Contents *Page*

1 NON-DIRECTIONAL EARTH-FAULT OVERCURRENT PROTECTION FOR SOLIDLY EARTHED NETWORKS

1.1 Application

In case of single-phase earth-faults, the primary fault resistance will vary with the network conditions and location of the fault. In many cases, the fault resistance is much higher than the resistance that can be covered by an impedance measuring distance relay.

Earth-faults with high fault resistances can be detected by measuring the residual current ($3I_0$). This type of protection provides maximum sensitivity to earth-faults with moderate fault resistance.

The best selectivity is generally obtained by using inverse time delay, all relays having the same type of inverse characteristic. An earth-fault in a line will be selectively tripped if the difference between the residual in the line and the residual current ($3I_0$) in the other lines gives a time difference of 0,3-0,4 seconds. A logarithmic characteristic is generally the most suitable for this purpose, since the time difference is constant for a given ratio between the currents, see Fig. 2.

The non-directional earth-fault overcurrent protection module for relay REL 5xx has available independent time delay plus four inverse time characteristics, viz.

- Normal inverse (NI) — according to IEC 255-3
- Very inverse (VI) — according to IEC 255-3
- Extremely inverse (EI) — according to IEC 255-3
- Logarithmic inverse (IDG) — according to the formula $t = 5{,}8\text{-}1{,}35 \cdot l_n\, I / I_a$ (s) where I_a is the set characteristic value ($3I_0>$)

The inrush current can cause unwanted tripping of the earth-fault overcurrent relay when energizing a directly earthed power transformer. The earth-fault overcurrent protection is therefore provided with second harmonic restraint, which blocks the operation if the residual current ($3I_0$) contains 20% or more of the second harmonic component.

In some cases, the selectivity can be improved by adding a settable minimum operating current (IMin) and a minimum operating time (tMin) to the inverse characteristic. These functions are included in the earth-fault protection modules.

Due to its sensitivity, the non-directional earth-fault overcurrent protection can detect serial faults. A serial fault can be caused by broken phase conductor(s) with no contact to earth, or pole discrepancy in a circuit-breaker or a disconnector. The most common type of series fault is pole discrepancy at breaker manoeuvring. To minimise the operating time, the earth-fault overcurrent protection module is provided with a switch-onto-fault logic, which can be activated at breaker closure, which temporarily reduces the tripping time to 300 ms.

1.2 Theory of operation

The non-directional earth-fault overcurrent protection measures the residual current ($3I_0$). The current measuring, time delay, and logic circuits of this protection are shown in Fig. 1.

