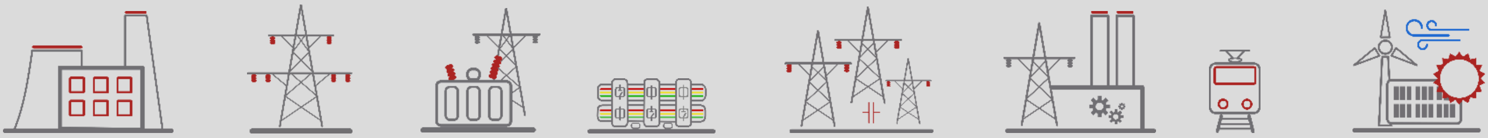

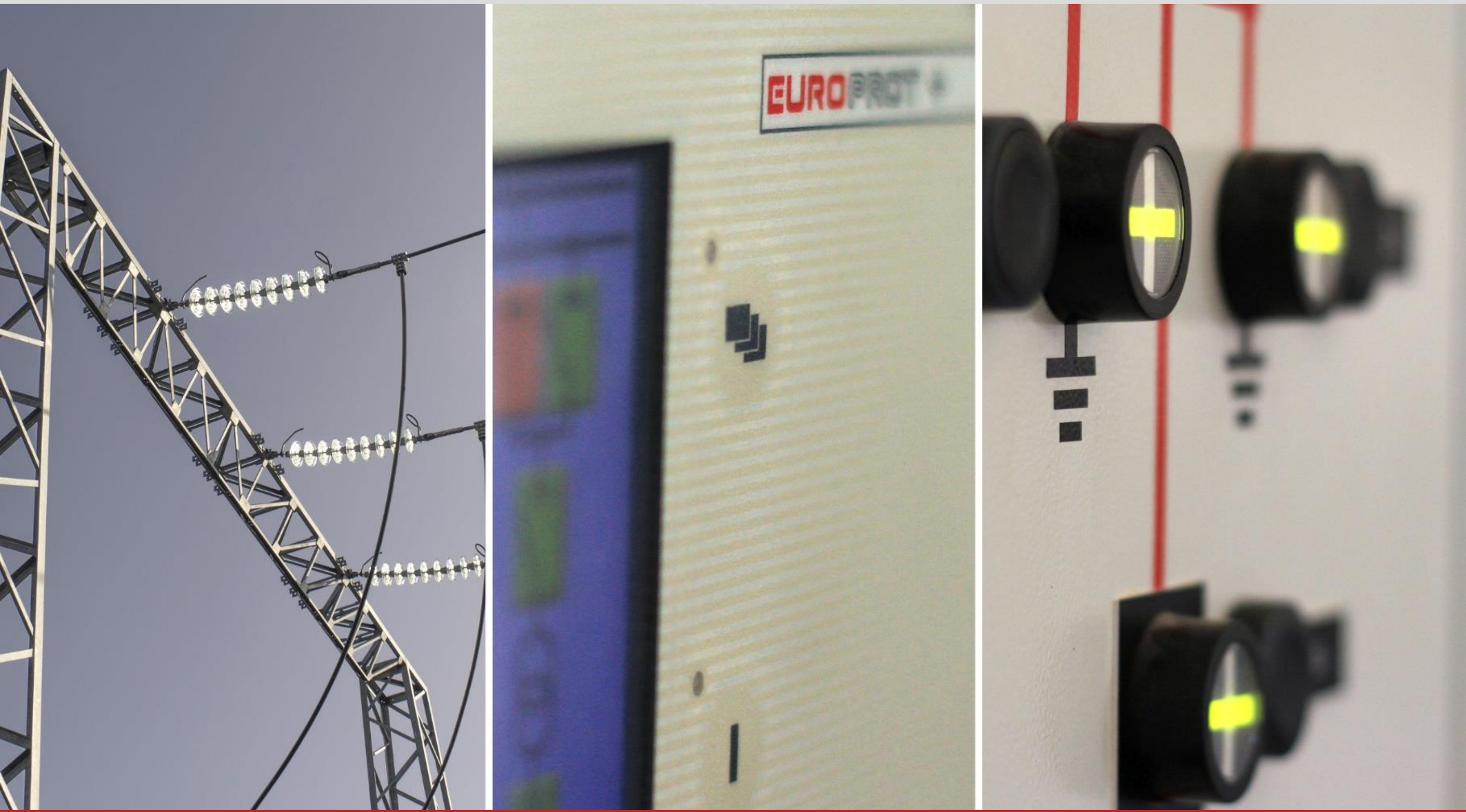

FUNCTION BLOCK DESCRIPTION

Impedance protection with compounded circular characteristic

ANSI: 21, IEC: Z<

DOCUMENT ID: PP-13-22960
VERSION: 2.0
2024-07-30, BUDAPEST

PROTECTION, AUTOMATION AND CONTROL FOR POWER INDUSTRY

VERSION INFORMATION

VERSION	DATE	MODIFICATION	COMPILED BY
Preliminary	2009-10-30	Preliminary version, without technical information	Petri
	2010-10-05	Nameing revision	Csipke
	2010-10-26	New Fig. 1.5	Petri
1.0	2010-11-11	First edition	Petri
2.0	2024-07-30	New documentation design Function block overview, testing notes chapter added	Ádám, Erdős

CONTENTS

USED SYMBOLS

Additional information

Useful information for settings.

Important part for proper usage.

1 Operation principle

This impedance protection function can be applied as impedance protection with an offset circular characteristic or as a loss-of-field protection function for synchronous machines. Its main features are as follows:

- A full-scheme system provides continuous measurement of impedances separately in three independent phase-to-phase measuring loops as well as in three independent phase-to-earth measuring loops.
- Impedance calculation is conditional on the values of phase currents being sufficient.
- Full-scheme faulty phase identification is provided.
- The operate decision is based on offset circle characteristics.
- The impedance calculation is dynamically based on:
    - Measured loop voltages if they are sufficient for decision,
    - Voltages stored in the memory if they are available,
    - Optionally, the decision can be non-direction; in that case, the center of the circle is not shifted away from the origin.
- Binary input signals and conditions can influence the operation:
    - Blocking/enabling.
    - VT failure signal.

1.1 Structure of the impedance protection algorithm

Figure 1-1 shows the structure of the impedance protection function with compounded circular characteristic.

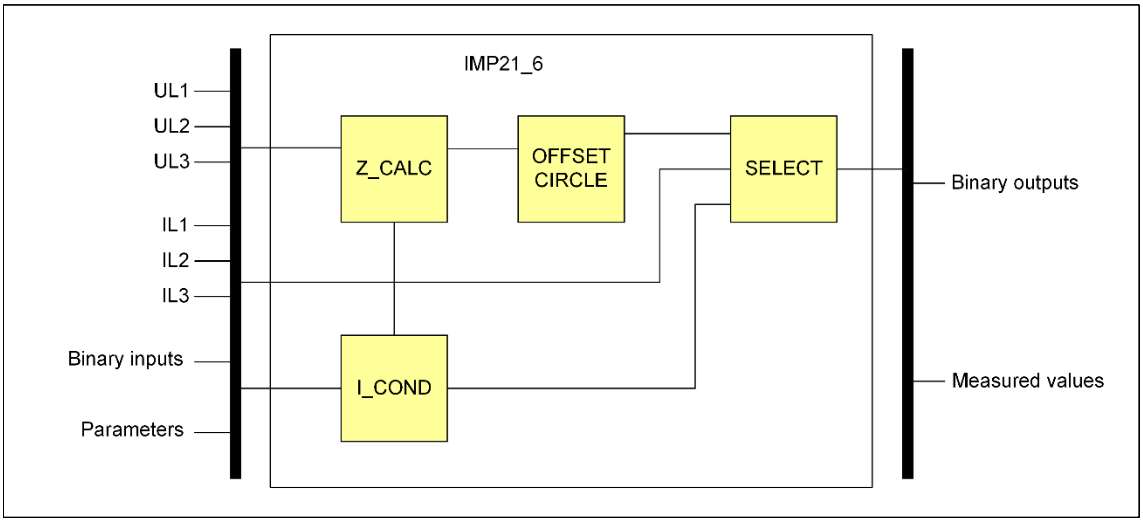

Figure 1-1 Structure of the impedance protection algorithm

The **inputs** are

- the Fourier components of three phase voltages,
- the Fourier components of three phase currents,
- binary inputs,
- parameters.

The **outputs** are

- the binary output status signals,
- the measured values.

The **software modules** of the impedance protection function are as follows:

Z_CALC calculates the impedances (R+jX) of the six measuring current loops:

- three phase-phase loops,
- three phase-ground loops.

OFFSET CIRCLE compares the calculated impedances with the setting values of the compounded circle characteristics. The result is the decision for all six measuring loops if the impedance is within the offset circle.

SELECT is the phase selection algorithm to determine which decision is caused by a faulty loop and to exclude the false decisions in healthy loops.

I_COND calculates the current conditions necessary for the phase selection logic.

The following description explains the details of the individual components.

1.2 The impedance calculation (Z_CALC)

1.2.1 Principle of operation

The impedance protection supplied by PROTECTA Ltd. continuously measures the impedances in the six possible fault loops. The calculation is performed in the phase-to-phase loops based on the line-to-line voltages and the difference of the affected phase currents, while in the phase-to-earth loops the phase voltage is divided by the phase current compounded with the zero sequence current. These equations are summarized in Table 1-1 for different types of faults. The result of this calculation is the positive sequence impedance of the fault loop, including the positive sequence fault resistance at the fault location.

