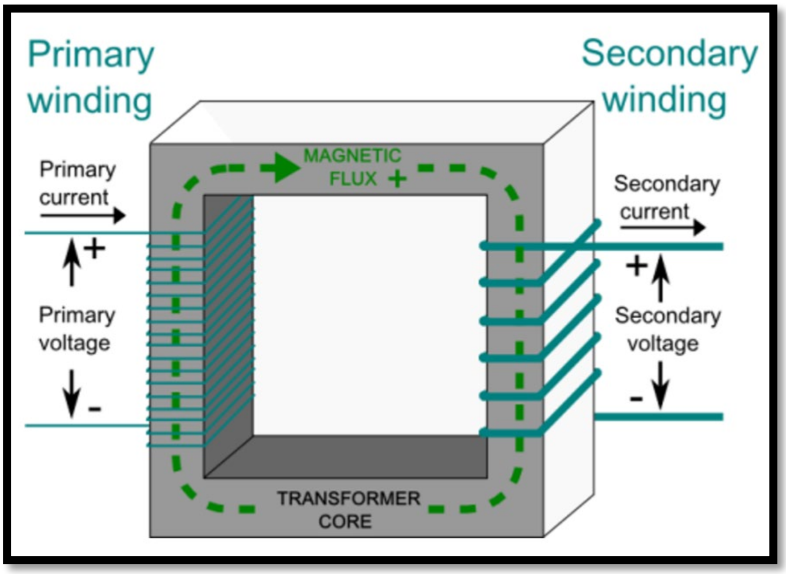
5.2.1 Transformer nominal power

Transformers are an essential part of power transmission. Medium-voltage transformers are commonly used to transport energy where they turn one level of voltage into another potential level. When the transmission distances are longer, using a higher voltage of 200…600 kV helps avoid power losses since the current is smaller. When nearing the destination and the end users, voltage is then brought back to a MV or LV level with distribution transformers.

MV transformers are also often used to power advanced machines. It is easier for generators in power plants to produce power at a lower voltage level. So-called block transformers (aka. step-up transformers) are used to raise that level more suitable for energy transmission.

A transformer's nominal power determines the maximum apparent power that can pass through it between the HV side and the LV side in both directions. The voltage range of a typical oil-isolated transformer (power and distribution) varies between 3…230 kV. The nominal power range therefore begins below 1 MVA and goes up to 63 MVA and beyond.

Figure 5-8. Nominal power.

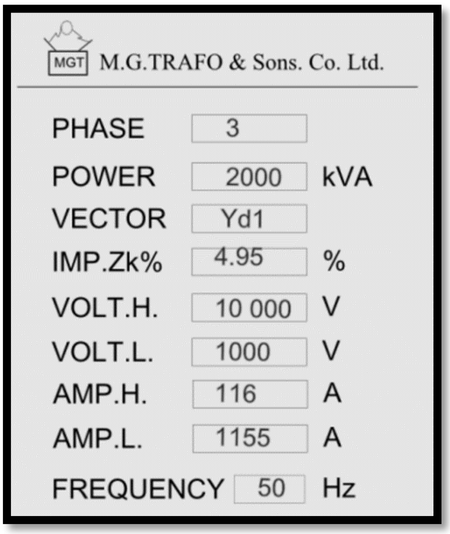


5.2.2 HV side and LV side nominal voltages

Power and distribution transformers turn a certain level of voltage into another potential level through electromagnetic induction. This varying magnetic field in the secondary induces a changing electromagnetic force which appears as the voltage in the secondary winding. Transformers can be designed to efficiently change AC voltages from one potential level to another within power networks.

The name plate values for both HV and LV side nominal voltages are always states as line-to-line voltages. For example, in the figure below the name plate values show that the HV side has the voltage 10 000 V, whereas the LV side is 1 000 V. Additionally, the name plate shows that the HV side is connected in wye configuration, while the LV side is connected in delta configuration.

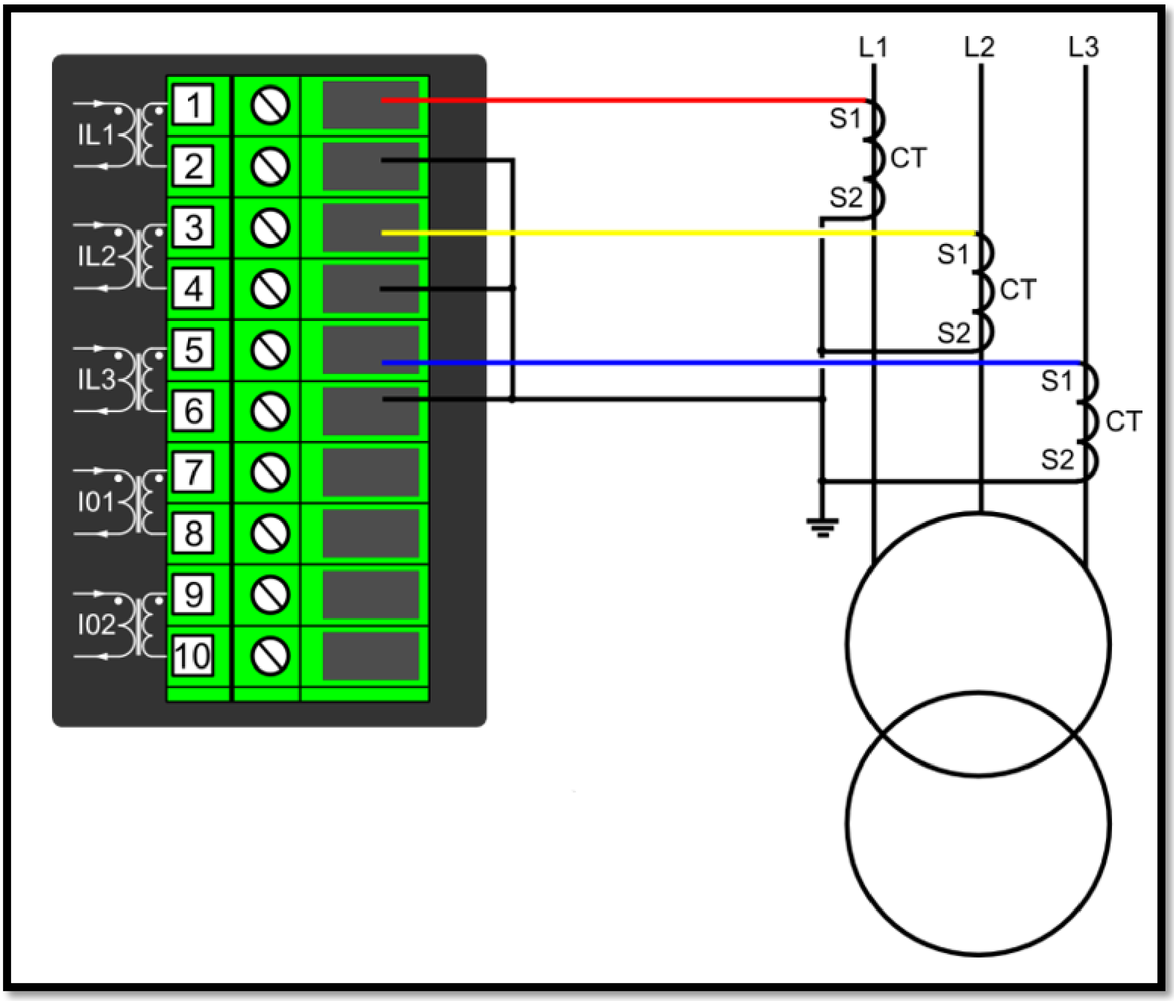
Figure 5-9. Nominal voltages for HV and LV sides.