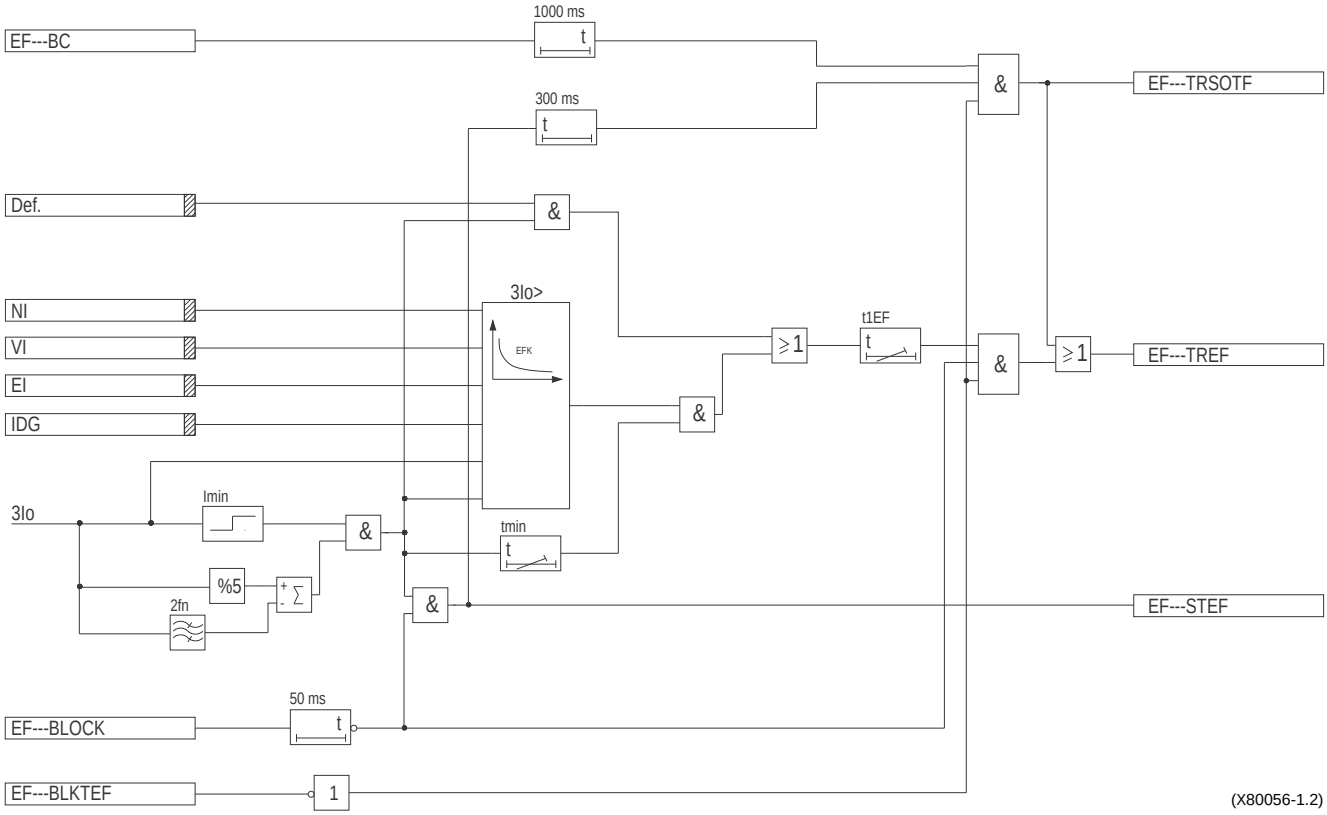

Fig. 1 Logic diagram for the non-directional earth-fault overcurrent protection.

The symbol indicates parameter setting. Generally, setting according to the text within the figure gives logical 1 on the output. For inverse time curves (NI, VI etc.), the setting activates the selected inverse time characteristic.

When placed at the left-hand side of the diagram, the symbol indicates a binary input to the module. This must be connected to a binary input of the REL 5xx relay before it can be activated.

When placed at the right-hand side, the symbol indicates a binary output from the module.

The connections to binary inputs and outputs of the module are made in the setting menu for the REL 5xx relay.

The independent time delay function is activated by setting CurveType= Def. The timer t1 starts when the current $3I_0$ to the relay is equal to or higher than the set operating value for IMin and the content of the second harmonic in $3I_0$ is less than 20%.

The inverse time calculation starts when $3I_0$ is equal to or higher than the set operating value for IMin and the content of the second harmonic in $3I_0$ is less than 20%. The inverse time delay is determined by the selection of the characteristic (NI, VI etc.) under setting “CurveType=” and the setting of the characteristic current $3I_0$>. The timer t1 starts when both the inverse time characteristic and the timer t_{Min} operate. Timer t1 is normally set to zero. It can be used to add a constant time to the inverse time delay.

The effect of the settings IMin and tMin on the inverse characteristic is shown in Fig. 2.

