SIEMENS

SIPROTEC 5 Compact

Directional ground fault detection in resonant-grounded or isolated networks

APN – C.014

siemens.com/siprotec5

SIPROTEC 5 Compact Application

Directional ground fault detection in resonant-grounded or isolated networks

APN-C.014, Edition 1

Content

1 Introduction

This application note provides information about:

- Directional ground fault detection in resonant-grounded or isolated networks
- Proposed standard functions to be applied, depending on network grounding, network structure and ground fault type
- Configuration recommendations for these functions
- Recommendations for threshold settings, explained by an application example
- General configuration recommendation (e.g. recording, avoiding signals floods in case of intermittent ground faults)

2 Overview about available functions and their application

The following table provides an overview about which functions are applicable for:

a. Different **ground fault types:** permanent, intermittent, transient
b. **Network grounding:** resonant, isolated
c. **Network structure:** radial, meshed / ring

Function (block) type	Ground fault type	Network grounding	Network structure
Dir. 3I0> stage with cosφ measurement	o permanent	o resonant	o radial
Dir. 3I0> stage with sinφ measurement	o permanent	o isolated	o radial o meshed / ring
Directional stage with phasor measurement of a harmonic (will be considered in a later document version)	o permanent	o resonant o isolated	o radial o meshed
Directional transient ground-fault stage	o Permanent o Intermittent o transient	o resonant o isolated	o radial o meshed / ring
Directional intermittent ground-fault protection [1]	o intermittent	o resonant o isolated	o radial o meshed / ring

Table 1: function overview

[1] The function **Directional intermittent ground-fault protection** has been innovated with version V7.3 in 07/2016 (e.g. sampling frequency change from 1 to 8 kHz; improved direction determination, ...).

The functions according to table 1 are the standard functions for this application. Further directional functions are available, which are used by specific customers due to their application history / philosophy.

2.1 General function selection considerations and recommendations

The following figure provides a tree-structure view on the recommended functions, depending on Ground fault type, Grounding type and Network structure.

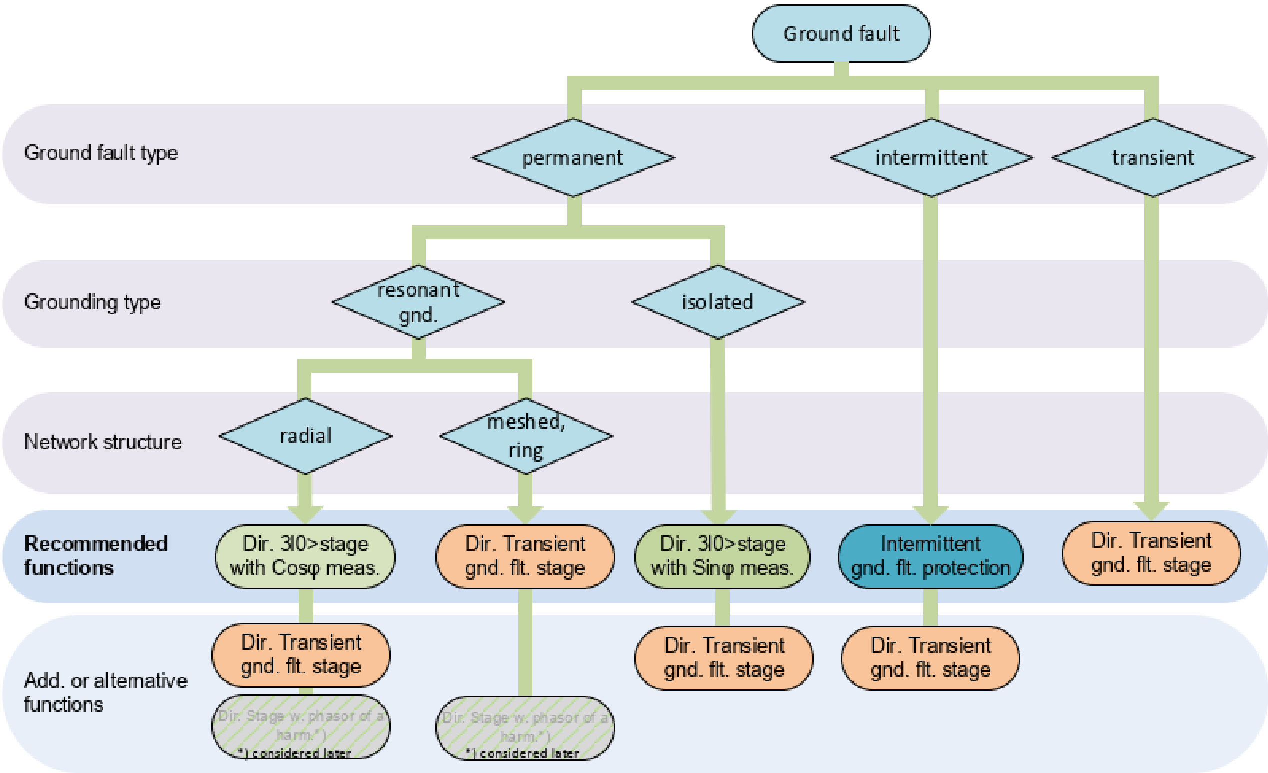


Figure 1: function selection tree-structure

Referring to Table 1 and Figure 1 the following conclusions / recommendations can be made:

<u>**Permanent ground faults**</u>

For the directional detection of a permanent ground fault, we recommend applying a function with **stationary** directional measurement if this is possible with regards to grounding type and network structure. Stationary directional measurement provides the best reliability if the signals allow a clear direction determination. Stationary directional measurement is provided by the function **Directional 3I0> stage with cosφ or sinφ measurement**. The function **directional transient ground-fault stage** provides no stationary directional measurement. The direction determination is only made during the ground fault inception.

▶ in case of **resonant grounded radial networks** we recommend applying **directional 3I0> stage with cosφ measurement**. An exception is the condition that the active ground fault current is very low due to marginal losses of the arc-suppression coil (Peterson coil). If the active ground fault current is too small to allow a reliable directional result, we recommend applying the **directional transient ground-fault stage**.

▶ in case of **resonant grounded** and **meshed networks** operational circulating ground currents are common which normally allow no reliable directional result via the active ground fault current. Therefore, we recommend applying **Directional transient ground- fault stage**.

▶ in case of **isolated networks** the reactive ground fault current generally allows a reliable directional result, independent of operational circulating ground currents. Therefore, we recommend applying the function **Directional 3I0> stage with sinφ measurement**.

Intermittent ground faults

For intermittent ground fault detection, we recommend applying the function **Directional intermittent ground fault protection**, in parallel to the function selected for the permanent ground fault detection.

Transient ground faults

The **Directional transient ground-fault stage** must be applied. The application of this function is without alternative if transient ground faults shall be detected.

2.2 Location of the functions in the DIGSI library

The above listed functions are available in the DIGSI global library for defined devices types and defined function group types:

Directional ground fault function (block) type	Function block name in DIGSI	Function block name in DIGSI	Available in function groups
Directional 3I0> stage with cosφ or sinφ measurement	3I0> cos/sinφ	Gnd.flt.prot. for resonant-gnd./isol. 51Ns Sens. GFP 67Ns Dir.sens GFP 67Ns Dir.sens GFP	FG Voltage/current 3ph VI 3ph FG Voltage/current 1ph VI 1ph
Directional stage with phasor measurement of a harmonic	V0>dir.harm.	Gnd.flt.prot. for resonant-gnd./isol. 51Ns Sens. GFP 67Ns Dir.sens GFP 67Ns Dir.sens GFP	FG Voltage/current 3ph VI 3ph FG Voltage/current 1ph VI 1ph
Directional transient ground-fault stage	Trans.Gnd.flt	Gnd.flt.prot. for resonant-gnd./isol. 51Ns Sens. GFP 67Ns Dir.sens GFP 67Ns Dir.sens GFP	FG Voltage/current 3ph VI 3ph FG Voltage/current 1ph VI 1ph
Directional intermittent ground-fault protection	Dir. interm.gnd.flt.	Current protection Dir. intermittent ground-fault prot. Dir. interm.gnd.flt.	FG Voltage/current 3ph VI 3ph FG Voltage/current 1ph VI 1ph

3 General configuration notes

3.1 Fault recording

With SIPROTEC 5 the oscillography recording capacity was extremely extended compared to SIPROTEC 4. Limited recording capacity is **no** issue for SIPROTEC 5.

Recommendation: SIEMENS generally recommends recording ground faults. This is essential for later ground fault analysis.

Further recommendations about recording function specific signals is given in the application description for the respective functions.

<u>**Configuration notes**</u>

1. Ground fault stages (function blocks)

For each protection / detection stage you can select if the fault recording shall be stated automatically, by keeping the following default setting:

Operate & flt.rec. blocked:	no

With this setting also general pickup and tripping takes place. If this is not desired the setting can be changed to ***yes*** and fault recording can be started manually.

2. Fault recorder

The following figure shows the fault recorder setting list. The fault recording is started automatically with pickup. This requires that the parameter **Operate & flt.rec. blocked** of each stage or function is set to ***no*** (refer to above). If the parameter is set to ***yes*** the fault recording must be started manually.

The only change compared to the default is marked in red. Especially if one of the functions **Directional transient ground-fault stage** or **Directional intermittent ground-fault protection** is applied, it is essential setting the sampling frequency to ***8 kHz***. In case that none of these functions is applied the sampling frequency can remain on the default of 2 kHz.

81.791.2761.130	Fault recording:	with pickup	
81.791.2761.131	Storage:	always	
81.791.2761.111	Maximum record time:	5.00	s
81.791.2761.112	Pre-trigger time:	0.50	s
81.791.2761.113	Post-trigger time:	0.50	s
81.791.2761.116	Manual record time:	0.50	s
81.791.2761.140	Sampling frequency:	8 kHz	
81.791.2761.141	Sampl. freq. IEC 61850 rec.:	1 kHz	
81.791.2761.151	COMTRADE revision year:	COMTRADE 1999	
81.791.2761.128	Scaling COMTRADE:	Secondary values	
81.791.2761.129	Cal.zero.seq.cur.channel:	no	
81.791.2761.132	Cal.zero seq.volt.channel:	no	

Figure 2: Setting list

Setting and routing recommendations to avoid recording floods are given in the individual function descriptions, in the "Further notes" chapter.

3.2 Fault logging

Setting and routing recommendations to avoid signals floods in a log are given in the individual function descriptions, in the "Further notes" chapter.

3.3 No tripping on ground faults

It could be required to keep the power system in operation during ground faults. Consequently, the ground fault protection functions shall only detect the ground fault but shall not trip.

Recommendation:

To avoid tripping, we do not recommend setting **Operate & flt.rec. blocked** to ***yes***, because by this the automatic fault recording is disabled as well.

To avoid tripping, we recommend using the **Circuit-breaker interaction** matrix, by taking the respective functions and stages out of the trip-interface, as shown in the following figure for the **3I0>cos/sinφ** stage. By this the protection stage operates but this signal is not forwarded to the tripping logic.

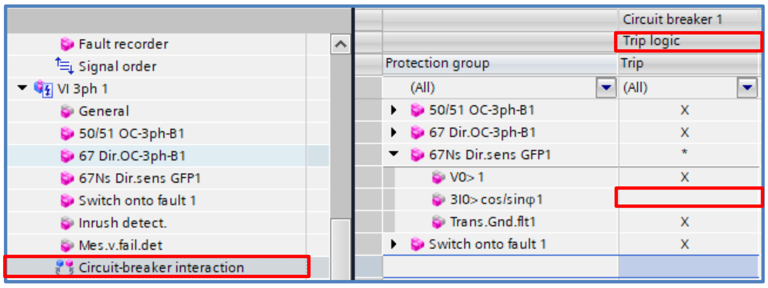


Figure 3: Circuit-breaker interaction matrix

4 Permanent ground fault detection

According to chapter 2.1 the function selection tree for a permanent ground fault is as following.

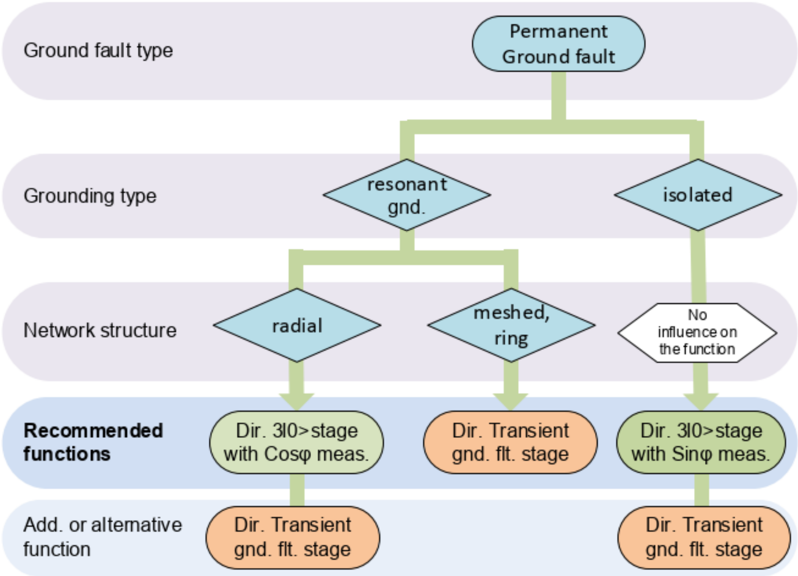


Figure 4: function selection tree-structure for a permanent ground fault

The following sub chapters are following the further selection according “grounding type” and “network structure”.

4.1 Resonant-grounded, radial network

4.1.1 Function "Dir. 3I0>stage with Cosφ measurement"

Remark: For simplification this function (stage) is named as **Cosφ** in the following.

4.1.1.1 Setting notes

The following figure shows the stage settings. In the following setting notes and recommendations are given. The **standard function control** is not explained here. Further information can be taken from the device manual.

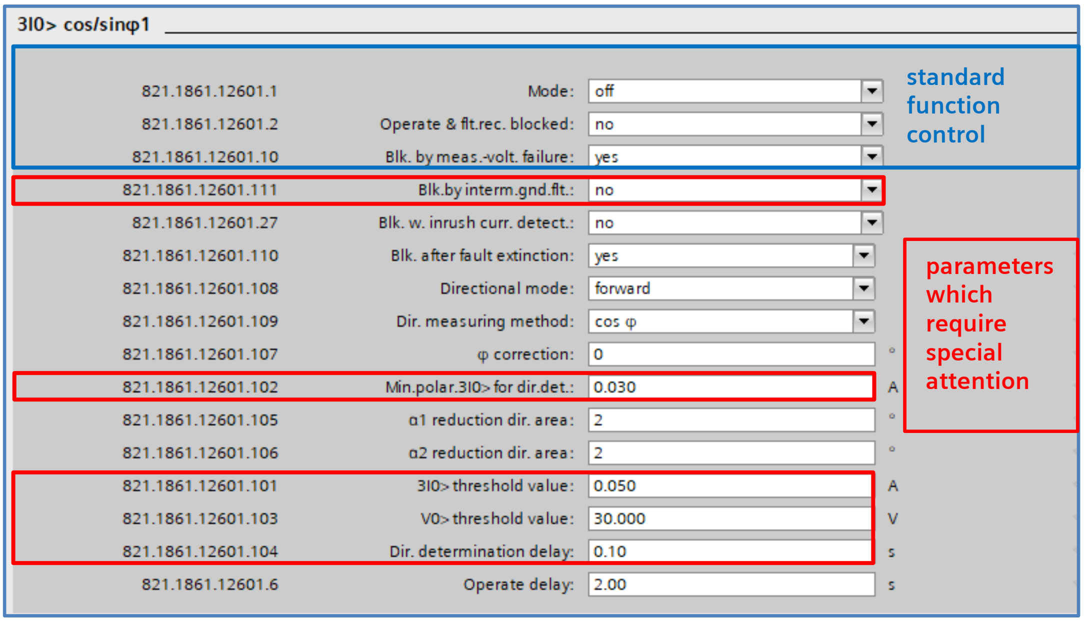


Figure 5: Setting list (in default state)

Blk.by interm.gnd.flt. special attention should be given

During intermittent ground faults, stages designed for detecting permanent ground faults (based on continuous RMS measurement, like the **Cosφ** stage) tend to generate a flood of signals and probably even temporary wrong directional information. This can be avoided by blocking these stages in case of an intermittent ground fault. If intermittent ground faults are probable in your network, Siemens strongly recommends enabling the blocking.