Table 1-1 Formulas for the calculation of the impedance to fault

FAULT	CALCULATION OF Z	OTHER POSSIBLE CALCULATION
L1L2L3(N)	$Z_{L2L3}=\frac{U_{L2}-U_{L3}}{I_{L2}-I_{L3}}$	Z_{L1L2} , Z_{L2L3} , Z_{L3L1} Z_{L1N} , Z_{L2N} , Z_{L3N}
L1L2	$Z_{L1L2}=\frac{U_{L1}-U_{L2}}{I_{L1}-I_{L2}}$	
L2L3	$Z_{L2L3}=\frac{U_{L2}-U_{L3}}{I_{L2}-I_{L3}}$	
L3L1	$Z_{L3L1}=\frac{U_{L3}-U_{L1}}{I_{L3}-I_{L1}}$	
L1L2N	$Z_{L1L2}=\frac{U_{L1}-U_{L2}}{I_{L1}-I_{L2}}$	Z_{L1N} , Z_{L2N}
L2L3N	$Z_{L2L3}=\frac{U_{L2}-U_{L3}}{I_{L2}-I_{L3}}$	Z_{L2N} , Z_{L3N}
L3L1N	$Z_{L3L1}=\frac{U_{L3}-U_{L1}}{I_{L3}-I_{L1}}$	Z_{L3N}, , Z_{L1N}
L1N	$Z_{L1N}=\frac{U_{L1}}{I_{L1}+3I_0K_N}$	
L2N	$Z_{L2N}=\frac{U_{L2}}{I_{L2}+3I_0K_N}$	
L3N	$Z_{L3N}=\frac{U_{L3}}{I_{L3}+3I_0K_N}$	

The central column of Table 1-1 contains the correct formula for calculation. The formulas referred to in the right-hand-side column yield the same correct impedance value.

In Table 1-1:

$$K_N=\frac{Z_0-Z_1}{3Z_1}=\frac{1}{3}\left(\frac{Z_0}{Z_1}-1\right)$$

is the *complex* earth fault compensation factor.

Table 1-1 shows that the formula containing the complex earth fault compensation factor yields the correct impedance value in case of phase-to-earth faults only; the other formula can be applied in case of phase-to-phase faults without ground. In case of other kinds of faults (three-phase (-to-earth), phase-to-phase-to-earth) both formulas give the correct impedance value if the appropriate voltages and currents are applied.

The separation of the two types of equation is based on the presence or absence of the earth (zero sequence) current. In case of a fault involving the earth (on a solidly grounded network), and if the earth current is over a certain level, the formula containing the *complex* earth fault compensation factor will be applied to calculate the correct impedance, which is proportional to the impedance-to-fault.

It can be proven that if the setting value of the *complex* earth fault compensation factor is correct, the appropriate application of the formulas in Table 1-1 will always yield the positive sequence impedance between the fault location and the relay location.

1.2.2 General method of calculation of the impedances of the fault loops

The numerical processes apply the following simple model.

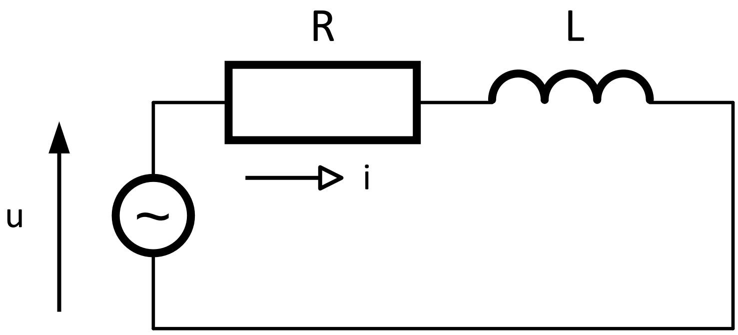

Figure 1-2 Equivalent circuit of the fault loop

For the equivalent impedance elements of the fault loop in Figure *1-2*, the following differential equation can be written:

$$u = Ri + L\frac{di}{dt}$$

If current and voltage values sampled at two separate sampling points in time are substituted in this equation, two equations are derived with the two unknown values R and L, so they can be calculated.

This basic principle is realized in the algorithm by substituting the Fourier fundamental component values of the line-to-line voltages for *u* and the difference of the Fourier fundamental components of two phase currents in case of two- or three-phase faults without ground for *i*. For example, in case of an L2L3 fault:

$$u_{L2} - u_{L3} = R_1\left(i_{L2} - i_{L3}\right) + L_1\frac{d}{dt}\left(i_{L1} + \propto_L 3i_0\right)$$

In case of a phase-to-earth fault, the phase voltage and the phase current modified by the zero sequence current have to be substituted:

$$u_{L1} = R_1\left(i_{L1} - \propto_R 3i_0\right) + L_1 \frac{d}{dt}\left(i_{L1} + \propto_L 3i_0\right)$$

Where

R_1 is the positive sequence resistance of the line or cable selection between the fault location and the relay location,

L_1 is the positive sequence inductance of the line or cable section between the fault location and the relay location,

L1 is the faulty phase,

$3i_o$ $=iL1+iL2+iL3$ is the Fourier fundamental component value of the zero sequence current of the protected line.

$$\propto_R = \frac{R_0 - R_1}{3R_1}$$

$$\propto_L = \frac{L_0 - L_1}{3L_1} = \frac{X_0 - X_1}{3X_1}$$

The formula above shows that the factors for multiplying R and L values contain different "α" factors but they are real (not complex) numbers.

The applied numerical method is solving the differential equation of the faulty loop, based on the orthogonal components of the Fourier fundamental component vectors.

To achieve better filtering effect, the calculation is performed using the fundamental Fourier components of the voltages, currents and current derivatives. In Table 1-1, the voltages and currents are complex vectors. The calculation results complex impedances on the network frequency.

1.2.3 The principal scheme of the impedance calculator

Figure 1-3 shows the principal scheme of the impedance calculation Z_CALC.

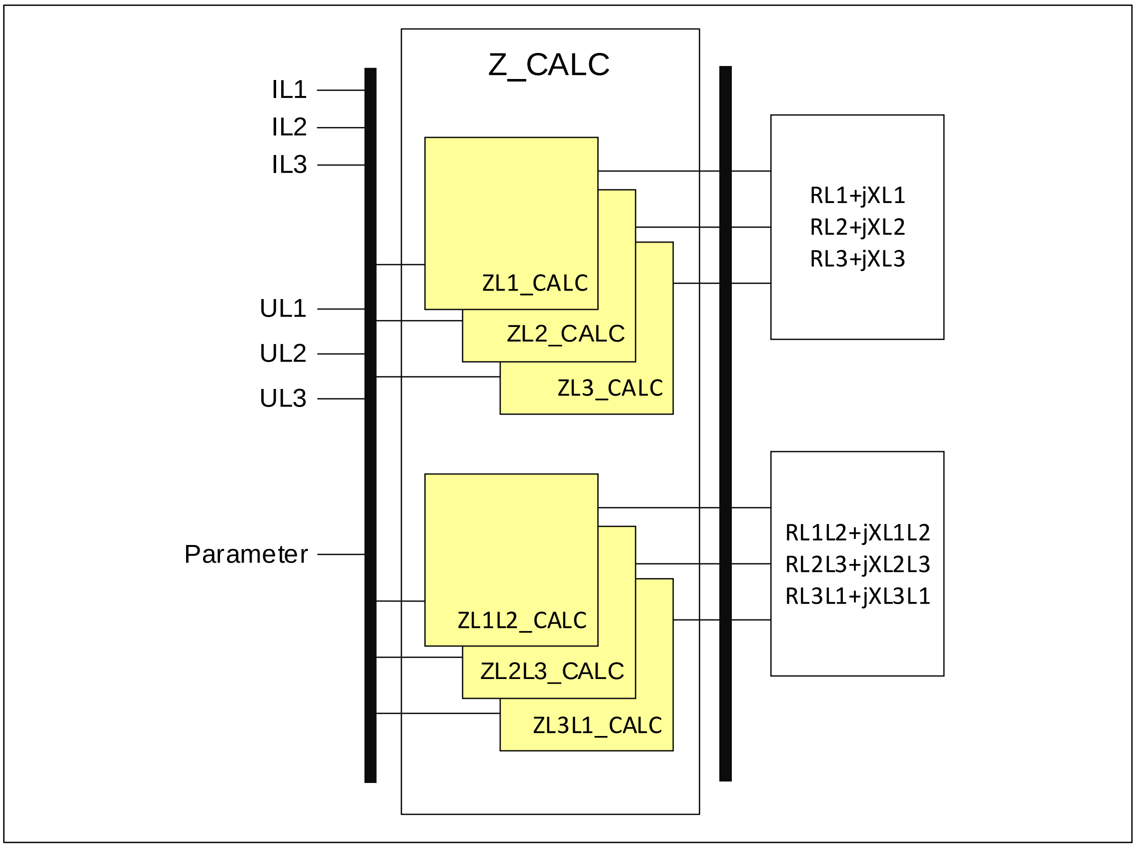

Figure 1-3 Principal scheme of the impedance calculation Z_CALC

The **inputs** are the Fourier components of:

- the three phase voltages,
- the three phase currents,
- parameters.

The **outputs** are the calculated positive sequence impedances (R+jX) of the six measuring loops:

- Impedances of the three phase-phase loops,
- Impedances of the three phase-ground loops.

The **measured values** of the Z_CALC module

Table 1-2 The measured values of the Z_CALC module

MEASURED VALUE	DIM.	EXPLANATION
RL1+j XL1	ohm	Measured positive sequence impedance in the L1N loop
RL2+j XL2	ohm	Measured positive sequence impedance in the L2N loop
RL3+j XL3	ohm	Measured positive sequence impedance in the L3N loop
RL1L2+j XL1L2	ohm	Measured positive sequence impedance in the L1L2 loop
RL2L3+j XL2L3	ohm	Measured positive sequence impedance in the L2L3 loop
RL3L1+j XL3L1	ohm	Measured positive sequence impedance in the L3L1 loop

Float parameters

Table 1-3 The float parameters of the impedance calculation

PARAMETER NAME	TITLE	UNIT	MIN	MAX	STEPS	DEFAULT
The zero sequence current compensation factor, calculated with X values						
IMP21_AlfaL_FPar_	(Xo-X1)/3X1	-	0	5	0.01	0
The zero sequence current compensation factor, calculated with R values						
IMP21_AlfaR_FPar_	(Ro-R1)/3R1	-	0	5	0.01	0

Z_CALC includes six practically identical software modules for impedance calculation:

- The three routines of the phase group are activated by phase voltages, phase currents and the zero sequence current calculated from the phase current.
- The three routines for the phase-to-phase loops get line-to-line voltages calculated from the sampled phase voltages and they get differences of the phase currents. They do not need zero sequence currents for the calculation.