5.2.3 HV/LV current transformer direction

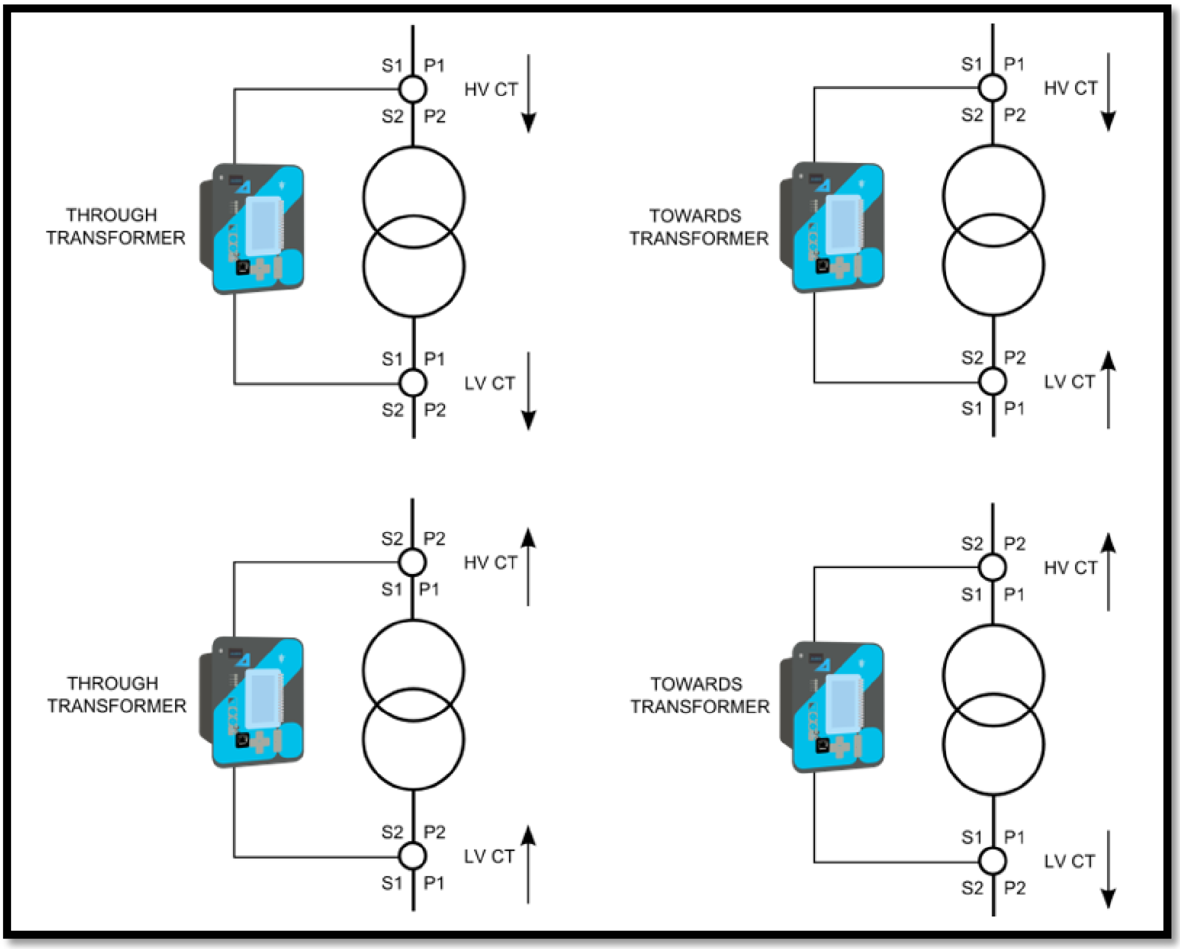
Selecting the correct CT direction is essential in differential protection to ensure the current transformer's proper operation. In order to solve whether a fault is internal or external, you must know both the size of the current amplitude as well as the angle of the measured current. The CT is always connected to the protection device according to the figure (*5-9*) below. As you can see, the secondary side of each CT is connected to the device's evenly-numbered terminals (pins 2, 4, and 6).

Figure 5-10. CT-to-device connection diagram.



Once the CT's secondaries are connected correctly, you then have to select whether the CT direction is towards the transformer ("Towards trafo") or through it ("Through trafo"). Please note that the power flow's direction is irrelevant to differential protection. See *Figure 5-11* on the following page for how the two selection options cover the four direction combinations.

Figure 5-11. CT direction combinations.



5.2.4 Transformer Zk%

A transformer's nominal power determines the maximum apparent power that can pass through from LV to HV or vice versa. A part of that maximum value is turned into heat due to the various losses inside the transformer. During a fault, both the maximum apparent power and the short-circuit impedance (Z_k) contribute to how large the maximum short-circuit fault will be. Short-circuit losses mostly consist of inductive losses caused by the transformer core's metal. Additionally, the windings cause a small amount of the resistive part of the losses.

The short-circuit impedance percentage (Z_k%) for distribution transformers below 1 MV ranges between 3.5 and 6.0 %. For bigger power transformers, this value ranges from 7…12 %. The difference is due to the fact that larger transformers have more core material (usually annealed silicon steel sheet) and larger windings which then result in more losses.

Table 6 on the following page presents the short-circuit impedance percentages of oil-isolated power transforms, sized between 10…63 MVA.

Table 6. Values for oil-isolated power transformers (110 kV, 10...63 MVA)..

Power	P0	Pk	Zk	S0	Total weight	Oil weight
10 MVA	9.0 kW	51 kW	10 %	0.30 %	25.0 t	6.0 t
16 MVA	11.0 kW	74 kW	10 %	0.25 %	36.0 t	9.5 t
20 MVA	13.5 kW	87 kW	10 %	0.20 %	36.0 t	9.6 t
25 MVA	15.5 kW	100 kW	10 %	0.20 %	40.0 t	9.7 t
31.5 MVA	18.0 kW	122 kW	10 %	0.20 %	46.5 t	11.1 t
40 MVA	23.5 kW	146 kW	12 %	0.20 %	56.5 t	13.2 t
50 MVA	27.0 kW	175 kW	12 %	0.20 %	63.0 t	14.8 t
63 MVA	32.0 kW	210 kW	12 %	0.20 %	73.0 t	17.3 t

5.2.5 Transformer nominal frequency

A CT's primary winding must be designed to match both the voltage and the frequency of the transformer's power source. It must also be able to transfer the necessary apparent power to the secondary circuits without overheating. Although you can install a CT designed for 50 Hz into a network of 60 Hz, the opposite is not possible.

5.2.6 Transformer magnetizing current

A transformer's magnetizing current is the current which flows in the primary winding. Since it only runs on the primary side, it needs to be considered when calculating the differential characteristic setting. The magnetizing current's approximate value can be calculated with Equation (5):

$$I_{TM} = \frac{U_{pri}}{j\omega L_p} \tag{5}$$

5.2.7 Transformer vector group

Matching the nominal current is only one part of differential protection settings. Since the differential function is interested in the angle difference between the measured current vectors, it makes the transformer's vector group important.

In the example on the following two pages (*Figures 5-12* and *5-13*) is a transformer whose vector group is Yd5. This means that inside the transformer its HV side is connected in wye configuration and its LV side in delta configuration in such a way that the vectors of the LV side lag 150 degrees

(360°/12×5=150°) behind those of the HV side. If this same transformer were to be connected according to vector group Yd11, the LV side would lead the HV side by 30 degrees (360°/12×11=330°).

The connection group also shows whether the star point of the wye-configurated transformer is earthed or isolated from the earth. The letter N in the group name denotes that the star point is earthed. When the HV side star point is earthed, an uppercase N follows the HV side wye-configuration marker "Y" in the group name (for example, YNx). Similarly, when the LV side star point is earthed, the group name has a lowercase n following the LV side wye-configuration marker "y" (for example, Xyn). When both sides are earthed, both markers appear in the group name (for example, YNyn).

The delta side cannot be earthed without a separate grounding transformer, also known as a zigzag transformer. This earthing transformer is on the LV side of a Yd-connected transformer. Because a zigzag transformer is usually outside the protected zone, the connection group remains as Yd and the earthing transformer has no effect on the protection calculations.

Figure 5-12. Example of a Yd5 connected transformer.

