

EUROPROT +

**Setting guide to the directional residual
overcurrent protection**



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Setting guide version information

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1 Enabling and characteristic setting for the TOC67N directional residual overcurrent function

The main application area for the TOC67N directional residual overcurrent protection function is the earth-fault protection.

Disabling/Enabling of the function and selection of the operating characteristic is performed by setting the „Operation” enumerated type parameter:

Parameter name	Title	Selection range	Default
Enabling and operating characteristic selection			
TOC67N_Oper_EPar_	Operation	Off,DefiniteTime,IEC Inv,IEC VeryInv,IEC ExtInv,IEC LongInv,ANSI Inv,ANSI ModInv,ANSI VeryInv,ANSI ExtInv,ANSI LongInv,ANSI LongVeryInv,ANSI LongExtInv	DefiniteTime

To disable the function select parameter value „Off”.

Any other selection enables operation of the function.

When selecting „DefiniteTime” option, only one timer type parameter has a function: „Definite Time Delay”. The correct setting of this timer parameter serves coordination with other protective devices on the same network:

Parameter name	Title	Unit	Min	Max	Step	Default
Definite time delay						
TOC67N_DefDel_TPar_	Definite Time Delay	msec	0	60000	1	100

The current threshold, above which the timer is started is set by the integer type parameter „Start Current”:

Parameter name	Title	Unit	Min	Max	Step	Default
Start current, related to the rated current of the input channel of the device, in %						
TOC67N_StCurr_IPar_	Start Current	%	10	1000	1	50

The correct value for the „Start Current” parameter is calculated by fault simulation procedure. The setting is correct if the function starts in any case when fault occurs within the protected zone, considering also the highest possible fault resistance at the fault location. The setting value should be below the calculated minimal 3I_o fault current, considering the usual tolerance band. The setting is correct only if the maximum 3I_o current caused by network asymmetry does not result starting the function. Similarly, if a grounding resistor or a coil (not specifically for arc suppression) is connected between the network neutral point and the ground, the 3I_o capacitive current may not result starting.

These setting considerations of the „Start Current” are valid also for any IDMT type characteristics.

When any of the IDMT type characteristics is selected then the details of the selected characteristic, including the parameter values and the formulas for the mathematical description, are described in the document TOC 51 „Three-phase overcurrent protection function block description”. When selecting one of the available eleven IDMT characteristics, the operating curve is to be matched to all other overcurrent protections of the network. The available characteristic types are: IEC Inv, IEC VeryInv, IEC ExtInv, IEC LongInv, ANSI Inv, ANSI ModInv, ANSI VeryInv, ANSI ExtInv, ANSI LongInv, ANSI LongVeryInv, ANSI LongExtInv.

For coordination of the selected IDMT characteristic to all other similar protection of the network, the correct setting of the following parameters are needed: „Start Current” as it is described above, for shifting the characteristic along the current axis, the „Time Multiplier” parameter to compress or expand the characteristic along the time axis, „Min Time Delay” to limit the fastest operation, and additionally „Reset time” to control the reset behavior of the function. NOTE: When selecting „DefiniteTime” characteristic, only the parameter „Start Current” is considered, all other parameters mentioned in this paragraph are automatically neglected. The summary of these parameters are as follows:

Integer parameter

Parameter name	Title	Unit	Min	Max	Step	Default
Start current , related to the rated current of the input channel of the device, in %						
TOC67N_StCurr_IPar_	Start Current	%	10	1000	1	50

Timer parameters:

Parameter name	Title	Unit	Min	Max	Step	Default
Minimal time delay for the inverse characteristics						
TOC67N_MinDel_TPar_	Min Time Delay	msec	50	60000	1	100
Reset time delay for the inverse characteristics						
TOC67N_Reset_TPar_	Reset Time	msec	0	60000	1	100

Floating point parameter:

Parameter name	Title	Unit	Min	Max	Step	Default
Time multiplier of the inverse characteristics						
TOC67N_Multip_FPar_	Time Multiplier		0.05	999	0.01	1.0

For the selection of correct parameter values, the setting of all other similar protection of the network should be considered and coordinated.