The calculated impedances are analogue outputs of the impedance protection function. They serve the purpose of checking possibility at commissioning.

1.2.4 Internal logic of the impedance calculation

Figure 1-4 shows the internal logic of the impedance calculation.

The decision needs logic parameter settings and, additionally, internal logic signals. The explanation of these signals is as follows:

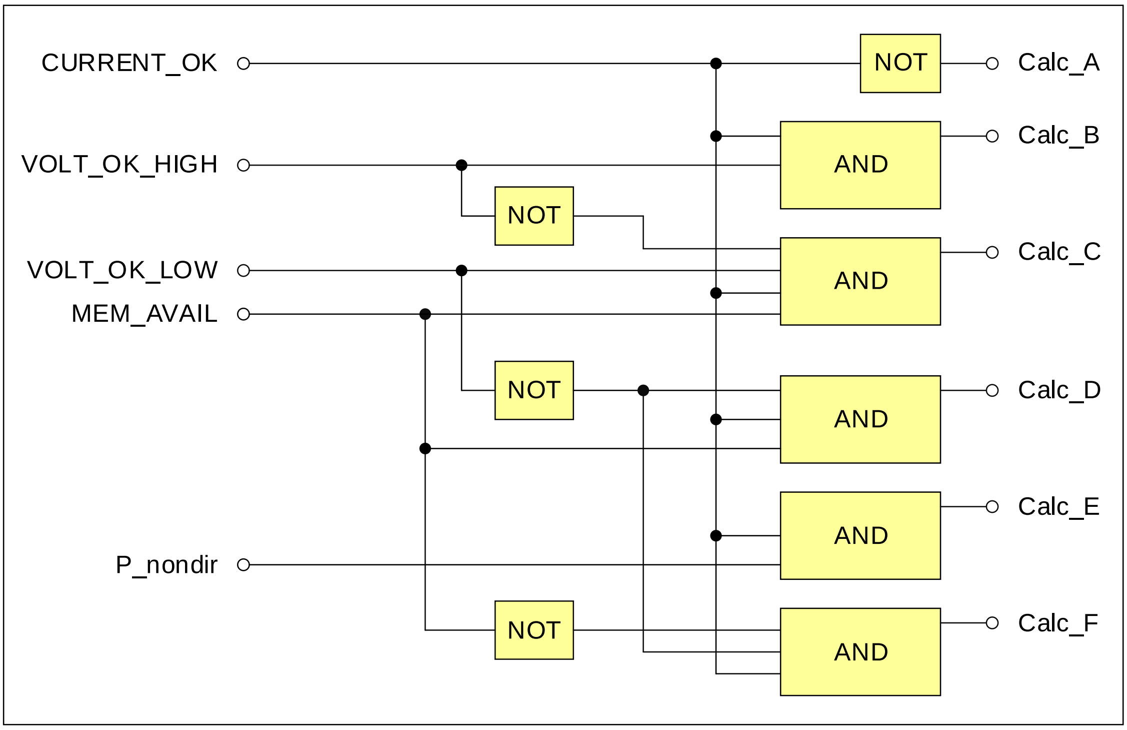

Figure 1-4 Internal logic of the impedance calculation Z_CALC

Table 1-4 Enumerated parameters for the Z_CALC module

PARAMETER	EXPLANATION
P_nondir	This logic variable is true if no directionality is programmed, i.e., the IMP21_Zn_EPar_(Operation) parameter is set to “*NonDirectional*”.

Table 1-5 Binary signals for the Z_CALC module

INPUT STATUS SIGNAL	EXPLANATION
CURRENT_OK	The current is suitable for impedance calculation in the processed loop if, after a zero crossing, there are three sampled values above a defined limit (~0.1In). For a phase-ground loop calculation, it is also required that the sum of the phase currents (3Io) should be above Iphase/4. This status signal is generated within the *Z_CALC* module based on the parameter IMP21_Imin_IPar_ (I minimum) and in case of phase-ground loops on parameters IMP21_IoBase_IPar_ (Io Base sens.) and IMP21_IoBias_IPar_ (Io Bias)
VOLT_OK_HIGH	The voltage is suitable for the calculation if the most recent ten sampled values include a sample above the defined limit (35% of the nominal loop voltage). This status signal is generated within the *Z_CALC* module.
VOLT_OK_LOW	The voltage can be applied for the calculation of the impedance if the three most recent sampled three values include a sample above the defined lower limit (5% of the nominal loop voltage), but in this case the direction is to be decided using the voltage samples stored in the memory because the secondary swings of the capacitive voltage divider distort the sampled voltage values. Below this level, the direction is decided based on the sign either of the real part of the impedance or that of the imaginary part of the impedance, whichever is higher. This status signal is generated within the *Z_CALC* module.
MEM_AVAIL	This status signal is true if the voltage memory is filled up with available samples above the defined limit for 80 ms. This status signal is generated within the *Z_CALC* module.

The outputs of the scheme are calculation methods applied for impedance calculation for the individual zones.

Table 1-6 Calculation methods applied in the Z_CALC module

CALCULATION METHOD	EXPLANATION
Calc(A)	No current is available, the impedances are supposed to be higher than the possible maximal setting values R=1000000 mohm, X=1000000 mohm
Calc(B)	The currents and voltages are suitable for the correct impedance calculation and directional decision R, X=f(u, i)
Calc(C)	The currents are suitable, but the voltages are in the range of the CVT swings, so during the first 35 msec the directional decision is based on pre-fault voltages stored in the memory R, X=f(u, i) direction = f(Umem, i) /in the first 35 msec/ R, X=f(u, i) direction = f(u, i) /after 35 msec/
Calc(D)	The currents are suitable, but the voltages are too low. The directional decision is based on pre-fault voltages stored in the memory R, X=f(u, i) direction = f(max{R(Umem, i), X(Umem,i)})
Calc(E)	If no directional decision is required, the decision is based on the absolute value of the impedance R=abs(R), X=abs(X)
Calc(F)	If the decision is not possible (no voltage, no pre-fault voltage), the impedance is set to a value above the possible impedance setting R=1000500 mohm, X=1000500 mohm

1.2.5 The impedance calculation methods

The short explanation of the internal logic for the impedance calculation is as follows:

Calculation method Calc(A):

If the CURRENT_OK status signal is false, the current is very small, therefore no fault is possible. In this case, the impedance is set to extreme high values and no further calculation is performed:

R=1000000, X=1000000.

The subsequent decisions are performed if the current is sufficient for the calculation.

Calculation method Calc(B):

If the CURRENT_OK status signal is true and the VOLT_OK_HIGH status signal is true as well, then the current is suitable for calculation and the voltage is sufficient for the directionality decision. In this case, normal impedance calculation is performed based on the sampled currents and voltages. (The calculation method - the function "f"- is explained later.)

R, X=f(u, i)

Calculation method Calc(C):

If the CURRENT_OK status signal is true but the VOLT_OK_HIGH status signal is false or there are voltage swings, the directionality decision cannot be performed based on the available voltage signals temporarily. In this case, if the voltage is above a minimal level (in the range of possible capacitive voltage transformer swings), then the VOLT_OK_LOW status is "true", the magnitude of R and X is calculated based on the actual currents and voltages but the direction of the fault (the +/- sign of R and X) must be decided based on the voltage value stored in the memory 80 msec earlier. (The high voltage level setting assures that during the secondary swings of the voltage transformers, no IMPtorted signals are applied for the decision). This procedure is possible only if there are stored values in the memory for 80 msec and these values were sampled during a healthy period.

R, X=f(u, i)   direction = f(Umem, i) /in the first 35 msec/

After 35 ms (when the secondary swings of the voltage transformers decayed), the directional decision returns to the measured voltage signal again:

R, X=f(u, i)   direction = f(u, i) /after 35 msec/

Calculation method Calc(D):

If the voltage is below the minimal level, then the VOLT_OK_LOW status is "false" but if there are voltage samples stored in the memory for 80 ms, then the direction is decided based on the sign either of the real part of the impedance or that of the imaginary part of the impedance, whichever is higher.

R, X=f(u, i)   direction = f(max{R(Umem, i), X(Umem,i)})

Calculation method Calc(E):

If no directional decision is required, the decision is based on the absolute value of the impedance (forward fault is supposed)

R=abs(R), X=abs(X)

Calculation method Calc(F):

If the voltage is not sufficient for a directional decision and no stored voltage samples are available, the impedance is set to a high value:

R=1000500, X=1000500

1.3 The characteristics of the impedance protection (OFFSET CIRCLE)

The operate decision is based on offset circle characteristics.

The calculated R_1 and $X_1=\omega L_1$ co-ordinate values define six points on the complex impedance plane for the six possible measuring loops. These impedances are the positive sequence impedances. The protection compares these points with the „offset circle" characteristics of the impedance protection, shown in Figure 1-5. The main setting values of "Rcompaund" and "Xcompaund" refer to the positive sequence impedance of the fault loop, including the fault positive sequence resistance of the possible electric arc and, in case of a ground fault, the tower grounding positive sequence resistance as well. (When testing the device using a network simulator, the resistance of the fault location is to be applied to match the positive sequence setting values of the characteristic lines.)