Recommendation: We propose to set ***Yes***.

Additionally, the function block **Blk.interm.GF** need to be configured. Please refer to chapter 5.3.

Blk.w. inrush curr. detec.

You specify whether the operate is blocked during detection of an inrush current. Siemens recommends disabling the blocking. The fundamental component of the zero-sequence voltage is a reliable criterion for the ground fault detection and remains almost unaffected by switching-on procedures.

Recommendation: We propose disabling the blocking, set to ***No***.

Blk.after fault extinction

Pickup can be blocked after detection of the fault extinction. With this, pickups are avoided due to the decay process in the zero- sequence system after the fault extinction.

Recommendation: We propose to set ***Yes***.

Directional mode

The parameter **Directional mode** defines whether the pickup of the stage occurs in forward or backward direction. Usually, the stage should operate in case of forward ground faults, which requires to set ***forward***.

Dir. Measuring method, φ Correction

These parameters are used to define the direction characteristic of the stage. The direction characteristic depends on the neutral- point treatment of the system, which is in this consideration "arc-suppression coil (resonant) grounded".

The settings must be set to:

Dir. Measuring method = ***Cos φ***
φ **Correction** = ***0°***

Min. polar.3I0> for dir.det. **special attention should be given**

For Cos φ measuring method with 0° *φ* correction the polarizing 3I0> for the direction determination is the active (ohmic) component of the total 3I0. Consequently, this setting is made with relation to the active (ohmic) component of the total 3I0.

In the following we are providing two setting recommendations:

1. **Rule of thumb approach**: this approach is simple and gives good detection results if no detection up to a defined ground fault resistance is required
2. Approach to detect ground faults till a **defined ground-fault resistance**: this approach should be followed if ground faults must be detected up to a defined ground-fault resistance.

Recommendation A: rule of thumb approach:

The threshold is set in a range between 25% to 50% of the active zero sequence current $3I0_{active}$. $3I0_{active}$ can easily be determined from the known I_{CE} and the known network damping d (for further information about the formula and a setting example, please refer to chapter 7.2.1):

$$3I0_{active} = d \cdot I_{CE}$$

Min. polar.3I0> for dir.det. = 0.25 … 0.5 · $3I0_{active}$, e.g. 0.3 · $3I0_{active}$

Recommendation B: approach to detect ground faults till a defined maximum ground fault resistance

The threshold value is determined according to the approach to detect ground faults till a defined maximum ground fault resistance, e.g. 3 kΩ. The respective description, including a specific network example, is given in chapter 7.2.

Note: this setting is not feeder specific. The same setting applies to all feeders.

α1reduction dir. area, α2 reduction dir. area

With the α1 reduction dir. area and α2 reduction dir. area parameters, you specify the angle for the limitation of the direction range. In feeders with a very large reactive current, it can be practical to set a larger angle than 2° to avoid a false pickup based on transformer and algorithm tolerances. You should only do this if you are aware of problems with the default setting of 2°.

Recommendation: We propose to keep the default of ***2°***.

3I0> threshold value **special attention should be given**

This setting relates to the total 3I0.

In the following we are providing two setting recommendations:

1. **Rule of thumb approach**: this approach is simple and gives good detection results if no detection up to a defined ground fault resistance is required
2. Approach to detect ground faults till a **defined ground-fault resistance**: this approach should be followed if ground faults must be detected up to a defined ground-fault resistance.

Recommendation A: rule of thumb approach:

Set this parameter to the same value as setting **Min. polar.3I0> for dir.det.** (refer to above). The total 3I0 is always higher than the active 3I0. Setting the same value ensures that the stage will always pickup if the active 3I0 is greater the setting **Min. polar.3I0> for dir.det.**

3I0> threshold value = Min. polar.3I0> for dir.det.

Recommendation B: approach to detect ground faults till a defined maximum ground fault resistance

This setting is made with relation to the total 3I0 of the specific feeder and with relation to a defined maximum ground-fault resistance, e.g. 3 kΩ. The respective description, including a specific network example, is given in chapter 7.2.2.

V0> threshold value special attention should be given

The V0 threshold setting is derived for the network. The derived setting is identically for all feeders.
In the following we are providing two setting recommendations:

1. **Rule of thumb approach**: this approach is simple and gives good detection results if no detection up to a defined ground fault resistance is required
2. Approach to detect ground faults till a **defined ground-fault resistance**: this approach should be followed if ground faults must be detected up to a defined ground-fault resistance.

Recommendation A: rule of thumb approach:

The threshold is set to a typical percentage value of the full displacement voltage (for further information please refer to the description / example given in chapter 7.1), e.g. 40%:

V0> threshold value = 0.4 · 57.7 V ≈ ***23 V***

Recommendation B: approach to detect ground faults till a defined maximum ground fault resistance

This setting is made with relation to a defined maximum ground-fault resistance, e.g. 3 kΩ. The respective description, including a specific network example, is given in chapter 7.1.1.

Dir. determination delay special attention should be given

The start of the ground fault normally shows a transient behavior. This can lead to an incorrect direction decision. The direction determination can be delayed from the occurrence of the zero-sequence voltage with the Dir. determination delay parameter to achieve steady-state measurands.

Recommendations:

1) **without considering intermittent ground fault** (if no intermittent ground fault occurs): 50 ms usually serves to pass the transient process.

   Dir. determination delay = ***50 ms***

2) **with considering intermittent ground fault** (intermittent ground faults can occur): If this time is set to a value which allows to classify an intermittent ground fault as "intermittent" and additionally, the intermittent ground fault blocking is configured, annunciation (signal floods and wrong directional results) by e.g. the **Cosφ** stage can be avoided. Intermittent cable faults should be classified as such within 200 ms (if the setting recommendations for the

Intermittent ground-fault blocking stage are applied, refer to chapter 5.3.1). For overhead lines intermittent ground faults are rare and classification usually last longer. We recommend focusing on intermittent cable faults and setting a delay of 200 ms.

Dir. determination delay = ***200 ms***

Note: this delay time also delays the start of the operate delay timer. If you want to achieve a defined operate (trip) time with reference to the ground fault entry (V0 occurrence) you must reduce the operate delay by this time.

Example: Tripping shall occur 1 s after ground fault entry (V0 occurrence):

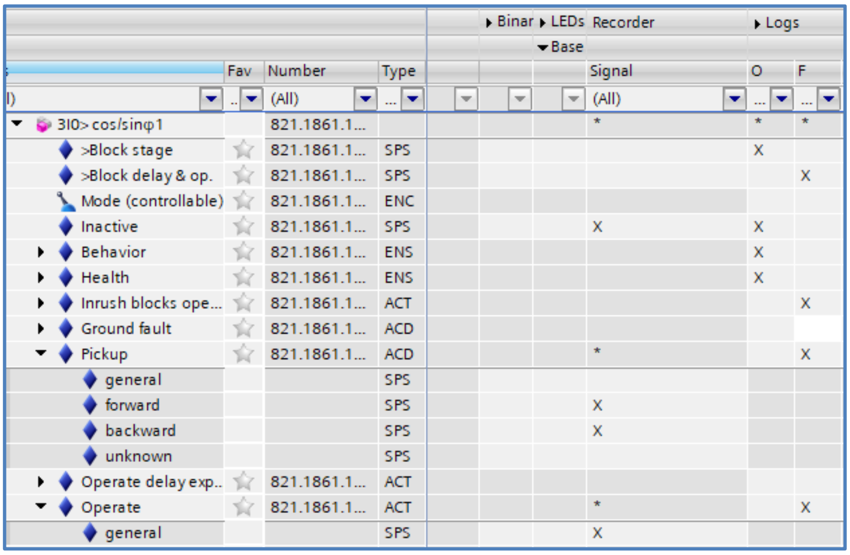
Dir. determination delay = ***200 ms***
Operate delay = ***0.80 s***

Operate delay

Must be set according to individual application requirements.

4.1.1.2 Routing notes

We recommend the following routing for operational log (column O), fault log (column F) and Recorder. This routing allows reliable ground fault clarification.



	Fav	Number	Type	Binar	LEDs	Base	Recorder Signal	Logs O	Logs F
3I0> cos/sinφ1		821.1861.1...					*	*	*
>Block stage		821.1861.1...	SPS					X	
>Block delay & op.		821.1861.1...	SPS						X
Mode (controllable)		821.1861.1...	ENC						
Inactive		821.1861.1...	SPS				X	X	
Behavior		821.1861.1...	ENS					X	
Health		821.1861.1...	ENS					X	
Inrush blocks ope...		821.1861.1...	ACT						X
Ground fault		821.1861.1...	ACD						
Pickup		821.1861.1...	ACD				*		X
general			SPS						
forward			SPS				X		
backward			SPS				X		
unknown			SPS						
Operate delay exp..		821.1861.1...	ACT						
Operate		821.1861.1...	ACT				*		X
general			SPS				X		

Figure 6: Signal list with recommended routing

Remark: since all relevant information of the **Pickup** signal are routed additional routing of the **Ground fault** signals is not required.

4.1.1.3 Further notes

Avoiding floods of logs and recordings in case of intermittent ground faults

Option A (recommended):

The stage can be automatically blocked during intermittent ground faults (by configuration, refer to the setting notes above). By this blocking floods of logs and recordings are effectively avoided if the Intermittent ground-fault blocking stage is well configured. Especially the parameter Reset time must not be set too short. For the description of this blocking stage and its setting recommendations please refer to chapter 5.3.

Option B (alternative):

If the blocking-feature cannot be applied for any reason, the following configuration can be applied to avoid log and recording floods:

1. Set the Fault recorder to user-defined recording. By this the fault recording and fault logging is no longer controlled via the pickup sate of the protection function but via the signals routed into the recorder trigger column (refer to further below).

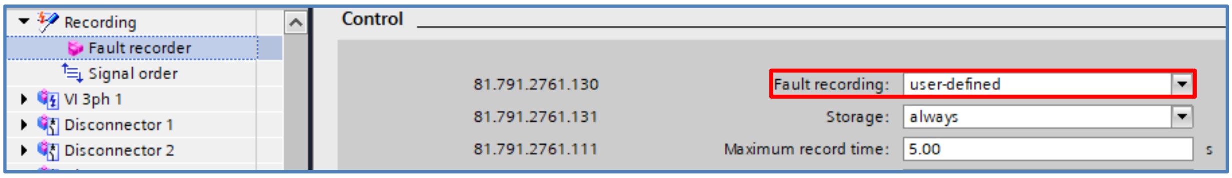


Figure 7: Fault recorder configuration

2. Setting the recording to **user-defined** offers the new recorder column **Trigger**. The recording duration is now determined from the logical OR operation of all active signals routed into the trigger column. Controlling fault recording (and fault logging) for ground-faults requires to only route the **Ground fault.general** SPS signal of the function block **General** into the trigger column.

   Note 1: Do not mix this up with the **Ground fault.general** SPS signal of the **Transient ground-fault function**. It is essential to route the signal out of the function block **General.**

   Note 2: If also short-circuit protection is applied in the device you must also route the **Pickup** group indications of each applied protection function group into the Trigger column.

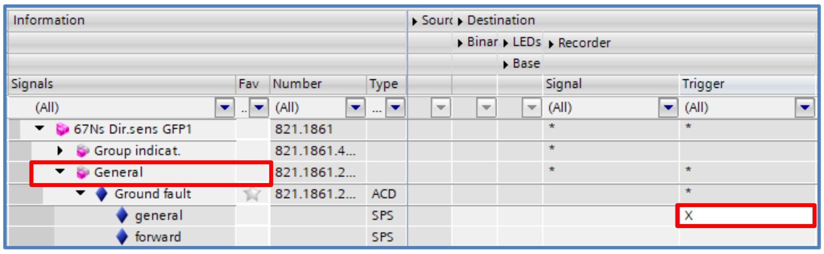


Figure 8: Controlling the fault recording via the Ground fault signal

3. For Parameter **Dropout delay** in the function block **General** the default value of **1 s** should be kept. This value must not be set lower. With this setting the **Ground fault.general** signal of the function block **General** is hold during an intermittent fault till the next re-strike. In this way this signal remains active over the intermittent fault and the recording is not closed, i.e. no new recording is started. Consequently, a flood of recordings and logs is avoided.

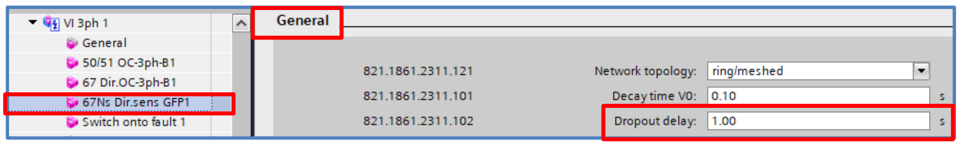


Figure 9: Dropout delay setting in FB General

Avoiding floods of signals in case of intermittent ground faults

Option A (recommended):

The **Cosφ** stage can be automatically blocked during intermittent ground faults (by configuration, refer to the setting notes above). By this blocking signal floods are effectively avoided.

Option B (alternative):

If the blocking-feature cannot be applied for any reason, we recommend a different signal routing as the one proposed in chapter 4.1.1.2. The signal Ground fault (including the directional information) is stabilized against signal floods, as indicated in the following diagram. For this signal only a defined number of signal changes are recorded for one ground fault. After that logging for this signal is stopped.

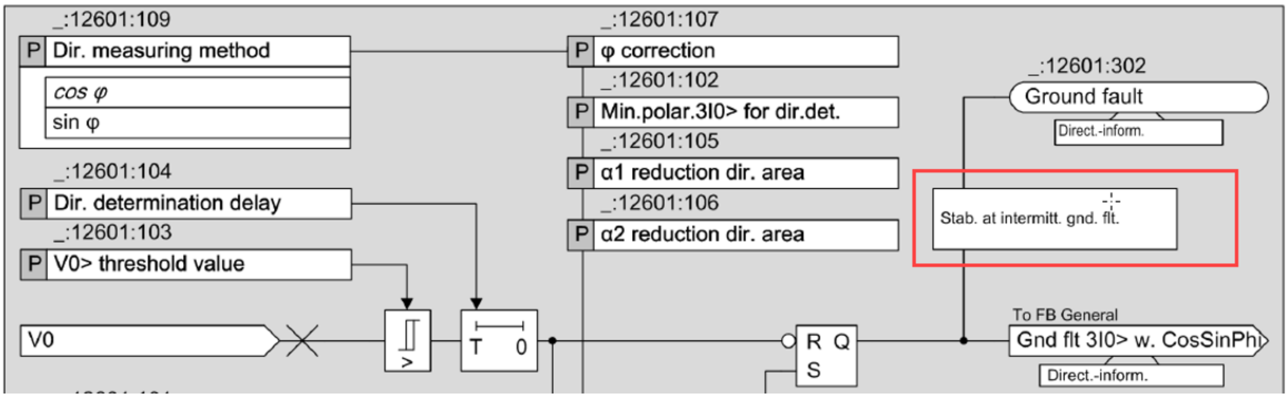


Figure 10: Excerpt from stage logic

The following diagram shows the recommended signal routing if the automatic blocking feature is not applied.