2 Setting the directionality of the function

The directionality of the TOC67N directional residual overcurrent function is shown in Figure 2-1.

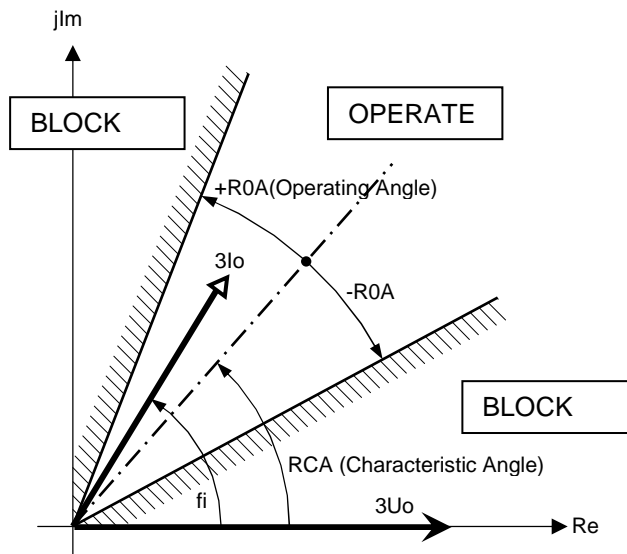


Figure 2-1 Directionality of the TOC67N directional residual overcurrent function

There are several choices available for setting the directionality. These are summarized in the following table:

Parameter name	Title	Selection range	Default
Directionality of the function			
TOC67N_Dir_EPar_	Direction	NonDir,Forward-Angle,Backward-Angle,Forward-I*cos(fi),Backward-I*cos(fi),Forward-I*sin(fi),Backward-I*sin(fi),Forward-I*sin(fi+45),Backward-I*sin(fi+45)	Forward-Angle

When selecting „NonDir” for this „Direction” parameter, the overcurrent function does not consider the vector position of the current, the function operates as a non-directional function.

The meanings of these choices are summarized in the following table:

Short explanation of the enumerated parameter selection

Selected value	Explanation
NonDir,	Operation according to non-directional TOC51N
Forward-Angle	See Figure 2-1; set ROA and RCA as required
Backward-Angle	RCA=RCAset+180°; set ROA and RCA as required
Forward-I*cos(fi)	RCA=0°fix, ROA=85° max, the setting values RCA and ROA are not applied
Backward-I*cos(fi)	RCA=180°fix, ROA=85° max, the setting values RCA and ROA are not applied
Forward-I*sin(fi)	RCA=90°fix, ROA=85° max, the setting values RCA and ROA are not applied
Backward-I*sin(fi)	RCA=-90°fix, ROA=85° max, the setting values RCA and ROA are not applied
Forward-I*sin(fi+45)	RCA=45°fix, ROA=85° max, the setting values RCA and ROA are not applied
Backward-I*sin(fi+45)	RCA=-135°fix, ROA=85° max, the setting values RCA and ROA are not applied

The selection of these parameter values should consider the neutral grounding of the network.

In the figures below the simplified zero sequence equivalent of the network is shown and the phasors are drawn. The supposed VT and CT connection is shown in Figure 4-3. This figure indicates also the supposed parameter setting for the VT and CT module.

In the zero sequence equivalent network „A” is the faulty bay, „B” is the joint equivalent of all other bays.

According to the symmetrical component calculation method, in case of a single phase fault, the zero sequence network is connected serially to the negative and positive sequence networks at the indicated „h0” and „n0” points. The supposed positive direction of the currents is indicated by arrows.