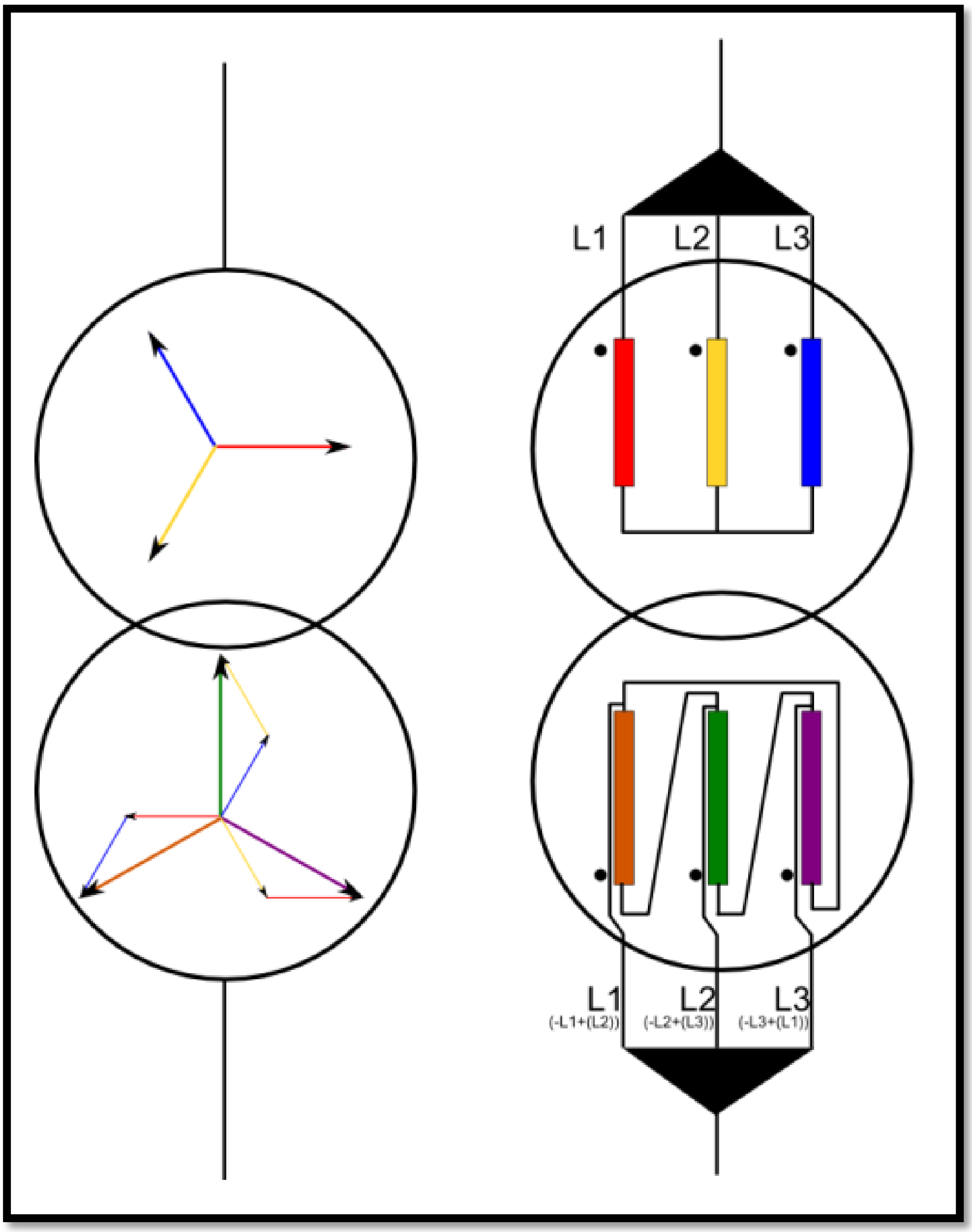
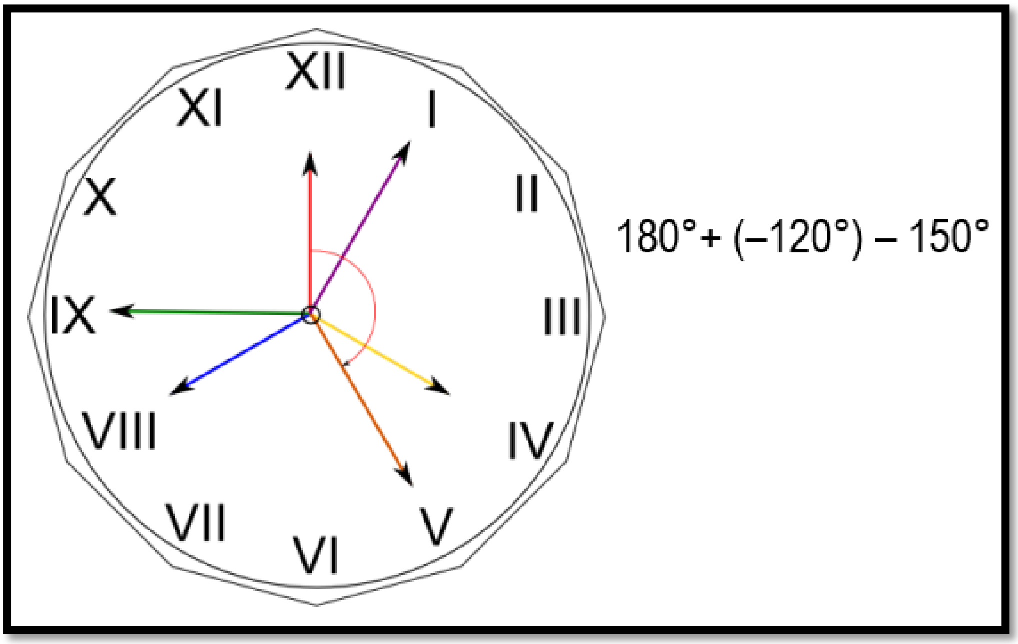


Figure 5-13. The LV side lagging behind the HV side by 150 degrees.



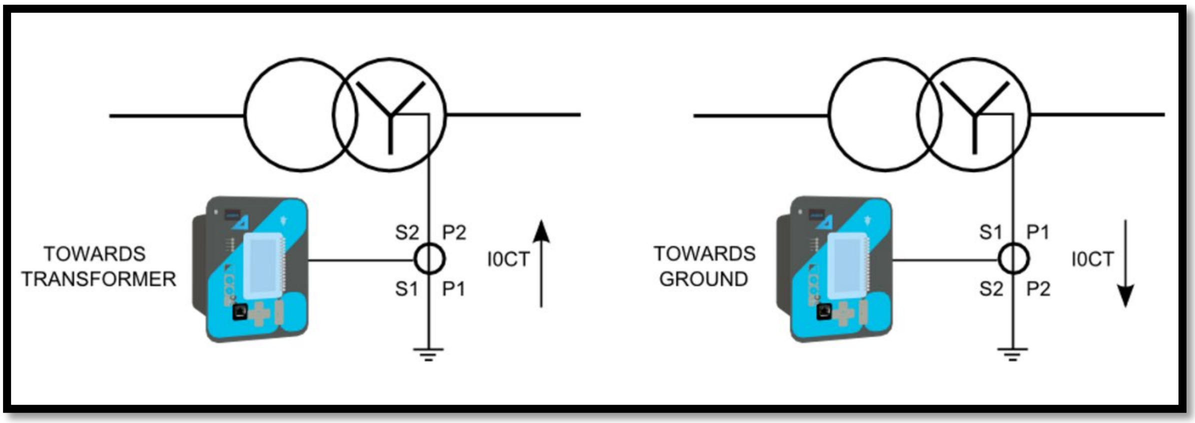
5.2.8 Id0> (REF) HV side and LV side

When the transformer's start point or network is solidly earthed or resistance earthed, you can use restricted earth fault (REF) protection to detect in-zone phase-to-earth faults. REF protection provides more accuracy than regular differential protection because the neutral point compensation affects differential calculation.