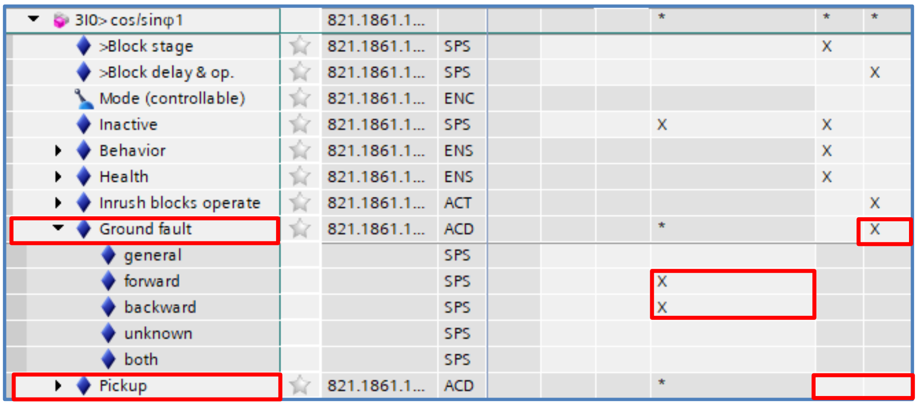


Figure 11: Recommended routing to avoid signal flooding during intermittent ground faults.

Remark: take the routing for the **Pickup** signal away and use instead the stabilized **Ground fault** signal

4.1.2 Function “Dir. Transient ground fault stage”

4.1.2.1 Setting notes

The following figure shows the stage settings. In the following setting notes and recommendations are given. The **standard function control** is not explained here. Further information can be taken from the device manual.

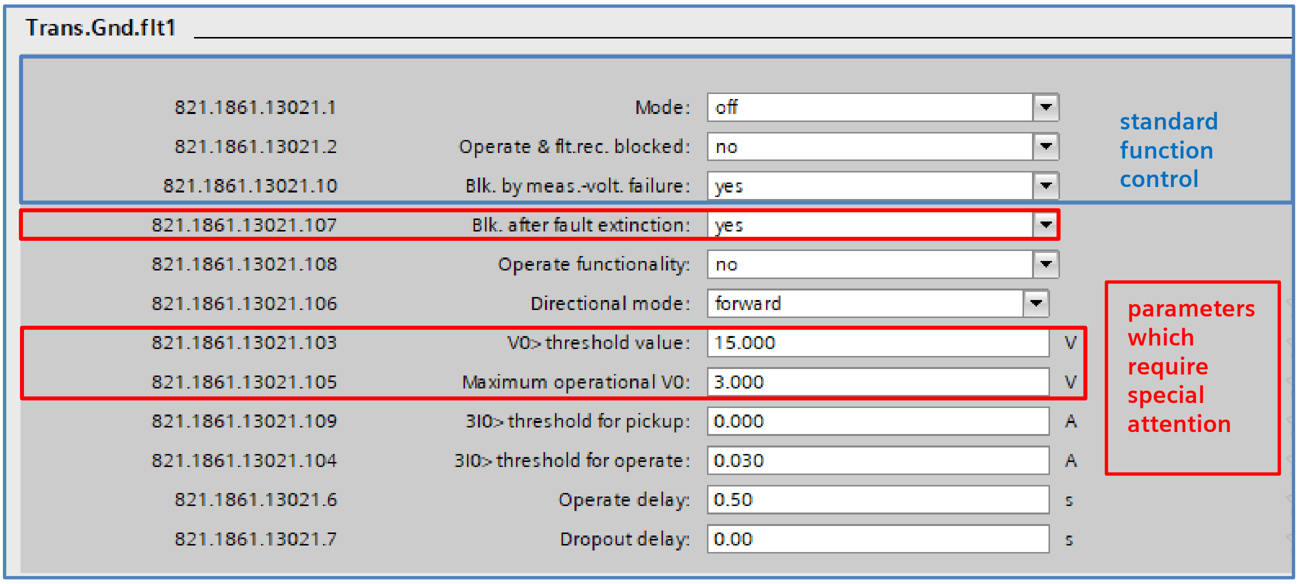


Figure 12: Setting list (in default state)

<u>**Blk.after fault extinction**</u> **special attention should be given**

If the **Blk. after fault extinction** parameter is set to ***yes***, the tripping delay is reset after the detection of the fault extinction. During intermittent faults fault extinction will be detected if the time between fault extinction and next restrike is long enough. If the function shall trip on intermittent faults this setting must be set to ***no***.

In this application scenario (this chapter) the stage is applied for permanent ground faults this setting can be set y***es***.

<u>**Operate functionality**</u>

If the stage is used only to indicate the ground fault direction, this optional trip logic is not required and can remain disabled. If the stage is used to trip a permanent or intermittent ground fault the optional trip logic must be switched on.

Setting is application dependent: must be set to ***yes*** if the stage shall support tripping

<u>**Directional mode**</u>

The parameter **Directional mode** defines whether the pickup of the stage occurs in forward or backward direction. Usually, the stage should operate in case of forward ground faults, which requires to set ***forward***.

<u>**V0> threshold value**</u> **special attention should be given**

The V0 threshold setting is derived for the network. The derived setting is identically for all feeders.

In the following we are providing two setting recommendations:

1. **Rule of thumb approach**: this approach is simple and gives good detection results if no detection up to a defined ground fault resistance is required
2. Approach to detect ground faults till a **defined ground-fault resistance**: this approach should be followed if ground faults must be detected up to a defined ground-fault resistance.

Recommendation A: rule of thumb approach:

The threshold is set to a typical percentage value of the full displacement voltage (for further information please refer to the description / example given in chapter 7.1), e.g. 40%:

V0> threshold value = 0.4 · 57.7 V ≈ ***23 V***

Recommendation B: approach to detect ground faults till a defined maximum ground fault resistance

This setting is made with relation to a defined maximum ground-fault resistance, e.g. 3 kΩ. The respective description, including a specific network example, is given in chapter 7.1

Maximum operational V0 **special attention should be given**

With the parameter Maximum operational V0, you define the maximum operational zero-sequence voltage $V0_{op,max}$. The setting is needed for special reset conditions.

The secondary operational zero-sequence voltages can be obtained by reading the residual voltage VN_{sec} or the zero-sequence voltage $V0_{sec}$ under the symmetrical components from the device or via DIGSI.

In case you read the secondary residual voltage VN_{sec}, you convert it to $V0_{sec}$ with the **Matching ratio Vph / VN** parameter. Its setting is usually √3.

Recommendation:

- If the maximum operational zero-sequence voltage is known, set the threshold to 1.2 $V0_{op,max}$
- If the maximum operational zero-sequence voltage is unknow and cannot be determined for any reason, please keep the default of ***3V***

Example:

Maximum operational secondary residual voltage reading: VN_{sec} = 5.0 V

Matching ratio Vph / VN = √3

$V0_{sec}$ = 5.000 V ·√3 / 3 = 2.887 V

Maximum operational V0 = 2.887 V · 1.2 = ***3.464 V***

3I0> threshold for pickup

In ring or meshed systems, you can use this parameter to reduce the number of ground-fault reporting devices. The parameter needs to be set according to the user experience on the specific network. For radial systems, normally you can keep the default value of 0 A which sets this parameter to inactive.

Recommendation: set this functionality inactive by keeping the default value of ***0 A***

3I0> threshold for operate

The setting is significant only for optional trip logic for switching off permanent ground faults. Select the setting such that the static ground-fault current exceeds the threshold value. You can disable this criterion by setting the value to 0 A.

If the function shall be applied to trip intermittent ground faults (which is the case for this specific chapter description) the threshold could be undershoot during the phase between fault extinction and next restrike, causing the operate delay timer to reset. To avoid this risk the threshold should be set to 0 A.

Recommendation: set this criterion inactive by setting the threshold to ***0 A***

Operate delay

Must be set according to individual application requirements.

Dropout delay

Parameter **Dropout delay** allows you to use the stage effectively for tripping intermittent ground faults. For respective setting recommendations please refer to chapter 5.2.1.

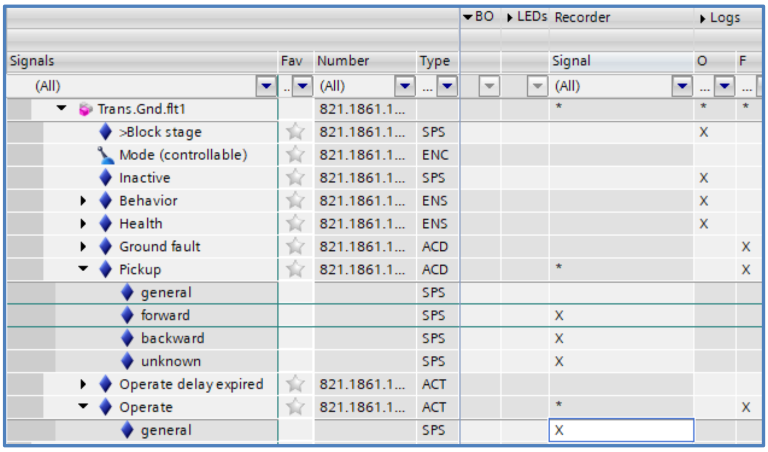
Since in this application scenario (this chapter) the stage is applied for permanent ground faults this setting can be set ***0 s***.

Recommendation: set this functionality inactive by keeping the default value of ***0.00 s***

4.1.2.2 Routing notes

We recommend the following routing for operational log (column O), fault log (column F) and Recorder. This routing allows reliable ground-fault clarification.

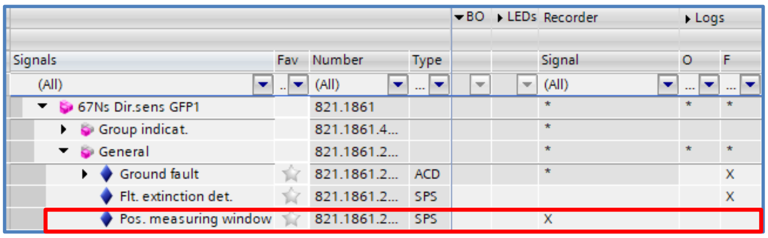
Transient Ground Fault Function:



Signals	Fav	Number	Type	BO	LEDs	Recorder Signal	Logs O	Logs F
(All)		(All)				(All)		
Trans.Gnd.flt1		821.1861.1...				*	*	*
>Block stage		821.1861.1...	SPS				X	
Mode (controllable)		821.1861.1...	ENC					
Inactive		821.1861.1...	SPS				X	
Behavior		821.1861.1...	ENS				X	
Health		821.1861.1...	ENS				X	
Ground fault		821.1861.1...	ACD					X
Pickup		821.1861.1...	ACD			*		X
general			SPS					
forward			SPS			X		
backward			SPS			X		
unknown			SPS			X		
Operate delay expired		821.1861.1...	ACT					
Operate		821.1861.1...	ACT			*		X
general			SPS			X		

Figure 13: Signal list with recommended routing for the Transient Ground Fault Function

Function block **General:**



Signals	Fav	Number	Type	BO	LEDs	Recorder Signal	Logs O	Logs F
(All)		(All)				(All)		
67Ns Dir.sens GFP1		821.1861				*	*	*
Group indicat.		821.1861.4...				*		
General		821.1861.2...				*	*	*
Ground fault		821.1861.2...	ACD			*		X
Flt. extinction det.		821.1861.2...	SPS					X
Pos. measuring window		821.1861.2...	SPS			X		

Figure 14: Signal list with recommended routing for the FB General

We recommend routing the signal **Pos. measuring window** into the fault recorder. This signal is essential for later ground-fault clarifications.

4.1.2.3 Further notes

Avoiding floods of logs and recordings in case of intermittent ground faults

The stage is fully immune against generating such floods during intermittent ground faults. No measures need to be taken.

Avoiding floods of signals in case of intermittent ground faults

The stage is fully immune against generating such floods during intermittent ground faults. No measures need to be taken.

4.2 Resonant-grounded, meshed / ring network

[To be added at a later state]

4.3 Isolated network

For the detection of permanent ground faults in isolated networks the **Dir. 3I0>stage with Sinφ measurement** is the most applied standard function.

4.3.1 Function "Dir. 3I0>stage with Sinφ measurement"

Remark: For simplification this function (stage) is named as ***Sinφ*** in the following.

4.3.1.1 Setting notes

The following figure shows the stage settings. In the following setting notes and recommendations are given. The **standard function control** is not explained here. Further information can be taken from the device manual.

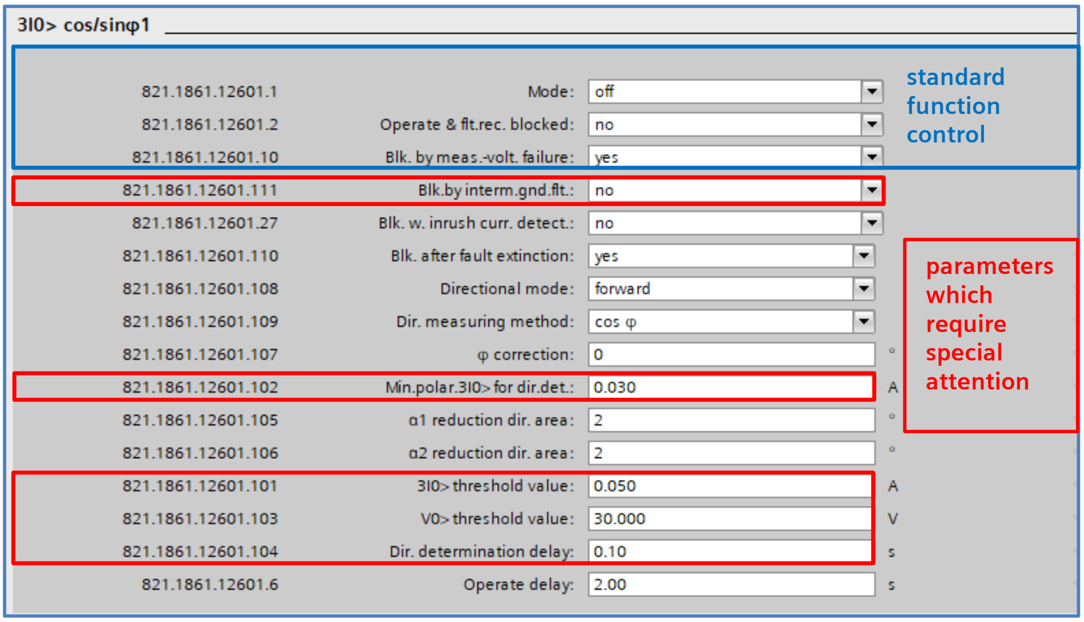


Figure 15: Setting list (in default state)

<u>Blk.by interm.gnd.flt</u>. **special attention should be given**

During intermittent ground faults, stages designed for detecting permanent ground faults (based on continuous RMS measurement, like the ***Sinφ*** stage) tend to generate a flood of signals and probably even temporary wrong directional information. This can be avoided by blocking these stages in case of an intermittent ground fault. If intermittent ground faults are probable in your network, Siemens strongly recommends enabling the blocking.