Parameter settings decide the size and the position of the circle. Optionally, the center of the circle can be the origin of the impedance plane, or the circle can be shifted along an impedance lime. The possibilities are shown in Figure 1-5:

- Off
- NoCompound,
- FWCompound
- BWCompound

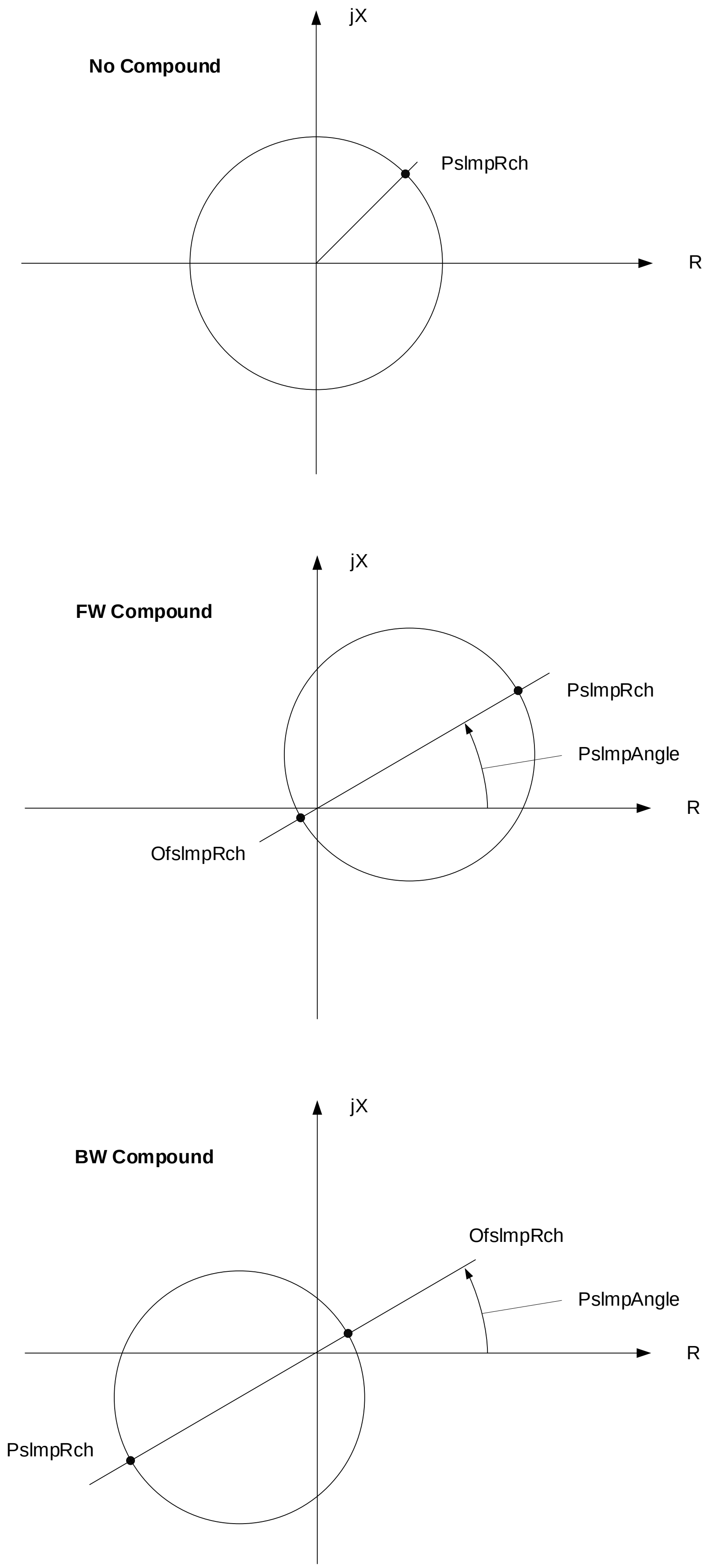

Figure 1-5 The offset circle characteristic

If a measured impedance point is inside the circle, the algorithm generates the true value of the related output binary signal.

The calculated impedance values are compared one by one with the setting values of the „offset circle” characteristics. This procedure is shown schematically on Figure 1-6.

The procedure is processed for each line-to-ground loop and for each line-to-line loop. The result is the setting of 6 status variables. This indicates that the calculated impedance is within the processed “offset circle” characteristics.

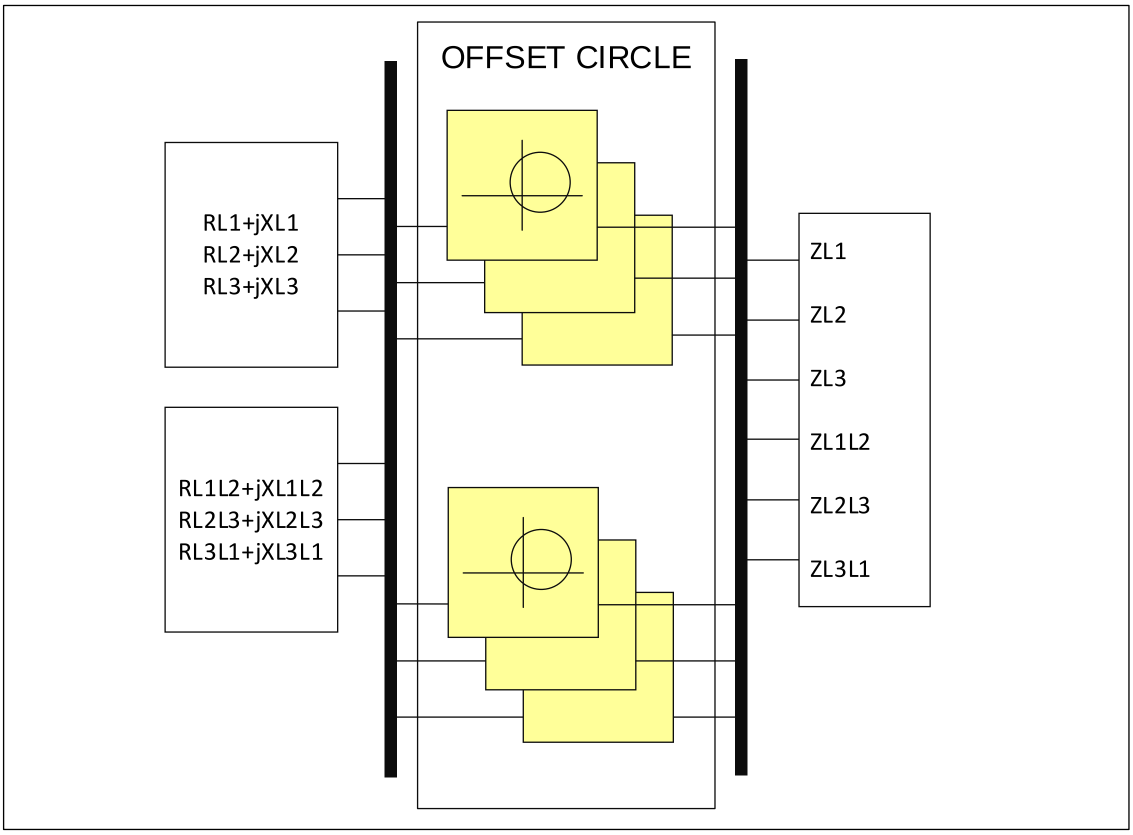

Figure 1-6 Principal scheme of the OFFSET CIRCLE module

Input values

The input values are calculated by the module Z_CALC.

Table 1-7 The input calculated impedances of the OFFSET CIRCLE module

INPUT VALUES	EXPLANATION
RL1+j XL1	Calculated impedance in the fault loop L1N
RL2+j XL2	Calculated impedance in the fault loop L2N
RL3+j XL3	Calculated impedance in the fault loop L3N
RL1L2+j XL1L2	Calculated impedance in the fault loop L1L2
RL2L3+j XL2L3	Calculated impedance in the fault loop L2L3
RL3L1+j XL3L1	Calculated impedance in the fault loop L3L1

Output values

Table 1-8 The output status signals of the OFFSET CIRCLE module

OUTPUT VALUES	EXPLANATION
ZL1	The impedance in the fault loop L1N is inside the characteristics
ZL2	The impedance in the fault loop L2N is inside the characteristics
ZL3	The impedance in the fault loop L3N is inside the characteristics
ZL1L2	The impedance in the fault loop L1L2 is inside the characteristics
ZL2L3	The impedance in the fault loop L2L3 is inside the characteristics
ZL3L1	The impedance in the fault loop L3L1 is inside the characteristics

The parameters needed in the characteristic evaluation procedure of the impedance protection function are explained in the following tables.

Enumerated parameters

Table 1-9 The enumerated parameters of the offset circle module

PARAMETER NAME	TITLE	SELECTION RANGE	DEFAULT
Selection of the operating mode			
IMP21_Op_EPar_	Operation	Off, NoCompound, FWCompound, BWCompound	NoCompound

Integer parameters

Table 1-10 Integer parameters of the circular impedance protection function

PARAMETER NAME	TITLE	UNIT	MIN	MAX	STEPS	DEFAULT
Positive impedance angle						
IMP21_Angle_IPar_	Ps Impedance Angle	deg	0	90	1	90

Float parameters

Table 1-11 The float parameters of the offset circle module

PARAMETER NAME	TITLE	UNIT	MIN	MAX	STEPS	DEFAULT
Offset impedance reach						
IMP21_Z1_FPar_	Ofs Impedance Reach	ohm	-150.00	150.00	0.01	0.0
Positive impedance reach						
IMP21_Z2_FPar_	Ps Impedance Reach	ohm	0.10	250.00	0.01	10

1.4 The phase selection logic (SELECT) and timing

In case of faults, the calculated impedance value for the faulty loop is inside a polygon. If the fault is near the relay location, the impedances in the loop containing the faulty phase can also be inside the polygon. To ensure selective tripping, phase selection is needed. This chapter explains the operation of the phase selection logic.