Accordingly in the phasor diagrams, I_{0A} is the zero sequence current phasor detected in the current transformer of the faulty bay and I_{0B} shows the phasor position of the zero sequence current in the healthy bays. NOTE I_{0A} ’ capacitive current of the faulty bay is not detected directly by current transformers.

- If the network is isolated then the zero sequence network is capacitive (See *Figure 2-2.*) The faulty bay is „A”, and „B” represents all other bays. The related phasor diagram in *Figure 2-3* shows that in the faulty bay the zero sequence current related to the zero sequence voltage is measured as an inductive current. Consequently the required selection is either „Forward-Angle” applying $RCA = -90^\circ$ and $ROA = 85^\circ$, or the alternative selection can be Backward- $I \cdot \sin(\phi_i)$.

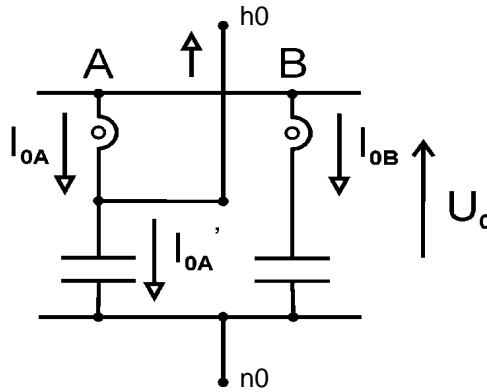


Figure 2-2 Zero sequence network equivalent for isolated networks

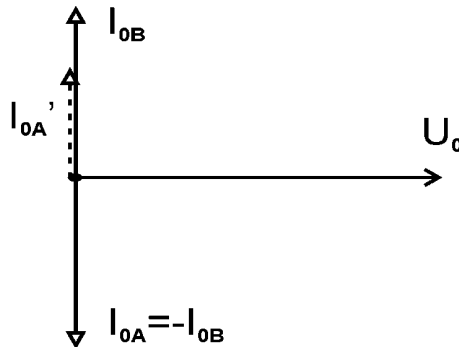


Figure 2-3 Zero sequence phasor diagram for isolated networks

- If the network is grounded using a resistor (the related figures are *Figure 2-4* and *Figure 2-5*) then the active component dominates in the single phase fault current. With the indicated positive directions the required setting is either „Forward-Angle” applying $RCA = 180^\circ$ and $ROA = 85^\circ$, or the alternative selection can be Backward- $I \cdot \cos(\phi_i)$.

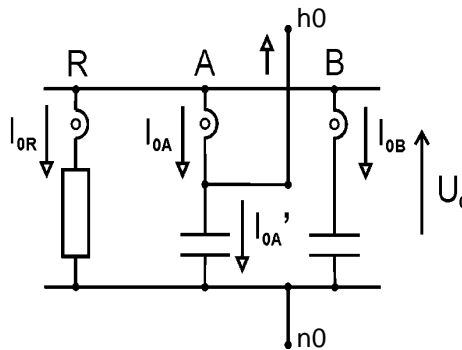


Figure 2-4 Zero sequence network equivalent for networks grounded with a resistance

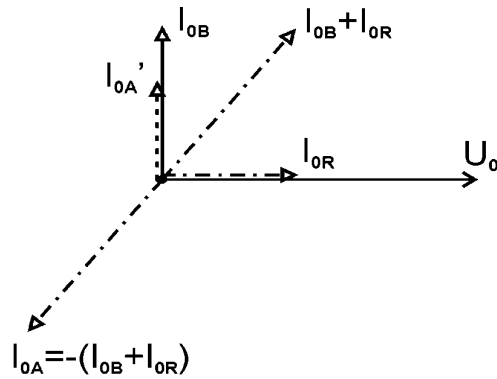


Figure 2-5 Zero sequence phasor diagram for networks grounded with a resistance

- If the network is compensated, i.e. an arc suppression coil is connected in the neutral of the network, then Figure 2-6, Figure 2-7 and Figure 2-8 are applicable. The sign of the reactive current component in the faulty bay depends on the degree of compensation. Figure 2-7 shows the phasors in an overcompensated state and Figure 2-8 does in turn at an undercompensation. The arc suppression coil however contains also active current component, which flows in reverse direction through the CT of the faulty bay.