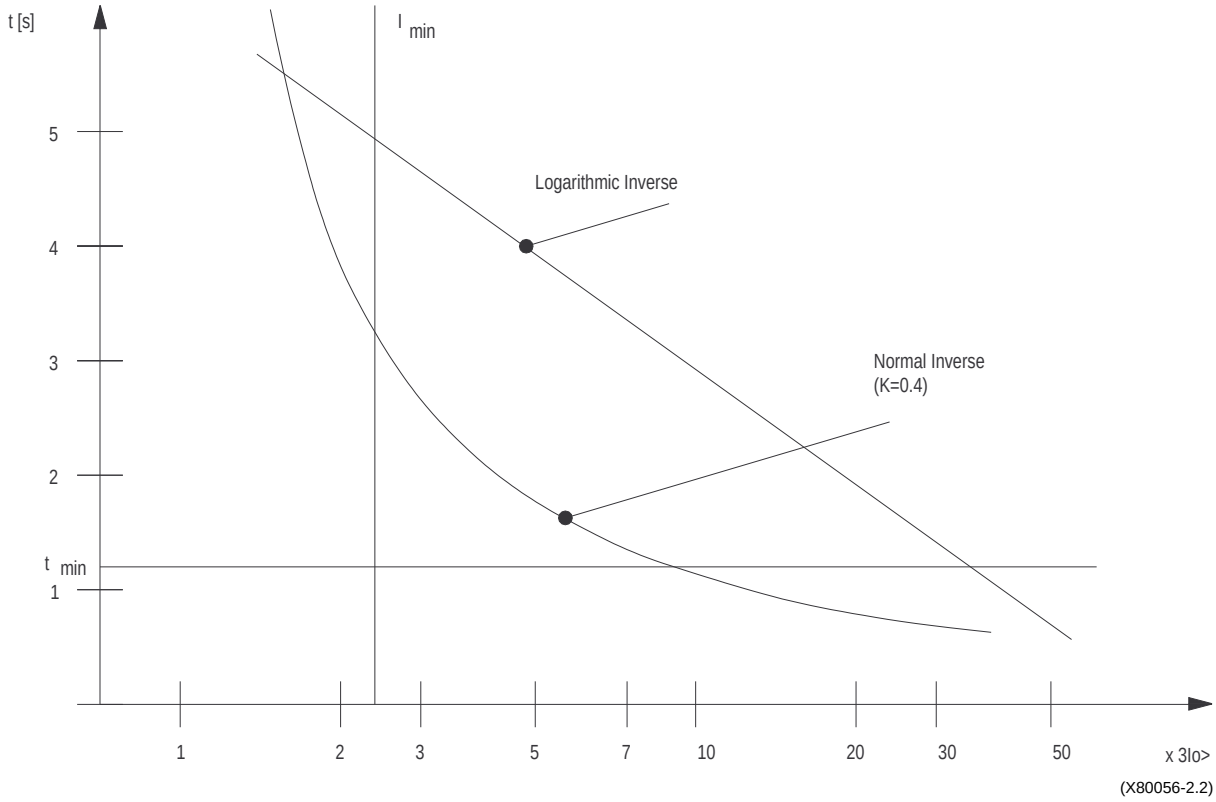

Fig. 2 Normal inverse and logarithmic inverse time characteristics

The SOTF-function is used to minimise the operate time in case of pole discrepancy at breaker closing. The function is released by activating the binary input EF---BC. A time circuit with a fixed time delay of 300 ms starts when $3I_0$ is equal or higher than the set operating value for IMin and the content of the second harmonic in $3I_0$ is less than 20%. The function is activated for 1 second after the reset of the binary input EF---BC.

All measuring functions are blocked by activating binary input EF---BLOCK.

EF---BLKTEF blocks the digital outputs EF---TREF and EF-TRSOTF and the tripping output.

1.3 Setting

To detect high resistive earth-faults, a low operating current is required. On the other hand, a low setting will increase the risk for unwanted operation due to unbalance in the network and the current transformer circuits. The minimum operating current (IMin) of the earth-fault overcurrent protection must be set higher than the maximum false residual current.

The unbalance in the network that causes false earth-fault currents is caused mainly by untransposed or not fully transposed parallel lines with strong zero-sequence mutual coupling. This false residual current is directly proportional to the load current.

In a well transposed system, the false earth-fault current is normally lower than 5% of the line current, except for extremely short parallel lines (less than 5 kilometres), where a higher false residual current may be found.

In case of extremely short or not fully transposed parallel lines, the false residual current must be measured or calculated when maximum sensitivity is desired. Generally, 80 A is recommended as a minimum primary operating value for the earth-fault overcurrent protection.

The choice of time delay characteristic, independent (definite time), normal inverse, very inverse, extremely inverse or logarithmic inverse, depends on the network.

To achieve optimum selectivity, the same type of characteristic should be used for all earth-fault overcurrent protections in the network. Therefore, in networks already equipped with earth-fault overcurrent relays, the best selectivity will normally be achieved by using the same type of characteristic as that in the existing relays.

The following formulas for the operating time in seconds apply to the characteristics used within the REL 5xx line protection terminal:

Characteristic:	**Operating time (s):**
Normal inverse	$t = \frac{0,14}{I^{0,02} - 1} \cdot k$
Very inverse	$t = \frac{13,5}{I - 1} \cdot k$
Extremely inverse	$t = \frac{80}{I^{2} - 1} \cdot k$
Logarithmic inverse	$t = 5,8 - 1,35 \cdot \ln I$

where:

I is a multiple of set current $3I_0>$

k is a time multiplying factor, settable in the range of 0,05 to 1,1

All inverse time characteristic settings will be a compromise between short fault clearing time and selective operation in a large current range. The main determining factors are the maximum acceptable fault clearing time at the maximum fault resistance to be covered, and the selectivity at maximum fault current.