Recommendation: We propose to set ***Yes***.

Additionally, the function block **Blk.interm.GF** need to be configured. Please refer to chapter 5.3.

<u>Blk.w. inrush curr. detec.</u>

You specify whether the operate is blocked during detection of an inrush current. Siemens recommends disabling the blocking. The fundamental component of the zero-sequence voltage is a reliable criterion for the ground fault detection and remains almost unaffected by switching-on procedures.

Recommendation: We propose disabling the blocking, set to ***No***.

Blk.after fault extinction

Pickup can be blocked after detection of the fault extinction. With this, pickups are avoided due to the decay process in the zero- sequence system after the fault extinction.

Recommendation: We propose to set Yes.

Directional mode

The parameter **Directional mode** defines whether the pickup of the stage occurs in forward or backward direction. Usually, the stage should operate in case of forward ground faults, which requires to set ***forward***.

Dir. Measuring method, φ Correction

These parameters are used to define the direction characteristic of the stage. The direction characteristic depends on the neutral- point treatment of the system, which is in this consideration "isolated".

The settings must be set to:

Dir. Measuring method = ***Sin φ***
φ **Correction** = ***0°***

Min. polar.3I0> for dir.det. **special attention should be given**

For Sin *φ* measuring method with 0° *φ* correction the polarizing 3I0> for the direction determination is the capacitive component of the total 3I0. However, in an isolated network the active (ohmic) component of the total 3I0 is neglectable. Consequently, the capacitive 3I0 and the total 3I0 are the same.

In the following we are providing two setting recommendations:

1. **Rule of thumb approach:** this approach is simple and gives good detection results if no detection up to a defined ground fault resistance is required
2. Approach to detect ground faults till a **defined ground-fault resistance**: this approach should be followed if ground faults must be detected up to a defined ground-fault resistance.

Recommendation A: rule of thumb approach

The threshold is set in to 30% of the capacitive zero-sequence current $3I0_{cap.fd}$ flowing in the faulty feeder. $3I0_{cap.fd}$ can easily be determined from the known I_{CE} for the network and the known I_{CE} of the individual feeder:

$$3I0_{cap.fd} = I_{CE} - I_{CE,feeder}$$

Min. polar.3I0> for dir.det. $= 0.3 \cdot (I_{CE} - I_{CE,feeder})$

Example:

$I_{CE} = 200$ A

$I_{CE,feeder} = 40$ A

Min. polar.3I0> for dir.det. = 0.3 · (200 A – 40 A) = 48 A (primary)

Recommendation B: approach to detect ground faults till a defined maximum ground fault resistance

The threshold value is determined according to the approach to detect ground faults till a defined maximum ground fault resistance, e.g. 300 Ω. The respective description, including a specific network example, is given in chapter 7.2.3.

Note: this setting is feeder specific. The setting needs to be determined for each feeder individually.

α1 reduction dir. area, α2 reduction dir. area

With the α1 reduction dir. area and α2 reduction dir. area parameters, you specify the angle for the limitation of the direction range. In feeders with a very large reactive current, it can be practical to set a larger angle than 2° to avoid a false pickup based on transformer and algorithm tolerances. You should only do this if you are aware of problems with the default setting of 2°.

Recommendation: We propose to keep the default of *2°*.

3I0> threshold value **special attention should be given**

This setting relates to the total 3I0. As the capacitive 3I0 and the total 3I0 are the same in an isolated network this setting is set to the same value as determined for parameter **Min. polar.3I0> for dir.det.**, refer to above.

V0> threshold value **special attention should be given**

The V0 threshold setting is derived for the network. The derived setting is identically for all feeders.

In the following we are providing two setting recommendations:

1. **Rule of thumb approach:** this approach is simple and gives good detection results if no detection up to a defined ground fault resistance is required
2. Approach to detect ground faults till a **defined ground-fault resistance:** this approach should be followed if ground faults must be detected up to a defined ground-fault resistance.

Recommendation A: rule of thumb approach

The threshold is set to a typical percentage value of the full displacement voltage (for further information please refer to the description / example given in chapter 7.1). For isolated networks we recommend a rather low typical percentage (30 %) as the zero-sequence voltage drops rather fast for increasing fault resistance.

V0> threshold value = 0.3 · 57.7 V ≈ ***17 V***

Recommendation B: approach to detect ground faults till a defined maximum ground fault resistance

This setting is made with relation to a defined maximum ground-fault resistance, e.g. 300 Ω. The respective description, including a specific example, is given in chapter 7.1.2.

Dir. determination delay **special attention should be given**

The start of the ground fault normally shows a transient behavior. This can lead to an incorrect direction decision. The direction determination can be delayed from the occurrence of the zero-sequence voltage with the Dir. determination delay parameter to achieve steady-state measurands.

Recommendations:

1) **without considering intermittent ground fault** (if no intermittent ground fault occurs): 50 ms usually serves to pass the transient process.

   Dir. determination delay = *50 ms*

2) **with considering intermittent ground fault** (intermittent ground faults can occur): If this time is set to a value which allows to classify an intermittent ground fault as "intermittent" and additionally, the intermittent ground fault blocking is configured, annunciation (signal floods and wrong directional results) by e.g. the **Cosφ** stage can be avoided. Intermittent cable faults should be classified as such within 200 ms (if the setting recommendations for the **Intermittent ground-fault blocking** stage are applied, refer to chapter 5.3.1). For overhead lines intermittent ground faults are rare and classification usually last longer. We recommend focusing on intermittent cable faults and setting a delay of 200 ms.

   Dir. determination delay = *200 ms*

Note: this delay time also delays the start of the operate delay timer. If you want to achieve a defined operate (trip) time with reference to the ground fault entry (V0 occurrence) you must reduce the operate delay by this time.

Example: Tripping shall occur 1 s after ground fault entry (V0 occurrence):

> **Dir. determination delay = *200 ms***
> **Operate delay = *0.80 s***

Operate delay

Must be set according to individual application requirements.

4.3.1.2 Routing notes

We recommend the following routing for operational log (column O), fault log (column F) and Recorder. This routing allows reliable ground fault clarification.

	Fav	Number	Type		▸ Binar	▸ LEDs	Recorder ▾ Base Signal	▸ Logs O	F
)	..	(All)	...				(All)	...	...
3I0> cos/sinφ1		821.1861.1...					*	*	*
>Block stage		821.1861.1...	SPS					x	
>Block delay & op.		821.1861.1...	SPS						x
Mode (controllable)		821.1861.1...	ENC						
Inactive		821.1861.1...	SPS				x	x	
Behavior		821.1861.1...	ENS					x	
Health		821.1861.1...	ENS					x	
Inrush blocks ope...		821.1861.1...	ACT						x
Ground fault		821.1861.1...	ACD						
Pickup		821.1861.1...	ACD				*		x
general			SPS						
forward			SPS				x		
backward			SPS				x		
unknown			SPS						
Operate delay exp..		821.1861.1...	ACT						
Operate		821.1861.1...	ACT				*		x
general			SPS				x		

Figure 16: Signal list with recommended routing

Remark: since all relevant information of the **Pickup** signal are routed additional routing of the **Ground fault** signals is not required.

4.3.1.3 Further notes

For

- Avoiding floods of logs and recordings in case of intermittent ground faults
- Avoiding floods of signals in case of intermittent ground faults

Refer to chapter 4.1.1.3.

4.3.2 Function "Dir. Transient ground fault stage"

[To be added at a later state]

5 Intermittent ground fault detection

According to chapter 2.1 the function selection tree for an intermittent ground fault is as following.

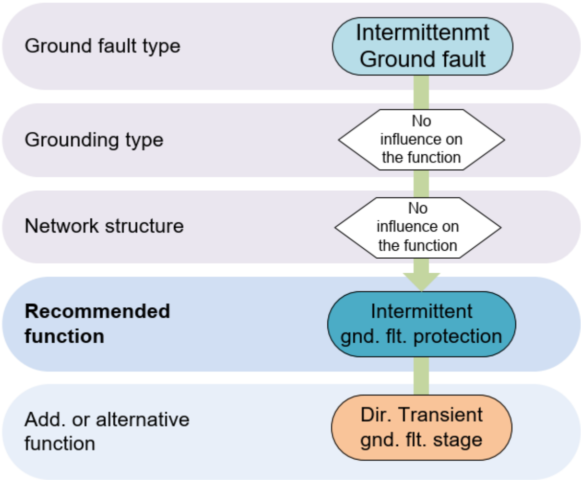


Figure 17: function selection tree-structure for an intermittent ground fault

The following two functions are available for the directional detection of intermittent ground faults:

- Directional intermittent ground-fault protection
- Directional transient ground-fault stage

Both functions can be applied independently of grounding type and network structure.
The main technical differences between these two functions are as following:

	Dir. Intermittent ground fault protection	**Dir. Transient ground fault function**
Basic ground-fault criterion magnitude (function trigger)	3I0	V0
Direction determination	With each new detected ground current peak (restrike)	Only at the ground fault entry (via charging transient). During the ongoing intermittent fault (restriking) no further direction determination is made.
Stationary measurement	Directional determination is “quasi stationary”	Direction is evaluated only with fault start and then kept. Direction changes during the intermittent faults are not detected.
Intermittent fault-type annunciation	Yes	No (no differentiation between permanent and intermittent fault type)
Detection of a permanent (steady state) fault	No (with pulse counting mode) Yes (with p.u. time integration)	Yes
Sensitivity	Medium	High

Table 2: function properties comparison

Function selection considerations / recommendations

In case that no preference for one or the other function is given by the customer (due to philosophy / experience), Siemens recommends applying the **Dir. Intermittent ground fault protection** function. The reason for this is the "quasi stationary" directional measurement which provides a maximized reliability and the fact that the function can characterize the fault as "intermittent".

5.1 Function "Dir. Intermittent ground fault protection"

5.1.1 Setting notes

The following figure shows the function settings. In the following setting notes and recommendations are given. The **standard function control** is not explained here. Further information can be taken from the device manual.

21.2241.16291.1	Mode:	off	
21.2241.16291.2	Operate & flt.rec. blocked:	no	
21.2241.16291.10	Blk. by meas.-volt. failure:	yes	
21.2241.16291.101	Directional mode:	forward	
21.2241.16291.102	Pickup mode:	with 3I0>	
21.2241.16291.103	Operating mode:	Counter	
21.2241.16291.3	Threshold:	1.000	A
21.2241.16291.105	Pickup extension time:	0.10	s
21.2241.16291.104	No.of pulses for interm.GF:	3	
21.2241.16291.107	Reset time:	300.00	s
21.2241.16291.108	No. of pulses for operate:	5	
21.2241.16291.112	Minimum operate delay:	0.00	s

standard function control

parameters which require special attention

Figure 18: Setting list

<u>Directional mode</u>

Here one defines if the function operates in forward or in reverse direction. Usually, the stage should operate in case of forward ground faults, which requires to set ***forward***.

<u>Pickup mode</u>

- ***With 3I0>***: pickup takes place if the absolute value of 3I0 exceeds the pickup threshold. The determined direction is not considered in the pickup condition.
- ***With direction***: pickup takes place if a) the absolute value of 3I0 exceeds the pickup threshold and b) the determined direction is equal to the set direction.

Recommendation: We propose setting ***with 3I0>***. In this way all intermittent faults are logged and recorded which serves for a better fault analysis.

<u>Operating mode & No. of pulses for operate</u> **special attention should be given**

Two operating modes for the operating (tripping) mode are available. They are explained by the following figures:

- ***Counter***: Counting directional 3I0 pulses

For each re-strike (3I0 pulse) the direction is determined. The directional pulses are counted. For the example in Figure 19 these are four pulses (red numbers 1 ... 4) and in Figure 20 eight pulses (red numbers 1...8), e.g. with the direction "forward".

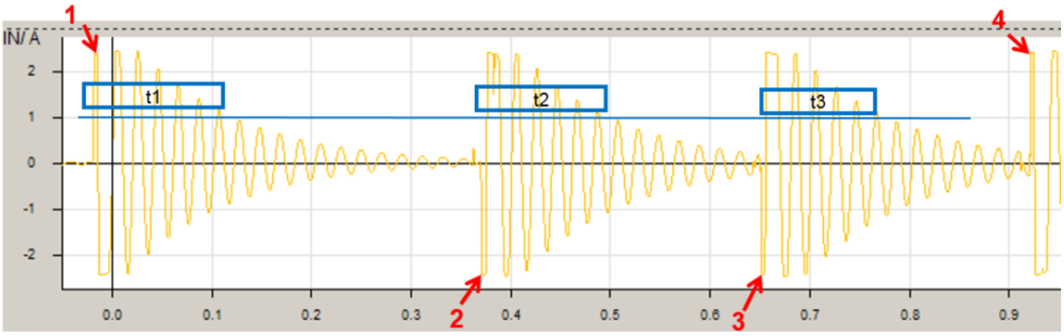


Figure 19 Typical intermittent ground fault, cable, characteristic 1

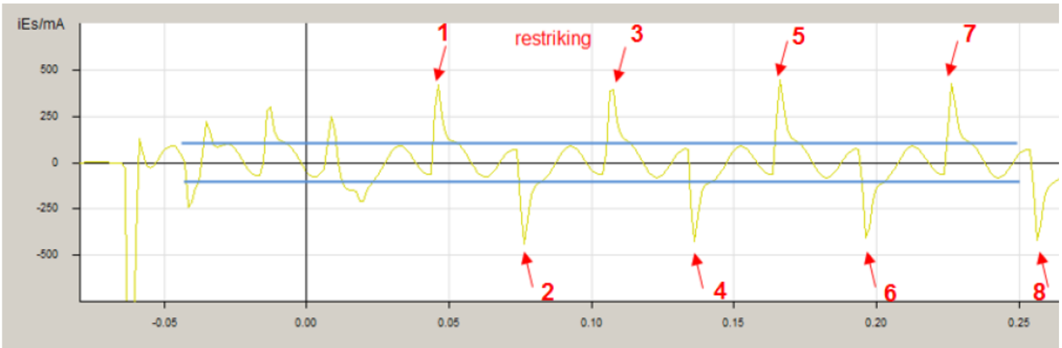


Figure 20: Typical intermittent ground fault, cable, characteristic 2

The following figure shows the counters. Assuming a detected forward direction for each pulse the pulse-forward-counter has the value 4 for the first example and 8 for the second example. And the two other counters have the value 0.