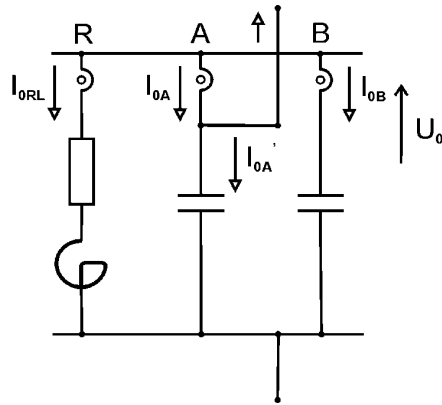


Figure 2-6 Zero sequence network equivalent for compensated networks

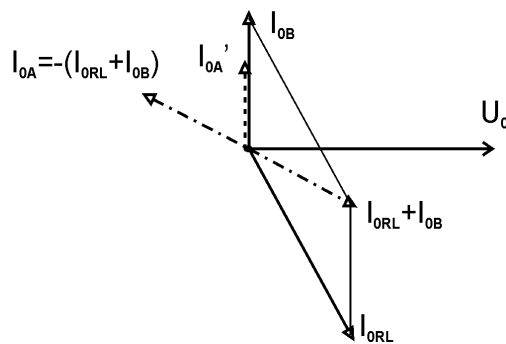


Figure 2-7 Zero sequence phasor diagram for compensated networks (overcompensated state)

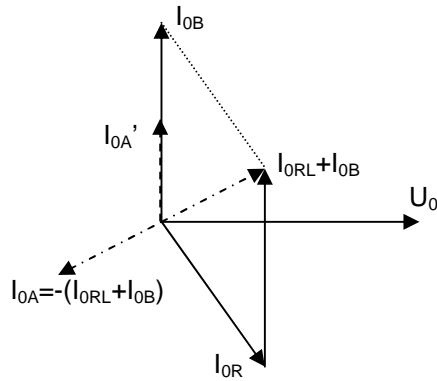


Figure 2-8 Zero sequence phasor diagram for compensated networks (undercompensated state)

According to the Figure 2-7 and Figure 2-8, the suggested setting would be „Forward Angle” RCA 180° and ROA 85°, or „Backward-Angle” applying RCA= 0° and ROA=85°. The alternative selection would be „Backward-I*cos(φ)”.

There is a problem if low-loss Petersen coil is installed and the active component is lower than the capacitive current component of the coil and the network. In this case, the phasor I_{0A} of the faulty bay is shown in Figure 2-9 at overcompensation and under-compensation.

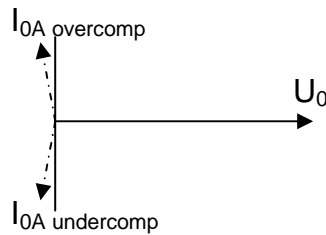


Figure 2-9 Current flowing through the CT of the faulty bay

It is shown the current phasor I_{0A} is very close to the pure reactive current value (perpendicular line) at the overcompensated state and also at the undercompensated state. The function should operate in both cases, but it is not allowed when any of the two currents lay similarly at the other (right) side of the line. Hence the characteristic line should be as the vertical line.

Since the CT of the faulty bay has angle error it can result instability and errors in the operation of the function. Therefore a directional residual overcurrent protection function is not advised to be applied as an earth fault protection function in a compensated network.

Apparently the problem could be solved if the network is always operated in an overcompensated state. But e.g. if a line is switched on then it causes an undercompensated state, which will be overcompensated during several minutes only. So the protection function becomes instable just at line switched on.