Each of the measurement cards in the protection device has three (3) phase measurement channels for phase currents and two (2) measurement channels for residual current (earth fault). You can select an earth fault current by using the I01 or the I02 channel. Please note that you have to select the channel that has been wired to be used for the REF protection function!

When it comes to REF protection, both the biasing current measurement and the differential current measurement are calculated based on the measured phase currents and earth fault currents. It is therefore important to know how each current transformer has been connected to the protection device. The I0CT can be wired in two ways, either towards the transformer's star point, or towards the earth.

Figure 5-14. Options for the I0CT wiring.



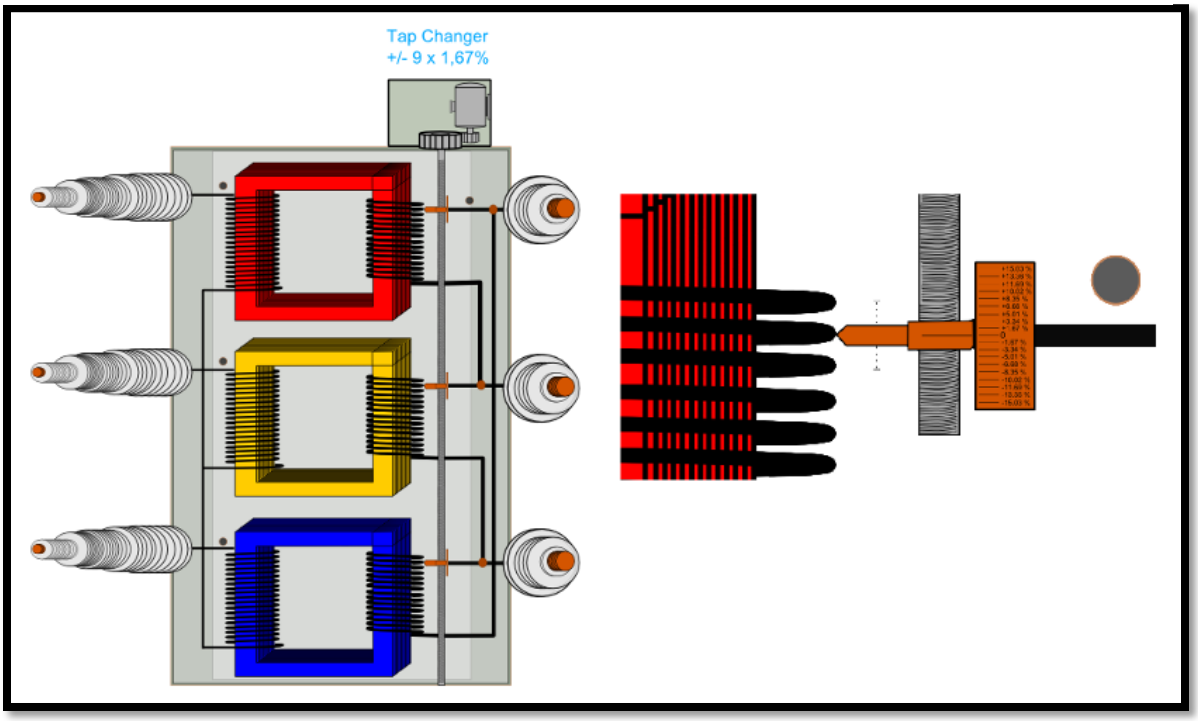
5.2.9 Tap changer, tap steps max (nom.to+/-), and tap step effect

A tap changer is a mechanism to select the connection point along a power transformer's winding in a specific number of steps. This produces a transformer with a variable turns ratio, which allows you to regulate the voltage output in steps. You can choose between automatic and manual tap changer mechanisms.

Large load changes on the transmission side can cause the voltage level to decrease or increase. A single power transformer cannot affect the voltage level's HV side locally, and therefore the tap changer is needed to adjust the voltage level on the load side and keep it on the nominal voltage level. When the tap changer modifiers the voltage level on the load side, the ratio between the HV voltage side and the LV voltage side changes. This ratio change causes differential which in turn causes the current levels to change. The differential current is therefore compensated with the Slope 1 differential characteristic setting.

Transformers can have either a de-energized tap changer (±5 % **or** ±2×2.5 % = 5 %) or an on-load tap changer (±6 % × 1.67 % = 10 % **or** ±9 % × 1.67 % = 15 % **or** ±9 % × 1.33 % = 12 %). Power transformers most commonly have an on-load tap changer. If the tap changer has an effect of ±9 % × 1.67 %, the setting value for the "Tap steps max (nom.to+/-)" parameter is 9. The effect of one tap position change must also be set to calculate the correct differential for Slope 1. If the tap changer has an effect of ±9 % × 1.67 %, the setting value for the "Tap step effect" parameter is 167.

Figure 5-15. Tap changer.

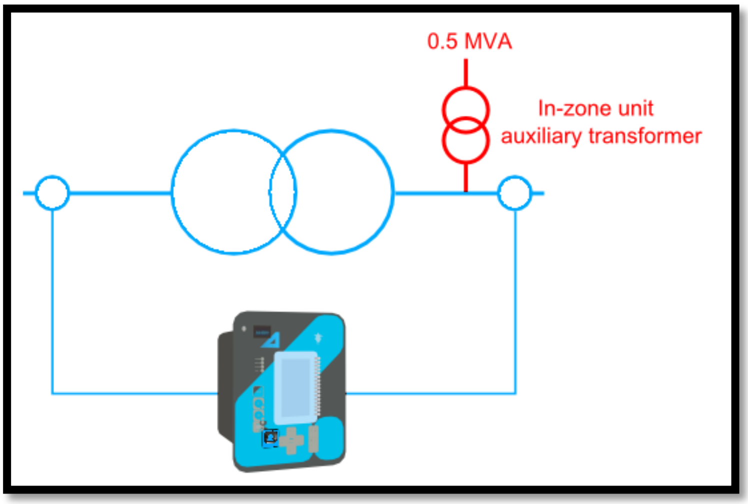


5.2.10 In-zone unit auxiliary transformer and its size

A unit auxiliary transformer is the power transformer that provides power to the auxiliary equipment of a power generating station during normal operation. Usually, auxiliary transformers are small and separate individual units. As they are installed inside the protected zone, they only affect the windings on one side of the transformer, and this causes differential. This differential must be considered when calculating the basic pick-up setting

If an auxiliary transformer unit is installed into the system, select "Yes" for the "In-zone unit auxiliary transformer" parameter. Also, add the auxiliary unit's size in MVA.

Figure 5-16. In-zone unit auxiliary transformer.



5.3 Device settings

Table 7. Setting parameters for the protection device.

Name	Range	Default
IED accuracy class	1: 0.5 2: 0.2	1: 0.5
Protection safety margin	0…20 %	5 %
Transformer max load current	1.0…3.0 xIn	1.0 xIn
Bias calculation mode	1: Average 2: Maximum	1: Average
Harmonic blocking	1: Enabled 2: Disabled	1: Enabled
Unbiased backup differential	1: Enabled 2: Disabled	1: Enabled

5.3.1 IED accuracy class

Protection relays' accuracy classes are defined by the IEC and ANSI standards, and are denoted either with a letter or a percentage. Arcteq relays use the IEC denomination for accuracy classes. The IEC 62053-22 standard only applies to newly manufactured static watt-hour meters with an accuracy class 0.2 S or 0.5 S. These static meters measure the alternating current electrical active energy in 50 Hz or 60 Hz networks, and the standard applies only to their type tests.

The IEC 62053-22 standard applies to all functional elements (exc. displays) enclosed in one meter case, as well as to operation indicator(s) and test output(s). Please note that additional standards may also apply. When the meter has a multi-energy meter (=measures more than one type of energy) or when the meter case encloses certain other functional elements (such as maximum demand indicators, electronic tariff registers, time switches, ripple control receivers, data communication interfaces), their relevant standards must also be noted.