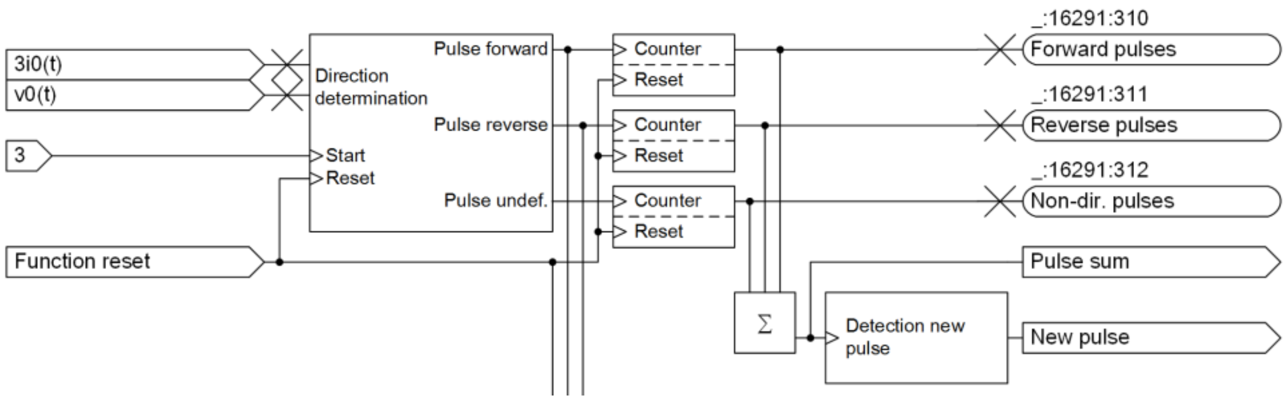


Figure 21: counting directional pulses

If the counter for the set direction reaches the setting value of parameter **No. of pulses for operate** the function trips.

Recommendation: We propose the operating mode ***Counter*** due to its simple principle.

However, it can be noted that the pulse counter is much faster increased for fast and periodically re-striking ground fault (refer to Figure 20, characteristic 2) than for a ground fault characteristic acc. Figure 19. If no specific tripping time requirements are given the following is a practical value for tripping:

No. of pulses for operate = ***5***

With this setting the tripping time for the two different characteristics is approx.:

1.3 s to 1.4 s for characteristic 1 and
0.25 s for characteristic 2

Remark: If a minimum trip delay time is required (e.g. 2 s), use the parameter **Minimum operate delay**

- ***Integrator and counter***: Counting directional 3I0 pulses and Integration of the pick-up time of the 3I0 RMS fault current stage, for time grading coordination

Additionally, to the directional pulse counting, the time periods in which the 3I0 is above the set threshold (blue line in Figure 19, periods t1, t2, t3) are integrated. If the integration value exceeds a set threshold this additional tripping criterion is fulfilled. In this way a time grading can be achieved. We consider this as a rare application. Therefore, we do not further explain this mode and the further involved setting.

Threshold **special attention should be given**

3I0 is calculated as true-RMS quantity to also measure non-fundamental components (the current peak). The threshold must be set in a way that the 3I0 peaks (pulses) significantly exceeds the threshold.

This setting value relates to the total 3I0.

In the following we are providing two setting recommendations:

1. **Rule of thumb approach**: this approach is simple and gives good detection results if no detection up to a defined ground fault resistance is required
2. Approach to detect ground faults till a **defined ground-fault resistance**: this approach should be followed if ground faults must be detected up to a defined ground-fault resistance.

Recommendation A: rule of thumb approach

Set this parameter to 50% of the active 3I0 component of the network and therefore independent from the individual feeder I_{CE}. By this the compensation type (over or under) and the compensation degree does not need to be considered as well. For further simplification the damping (active component) is considered as 3% of the network I_{CE}.

Threshold

value = $\boldsymbol{0.5 \cdot 0.03 \cdot I_{CE,network}}$

Recommendation B: approach to detect ground faults till a defined maximum ground fault resistance

This setting is made with relation to the total 3I0 of the specific feeder and with relation to a defined maximum ground-fault resistance, e.g. 3 kΩ. The respective description, including a specific network example, is given in chapter 7.2.2.

Note: The 3I0 threshold derived according to chapter 7.2.2 relates to a **permanent** ground-fault. During an **intermittent** ground fault, the 3I0 fault current level will not fully reach the fault current level for a permanent ground fault. Therefore, please follow the additional recommendation given in chapter 7.2.4.

Pickup extension time

This parameter is only required in case of time grading coordination with old relays that have different pickup and dropout timing. This is a very specific condition that is not further considered.

Recommendation: keep the default value

No. of pulses for interm. GF

With this parameter you set the total number of pulse counts (sum of forward, reverse, and non-dir. pulses) at which the ground fault is considered being intermittent.

Recommendation: keep the default value of ***3*** pulses

Note: this setting value must be set smaller or equal to the setting value of **No. of pulses for operate**

Reset time **special attention should be given**

The function is reset when it trips. Reset of the function mostly means that the pulse-counters are reset. If no trip occurs the function-reset is controlled by the **reset timer**. The reset timer is newly started (timer reset) with each new exceeding of the 3I0 threshold (with each new function pickup). If the timer expires the function resets.

Intermittent cable faults can show fast re-striking in the area of 1...2 network periods up to re-striking with intervals in the range of few seconds.

Depending on the pickup threshold setting and the intermittent fault characteristic (fast and periodically re-striking for a cable faults 3I0 does not drop below the dropout threshold during the intermittent fault. The reset timer is then not newly started (reset). Therefore, the reset timer must be set in a way that it does not expire before tripping.

Recommendation: a practical value to a) handle the condition that during the fault no dropout occurs and b) consider an intermittent fault as disappeared is e.g. ***10 s***.

Minimum operate delay

This parameter is only relevant in the operating mode Counter.

The Minimum operate delay parameter is used to avoid too fast tripping in case of frequent restriking (for example, restriking occurs every 30 ms).

5.1.2 Routing notes

We recommend the following routing for operational log (column O), fault log (column F) and Recorder. This routing allows reliable ground fault clarification.

Information				Destination		
				Recorder	Logs	
Signals	Fav	Number	Type	Signal	O	F
(All)		(All)		(All)		
Stage 1		21.2241.16...		*	*	*
>Block stage		21.2241.16...	SPS		X	
Mode (controllable)		21.2241.16...	ENC			
Inactive		21.2241.16...	SPS		X	
Behavior		21.2241.16...	ENS		X	
Health		21.2241.16...	ENS		X	
Pickup		21.2241.16...	ACD			
Stabilized pickup		21.2241.16...	ACD			
Limited pickup (l...		21.2241.16...	ACD	*		X
— general			SPS	X		
— forward			SPS	X		
— backward			SPS	X		
— unknown			SPS			
— both			SPS			
Intermittent gnd.flt.		21.2241.16...	SPS	X		X
Sum limit reached		21.2241.16...	SPS			X
Pulse no. reached		21.2241.16...	SPS	X		X
Reset time running		21.2241.16...	SPS	X		X
Operate		21.2241.16...	ACT	*		X
— general			SPS	X		
3I0 max.		21.2241.16...	MV			X
Forward pulses		21.2241.16...	MV			X
Reverse pulses		21.2241.16...	MV			X
Non-dir. pulses		21.2241.16...	MV			X

Figure 22: Signal list with recommended routing

5.1.3 Further notes

Avoiding floods of logs and recordings in case of intermittent ground faults

The function is specifically designed in a way that for one intermittent ground fault only one fault recording, and one fault log is created. However, this requires setting parameter **Reset time** in a correct way, as described under the setting notes.

No further measures need to be taken.

Avoiding floods of signals in case of intermittent ground faults

With the signal routing according to chapter 5.1.2 the fault log will not be flooded during an intermittent ground fault. The signal **Limited pickup (log)** serves this by limiting the signal state change during an intermittent ground fault.

5.2 Function "Dir. Transient ground fault stage"

5.2.1 Setting notes

The following figure shows the stage settings. In the following setting notes and recommendations are given. The **standard function control** is not explained here. Further information can be taken from the device manual.

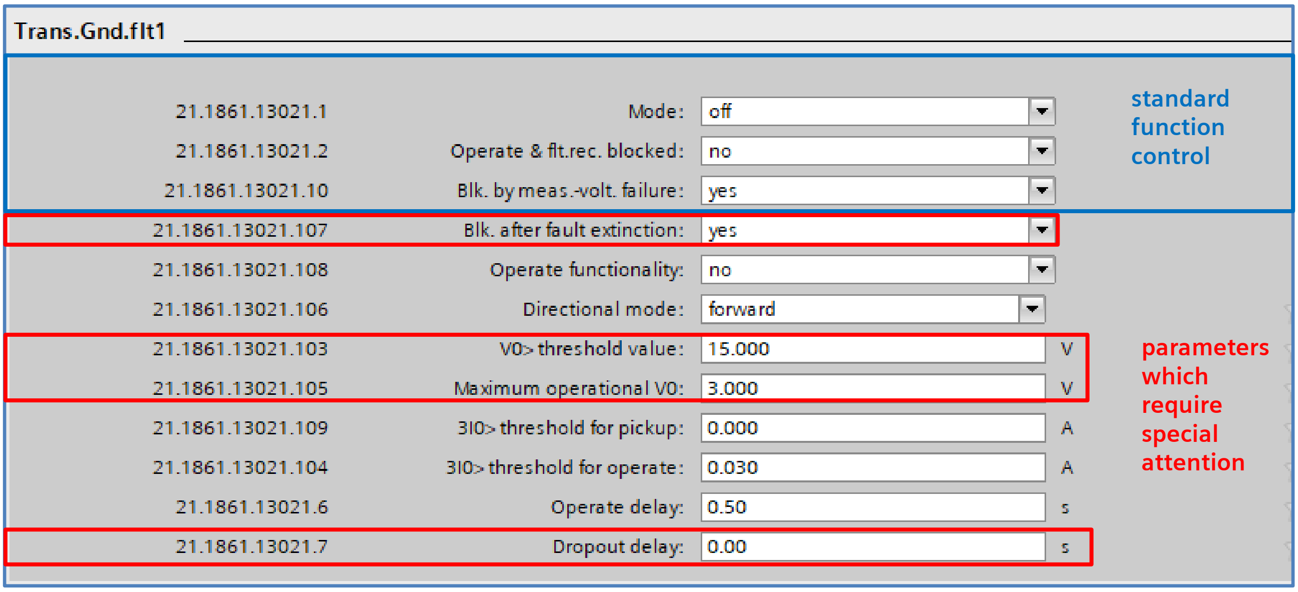


Figure 23: Setting list (in default state)

<u>**Blk.after fault extinction**</u> special attention should be given

If the **Blk. after fault extinction** parameter is set to ***yes***, the tripping delay is reset after the detection of the fault extinction. During intermittent faults fault extinction will be detected if the time between fault extinction and next restrike is long enough. Since in this application scenario this stage shall be applied to trip on intermittent faults this setting <u>must</u> be set to ***no***.

Setting is application dependent: <u>must</u> be set to ***no*** if the stage shall be applied for tripping intermittent faults

<u>**Operate functionality**</u>

If the stage is used only to indicate the ground fault direction, this optional trip logic is not required and can remain disabled. If the stage is used to trip a permanent or intermittent ground fault the optional trip logic must be switched on.

Setting is application dependent: must be set to ***yes*** if the stage shall support tripping

<u>**Directional mode**</u>

The parameter **Directional mode** defines whether the pickup of the stage occurs in forward or backward direction. Usually, the stage should operate in case of forward ground faults, which requires to set ***forward***.

<u>**V0> threshold value**</u> special attention should be given

The V0 threshold setting is derived for the network. The derived setting is identically for all feeders.

In the following we are providing two setting recommendations:

1. **Rule of thumb approach**: this approach is simple and gives good detection results if no detection up to a defined ground fault resistance is required
2. Approach to detect ground faults till a **defined ground-fault resistance**: this approach should be followed if ground faults must be detected up to a defined ground-fault resistance.

Recommendation A: rule of thumb approach

The threshold is set to a typical percentage value of the full displacement voltage (for further information please refer to the description / example given in chapter 7.1). Since the displacement voltage for an intermittent fault is not reaching the same level as for a permanent fault a lower typical percentage value of 30% is recommended:

V0> threshold value = 0.3 · 57.7 V ≈ ***17 V***

Recommendation B: approach to detect ground faults till a defined maximum ground fault resistance

This setting is made with relation to a defined maximum ground-fault resistance, e.g. 3 kΩ. The respective description, including a specific network example, is given in chapter 7.1.3

Maximum operational V0 special attention should be given

With the parameter Maximum operational V0, you define the maximum operational zero-sequence voltage $V0_{op,max}$. The setting is needed for special reset conditions.

The secondary operational zero-sequence voltages can be obtained by reading the residual voltage VN_{sec} or the zero-sequence voltage $V0_{sec}$ under the symmetrical components from the device or via DIGSI.

In case you read the secondary residual voltage VN_{sec}, you convert it to $V0_{sec}$ with the **Matching ratio Vph / VN** parameter. Its setting is usually √3.

Recommendation:

- If the maximum operational zero-sequence voltage is known, set the threshold to 1.2 $V0_{op,max}$
- If the maximum operational zero-sequence voltage is unknow and cannot be determined for any reason, please keep the default of ***3V***

Example:

Maximum operational secondary residual voltage reading: VN_{sec} = 5.0 V

Matching ratio Vph / VN = √3

$V0_{sec}$ = 5.000 V ·√3 / 3 = 2.887 V

Maximum operational V0 = 2.887 V ·1.2 = ***3.464 V***

3I0> threshold for pickup

In ring or meshed systems, you can use this parameter to reduce the number of ground-fault reporting devices. The parameter needs to be set according to the user experience on the specific network. For radial systems, normally you can keep the default value of 0 A which sets this parameter to inactive.

Recommendation: set this functionality inactive by keeping the default value of ***0 A***

3I0> threshold for operate

The setting is significant only for optional trip logic for switching off permanent ground faults. Select the setting such that the static ground-fault current exceeds the threshold value. You can disable this criterion by setting the value to 0 A.

If the function shall be applied to trip intermittent ground faults (which is the case for this specific chapter description) the threshold could be undershoot during the phase between fault extinction and next restrike, causing the operate delay timer to reset. To avoid this risk the threshold should be set to 0 A.

Recommendation: set this criterion inactive by setting the threshold to ***0 A***

Operate delay

Must be set according to individual application requirements.

Dropout delay **special attention should be given**

Parameter **Dropout delay** allows you to use the stage effectively for tripping intermittent ground faults. With the dropout delay, the pickup state after fault extinction is held until the next ignition (re-strike). Thus, the operate delay is not reset and can trip the fault. Set the time to a value within which the new ignition can still be assigned to the previous ignition. Typical values are in a range between several hundred milliseconds and a few seconds.

General Recommendation: The **Dropout delay** timer should not be set higher than 1/3 or the operate delay. Otherwise, there is a risk that the stage trips on one single ground fault transient.

E.g. if the operate delay is 2 s, the dropout delay timer should be set < 0.66 s.