- If the network is solidly grounded then the single phase fault current is inductive and related to the positive sequence voltage component it's position is lagging by the fault impedance angle. The angle between the zero sequence voltage and current is affected by the zero sequence source impedance only, the zero sequence impedance of the protected line and also the fault resistance is not to be considered. As the zero sequence voltage component is opposite related to the positive sequence voltage component, the optimal setting for the „Characteristic Angle” is $RCA = (180^\circ - \varphi)$. Here φ is the zero sequence source impedance

angle, it is in the range 30° ... 90°. The usual optimal setting for solidly grounded network is „Forward Angle”, the “Characteristic Angle” is RCA=135°, and the „Operating Angle” is in turn ROA = 50°.

The additional parameters needed for the directional decision are summarized in the table below:

Parameter name	Title	Unit	Min	Max	Step	Default
The threshold value for the 3U _o zero sequence voltage, below which no directionality is possible. % of the rated voltage of the voltage transformer input.						
TOC67N_UoMin_IPar_	URes Min	%	1	10	1	2
The threshold value for the 3I _o zero sequence current, below which no operation is possible. % of the rated current of the current transformer input.						
TOC67N_IoMin_IPar_	IRes Min	%	1	50	1	5
Operating angle (See Figure 2-1)						
TOC67N_ROA_IPar_	Operating Angle	deg	30	80	1	60
Characteristic angle (See Figure 2-1)						
TOC67N_RCA_IPar_	Characteristic Angle	deg	-180	180	1	60

The setting value for the “UResMin” parameter is determined by the minimum detected zero sequence voltage component at earth-fault (3U_{oFault_Min}) and the maximum detected zero sequence voltage component if no earth-fault is on the network (due e.g. to network asymmetry) (3U_{oAsymm_Max}). The setting value should be between them:

$$3U_{oAsymm_Max} < UResMin_{Setting} < 3U_{oFault_Min}$$

If the network is NOT solidly earthed then in case of earth-fault the residual voltage is approximately the phase voltage. In normal operation however the residual voltage component depends on the network asymmetry. If this is supposed not to be above 5 % of the phase voltage then proposed setting for NOT solidly earthed network is:

$$„UResMin” = 10 \%$$

If the network IS solidly earthed then in case of earth-fault the residual voltage is to be calculated. The 3U_{oFault_Min} is the result of calculation then this parameter setting value should be below this value.

In most cases, for solidly grounded network the following setting can be applied:

$$„UResMin” = 2 \%$$

The setting value for the “IRes Min” parameter is determined by the minimal residual current at earth-fault ($3I_{Fault_Min}$) and the maximum residual current due to the network asymmetry in normal operation ($3I_{Asym_Max}$). The setting values should be between them:

$$3I_{Asym_Max} < IRes\ Min_{Setting} < 3I_{Fault_Min}$$

The asymmetry current is the measured value, related to the network, and the residual current in case of earth fault is the result of fault calculation.

In compensated networks the fault current in the CT of the faulty bay is the vectorial sum of the compensating Petersen coil current and the capacitive zero sequence current of the healthy bays.

As an example if the required primary value is e.g. 5 A then this value should be related to the rated primary current of the CT, and expressed in percent. If the primary rated current of the CT is e.g. 150 A then:

$$100\% * 5 / 150 = 3,3 \%$$

This results the setting value to be:

$$IRes\ Min_{Setting} = 3 \%$$

3 Application of the binary signals

The binary output signals, generated by the TOC67N directional residual overcurrent protection are:

Binary status signal	Title	Explanation
TOC67N_GenSt_Grl_	Start	General start signal of the function
TOC67N_GenTr_Grl_	Trip	General trip command of the function

The usual application of these signals is warning and faulty bay identification. For any other purposes these signals may be applied in the graphic logic editor as input signals.

The binary input signal, needed by the TOC67N directional residual overcurrent protection is:

Binary status signal	Title	Explanation
TOC67N_Blk_GrO_	Block	Blocking input status signal

Using this input, the function may be blocked by external signals. The logic combination of the blocking conditions is to be edited by the user according to the requirements, using the graphic logic editor.