The minimum operating current (IMin) of the earth-fault overcurrent protection is settable, one to four times the set characteristic quantity ($3I_0$>) of the inverse time delay. Hence, an inverse characteristic with a low set 3I0> to get a short operating time at minimum fault current can be combined with a higher set minimum operating current IMin, in order to avoid unwanted operation due to false earth-fault currents.

The minimum operate time is set independent of the inverse time characteristic. This time is normally set to be longer than the time delay of distance Zone 2 in REL 5xx, in order to avoid interference with the impedance measuring system in case of earth-faults with moderate fault resistance within Zone 2.

When a solidly earthed power transformer is energised, an inrush current will normally flow in the neutral-to-earth connection of the transformer. This current will be divided up between other earthed transformers and lines connected to the same bus, inversely proportional to their zero-sequence impedance. The amplitude and time duration of this current can be sufficiently large to cause the unwanted operation of a sensitive earth-fault overcurrent relay.

The earth-fault overcurrent protection within REL 5xx has a built-in second harmonic current stabilization, which prevents unwanted operation if the inrush current has a second harmonic content of 20% or more. This is normally the case. On rare occasions, it may be necessary to increase the setting of the operating value for the non-directional earth-fault overcurrent protection to avoid unwanted operation due to transformer inrush current.

When single-phase autoreclosing is used, the minimum time setting of the earth-fault overcurrent protection must be longer than the time from the occurrence of the fault to the reclosing of the breaker at both line terminals. This is necessary to avoid unwanted three-phase tripping during a single-phase autoreclosing cycle.

1.4 Testing

A single-phase test set with variable current output and time measuring is sufficient for the testing of the non-directional earth-fault overcurrent protection. Normally, the earth-fault overcurrent protection is tested in conjunction with the testing of the distance protection functions, using the same multi-phase test set. Fig. 3 below shows the connection of a three-phase test set at the test of a directional relay.

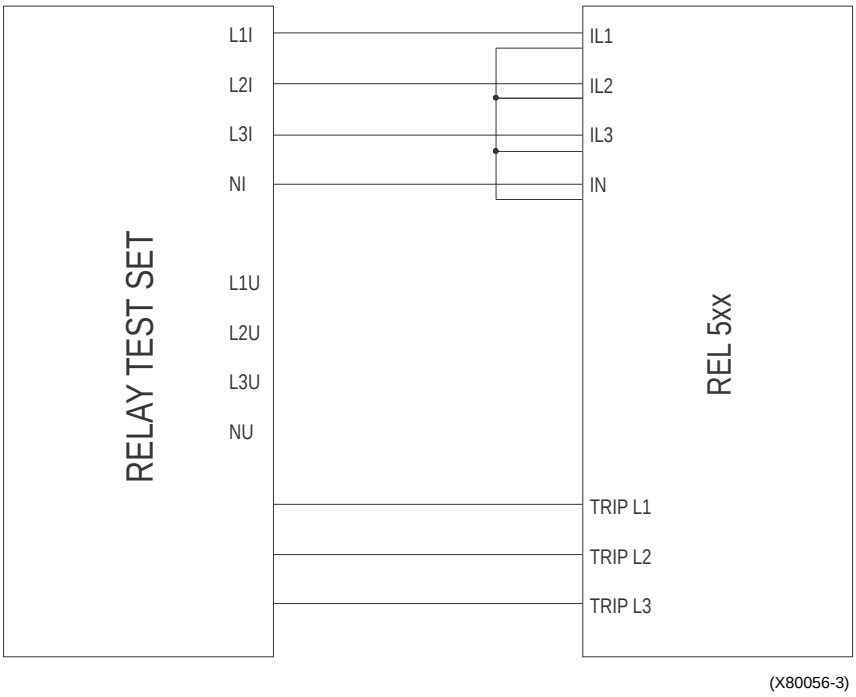

Fig. 3 Connection of a test set to the relay.

Make the appropriate settings, including the connections to the digital inputs and outputs. The logic diagram of the tested protection function is suitably considered when performing the test.