Example 1:

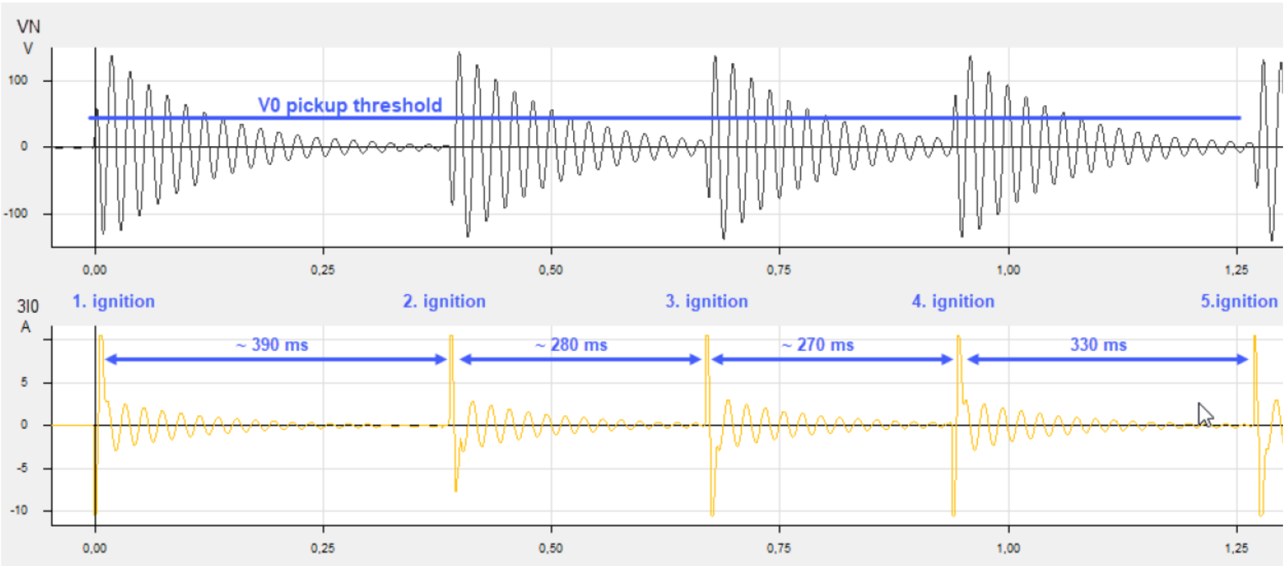


Figure 24: Intermittent ground fault in a cable

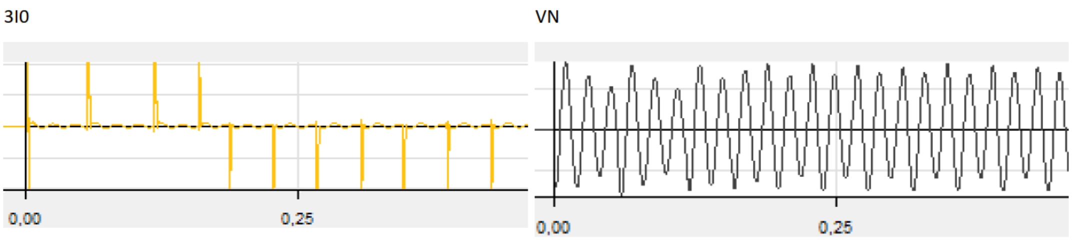
In the preceding figure an ordinary intermittent cable ground-fault is presented. Immediately after an ignition the extinction takes place, and the zero sequence signals are decaying. During the decaying phase the V0> pickup threshold is undershooting (as indicated in the figure). Without applying the dropout delay the **operate delay** timer would be reset and no tripping would take place.

The duration between the single ignitions varies in the range from approx. 270 ms to 390 ms. A set dropout delay of e.g. 500 ms would safely ensure that the V0> pickup threshold is exceeded again with the next ignition and that the operate delay timer continues to run. If the operate delay would be set to e.g. 2 s the stage would trip after 2 s.

For the example 1: **dropout delay** = ***0.5 s***

It must be noted that tripping could then take place 2 s (= operate delay) after the first fault ignition with only 2 re-strikes (assumptions that a) **V0> threshold value** is set to a quite low value so that undershooting this value takes place ~200 ms after fault extinction, and b) the re-striking take place shortly before the dropout delay expires)

Example 2:



Example 2 is an intermittent ground fault with much more frequent re-striking (ignitions). Consequently, the decaying time between extinction and next ignition is too short to allow VN dropping below the V0> pickup threshold. If one could rely on this periodically frequent re-striking no dropout delay would be required. However, since such a characteristic is not fully reliable, we recommend to also set a dropout delay of e.g. 0.5 s, if the operate delay is set at least 3 times higher (> 1.5 s).

For the example 2: **dropout delay** = ***0.5 s***

5.2.2 Routing notes

We recommend the following routing for operational log (column O), fault log (column F) and Recorder. This routing allows reliable ground-fault clarification.

Transient Ground Fault Function:

				Recorder	Logs	
Signals	Fav	Number	Type	Signal	O	F
(All)	..	(All)	...	(All)	...	...
Trans.Gnd.flt1		21.1861.13...		*	*	*
>Block stage		21.1861.13...	SPS		X	
Mode (controllable)		21.1861.13...	ENC			
Inactive		21.1861.13...	SPS		X	
Behavior		21.1861.13...	ENS		X	
Health		21.1861.13...	ENS		X	
Ground fault		21.1861.13...	ACD			X
Pickup		21.1861.13...	ACD	*		X
general			SPS			
forward			SPS	X		
backward			SPS	X		
unknown			SPS	X		
Operate delay exp..		21.1861.13...	ACT			
Operate		21.1861.13...	ACT	*		X
general			SPS	X		

Figure 25: Signal list with recommended routing for the Transient Ground Fault Function

Function block **General:**

				Recorder	Logs	
Signals	Fav	Number	Type	Signal	O	F
(All)	..	(All)	...	(All)	...	...
67Ns Dir.sens GFP1		21.1861		*	*	*
Group indicat.		21.1861.4501				
General		21.1861.2311		*	*	*
Ground fault		21.1861.23...	ACD			X
Flt. extinction det.		21.1861.23...	SPS			X
Pos. measuring wi..		21.1861.23...	SPS	X		
Phi(I,V)		21.1861.23...	MV			

Figure 26: Signal list with recommended routing for the FB General

We recommend routing the signal **Pos. measuring window** into the fault recorder. This signal is essential for later ground-fault clarifications.

5.2.3 Further notes

Avoiding floods of logs and recordings in case of intermittent ground faults

The stage is fully immune against generating such floods during intermittent ground faults. No measures need to be taken.

Avoiding floods of signals in case of intermittent ground faults

The stage is fully immune against generating such floods during intermittent ground faults. No measures need to be taken.

5.3 Intermittent Ground Fault Blocking Stage

Most functions designed for the detection of permanent ground faults may show a disadvantageous behavior in case of intermittent ground faults. An example of these functions is the **3I0> stage with cosφ or sinφ measurement**. In case of an intermittent ground fault, these functions may cause a flood of information due to continuously exceeding and dropping below thresholds. Also, short-term wrong directional results are possible due to the nature of the intermittent signals. To avoid this disadvantage, these functions should be blocked in case of intermittent grounds faults. The **Intermittent ground-fault blocking** stage detects and classifies a ground fault as intermittent and sends a blocking signal to the respective stages. The receiving stages – if configured accordingly – are then automatically blocked.

5.3.1 Setting notes

The following figure shows the function settings. In the following setting notes and recommendations are given.

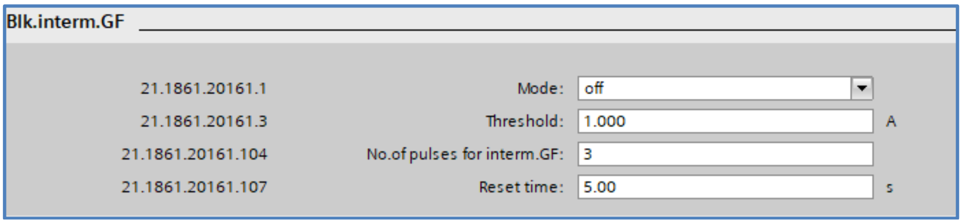


Figure 27: Setting list (in default state)

Mode

With the mode parameter the function block is switched on.

Threshold

With the parameter **Threshold**, you set the intermittent ground-fault pickup threshold. This setting must be coordinated with the applied protection stage for detecting a permanent ground fault, which shall be blocked for an intermittent fault, for example, the **3I0> stage with cos φ or sin φ measurement**. The parameter **Threshold** must be set to the same value as the respective **3I0> threshold value** of the protection stage.

In case of the **3I0> stage with cosφ or sinφ measurement**, the value from the parameter **(_:12601:101) 3I0> threshold value** must be applied for the parameter **Threshold**. It is not required to set a lower value than the respective **3I0> threshold value** of the protection stage.

Example:

- Stage **3I0> stage with cosφ or sinφ measurement**, parameter **3I0> threshold value = *105 mA*** (secondary)
- Stage **Intermittent ground-fault blocking,** parameter **threshold = *105 mA*** (secondary)

No.of pulses for intermittent.GF

With the parameter **No.of pulses for interm.GF**, you set the total number of pulse counts at which the ground fault is classified as an intermittent fault. We consider three pulses as a good classification criterion.

Recommendation: We recommend keeping the default, which is ***3***.

The following figure shows a typical intermittent ground fault in a cable with high-frequent re-striking. The detected pulses and their counts are indicated. For this specific case the fault would be classified as "intermittent" with pulse indication "3", approx. 170 ms after ground fault entry.

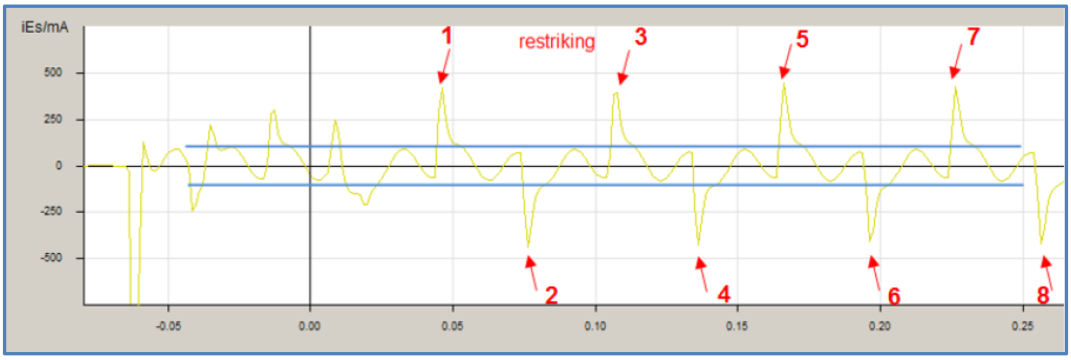


Figure 28: Typical intermittent cable ground-fault with high-frequent re-striking

The following figure shows an intermittent ground fault with lower frequent re-striking. For this specific case the fault would be classified as “intermittent” with pulse indication “3”, approx. 650 ms after ground fault entry.

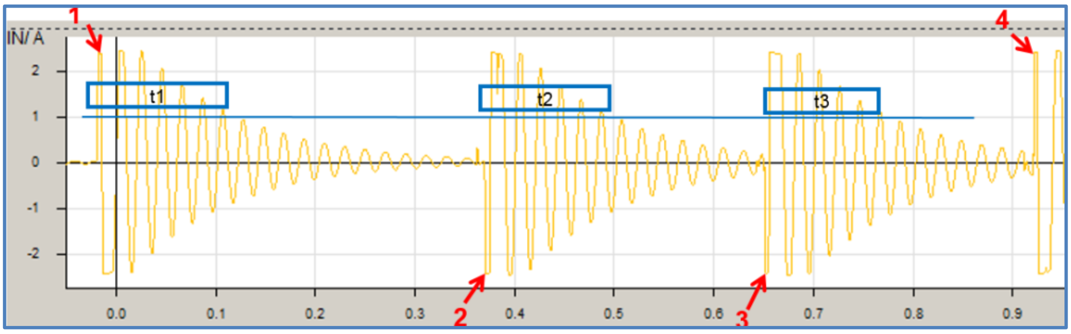


Figure 29: Intermittent cable ground-fault with lower frequent re-striking

Reset time

With the parameter **Reset time**, you define the minimum time between 2 adjacent ground faults. If the time is larger than the Reset time, the intermittent ground fault is considered as disappeared. This can mean that the ground fault has disappeared or that the intermittent ground fault has changed to a static ground fault. The function resets and a blocking is terminated. A typical value to consider an intermittent fault as gone is 5 s.

Recommendation: We recommend keeping the default, which is ***5 s***.

5.3.2 Routing notes

We recommend the following routing for operational log (column O), fault log (column F) and Recorder. This routing allows reliable ground fault clarification.

				Recorder	Logs	
Signals	Fav	Number	Type	Signal	O	F
(All)	..	(All)	...	(All)	...	...
Blk.interm.GF		21.1861.20...		*	*	*
>Reset blocking		21.1861.20...	SPS		X	
Intermittent gnd.flt.		21.1861.20...	SPS	X	X	X
Reset time running		21.1861.20...	SPS		X	X

Figure 30: Signal list

6 Transient ground fault detection

According to chapter 2.1 the function selection tree for an transient ground fault is as following.

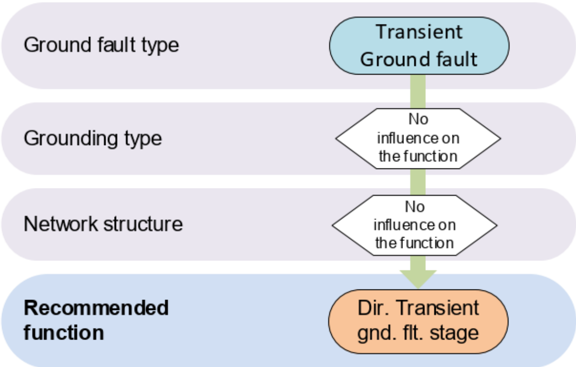


Figure 31: function selection tree-structure for a transient ground fault

Note: the function application in this chapter assumes that the function shall be only applied to detect a transient ground fault. I.e. the function is not applied for tripping.

6.1 Function "Dir. Transient ground fault stage"

6.1.1 Setting notes

The following figure shows the stage settings. In the following setting notes and recommendations are given. The **standard function control** is not explained here. Further information can be taken from the device manual.

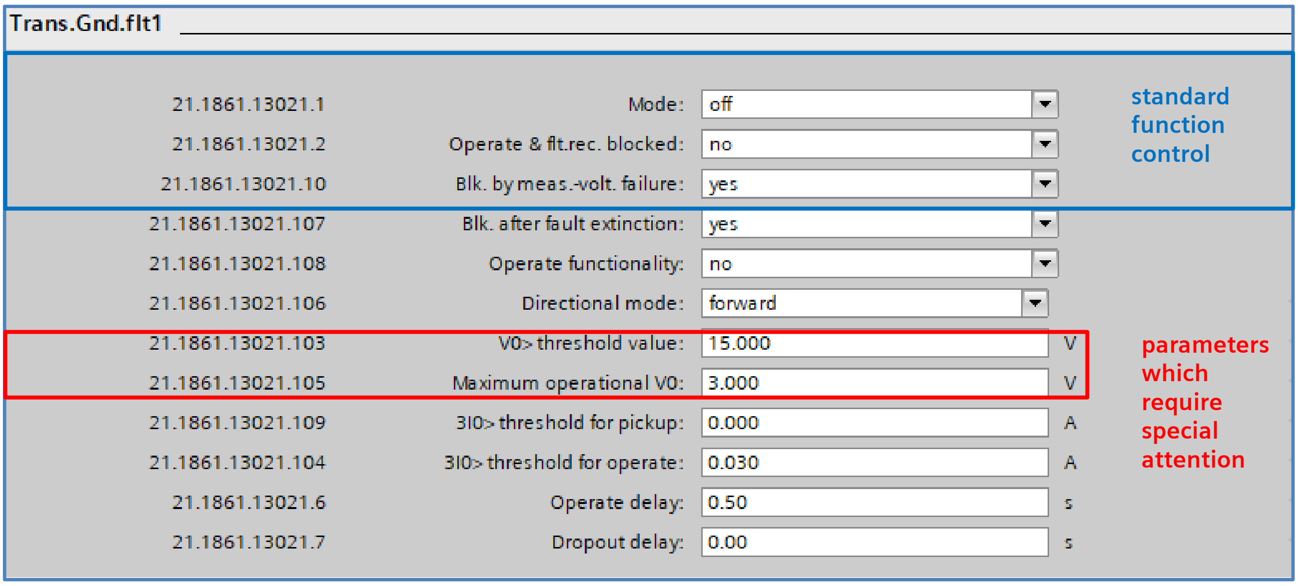


Figure 32: Setting list (in default state)

<u>**Blk.after fault extinction**</u>

Since in this application scenario (this chapter) the stage is applied for transient ground fault detection, the default setting can be applied, which is ***yes***.