4 Testing the directionality of the residual overcurrent protection

In the examples below the basic connection of the device according to Figure 4-3 is supposed.

4.1 Testing in the laboratory or on site in state „out of operation”

There are several methods for testing the directionality of the TOC67N directional residual overcurrent protection function. The simple method described in the following paragraphs is one of them.

- 1) Connect zero sequence voltage to the voltage inputs of the device. This means that identical voltage should be connected to all phase voltage inputs. (e.g. 10 V and identical phase angle 0°). Consider the polarity: the marked coil ends are the VT connectors 1-3-5 (normal polarity). The VT connectors 7-8 may also be applied for zero sequence voltage input; for this application please consult the device configuration manual. If this input is applied for zero sequence voltage measurement then connect here a voltage (e.g. 10 V and phase angle 0°). Here the marked coil end is the VT connector 7 (normal polarity). See Figure 4-3.
- 2) Check the on-line data (either on the display of the device or use the computer communication). The expected values of the VT input online data are 10 V and 0 degree.
- 3) Connect zero sequence current to the CT inputs. For this purpose generate three identical currents using a relay test set or connect the CT inputs in serial connection. This means connection of CT inputs 2-3 and 4-5, and the current source is connected to connectors CT 1-6 (e.g. 1 A and phase angle 0°). When connecting the current, please consider that the marked coil end is the CT connector 1 (CT setting: „Starpoint: line”). In some device configurations the CT input 7-8 can also serve for measuring the zero sequence current. Please consult the device configuration manual. In this case, connect here the zero sequence current (e.g. 1 A and 0 degree). When connecting the current, please consider that the marked coil end is the CT connector 7 (CT setting: „Normal”).
- 4) Check the on-line data (either on the display of the device or use the computer communication). The expected values of the CT input online data are 1 A and 0 degree.
- 5) The „Line measurement” displays also the calculated power. The active power must be positive and the reactive power is zero.

The procedure above checked the correct internal VT and CT connection.

- 6) Modify the current phase angle to -90° (inductive current). Do not change the current input connectors.
- 7) Check the on-line data (either on the display of the device or use the computer communication). The expected values of the CT input online data are 1 A and -90 degree.
- 8) NOTE: An additional checking procedure is the evaluation of the disturbance record. Perform a manual start and check the phase angle of the voltage and currents. The current should be lagging, according to the injected values.
- 9) The „Line measurement” displays also the calculated power. The expected active power is zero and the reactive power is positive.

The procedure above checked the correct positive directions and the correct power measurement.

- 10) Set the directional residual overcurrent protection function with the following setting values:
- Characteristic Angle: RCA = 30 degree
 - Operating Angle: ROA = 60 degree

Using this setting, the operating range of the phase angle is -30 to $+90$ degrees. The reference is the voltage phasor.

- If the current angle is -35 degree then the function is expected NOT to operate.
- If the current angle is -25 degree then the function is expected to operate.
- If the current angle is $+85$ degree then the function is expected to operate.
- If the current angle is $+95$ degree then the function is expected NOT to operate.

The operation can be checked on the on-line window of the directional residual overcurrent protection function. If the operation is correct, then the test is finished.

4.2 Checking the directionality during normal operation of the network

Checking the TOC67N directional residual overcurrent protection function during normal operation of the network means full scale test. This means testing the directionality and also the correct connection of the input signals.

The first step of the tests is to disable the trip command at the trip connectors. The function should be enabled (The „Operation“ parameter may not be „Off“, and no active signal may be connected to the function block graphic input „Blk“).

There are several methods for testing the directionality of the TOC67N directional residual overcurrent protection function during normal operation of the network. The simple method described in the following paragraphs is one of them.