Binary inputs processed by the "OFFSET CIRCLE" logic

Table 1-12 Binary input signals from the OFFSET CIRCLE logic

BINARY INPUT SIGNALS FROM OFFSET CIRCLE LOGIC	EXPLANATION
ZL1	The calculated impedance for the loop L1 is inside the characteristics
ZL2	The calculated impedance for the loop L2 is inside the characteristics
ZL3	The calculated impedance for the loop L3 is inside the characteristics
ZL1L2	The calculated impedance for the loop L1L2 is inside the characteristics
ZL2L3	The calculated impedance for the loop L2L3 is inside the characteristics
ZL3L1	The calculated impedance for the loop L3L1 is inside the characteristics

Binary output status signals

Table 1-13 Binary output signals of the phase selection logic

BINARY STATUS SIGNAL	TITLE	EXPLANATION
IMP21_**GenSt**_Grl_	General Start	General start signal of the function
IMP21_**StL1**_Grl_	Start L1	The impedance of phase L1 is within the characteristics
IMP21_**StL2**_Grl_	Start L2	The impedance of phase L2 is within the characteristic
IMP21_**StL3**_Grl_	Start L1	The impedance of phase L3 is within the characteristics
IMP21_**GenTr**_Grl_	General Trip	General trip signal of the function

Boolean parameters

Table 1-14 The Boolean parameters of the phase selection logic

PARAMETER NAME	TITLE	DEFAULT	EXPLANATION
IMP21_StOnly_BPar_	Impedance Start Only	0	Set 0 value to also generate an operate signal

Timer parameters

Table 1-15 Timer parameters of the phase selection logic

PARAMETER NAME	TITLE	UNIT	MIN	MAX	STEP	DEFAULT
Time delay						
IMP21_Del_TPar_	Time delay	msec	0	60000	1	500

1.4.1 Three phase fault detection

The logic processing of diagrams in the following figures is sequential. If the result of one of them is true, no further processing is performed.

Figure 1-7 shows that if

- all three line-line loops caused start of the polygon impedance logic, and
- the currents in all three phases are above the setting limit,

then a three-phase fault is detected, and no further check is performed. The three-phase fault detection resets only if none of the three line-to-line loops detect fault any longer.

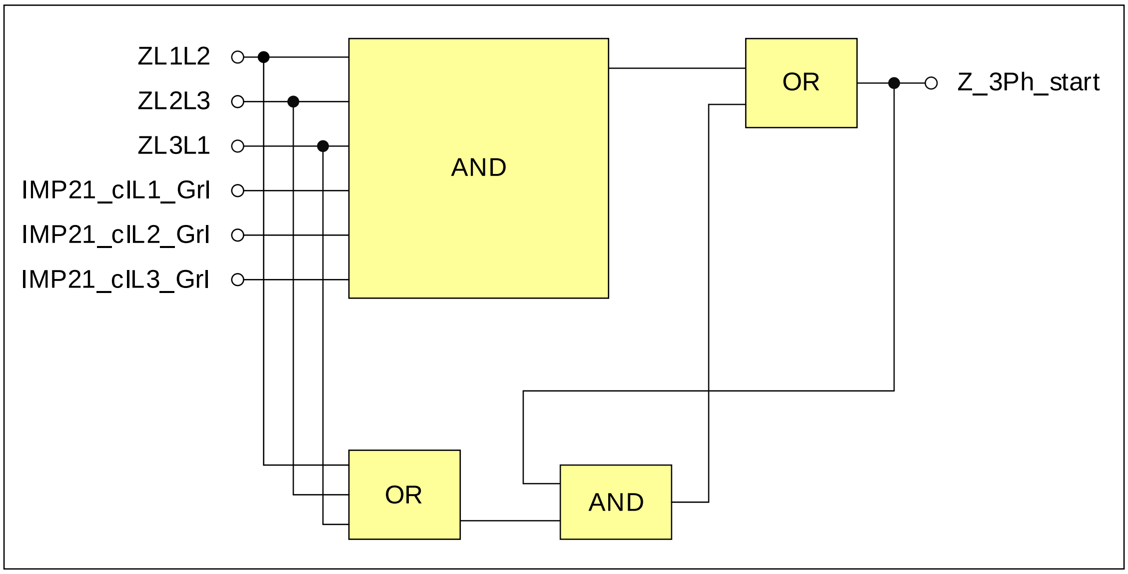

Figure 1-7 Three-phase fault

Table 1-16 Three-phase start of the impedance protection function

OUTPUT STATUS SIGNALS	EXPLANATION
Z_3Ph_start	Three-phase start of the impedance protection function

Table 1-17 Inputs needed to decide the three-phase start of the impedance protection function

INPUT STATUS SIGNALS	EXPLANATION
ZL1L2	The calculated impedance of the fault loop L1L2 is within the characteristic
ZL2L3	The calculated impedance of fault loop L2L3 is within the zone characteristic
ZL3L4	The calculated impedance of the fault loop L3L1 is within the characteristic
IMP21_cIL1_GrI	The current in phase L1 is sufficient for impedance calculation
IMP21_cIL2_GrI	The current in phase L2 is sufficient for impedance calculation
IMP21_cIL3_GrI	The current in phase L3 is sufficient for impedance calculation

1.4.2 Detection of “L1L2”, “L2L3”, “L3L1” faults

Figure 1-8 explains the detection of a phase-to-phase fault between phases “L1” and “L2”:

- no fault is detected in the previous sequential tests,
- the start of the polygon impedance logic in loop “L1L2” detects the lowest reactance, and
- “OR” relation of the following logic states:
  - no zero sequence current above the limit and no start of the function in another phase-to-phase loop, or
  - in the presence of a zero sequence current
    - start of the polygon impedance logic in loops “L1” and ”L2” individually as well, or
    - the voltage is small in the faulty “L1L2” loop and the currents in both phases involved are above the setting limit.

The “L1L2” fault detection resets only if none of the “L1L2” line-to-line, “L1N” or “L2N” loops detect fault any longer.

In Figures Figure 1-8, Figure *1-10* and Figure *1-11*:

minLL = Minimum (ZL1L2, ZL2L3, ZL3L1)

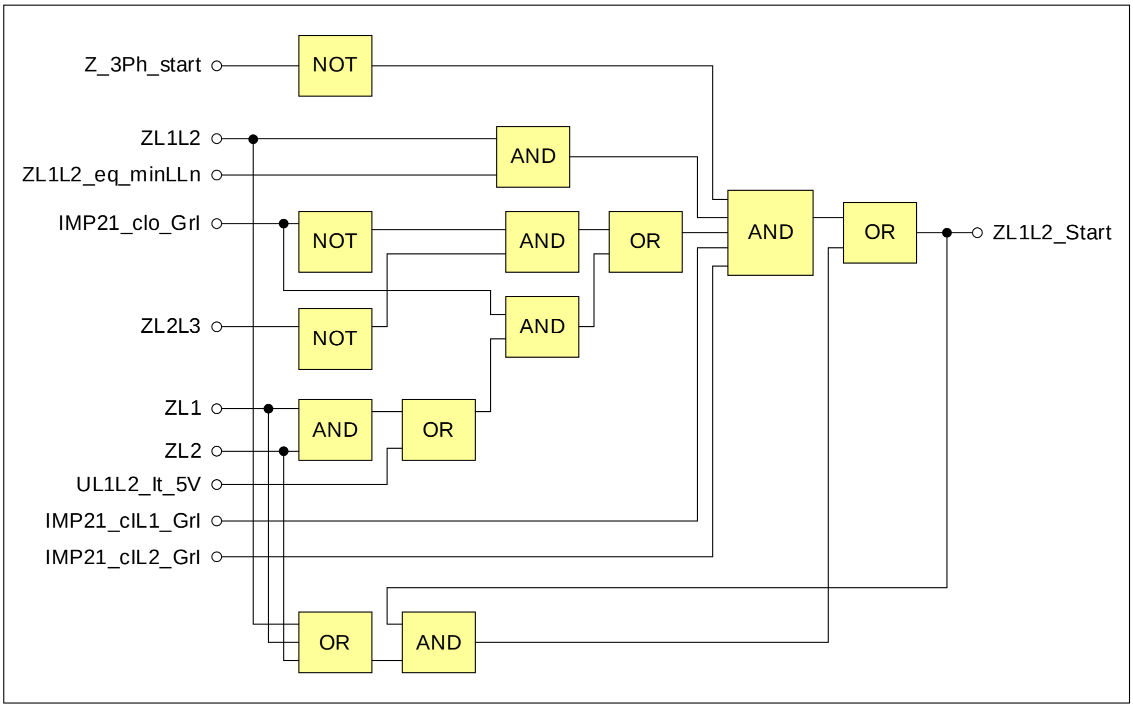

Figure 1-8 L1L2 fault detection

Figure *1-10* and Figure *1-11* show a similar logic for loops “L2L3” and “L3L1”, respectively.