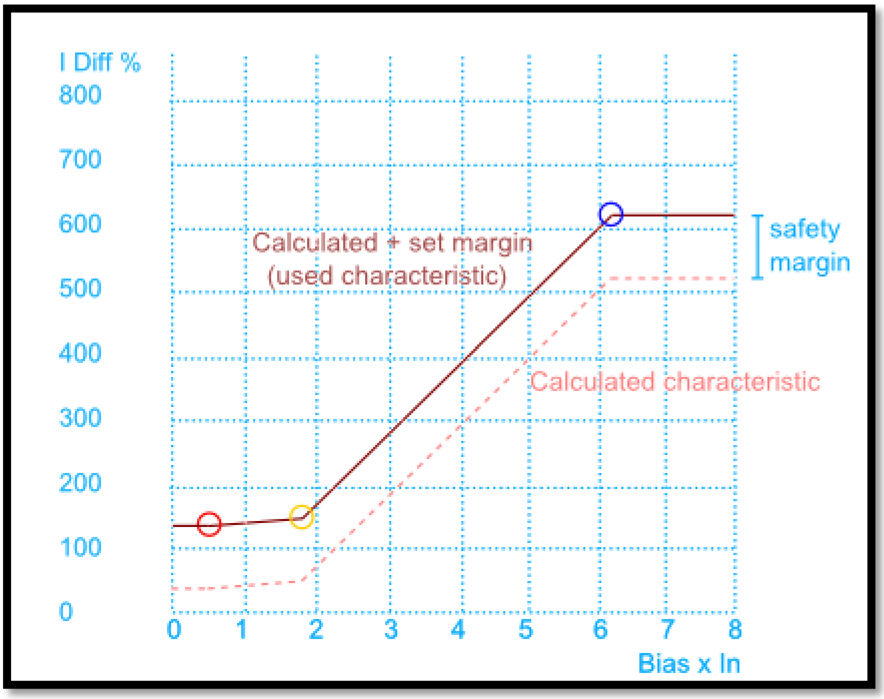
Accuracy class affects the pick-up characteristic calculation in differential protection. By default, Arcteq relays have an accuracy class of 0.5 S, but they can also be ordered with the class 0.2 S when required. This is defined via the ordering code when placing an order with us. Please note that differential protection does not need Class 0.2 S, and therefore Class 0.5 S is the default class selection in the Wizard.

5.3.2 Protection safety margin

The Transformer Wizard calculates the proper settings for the differential characteristic based on a set of values provided by the user. This calculated characteristic aims to be as accurate as possible, which means that the protection safety margin should be defined.

The characteristic is set in such a way that the protection device does not trip when the transformer is operated under normal conditions, or when a fault occurs outside the protected zone. When an in-zone fault takes place and the transformer malfunctions, the differential protection trips because the value of the calculated differential current sets the fault clearly inside the trip area. A proper protection safety margin can therefore be used. By default, the Wizard offers a safety margin of 5 %.

Figure 5-17. Protection safety margin.



5.3.3 Transformer max load current

A transformer differential characteristic consists of several areas, and each pick-up and slope is set according to the application. The main areas are the basic pick-up (Idb>), the tap changer effect area (Slope 1), the through fault area (Slope 2), and the no-bias pick-up (Idi>).

The Idb> pick-up is the basic pick-up for the differential characteristic, and it consists of various effects from the power/distribution transformer and the current transformer. At its simplest, the basic pick-up (Idb>) is the sum of the set protection safety margin and the following four (4) errors: the CT measurement accuracy errors from both HV and LV sides, the protection device's measurement accuracy error, the error caused by the primary side magnetizing effect of the protected transformer's core, and the error caused by the in-zone unit auxiliary transformer (is one is installed).

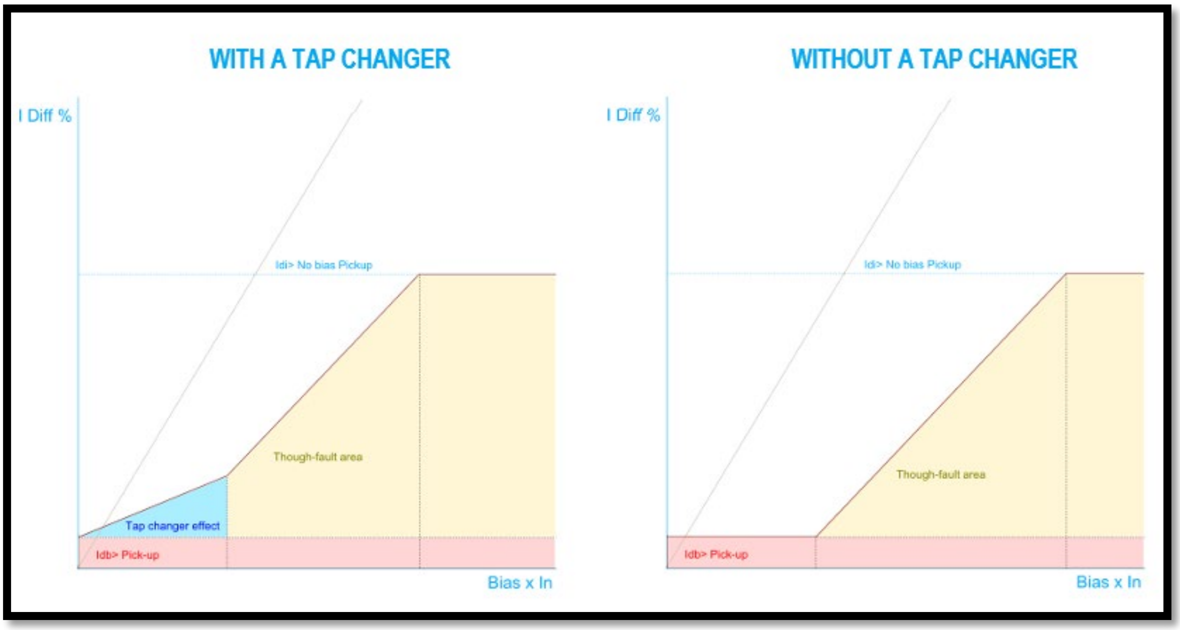
The tap changer effect (Slope 1) changes the protected transformer's voltage ratio, and this causes differential during the transformer's normal operation. This effect can, however, be compensated by increasing the differential error allowed in the transformer's normal load area. This requires that we define both the transformer's maximum load current and the maximum tap effect on their respective parameters. Please note that a power/distribution transformer can be used above its nominal range!

As the figures below show, the through fault area (Slope 2) begins where the tap changer effect end, or (if no tap changer is used) where the basic pick-up Idb> ends. Slope 2 helps avoid tripping during a through fault situation when the actual fault is outside the protected zone. The angle of the slope is determined by the selected bias calculation mode. For more information, please refer to the description for the "Bias calculation mode" parameter.

The Idi> is the no-bias pick-up limit, and its setting must be greater than the inrush current that appears on the protected transformer's primary side when the transformer is connected to the grid without a load. This is a normal procedure, and the amplitude of the inrush current is roughly 8…12 times the transformer's nominal current (which is the highest in small, appr. 1 MVA distribution transformers). Although the amplitude can be twelve times the nominal current, the FFT (Fast Fourier Transform) filters half of the actual peak-to-peak current. You can, therefore, use the sum of the set protection safety margin and a current value six times the transformer's nominal current ($= 6 \times I_n + P_{margin}$). Please note that the no-bias pick-up (Idi>) is not blocked internally with the 2^{nd} and 5^{th} harmonics (for more information, please refer to the description for the "Harmonic blocking" parameter).

> **NOTE!** The Idi> pick-up must not operate from dissimilar CT saturation caused by a DC offset during a high-current external fault. This means that the $6 \times I_n + P_{margin}$ setting may not be sufficient, and the pick-up must be set even higher. For more information, please refer to the description for the "Unbiased backup differential" parameter.

Figure 5-18. Tap changer's effect on the transformer maximum load current.



5.3.4 Bias calculation mode

Different protection relay manufacturers use different methods to calculate the biasing current. Some calculate the average bias value, while others use the maximum current method. With Arcteq protection relays you can select which of these methods is used to calculate the biasing current.