For this method an appropriate normal load is required: The load current should be above $0,15 \cdot I_n$, and in this example the phase angle of the current should be in the range (-30) and $(+60)$ degrees.

It is supposed that the load is symmetric, i.e. the zero sequence component of the voltage and that of the current is about zero.

The related phasor diagram is shown in Figure 4-1.

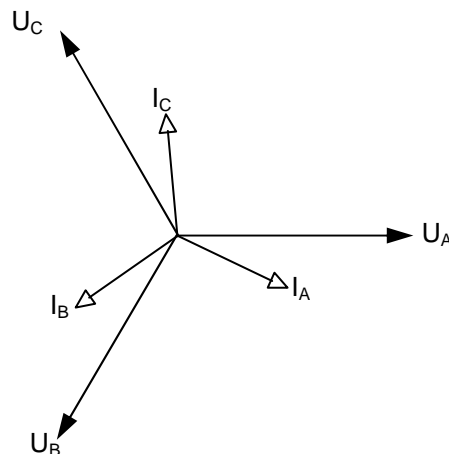


Figure 4-1 Phasor diagram of the normal load state, starting the directionality check

This testing method applies the normal load currents and voltages for the tests. The required zero sequence components are simulated by disclosing individual phase voltages and currents.

The parameters of the function are supposed to be set according to the application.

As an example, consider the following setting combination:

- a) Characteristic Angle: $RCA = +75^\circ$
- b) Operating Angle: $ROA = 60^\circ$

For the explanation consider Figure 4-2. Disconnect U_A voltage and I_C current by disconnecting the voltage wire and short-circuit the current input. This results the phasor configuration of Figure 4-2. The residual voltage is $3U_0 = -U_A$ which is opposite the missing phase voltage and the residual current is $3I_0 = -I_C$ which is opposite to the missing current. These phasors are highlighted and marked in the figure below.

The reference phasor of the directional characteristic is the $3U_0$ residual voltage. $RCA = 75^\circ$ characteristic angle and $ROA = 60^\circ$ operating angle are dotted lines in the figure.

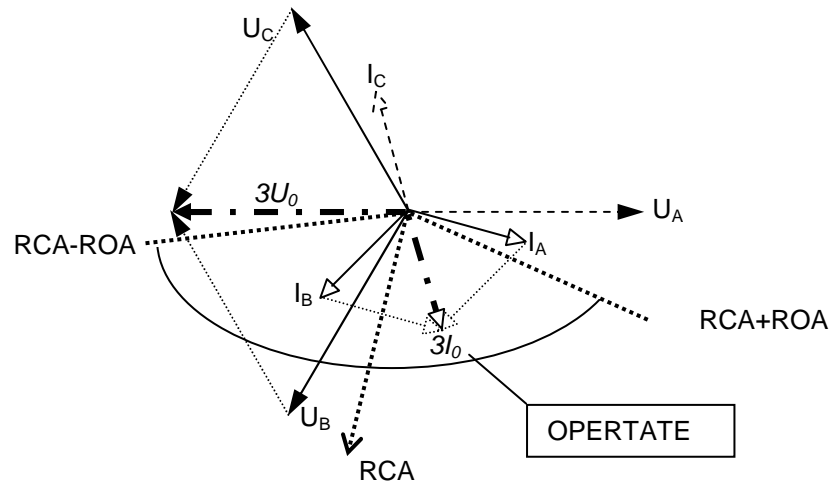


Figure 4-2 Simulated fault direction

The artificial residual components described in the procedure above should result operation of the function.

When changing I_C for I_A (reconnect I_C and short-circuit I_A) then the new residual current is $-I_A$, which is in this example out of the operating range. In this state no operation is expected.

Disconnecting I_B results also a residual $3I_0 = -I_B$ current which is again out of the operating range. In this state no operation is expected.

NOTE: When applying the setting values described above, with the load current angle range of $0 \dots -90^\circ$, the expected test result is positive.