1.1 Check the operate current of the IMin function. The function activates digital output EF---STEF.

1.2 When independent time delay is selected, check the operate time of timer t1 by injecting current two times the set operate value IMin.

When inverse time delay is selected, check the operate time at three points on the inverse characteristic. The formulas for operate time for different types of inverse time delay curves are given in item 1.3, page 5.

Check also the functions tMin (minimum operating time) and IMin (minimum operating current).

1.3 Activate the input EF---BC to check the function of the switch-onto-fault logic.

Check that digital output EF---DEFR is activated with time delay 300 ms when injecting current two times the set operate value IMin.

1.4 Check the blocking functions from digital inputs EF---BLOCK and EF---BLKTEF.

Input EF---BLKTEF blocks the output from the timers to digital outputs EF---TREF, EF---TRSOTF and the tripping output.

1.5 Technical data

Table 8:

	Setting range	**Accuracy**
Basic current $3I_0 >$	(5 - 300)% I_r in steps of 1%	±5% I_{set}
Independent time delay	(0-6,0) s in steps of 0,01	±0,5% ±10 ms
Normal inverse charact.	k = (0,05-1,1) in steps of 0,01	IEC 255-3 class 5 ±60 ms
Very inverse characteristic	k = (0,05-1,1) in steps of 0,01	IEC 255-3 class 7,5 ±60 ms
Extremely inverse charact.	k = (0,05-1,1) in steps of 0,01	IEC 255-3 class 7,5 ±60 ms
Logarithmic characteristic	See the formula below	±0,04 · [1 - I / I_{set}] at I = (1,3-29) I_{set}
tMin for dependent charact.	(0,05-6,0) s in steps of 0,01 s	±0,5% ±10 ms
Start current for independent and minimum operate current for inverse time characteristic IMin	(100-400)% of $3I_0 >$ in steps of 1%	±5% I_{set}