The "Average" mode calculates the sum of the current from the HV and LV sides and then divides it by two. The "Maximum" mode, on the other hand, uses the higher current (×I_n) directly as the biasing current, which makes this mode less sensitive. By default, the Wizard uses the "Average" mode for bias calculation. Equations (6) and (7) present the calculation for the "Average" and "Maximum" modes, respectively:

$$\mathrm{LxBIAS_{AVG}} = \frac{|\mathrm{ILx_{HV}}|+|\mathrm{ILx_{LV}}|}{2} \tag{6}$$

$$\mathrm{LxBIAS_{MAX}} = \max(|\mathrm{ILx_{HV}}|, |\mathrm{ILx_{LV}}|) \tag{7}$$

Table 8 presents how the mode selection affects the resulting biasing current. As you can see, the greater the difference between the HV and LV side currents, the bigger the difference in the resulting biasing current between the two modes.

Table 8. Comparison of the two bias calculation modes on the resulting biasing current.

	AVERAGE: $\mathrm{LxBIAS_{AVG}} = \frac{|\mathrm{ILx_{HV}}| + |\mathrm{ILx_{LV}}|}{2}$	MAXIMUM: $\mathrm{LxBIAS_{MAX}} = \max(|\mathrm{ILx_{HV}}|, |\mathrm{ILx_{LV}}|)$
IL1	$\frac{|1| + |3|}{2} = \frac{|4|}{2} = 2$	$\max(|1|, |3|) = 3$
IL2	$\frac{|1.5| + |1.5|}{2} = \frac{|3|}{2} = 1.5$	$\max(|1.5|, |1.5|) = 1.5$
IL3	$\frac{|0.8| + |6.2|}{2} = \frac{|7|}{2} = 3.5$	$\max(|0.8|, |6.2|) = 6.2$

5.3.5 Harmonic blocking

In transformer protection, the 2nd harmonic content is always present in energizing situations. When a power transformer's primary side is energized (and its secondary side is open), the transformer can be considered as simple inductance. The start-up transition during energization doubles the nominal flux values for the first half of the cycle. This causes saturation in the transformer's core, which lasts as long as the transition itself. During saturation the transformer's primary draws a very high current as well as a large amount of even harmonics, the highest of which is the 2nd. This current is generally called the magnetizing inrush current of the transformer.

The inrush current of a small distribution transformer can be 8…12 times higher than the nominal rated current of the transformer. The differential relay then sees this energizing current as a differential current because it only flows through the primary side winding. The purpose of detecting the 2nd harmonic content generated by saturation is to block the biased sensitive differential stage during energizing.

A typical set point for the 2nd harmonic restraint is the relay manufacturer's default or recommended setting of 15…20 % of the fundamental current, with some adjustments made based on the user's operating experience. However, some operating situations may result in 2nd harmonic current levels that are below 15 % during inrush, with levels even dipping down to 5 %. By default, the Transformer Wizard sets the 2nd harmonic pick-up at 5 %.

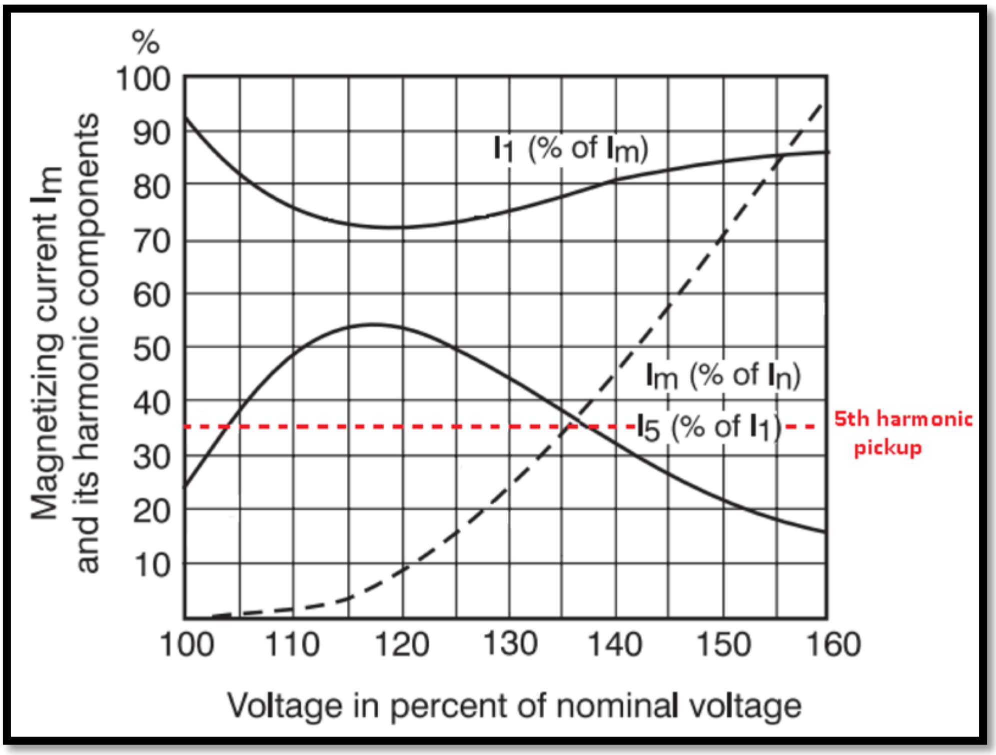
5th harmonic blocking, on the other hand, is commonly used to detect overfluxing or overexcitation. When the primary side voltage of a transformer increases, the V/Hz ratio increases beyond the designed limits and the transformer begins to overexcite. This can be due to a temporary overvoltage caused by the LV side fault throwing off the loading, or because the network's frequency has decreased for some reason (such as overloading). In both of these cases the differential device should not trip even when the measured currents are considerably higher on the primary side than on the secondary side, a situation caused by the overexcitation in the transformer's core.

Additionally, a transformer tends to overheat as a result of increased excitation current, hysteresis losses, and eddy currents. The increased excitation current produces an operating current in the differential calculation. However, since an immediate response is not necessary, tripping is undesirable, and the power system should be allowed some time to correct itself. For this reason, the differential stage should be blocked when the protection device detects overexcitation.

The 5th harmonic restrains if the amplitude exceeds the set limit of 35 % of the fundamental current. This equals a voltage range of approximately 104…138 % of the nominal voltage (see *Figure 5-19* below). The power system can be operated continuously at 105 % during normal operation, and dynamically it can be operated as high as about 115 % during a severe disturbance. The 5th harmonic blocking will therefore prevent tripping during these high system voltages.

If a transformer becomes faulty during a high-excitation condition, the protection device will operate as long as the fundamental current is sufficient to reduce the 5th harmonic component below the relay's restraint level. Such a reduction occurs due to the reduced excitation level caused by the fault current, and due to the increased fundamental frequency current itself.

Figure 5-19. 5th harmonic pick-up in relation to the magnetizing current and the nominal voltage.



5.3.6 Unbiased backup differential

The unrestrained element (commonly referred to as an unbiased backup differential) does respond to the operating current or to the differential current, but does so without the restraint functionality. It functions as a high-speed trip during severe internal faults. The only way unbiased backup differential can tell the difference between an internal fault and an inrush current is the magnitude of the current involved. This is why the setting for the "Unbiased backup differential" parameter must be greater than the expected inrush current. Additionally, it cannot operate from dissimilar CT saturation caused by a DC offset during high-current external faults. For these reasons, the unrestrained element setting is set to be fairly insensitive.

As stated previously, the unbiased backup differential needs to be set above the inrush current which is rich in harmonics and direct current. The amplitude of the inrush current may increase up to twelve times the nominal current, but since the FFT filters half of the actual peak-to-peak current, you can use the $6 \times I_n + P_{margin}$ setting value.

Table 9. Comparison of maximum inrush current first peak and maximum residual flux for different transformers.