When applying other setting parameter values of e.g. reverse flowing power, the expected results can be calculated similarly.

NOTE:

For the directional behavior of the function the correct assignment of the VT and CT connections and also the basic parameter setting of the VT and CT modules are of basic importance. These influence also the expected results of the tests. The configuration manual, delivered with the device configured with the function, describes these assignments.

In the examples above the basic connection of the device according to Figure 4-3 is supposed.

The marked coil ends of the VT-s are connected to the connecting points 1-3-5 of the VT module, the star point is connected to 2-4-6. If direct residual voltage measurement is expected then this is to be connected to point 7 and 8 of the VT input module (7 is the marked coil end).

In the example the star point of the CT secondary coil is towards the line which is connected to the interconnected 2-4-6 of the CT module. The other ends of the coils are connected to points 1-3-5 of the CT module.

The parameter setting of the VT module are "U1-3 polarity" = "Normal" and "U4 polarity" = "Normal".
 The parameter setting of the CT module are "Starpoint I1-3" = "Line" and "Direction I4" = "Normal".

When the connection of the measuring transformers is deviating then the parameters should be changed accordingly. E.g. if the star point of the CT-s is at the side of the busbar then the required parameter setting is "Starpoint I1-3" = "Busbar". With this modification the tests above conclude the same results.

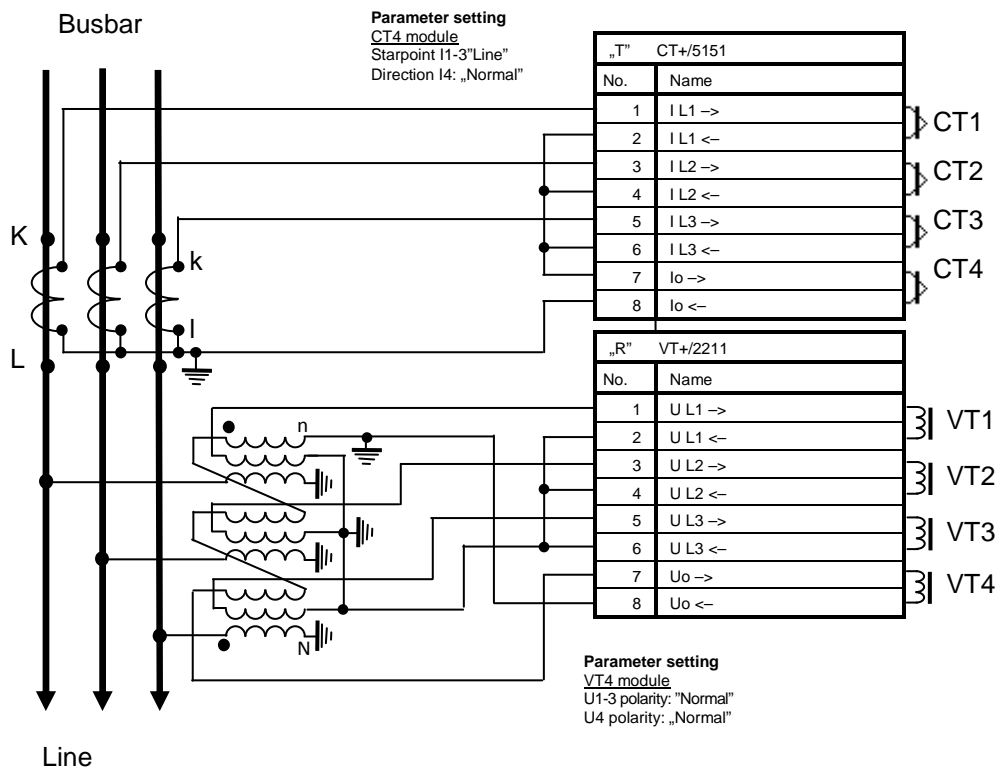


Figure 4-3 Reference connection of the instrument transformers for the tests