<u>**Operate functionality**</u>

Since in this application scenario (this chapter) the stage is applied for transient ground fault detection, the default setting can be applied, which is ***no***.

Directional mode

The parameter **Directional mode** defines whether the pickup of the stage occurs in forward or backward direction. Usually, the stage should operate in case of forward ground faults, which requires to set ***forward***.

V0> threshold value special attention should be given

The V0 threshold setting is derived for the network. The derived setting is identically for all feeders. In the following we are providing two setting recommendations:

1. **Rule of thumb approach**: this approach is simple and gives good detection results if no detection up to a defined ground fault resistance is required
2. Approach to detect ground faults till a **defined ground-fault resistance**: this approach should be followed if ground faults must be detected up to a defined ground-fault resistance.

Recommendation A: rule of thumb approach

The threshold is set to a typical percentage value of the full displacement voltage (for further information please refer to the description (example given in chapter 7.1). Since the displacement voltage for a transient fault is not reaching the same level as for a permanent fault a lower typical percentage value of 30% is recommended:

V0> threshold value = 0.3 · 57.7 V ≈ ***17 V***

Recommendation B: approach to detect ground faults till a defined maximum ground fault resistance

This setting is made with relation to a defined maximum ground-fault resistance, e.g., 3 kΩ. The respective description, including a specific network example, is given in chapter 7.1.3

Maximum operational V0 special attention should be given

With the parameter Maximum operational V0, you define the maximum operational zero-sequence voltage $V0_{op,max}$. The setting is needed for special reset conditions.

The secondary operational zero-sequence voltages can be obtained by reading the residual voltage VN_{sec} or the zero-sequence voltage $V0_{sec}$ under the symmetrical components from the device or via DIGSI.

In case you read the secondary residual voltage VN_{sec}, you convert it to $V0_{sec}$ with the **Matching ratio Vph / VN** parameter. Its setting is usually √3.

Recommendation:

- If the maximum operational zero-sequence voltage is known, set the threshold to 1.2 $V0_{op,max}$
- If the maximum operational zero-sequence voltage is unknow and cannot be determined for any reason, please keep the default of ***3V***

Example:

Maximum operational secondary residual voltage reading:

VN_{sec} = 5.0 V Matching ratio Vph / VN = √3

$V0_{sec}$ = 5.000 V ·√3 / 3 = 2.887 V

Maximum operational V0 = 2.887 V ·1.2 = ***3.464 V***

3I0> threshold for pickup

In ring or meshed systems, you can use this parameter to reduce the number of ground-fault reporting devices. The parameter needs to be set according to the user experience on the specific network. For radial systems, normally you can keep the default value of 0 A which sets this parameter to inactive.

Recommendation: set this functionality inactive by keeping the default value of ***0 A***

3I0> threshold for operate,

These settings are not relevant since the operate functionality is not applied. Default settings can be applied.

Operate delay,

These settings are not relevant since the operate functionality is not applied. Default settings can be applied.

Dropout delay

These settings are not relevant since the operate functionality is not applied. Default settings can be applied.

6.1.2 Routing notes

We recommend the following routing for operational log (column O), fault log (column F) and Recorder. This routing allows reliable ground-fault clarification.

Transient Ground Fault Function:

				Recorder	Logs	
Signals	Fav	Number	Type	Signal	O	F
(All)	..	(All)	...	(All)	...	...
Trans.Gnd.flt1		21.1861.13...		*	*	*
>Block stage		21.1861.13...	SPS		X	
Mode (controllable)		21.1861.13...	ENC			
Inactive		21.1861.13...	SPS		X	
Behavior		21.1861.13...	ENS		X	
Health		21.1861.13...	ENS		X	
Ground fault		21.1861.13...	ACD			X
Pickup		21.1861.13...	ACD	*		X
general			SPS			
forward			SPS	X		
backward			SPS	X		
unknown			SPS	X		
Operate delay exp..		21.1861.13...	ACT			
Operate		21.1861.13...	ACT	*		X

Figure 33 Signal list with recommended routing for the Transient Ground Fault Function

Function block **General:**

				Recorder	Logs	
Signals	Fav	Number	Type	Signal	O	F
(All)	..	(All)	...	(All)	...	...
67Ns Dir.sens GFP1		21.1861		*	*	*
Group indicat.		21.1861.4501				
General		21.1861.2311		*	*	*
Ground fault		21.1861.23...	ACD			X
Flt. extinction det.		21.1861.23...	SPS			X
Pos. measuring wi..		21.1861.23...	SPS	X		
Phi(I,V)		21.1861.23...	MV			

Figure 34 Signal list with recommended routing for the FB General

We recommend routing the signal **Pos. measuring window** into the fault recorder. This signal is essential for later ground-fault clarifications.

6.1.3 Further notes

Avoiding floods of logs and recordings in case of intermittent ground faults

The stage is fully immune against generating such floods during intermittent ground faults. No measures need to be taken.

Avoiding floods of signals in case of intermittent ground faults

The stage is fully immune against generating such floods during intermittent ground faults. No measures need to be taken.

7 V0 and 3I0 threshold considerations and examples

7.1 V0 Pickup threshold

In the following different approaches are described how the V0 setting value for a pickup or release threshold can be obtained.

A **V0 threshold** setting is derived for the network. The derived setting is identically for all feeders.

General V0 thresholds convention

All device V0 thresholds are set as **zero-sequence voltage V0** according to definition. In case of full voltage displacement, the open-delta voltage Ven is 100 V for a typical transformer ratio. The equivalent secondary V0 voltage is then 100/√3 = 57.7 V.

Different approaches to obtain the threshold value are:

1. The user has historical experiences and good experiences with a V0 threshold value. The user reuses his previous threshold values. Please consider setting the threshold with relation to V0. You might have to divide your former setting value (if this was set with reference to Ven) by e.g. √3.

2. A typical V0> threshold value is applied.
   Typical values are 30%, 40%, or 50% of the full voltage displacement condition:
   30%: V0> threshold = 57.7 * 0.3 ≈ 17 V
   40%: V0> threshold = 57.7 * 0.4 ≈ 23 V
   50%: V0> threshold = 57.7 * 0.5 ≈ 29 V

3. The threshold is set according to the requirement to detect ground faults till a defined maximum ground fault resistance, please refer to the following chapter.

7.1.1 V0 Pickup threshold related to a defined ground fault resistance, resonant-grounded networks

In this chapter a well proven approximation is given how to derive the V0 threshold from the network data and the preset ground fault resistance:

Equation 1: $V0 = v_{rel} \frac{V_{rated}}{\sqrt{3}}$ with

Equation 2: $v_{rel} = \frac{1}{\sqrt{1+2\cdot\varepsilon\cdot d+\varepsilon^2\cdot d^2+\varepsilon^2\cdot v^2}}$ with

Equation 3: $\varepsilon = \frac{\sqrt{3}\cdot R_F\cdot I_{CE}}{V_{rated}}$

V0: Zero sequence voltage (as primary value) for a defined network and a preset ground fault resistance R_F

V_{rated}: rated primary network voltage, in V primary (value given)

v_{rel}: factor that describes the reduction of the full displacement voltage in dependency of the ground fault resistance (calculated form given / known values)

ε: aux. quantity (calculated from given / known values)

d: Damping d, in % (value known, or can be taken from the arc-suppression coil controller)

v: detuning degree, in % (value given)
(for over-compensation: positive value, for under-overcompensation: negative value)

R_F: Ground fault resistance till which a ground fault shall be detected, in Ω (preset value)

I_{CE}: Capitative ground current of the network (value given)

Threshold calculation example acc. sample network S1 (radial, resonant-grounded)

In the following a V0 threshold calculation example is given for sample network S1, described in chapter 7.3.

- Ground faults up to a maximum ground fault resistance of 3kΩ shall be detected:
  - R_F = 3kΩ
- Network data is taken from the sample network S1:
  - I_{CE} = 300 A
  - V_{rated} = 20 kV
  - d = 3.1 %
  - ν = 4 %
- Voltage transformer ratio: r = 20 kV / 100 V = 200

Calculation:

Equation 3:

$$\varepsilon = \frac{\sqrt{3}\ \cdot\ 3000\,\Omega \cdot\ 300\,A}{20000\,V}$$

Result: $\varepsilon \approx 78$

Equation 2:

$$v_{rel} = \frac{1}{\sqrt{1+2\ \cdot\ 78\ \cdot\ 0.031\ +\ 78^2\ \cdot\ 0.031^2 +\ 78^2\ \cdot\ 0.04^2}}$$

Result: v_{rel} = 0.216

Equation 1:

$$V0 = 0.216\ \frac{20000\,V}{\sqrt{3}}$$

Result: V0 = 2494 V
$V0_{sec}$ = 2494 V / r = 2494 V / 200 = 12.47 V

Between theoretically calculated and real setting value we consider a safety margin of approx. 20%, resulting in the following threshold setting:

V0 threshold = 10 V

For the detection of ground faults up to 3kΩ ground fault resistance V0 pickup or release thresholds should be set to 10 V (secondary).

7.1.2 V0 Pickup threshold related to a defined ground fault resistance, isolated networks

For isolated networks the consideration according to chapter 7.1.1 can be simplified.

Referencing Equation 2:

$$v_{rel} = \frac{1}{\sqrt{1+2\ \cdot\ \varepsilon\ \cdot\ d\ +\ \varepsilon^2\ \cdot\ d^2 +\ \varepsilon^2\ \cdot\ v^2}}$$

For **isolated networks**:

d: Damping d is set to 0, because there is no damping through the arc-suppression coil and the remaining ohmic damping is neglectable

ν: detuning degree ν is set to -1 (= -100%) because no compensation is present

This simplifies Equation 2 to:

Equation 4: $$v_{rel} = \frac{1}{\sqrt{1+\varepsilon^2}}$$

with (Equation 3) $$\varepsilon = \frac{\sqrt{3} \cdot R_F \cdot I_{CE}}{V_{rated}}$$

and (Equation 1) $$V0 = v_{rel} \frac{V_{rated}}{\sqrt{3}}$$

v_{rel}: factor that describes the reduction of the full displacement voltage in dependency of the ground fault resistance (calculated form given / known values)

ε: aux. quantity (calculated from given / known values)

R_F: Ground fault resistance till which a ground fault shall be detected, in Ω (preset value)

I_{CE}: Capitative ground current of the network (value given)

V_{rated}: rated primary network voltage, in V primary (value given)

V0: Zero sequence voltage (as primary value) for a defined network and a preset ground fault resistance R_F

Threshold calculation example

In the following a V0 threshold calculation example is given

- Ground faults up to a maximum ground fault resistance of 300 Ω shall be detected:
  - R_F = 300 Ω
- Network data:
  - I_{CE} = 200 A
  - V_{rated} = 20 kV
- Voltage transformer ratio: r = 20 kV / 100 V = 200

Calculation:

Equation 3:

$$\varepsilon = \frac{\sqrt{3} \cdot 300\,\Omega \cdot 200\,A}{20000\,V}$$

Result: $\varepsilon \approx 5.2$

Equation 4:

$$v_{rel} = \frac{1}{\sqrt{1+5.2^2}}$$

Result: v_{rel} = 0.189

Equation 1:

$$V0 = 0.189 \frac{20000\,V}{\sqrt{3}}$$

Result: V0 = 2182 V
$V0_{sec}$ = 2182 V / r = 2494 V / 200 = 10.9 V

Between theoretically calculated and real setting value we consider a safety margin of approx. 20%, resulting in the following threshold setting:

V0 threshold = 8.7 V

For the detection of ground faults up to 300 Ω ground fault resistance V0 pickup or release thresholds should be set to 8.7V (secondary).

7.1.3 V0 Pickup threshold consideration for intermittent ground faults

From network simulations and real field case recordings it can be noted that frequent ground-fault re-striking significantly increases the zero-sequence voltage V0, but not completely to the same level as for a permanent ground fault. This is also true for high-ohmic ground faults. In this regard Figure 35 shows the VN voltage rise during the re-striking period for a very high ohmic ground fault (7…18 kΩ).

Recommendation: The V0 pickup threshold consideration made in chapter 7.1.1 are true for permanent ground faults. Since V0 for intermittent ground faults does not fully reach the V0 level for permanent faults we propose to set the **V0 threshold** to **60%** of the V0 value derived in chapter 7.1.1 if the function should detect intermittent ground faults and if ground-fault to a defined ground-fault resistance should be detected.

Example:

- $V0_{sec}$ value for permanent ground-faults up to 3kΩ ground fault resistance, according to chapter 7.1.1: **$V0_{sec}$** = 12.47 V
- V0 threshold for intermittent ground faults: **V0 threshold** = 12.47 V · 0.6 ≈ **7.5 V**

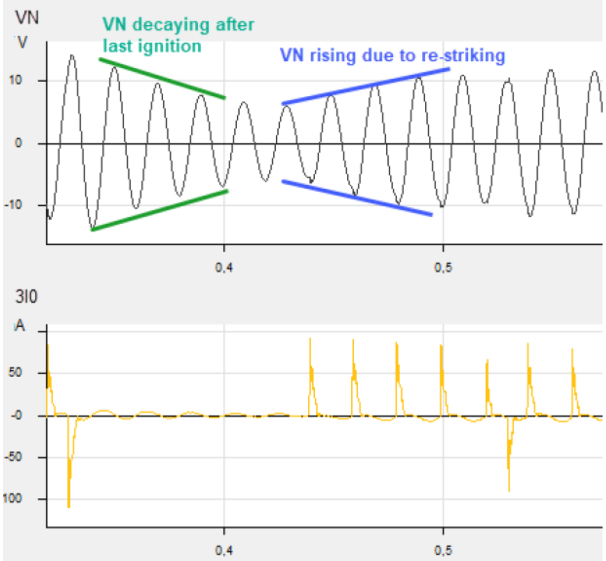


Figure 35: very high-ohmic intermittent ground fault (7…18 kΩ)

7.2 3I0 thresholds for radial networks

In the following different approaches are described how a 3I0 setting value for a pickup or release threshold can be obtained (for radial networks).

3I0 threshold settings related to the **total 3I0** (active and reactive current) **must be derived for each network feeder** individually. Each feeder requires a specific setting. Most 3I0 function thresholds relate to the total 3I0.

For the **Cosφ** function additionally one threshold relates to the active (ohmic) 3I0 component 3I0active. **The active (ohmic) 3I0 component $3I0_{active}$ is feeder independent**.

- The threshold **for the active (ohmic) 3I0 component** can be set **identically** for all feeders.

For both values ($3I0_{total}$ and $3I0_{active}$) considerations are made in the following.