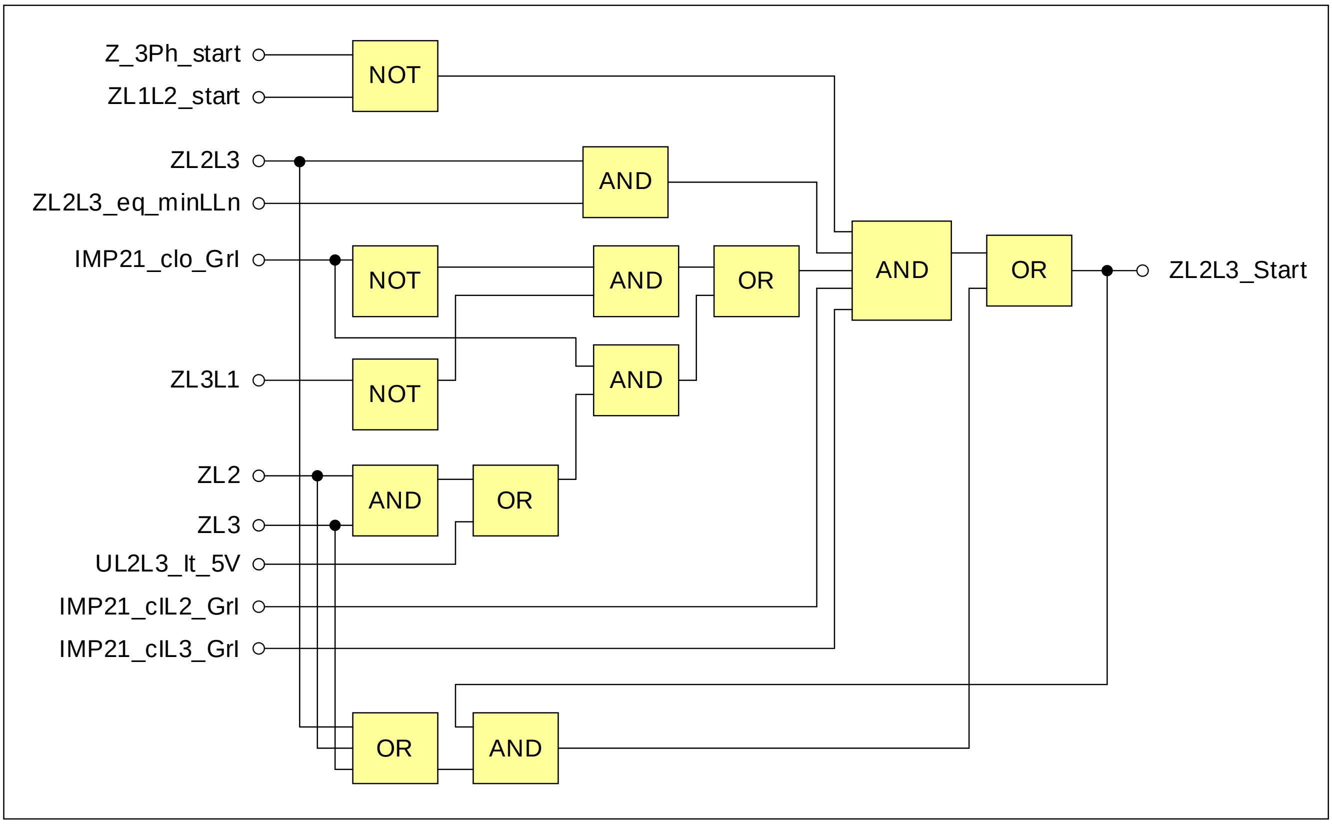

Figure 1-9 Figure 1-10 L2L3 fault detection

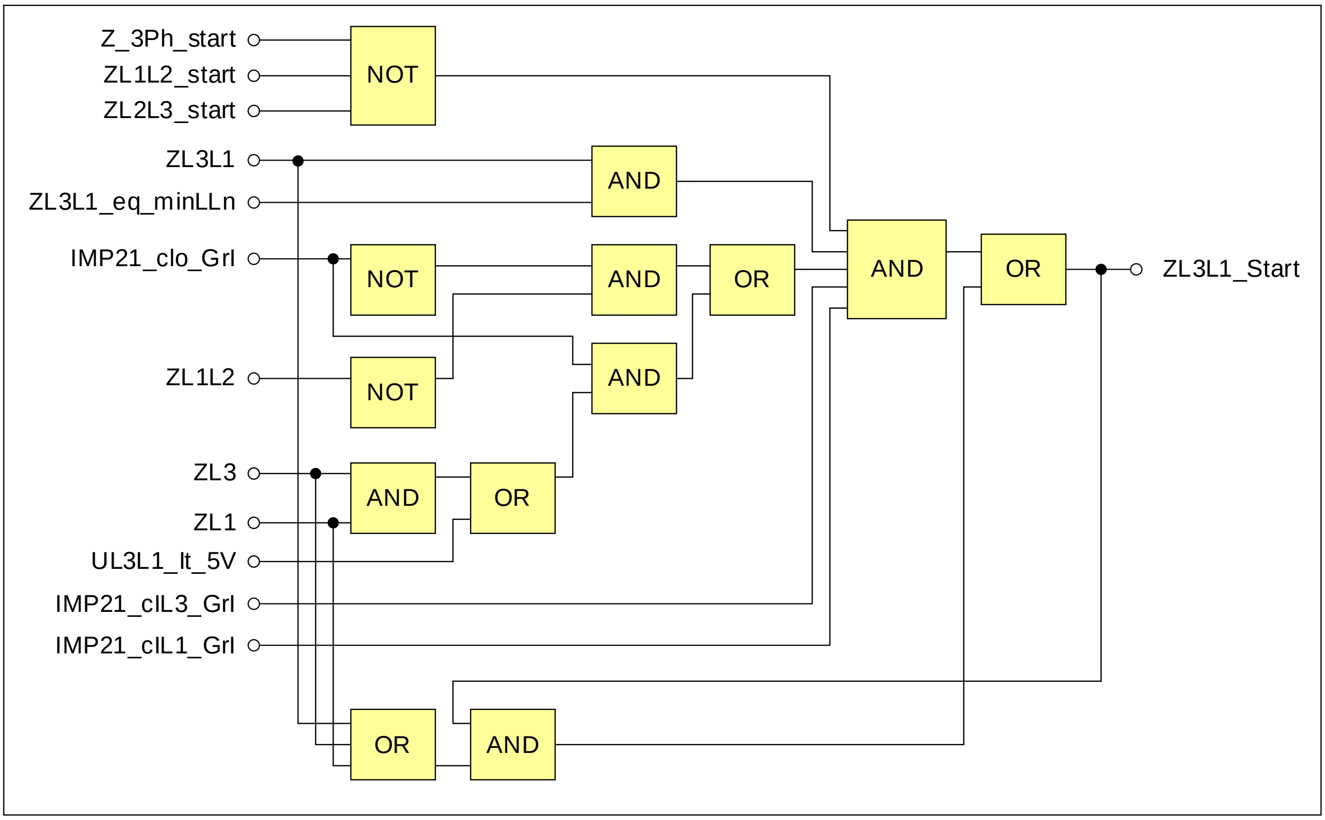

Figure 1-11 L3L1 fault detection in Zone “n” (n=1…5)

Table 1-18 Phase-to-phase loop start of the impedance protection function

OUTPUT STATUS SIGNALS	EXPLANATION
L1L2_Start	L1L2 loop start of the impedance protection function
L2L3_Start	L2L3 loop start of the impedance protection function
L3L1_Start	L3L1 loop start of the impedance protection function

Table 1-19 Inputs needed to decide LL loop start of the impedance protection function

INPUT STATUS SIGNALS	EXPLANATION
Z_3Ph_start	Outputs of the previous decisions
ZL1L2_Start	Outputs of the previous decisions
ZL2L3_Start	Outputs of the previous decisions
ZL1L2	The calculated impedance of the fault loop L1L2 is within the characteristic
ZL2L3	The calculated impedance of fault loop L2L3 is within the zone characteristic
ZL3L1	The calculated impedance of the fault loop L3L1 is within the characteristic
ZL1L2_equ_minLL	The calculated impedance of fault loop L1L2 is the smallest one
ZL2L3_ equ_minLL	The calculated impedance of fault loop L2L3 is the smallest one
ZL3L1_ equ_minLL	The calculated impedance of fault loop L3L1 is the smallest one
ZL1	The calculated impedance of the fault loop L1N is within the characteristic
ZL2	The calculated impedance of the fault loop L2N is within the characteristic
ZL3	The calculated impedance of the fault loop L3N is within the characteristic
IMP21_cIL1_GrI	The current in phase L1 is sufficient for impedance calculation
IMP21_cIL2_GrI	The current in phase L2 is sufficient for impedance calculation
IMP21_cIL3_GrI	The current in phase L3 is sufficient for impedance calculation
IMP21_cIo_GrI_	The zero sequence current component is sufficient for earth fault calculation
UL1L2_Lt_5V	The L1L2 voltage is less than 5V
UL3L3_Lt_5V	The L2L3 voltage is less than 5V
UL3L2_Lt_5V	The L3L1 voltage is less than 5V

1.4.3 Detection of “L1N”, “L2N”, “L3N” faults

Figure 1-12 explains the detection of a phase-to-ground fault in phase “L1”:

- no fault is detected in the previous sequential tests,
- start of the impedance logic in the loop “L1N”,
- the minimal impedance is measured in loop “L1N”,
- no start of the logic in another phase-to-ground loop,
- the zero sequence current above the limit,
- the current in the phase involved is above the setting limit,
- the minimal impedance of the phase-to-ground loops is less than the minimal impedance in the phase-to-phase loops.

In Figure 1-12, Figure 1-13 and Figure 1-14:

minLN = Minimum (ZL1N, ZL2N, ZL3N)