	300 kVA	800 kVA	50 MVA	300 MVA	300 MVA
Inrush first peak	241 A 20.5 p.u.	605 A 14.4 p.u.	1436 A 2.34 p.u.	1545 A 3.75 p.u.	2060 A 3.57 p.u.
Residual flux	0.33 Wb-t 0.54 p.u.	0.38 Wb-t 0.62 p.u.	13 Wb-t 0.45 p.u.	83 Wb-t 0.24 p.u.	231 Wb-t 0.67 p.u.
	L.M.	L.M.	F.M. 2	F.M. 1	F.M. 3

6 Calculated values

The Transformer Wizard tool calculates characteristic settings for differential protection, but it also produces some additional, informative data. The CT nominal currents are calculated as primary and secondary values, and the same applies to both three-phase and single-phase short-circuit currents. All are also calculated as per-unit values. The Wizard also presents CT saturation limits.

6.1 Characteristic values

Figure 6-1. Calculated values for the differential characteristic settings.

Differential characteristic settings

Turnpoint 1: Bias x In...	0,01	/ I diff %...	19,00	/ Slope1%...	21,27
Turnpoint2: Bias x In...	1,00	/ I diff %...	40,06	/ Slope2%...	200,00
Idi> Pickup: Bias x In...			3,82	Id> %...	605,00

The Transformer Wizard presents a full scale of differential characteristic values. It also presents the characteristic curve.

6.2 CT values

Figure 6-2. Calculated values for the current transformer.

High voltage side CTs

HV side nominal curent		209,9 Apri	2,10 Asec
HV side maximum 3ph fault current	1 749,6 Apri	17,50 Asec	8,34 xIn
HV side maximum 1ph fault current	850,9 Apri	8,51 Asec	8,51 xI0n

Low voltage side CTs

LV side nominal current		1 154,7 Apri	11,55 Asec
LV side maximum 3ph fault current	9 622,5 Apri	96,23 Asec	8,33 xIn

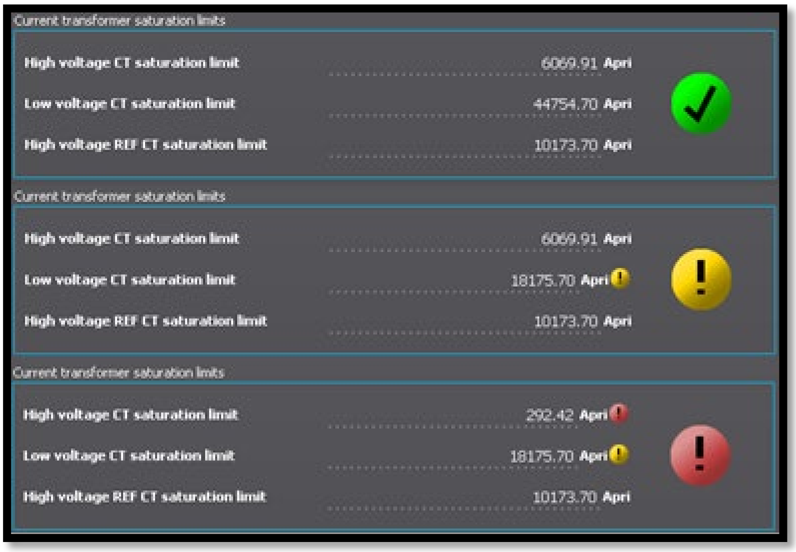
The Wizard calculates the following CT values:

- Nominal currents in amperes, both primary and secondary.
- The maximum three-phase short-circuit current in amperes and in per-unit values (×In), both primary and secondary.
- The single-phase short-circuit current in amperes and per-unit values, both primary and secondary.

> ⚠ Please note that the single-phase short-circuit current is only available in star-connected transformers!

6.3 CT saturation limits

Figure 6-3. Calculated values for CT saturation limits.



The magnitude that the current transformers are able to reproduce is calculated based on the CT technical values you have provided. Additionally, the wiring between the CT secondary and the device plays a significant role.

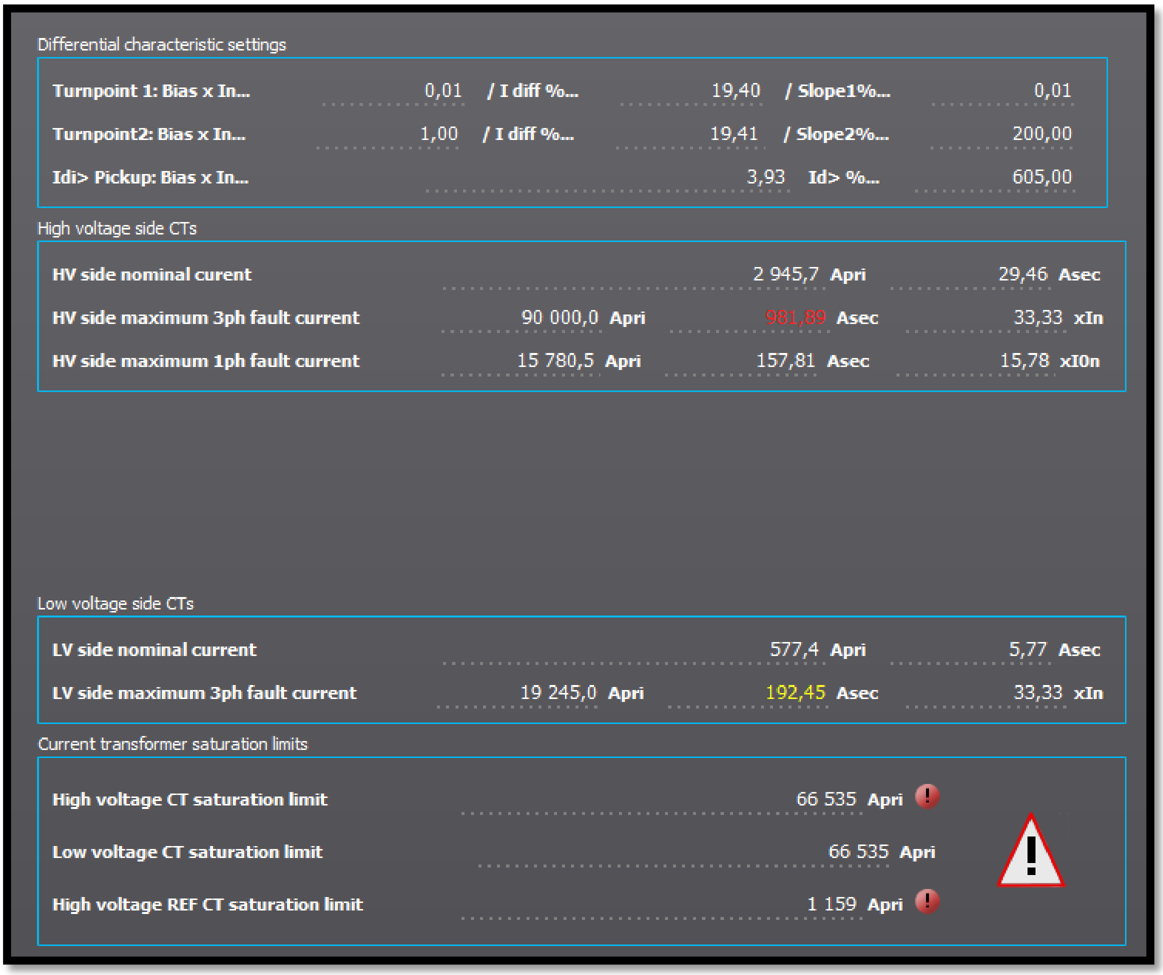
CT functionality is divided into three categories (*Table 10*):

Table 10. CT functionality icons.

Category icon	Description
	CT functionality is sufficient.
	The CT may saturate, and the operating time may be delayed in bigger faults.
	CT functionality is unreliable.

The Transformer Wizard gives more information related to CT operation in all three categories. Clicking the category icon also provides additional information of various problematic situations (such as when the maximum secondary fault current exceeds the device's measuring capabilities or when the transformer installation is faulty) and offer possible solutions to solve the situations. You can see the "offending" calculated values when they are presented with a red or yellow font.