Different approaches to obtain the threshold value are:

1. The user has historical experiences and good experiences with 3I0 threshold values per feeder. The user reuses his previous threshold values.

2. A “rule of thumb” setting value approach can be applied. This approach is simple, requires only very little calculation efforts and gives good detection results, when no detection up to a defined ground fault resistance is required. Please refer to chapter 7.2.1.

3. The threshold is set according to the requirement to detect ground faults till a defined maximum ground fault resistance, please refer to the chapter 7.2.2.

7.2.1 $3I0_{active}$ threshold related to "rule of thumb" approach, resonant-grounded networks

In this chapter a simple rule of thumb approach is given for the **$3I0_{active}$** determination, which is required for the **Cosφ** stage. $3I0_{active}$ **is feeder independent**.

The active ground current $3I0_{active}$ can be determined via the following formula:

Equation 5: $$3I0_{actice} = d \cdot I_{CE}$$

$3I0_{active}$: Active zero sequence current (as primary value) for zero ground fault resistance R_F, this value is identical for all feeders of the network

d: Damping d, in % (value known, or can be taken from the arc-suppression coil controller)

I_{CE}: Capitative ground current of the network (value given)

The rule of thumb is to set the respective threshold value in a range between 25% to 50% of the active ground current $3I0_{active}$.

$3I0_{active}$ threshold = 0.25 … 0.5 · $3I0_{active}$ e.g.: 0.3 · $3I0_{active}$

Threshold calculation example acc. sample network S1 (radial, resonant-grounded)

In the following a $3I0_{active}$ threshold calculation example is given for sample network S1, described in chapter 7.3.

- Network data:
  - I_{CE} = 300 A
  - d = 3.1 %
- Current transformer ratio: r = 80 A / 1 A = 80

Calculation:

Equation 5:

$3I0_{actice} = d \cdot I_{CE}$ $= 0.031 \cdot 300\,A$ = 9.3A

Result: $3I0_{active}$ = 9.3 A

$3I0_{active;sec}$ = 9.3 A / r = 9.3 A / 80 ≈ 116 mA

$3I0_{active}$ threshold = 0.3 · $3I0_{active}$ (rule of thumb)

$3I0_{active}$ threshold = 0.3 · 116 mA = **35 mA**

The parameter **Min. polar.3I0> for dir.det.** of the **Cosφ** stage is set to **35 mA for all feeders** in this network.

7.2.2 3I0 threshold related to a defined ground fault resistance, resonant-grounded networks

In this chapter a well proven approximation is given how to derive the 3I0 thresholds from the network data and the preset ground fault resistance, for resonant-grounded networks:

Equation 6: $$3I0_{total,fd} = \sqrt{(3I0_{active})^2 + (3I0_{reactive})^2}$$

Equation 7: $$3I0_{reactve} = v_{rel} \cdot (v \cdot I_{CE} + I_{CE.feeder})$$

Equation 8: $$3I0_{actice} = v_{rel} \cdot d \cdot I_{CE}$$

$3I0_{total,fd}$: Total zero sequence current (as primary value) for a preset ground fault resistance R_F, per feeder

$3I0_{active}$: Active zero sequence current (as primary value) for a preset ground fault resistance R_F for the network, acc. to Equation 8, this value is identical for all feeders of the network

$3I0_{reactive}$: Reactive zero sequence current (as primary value) for a preset ground fault resistance R_F, per feeder

$I_{CE,feeder}$: Capitative ground current of network feeder (value given)

v_{rel}: factor that describes the reduction of the full displacement voltage in dependency of the ground fault resistance (calculated form given / known values) acc. to Equation 2

ε: aux. quantity (calculated from given / known values) acc. to Equation 3

d: Damping d, in % (value known, or can be taken from the arc-suppression coil controller)

ν: detuning degree, in % (value given)
(for over-compensation: positive value, for under-overcompensation: negative value)

R_F: Ground fault resistance till which a ground fault shall be detected, in Ω (preset value)

I_{CE}: Capitative ground current of the network (value given)

V_{rated}: rated primary network voltage, in V primary (value given)

Threshold calculation example acc. sample network S1 (radial, resonant-grounded)

In the following a 3I0 threshold calculation example is given for sample network S1, described in chapter 7.3. The example is made for feeder F3.

- Ground faults up to a maximum ground fault resistance of 3kΩ shall be detected:
  - R_F = 3kΩ
- Network data is taken from the sample network S1:
  - I_{CE} = 300 A
  - $I_{CE,feeder F3}$ = 28 A
  - V_{rated} = 20 kV
  - d = 3.1 %
  - ν = 4.0 %
- Current transformer ratio: r = 80 A / 1 A = 80

Calculation:

Equation 3:

$$\varepsilon = \frac{\sqrt{3}\ \cdot\ 3000\,\Omega \cdot\ 300\,A}{20000\,V}$$

Result: $\varepsilon \approx 78$

Equation 2:

$$v_{rel} = \frac{1}{\sqrt{1 + 2\ \cdot\ 78\ \cdot\ 0.031\ +\ 78^2\ \cdot\ 0.031^2 +\ 78^2\ \cdot\ 0.04^2}}$$

Result: v_{rel} = 0.216

Equation 8:

$3I0_{actice} = v_{rel} \cdot d\ \cdot\ I_{CE}$ $= 0.216\ \cdot 0.031\ \cdot\ 300\,A$ = 2.01 A

Result: **$3I0_{active}$ = 2.01 A**
$3I0_{active;sec}$ = 2.01 A / r = 2.01 A / 80 ≈ **25.1 mA**

Equation 7:

$3I0_{reactve} =\ 0.216 \cdot (0.04\ \cdot\ 300\,A +\ 28\,A)$

Result: **$3I0_{reactiv}$ ≈ 8.6 A**

Equation 6:

$3I0_{total,fd} =\ \sqrt{(2.01)^2 + (8.6)^2}$

Result: **$3I0_{total,fd}$ ≈ 8.8 A**
$3I0_{total,fd;sec}$ = 8.8 A / r = 8.8 A / 80 ≈ **110 mA**

The threshold values are set approx. 20 % below the calculated values, which serves as safety margin:

- **$3I0_{total,fd\ F3}$ threshold** = 110 mA · 0.8 **≈ 88 mA**
- **$3I0_{active}$ threshold** = 25.1 mA · 0.8 **≈ 20 mA** **(required in CosPhi function)**

For the detection of ground faults in feeder F3 up to 3kΩ ground fault resistance the $3I0_{total}$ thresholds should be set to 88mA (secondary). The $3I0_{active}$ threshold which is additionally required in the CosPhi function should be set to 20mA (secondary).

7.2.3 3I0 threshold related to a defined ground fault resistance, isolated networks

In this chapter a well proven approximation is given how to derive the 3I0 thresholds from the network data and the preset ground fault resistance, for isolated networks:

Equation 9: $3I0_{cap,fd} = v_{rel} \cdot (I_{CE} - I_{CE,feeder})$

Equation 10: $3I0_{total,fd} \approx 3I0_{cap.,fd}$

Capacitive and total sequence current per feeder is approximately the same, since the active zero-sequence current is neglectable for an isolated network

$3I0_{cap.,fd}$: Capacitive zero sequence current (as primary value) for a preset ground fault resistance R_F, per feeder

$3I0_{total,fd}$: Total zero sequence current (as primary value) for a preset ground fault resistance RF, per feeder

I_{CE}: Capitative ground current of the network (value given)

$I_{CE,feeder}$: Capitative ground current of network feeder (value given)

v_{rel}: factor that describes the reduction of the full displacement voltage in dependency of the ground fault resistance (calculated form given / known values) acc. to Equation 4

ε: aux. quantity (calculated from given / known values) acc. to Equation 3

R_F: Ground fault resistance till which a ground fault shall be detected, in Ω (preset value)

V_{rated}: rated primary network voltage, in V primary (value given)

Threshold calculation example

In the following a 3I0 threshold calculation example is given:

- Ground faults up to a maximum ground fault resistance of 300 Ω shall be detected:
  - R_F = 300 Ω
- Network data:
  - I_{CE} = 200 A
  - $I_{CE,feeder}$ = 40 A
  - V_{rated} = 20 kV
- Current transformer ratio (core balanced CT): r = 80 A / 1 A = 80

Calculation:

Equation 3:

$$\varepsilon = \frac{\sqrt{3} \cdot 300\,\Omega \cdot 200\,A}{20000\,V}$$

Result: $\varepsilon \approx 5.2$

Equation 4:

$$v_{rel} = \frac{1}{\sqrt{1 + 5.2^2}}$$

Result: v_{rel} = 0.189

Equation 9:

$$3I0_{cap,fd} = 0.189 \cdot (200\,A - 40\,A)$$

Result: **$3I0_{cap,fd}$ ≈ 30 A**
$3I0_{cap,fd;sec}$ = 30 A / r = 30 A / 80 ≈ **375 mA**

Equation 10:

$$3I0_{total,fd} \approx 3I0_{cap.,fd}$$

Result: **$3I0_{total,fd}$ ≈ 30 A**
$3I0_{total,fd;sec}$ = 30 A / r = 30 A / 80 ≈ **375 mA**

The threshold values are set approx. 20 % below the calculated values, which serves as safety margin:

- **$3I0_{total,fd}$ threshold** = 375 mA · 0.8 **≈ 300 mA**

For the detection of ground faults in feeder up to 300 Ω ground fault resistance the $3I0_{total}$ thresholds should be set to 300 mA (secondary). The **$3I0_{capacitive}$ threshold** (parameter **Min.polar.3I0> for dir.det.**), which is additionally required in the SinPhi function, should be set to the same value (300 mA).

7.2.4 3I0 threshold related to a defined ground fault resistance consideration for intermittent ground faults

Recommendation:

The 3I0 threshold considerations made in chapter 7.2.2 relate to a **permanent** ground-fault. During an **intermittent** ground fault, the 3I0 ground fault current level will not fully reach the fault current level for a permanent ground fault. Therefore, we propose to set the **3I0 threshold** to **60%** of the value derived in chapter 7.2.2 if the function should detect intermittent ground faults and if ground-fault to a defined ground-fault resistance should be detected.

Example:

- 3I0 value for permanent ground-faults up to 3kΩ ground fault resistance, according chapter 7.2.2:
  $3I0_{total,fd,sec.}$ = 110 mA
- 3I0 threshold for intermittent ground faults: **3I0 threshold** = 110 mA · 0.6 = **66 mA**

7.3 Sample network S1: radial, resonant-grounded

The following figure shows a sample network for a radial, resonant-grounded 20 kV network, which serves for the explanation of setting recommendations given the “setting notes” chapters for the described functions.

This sample network consists of:

- radial pure overhead line feeders with different lengths (F1, F2)
- radial mixed overhead and cable feeders with similar length (F3, F4)
- radial pure cable feeders cable feeder with different lengths (F5, F6, F7, F8)
- closed cable ring (F9, F10)
- Network data:
    - Rated network voltage, V_{rated} = 20 kV
    - Capitative ground current of the network, I_{CE} = 300 A
    - 4% overcompensation = 12 A, Arc-suppression coil current I_{ASC} = 312 A
    - Ohmic coil losses = 6 A
    - Damping d = 3.1% (The damping should be known, e.g., it is provided as measuring value by the arc-suppression coil controller)
    - Active ground-current component I_R= 9.3 A (= d · I_{CE})
    - Operational V0 = 0.8 V (V0 under fault free condition)

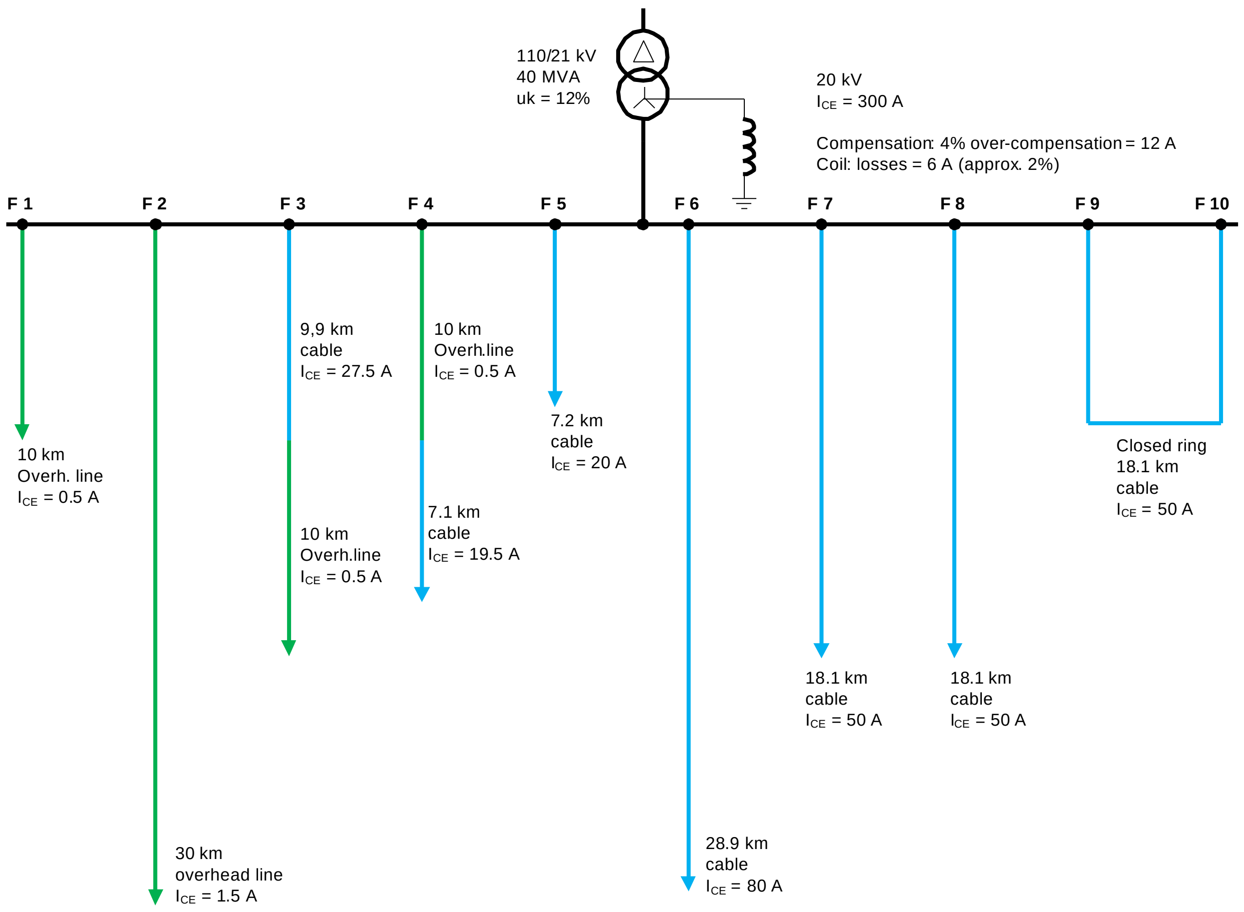


Figure 36: Sample network, resonant-grounded network

Published by
Siemens AG 2021

Smart Infrastructure
Digital Grid
Automation Products
Humboldtstr. 59
90459 Nuremberg, Germany

www.siemens.com/siprotec

Our Customer Support Center
provides a 24-hour service.
Siemens AG
Smart Infrastructure – Digital Grid
Customer Support Center
E-Mail:
energy.automation@siemens.com