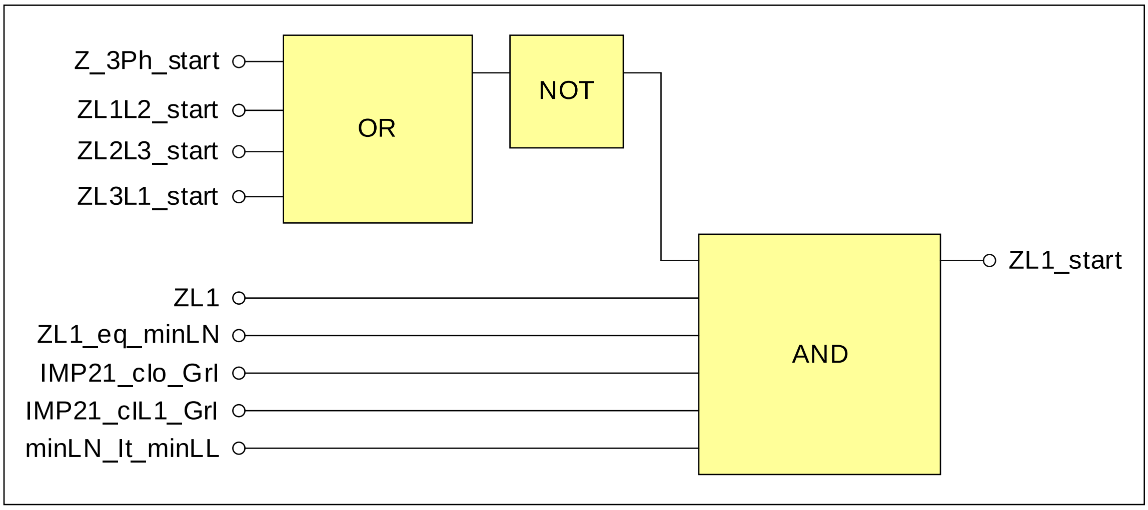

Figure 1-12 L1N fault detection

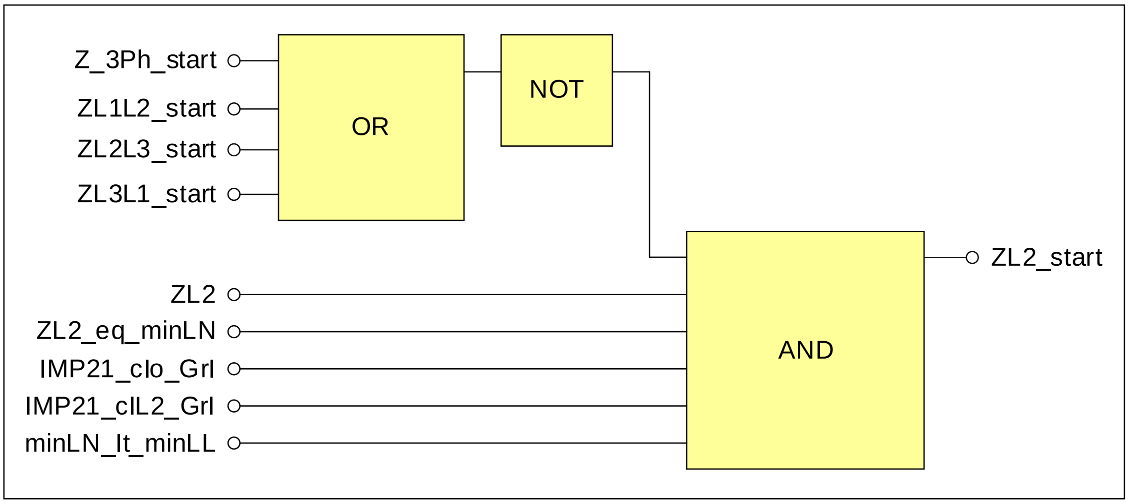

Figure 1-13 L2N fault detection

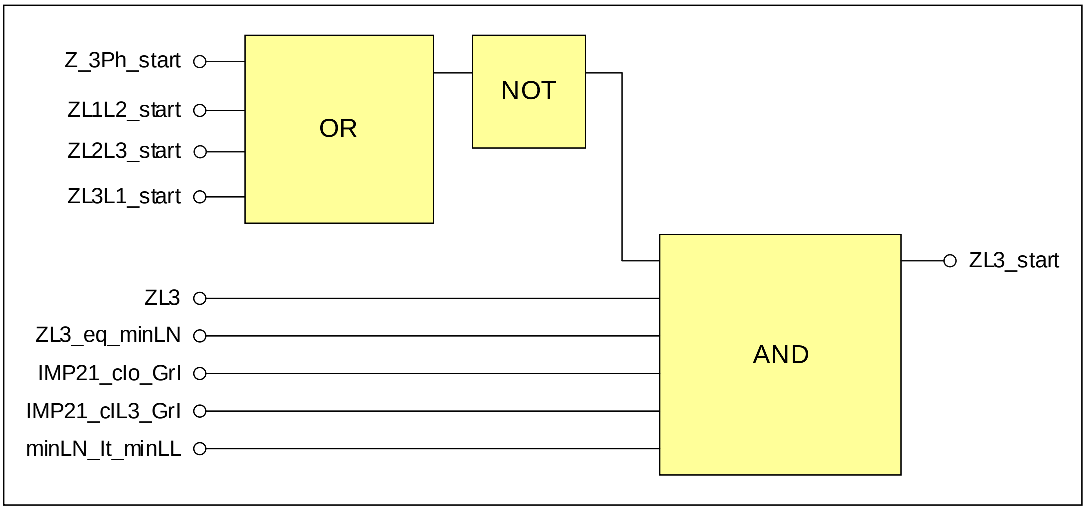

Figure 1-14 L3N fault detection

Table 1-20 Phase-to-neutral loop start of the impedance protection function

OUTPUT STATUS SIGNALS	EXPLANATION
ZL1_Start	L1L2 loop start of the impedance protection function
ZL2_Start	L2L3 loop start of the impedance protection function
ZL3_Start	L3L1 loop start of the impedance protection function

Table 1-21 Inputs needed to decide LN loop start of the impedance protection function

INPUT STATUS SIGNALS	EXPLANATION
ZL1L2_Start	Outputs of the previous decisions
ZL2L3_Start	Outputs of the previous decisions
ZL3L1_Start	Outputs of the previous decisions
ZL1_Start	Outputs of the previous decisions
ZL2_Start	Outputs of the previous decisions
ZL1_equ_minLN	The calculated impedance of fault loop L1is the smallest one
ZL2_ equ_minLN	The calculated impedance of fault loop L2 is the smallest one
ZL3_ equ_minLN	The calculated impedance of fault loop L3 is the smallest one
ZL1	The calculated impedance of the fault loop L1N is within the characteristic
ZL2	The calculated impedance of the fault loop L2N is within the characteristic
ZL3	The calculated impedance of the fault loop L3N is within the characteristic
IMP21_cIL1_GrI	The current in phase L1 is sufficient for impedance calculation
IMP21_cIL2_GrI	The current in phase L1 is sufficient for impedance calculation
IMP21_cIL3_GrI	The current in phase L1 is sufficient for impedance calculation
IMP21_clo_GrI	The zero sequence current component is sufficient for impedance calculation in LN loops

Figure 1-15 shows how the signals are processed for the output signals of the impedance protection function.

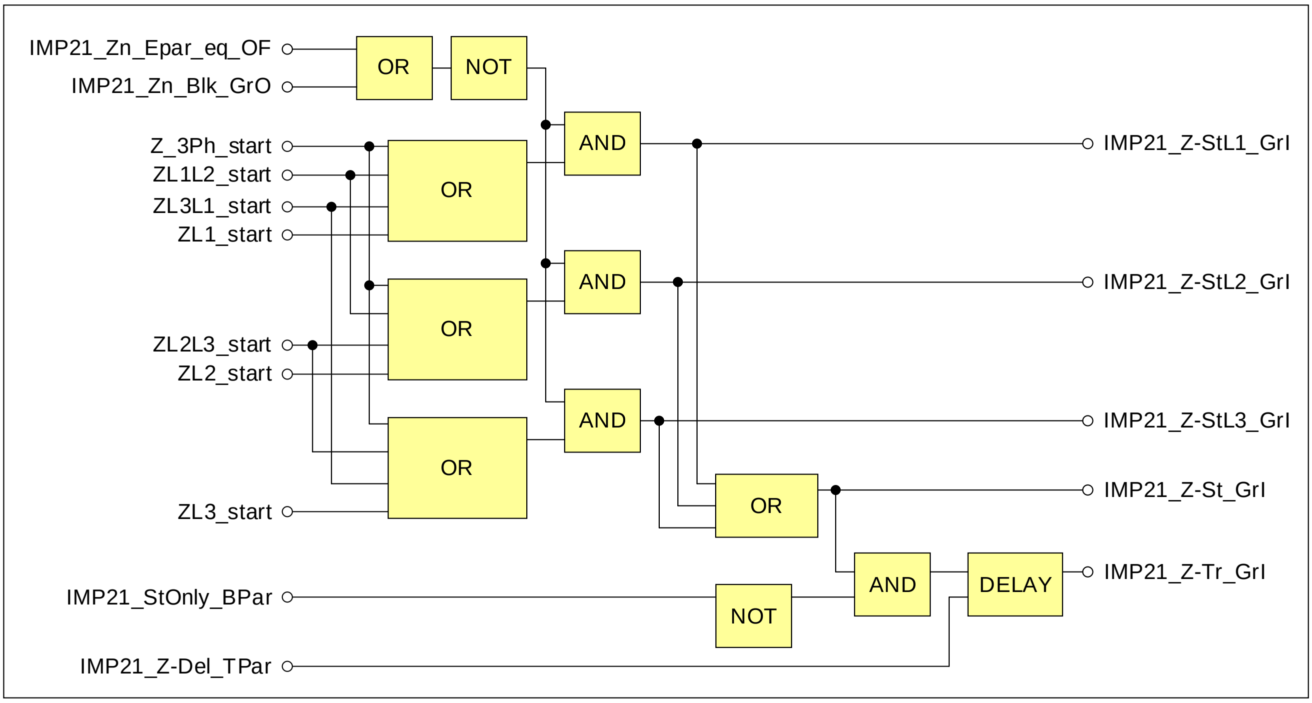

Figure 1-15 Output signals of the impedance protection function

- The operation of the impedance protection may be blocked either by parameter setting (IMP21_Z-_EPar_equ_Off) or by binary input (IMP21_Z-_Blk_GrO_)
- Starting in phase L1 if this phase is involved in the fault (IMP21_Z-StL1_GrI),
- Starting in phase L2 if this phase is involved in the fault (IMP21_Z-StL2_GrI),
- Starting in phase L2 if this phase is involved in the fault (IMP21_ZnStL3_GrI),
- General start if any of the phases is involved in the fault (IMP21_Z-St_GrI),
- A trip command is generated after the timer Delay expires. This timer is started if the zone is started and if trip command is required too, as it is set, using the parameter_IMP21_StOnly_BPar. The time delay is set by the timer parameter IMP21_Z-Del_TPar.

Figure 1-15 shows the method of post-processing the binary output signals to generate general start signals for the phases individually.

The **binary output status signals** of the impedance protection function.

Table 1-22 General phase identification of the impedance protection function

BINARY OUTPUT SIGNALS	SIGNAL TITLE	EXPLANATION
Impedance Phase identification		
IMP21_GenStL1_GrI_	GenStart L1	General start in phase L1
IMP21_GenStL2_GrI_	GenStart L2	General start in phase L2
IMP21_GenStL3_GrI_	GenStart L3	General start in phase L3

1.5 The current conditions of the impedance protection function (I_COND)

The impedance protection function can operate only if the current is sufficient for impedance calculation. Additionally, a phase-to-ground fault is detected only if there is sufficient zero sequence current. This function performs these preliminary decisions.