$$t = 5,8 + 1,35 \cdot \ln\frac{I}{3I_{0set}}$$

1.6 Appendix

1.6.1 Terminal diagrams

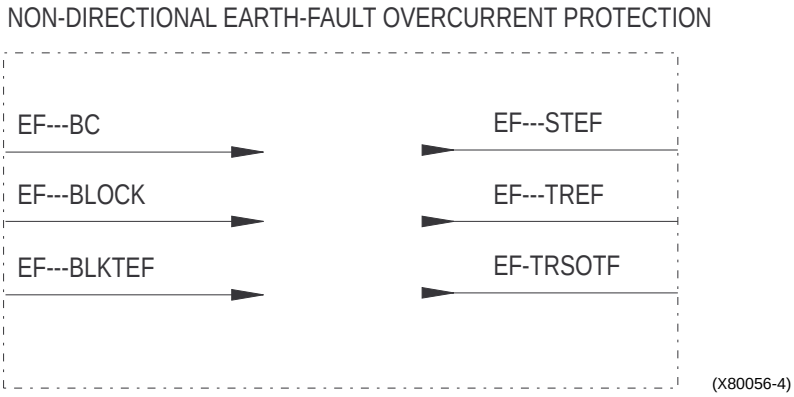

Fig. 4 Simplified terminal diagram of the function

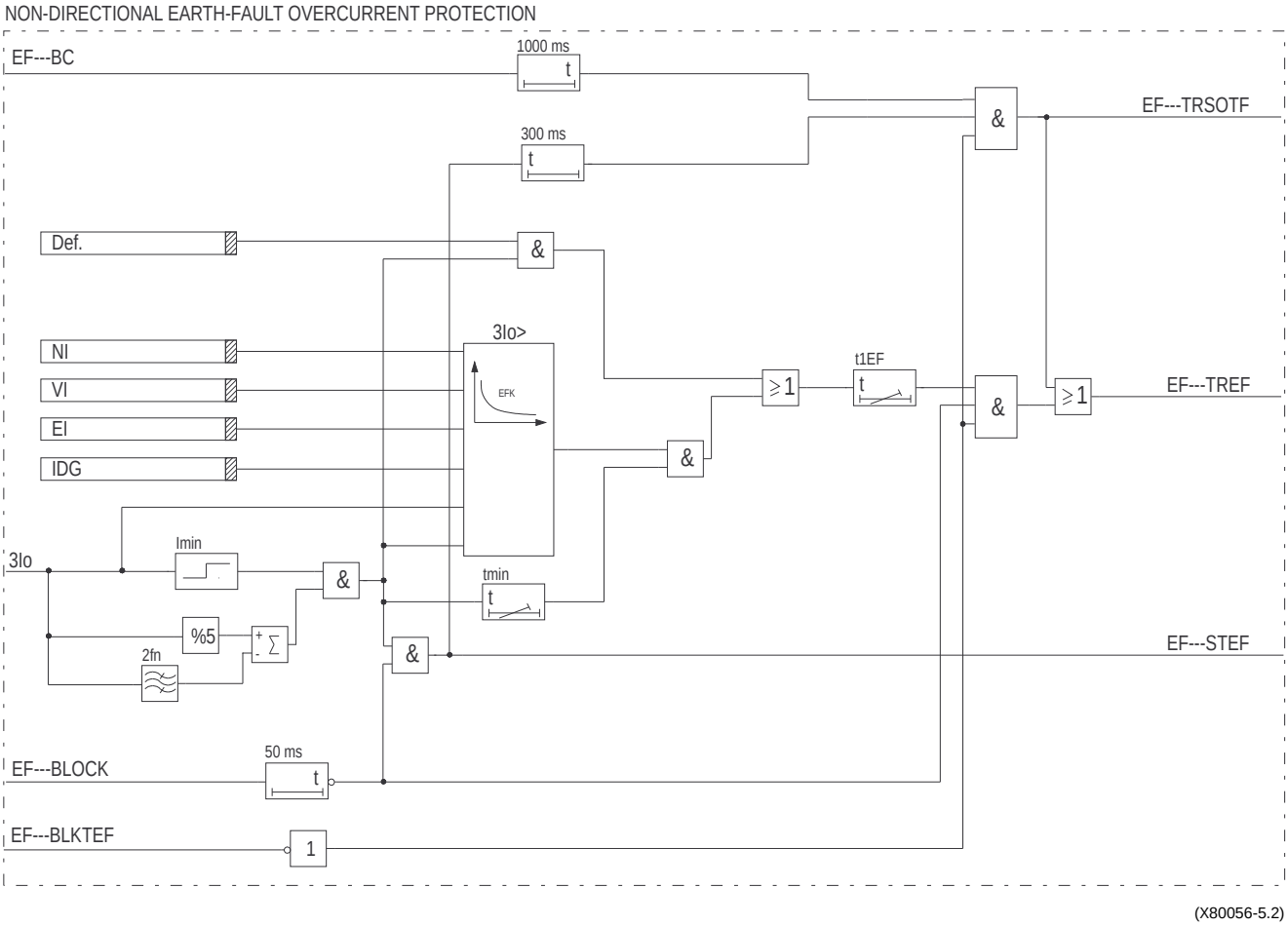

Fig. 5 Terminal diagram of the function.

1.6.2 Signal list

CONNECTIONS:	**TO:**	**SETTING:**	**DESCRIPTION:**
EF---BLOCK	BI		Block overcurrent E/F protection
EF---BLKTEF	BI		Block of trip timer
EF---BC	BI		Breaker closing
PRODUCTION:	**TO:**	**SETTING:**	**DESCRIPTION:**
EF---STEF	BO		E/F Pick-up
EF---TREF	BO		Trip E/F
EF---TRSOTF	BO		Trip E/F for switch-onto-fault condition

1.6.3 Setting table

PARAMETER:	**SETTING RANGE:**	**SETTING**				
		ACTUAL				
		Group 1	**Group 2**	**Group 3**	**Group 4**	**DESCRIPTION:**
Operation	On / Off					Activation of the protection function
dCurveType	Def / NI / VI / EI / IDG					Def=Independent (definite) time delay NI = Normal inverse VI =Very inverse EI = Extremely inverse IDG = Logarithmic inverse
3I0>	(5 - 300)% of I_r					Setting value of the characteristic quantity for the inverse time delay
IMin	(100 - 400)% of 3I0>					Starting current for independent time delay and min. operating current for inverse time delay
t1	0,00 - 6,00 s					Definite time delay setting, alternatively setting of a fixed time in addition to the inverse time delay
K	0,05 - 1,10					Time multiplier for inverse time delay
tMin	0,05 - 6,00 s					Minimum operate time for inverse time delay