Figure 6-4. Example of the Wizard showing CT functionality icons.



7 USING THE TRANSFORMER WIZARD

The format of a settings file (or a "wizard file") from the Transformer Wizard is *.aqwz. A single wizard file includes all the essential settings related to differential protection, including settings for a phase CT, a neutral CT, the connection direction as well as transformer and characteristic setting.

> ⚠ Please note that transformer back-up protection must be set separately. Additionally, breaker connections and I/O connections ("matrix") must also be set separately using the AQtivate 200 software.

7.1 Saving and opening a wizard file

You can save a wizard file with the **Save** button or the **Save as…** button. You can also open an existing project with the **Open** button. Please refer to *Table 1* on page 9 for the respective icons of these buttons.

> ⚠ Please note that AQtivate 200 setting files (*.aqs) and wizard files (*.aqwz) are fully independent, and they must be saved and opened separately!

7.2 Writing settings into a device

You can write a selected .aqwz file into a relay by clicking the **Write to relay** button (see *Table 1* on page 9 for the icon of this button). You must be connected to the relay for this button to work. If you have not established a connection, the button is gray and will not function.

When the software has finished writing the setting values from the wizard file into the connected device, a separate window pops up to inform you of this (*Figure 7-1*). Click **OK** to proceed.

Figure 7-1. Writing process complete.

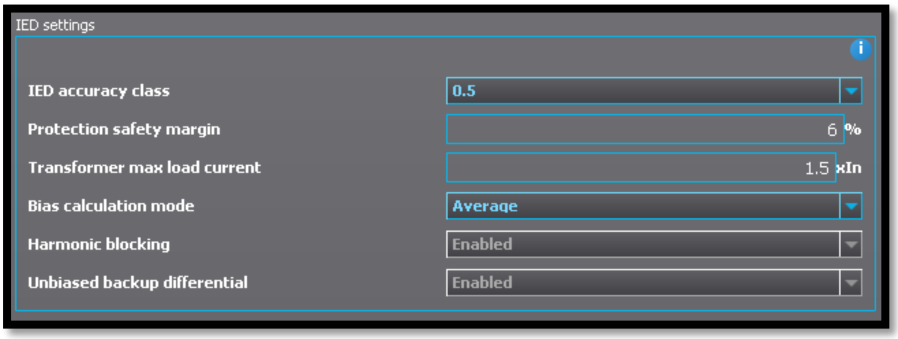
7.3 Changing setting parameters

All setting parameters which appear in blue text fields or drop-down menus in the wizard's main window can be modified. When one of these parameters appears in gray, it cannot be modified while the one or more parameters are defined the way they are at that moment. Its value is fixed and is only visible for informative purposes.

When you want to change the value of a setting parameter, place the cursor on top of the parameter box (either a text field or a drop-down menu). When you left-click the box, you can either type in a new value and press **Enter** (text fields) or select one of pre-set options (drop-down menus).

In *Figure 7-2* below, you can see an example of both types of changeable parameters. The parameters "Protection safety margin" and "Transformer max load current" are text fields, denoted by their white text and a unit to the right of the box. "IED accuracy class" and "Bias calculation mode" are examples of parameters with a drop-down menu, denoted by the triangle to the right of the box. You can also see examples of parameters in gray, meaning that they cannot be changed.

Figure 7-2. Parameter type examples.



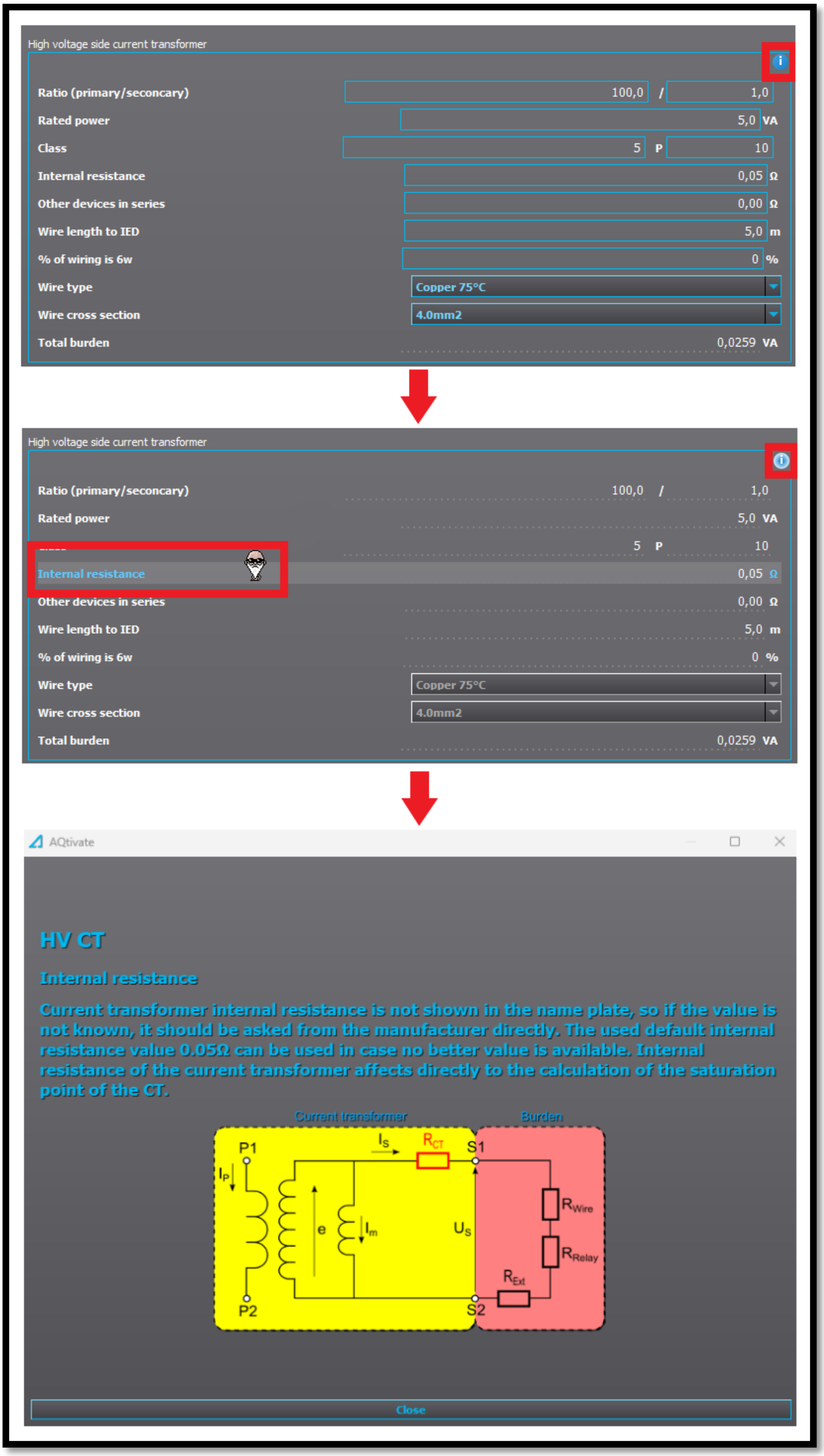
7.4 Accessing the built-in user manual

The Transformer Wizard has a built-in user manual that provides a detailed description for all visible parameters. Please refer to Chapter 5 ("Setting parameters") of this instruction booklet for these descriptions.

All parameter groups with descriptions have a circular blue icon on their top-right corner. Enter the information mode by left-clicking the blue circle icon. The icon turns light blue and your cursor becomes the face of a bearded wizard. Click the name of the parameter whose description you want to view to open its description window. You can close the window from the X at the window's top-right corner or by clicking the Close button at the bottom of the window. You can exit the information mode by clicking the circular icon again. See *Figure 7-3* on the following page for how to open a parameter description window.

Please note that you cannot change setting parameter values while in the information mode. You have to return to the default view mode to modify the parameters!

Figure 7-3. Opening a parameter description window.



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