Table 1-23 The binary output status signals of the current conditions module

BINARY OUTPUT SIGNALS	SIGNAL TITLE	EXPLANATION
Impedance function start conditions generated by the I_COND module (these signals are not published)		
IMP21_cIo_GrI_	Io condition	The zero sequent current component is sufficient for earth fault calculation
IMP21_cIL1_GrI_	I L1 condition	The current in phase L1 is sufficient for impedance calculation
IMP21_cIL2_GrI_	I L2 condition	The current in phase L2 is sufficient for impedance calculation
IMP21_cIL3_GrI_	I L3 condition	The current in phase L3 is sufficient for impedance calculation

Integer parameters

Table 1-24 Integer parameters for the current conditions module

PARAMETER NAME	TITLE	UNIT	MIN	MAX	STEP	DEFAULT
Definition of minimal current enabling impedance calculation:						
IMP21_Imin_IPar_	IPh Base Sens	%	10	30	1	20
Definition of zero sequence current characteristic enabling impedance calculation in phase-to-earth loops:						
IMP21_IoBase_IPar_	IRes Base Sens	%	10	50	1	10
IMP21_IoBias_IPar_	IRes Bias	%	5	30	1	10

The current is considered to be sufficient for impedance calculation if it is above the level set by parameter IMP21_Imin_IPar_.

To decide the presence or absence of the zero sequence current, biased characteristics are applied (see Figure *1-16*). The minimal setting current IMP21_IoBase_IPar_ (Io Base sens.) and a percentage biasing IMP21_IoBias_IPar_ (Io bias) must be set. The biasing is applied for the detection of zero sequence current in the case of increased phase currents.

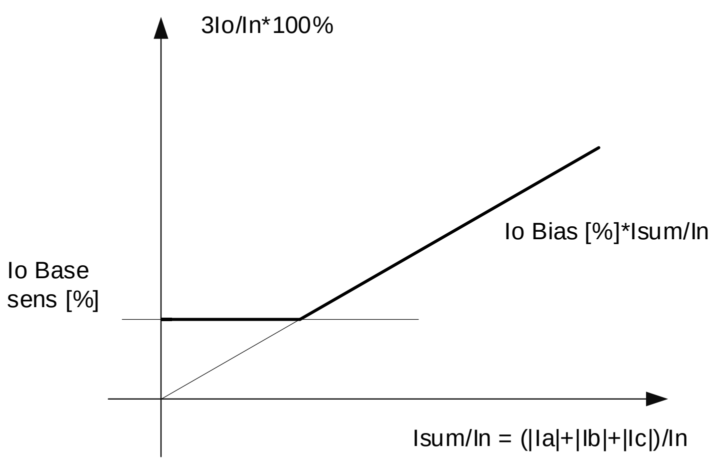

Figure 1-16 Percentage characteristic for earth-fault detection

2 Overview

The function block of the impedance protection function is shown in Figure 2-1. This block shows all binary input and output status signals that are applicable in the graphic equation editor. On the right, analogue inputs are shown as well (from system version 2.10 and up).

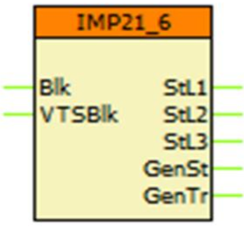

Figure 2-1 Graphic appearance of the function block of the Impedance protection with compounded circular characteristic

2.1 Settings

2.1.1 Parameters

The parameters are listed as they are seen on the local or remote HMI.

Table 2-1 Parameters of the circular impedance protection function

TITLE	DIM	RANGE	STEP	DEFAULT	EXPLANATION
Operation	-	Off, NoCompound, FWCompound, BWCompound	-	Off	Selection of the operating mode
Impedance Start Only	-	TRUE, FALSE	-	FALSE	FALSE to generate trip command
IPh Base Sens	%	10 - 30	1	20	Minimal current setting for phase currents
IRes Base Sens	%	10 - 50	1	10	Minimal current setting for the zero sequence current
IRes Bias	%	5 - 30	1	10	Slope of the percentage characteristic for earth-fault detection
Ps Impedance Angle	deg	0 - 90	1	90	Positive impedance angle
Ofs Impedance Reach	ohm	-150.00 – 150.00	0.01	0.00	Offset impedance reach
Ps Impedance Reach	ohm	0.10 – 250.00	0.01	10.00	Positive impedance reach
Zone1 (Xo-X1)/3X1	-	0.00 – 5.00	0.01	0.00	The zero sequence current compensation factor, calculated with X values
Zone1 (Ro-R1)/3R1	-	0.00 – 5.00	0.01	0.00	The zero sequence current compensation factor, calculated with R values
Time Delay	msec	0 - 60000	1	500	Time delay

2.1.2 Characteristics

The function uses an offset circle characteristic (see Figure 2-2).

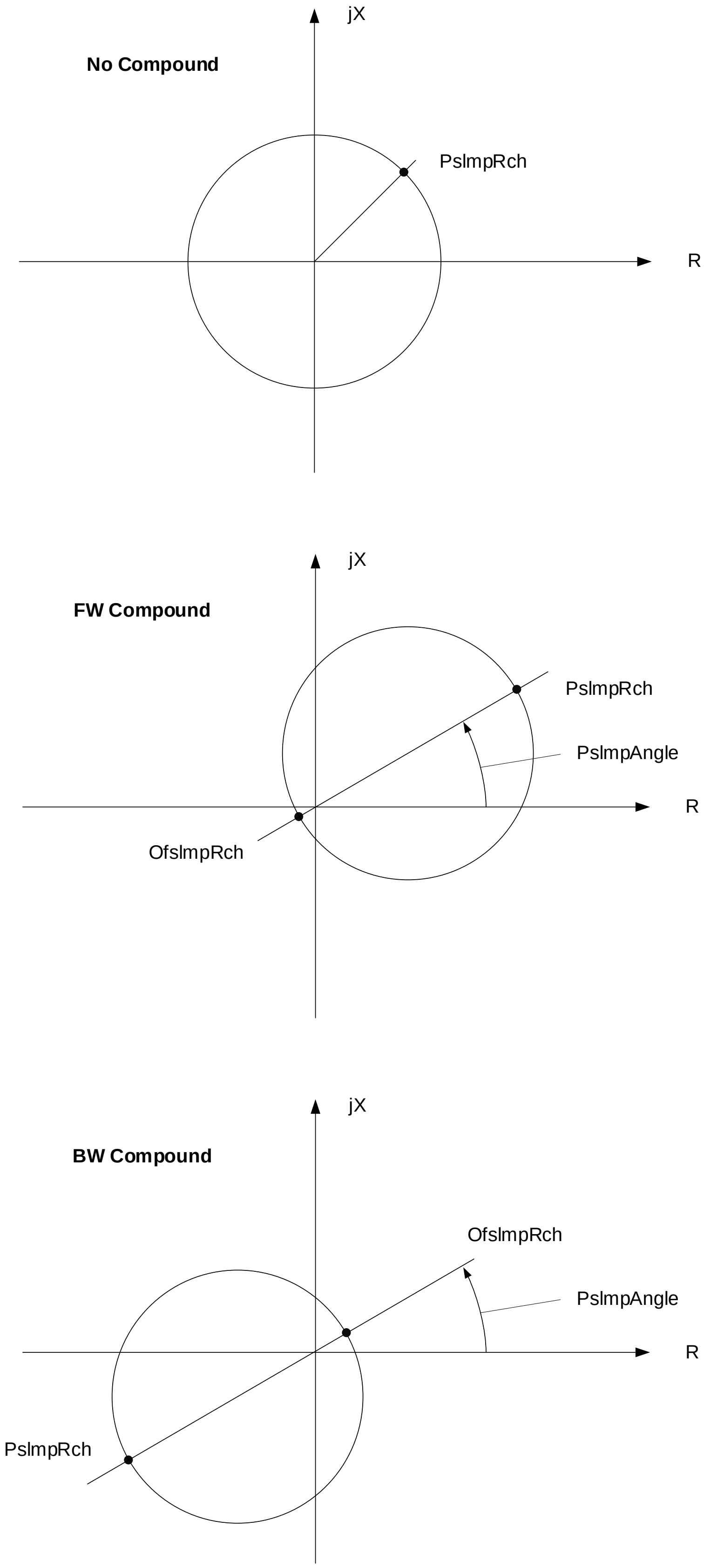

Figure 2-2 The offset circle characteristic

Earth-fault detection is based on a 1-slope biased characteristic, see Figure 2-3.

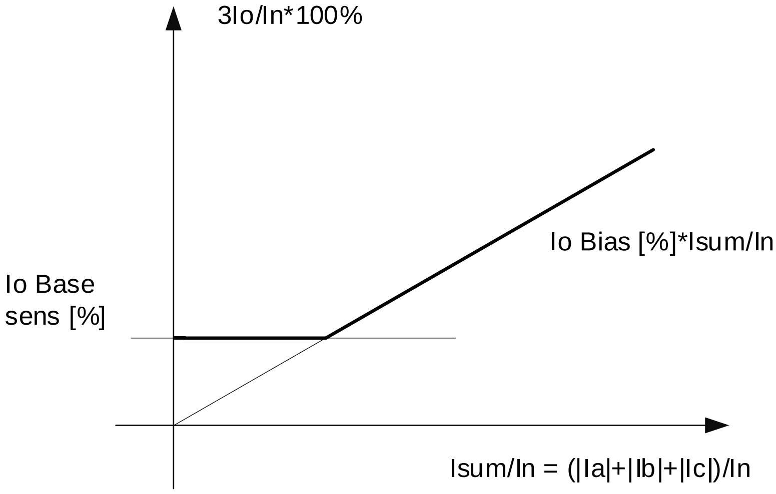

Figure 2-3 Percentage characteristic for earth-fault detection

2.2 Settings

This section describes briefly the analogue and digital inputs and outputs of the function block.

2.2.1 Analogue inputs

The function uses the following analogue signals as inputs:

- Sampled values of the three phase voltages
- Sampled values of the three phase currents
- Basic Fourier components of the three phase voltages
- Basic Fourier components of the three phase currents
- Calculated line-to-line values the three phase voltages
- Calculated line-to-line values the three phase currents

Graphic Analogue inputs *(only from firmware version 2.10.2.3010 and up)*

The sources of the analogue inputs are defined by the user, applying the graphic equation editor (*Logic Editor*). Parts written in **bold** are seen on the left side of the function block in the Logic editor.

Table 2-2 Analogue input signals of the impedance protection function

ANALOGUE INPUT SIGNAL	SIGNAL TITLE	EXPLANATION
IMP21_**U123**_AnIn_	3phase voltage	Input for 3-phase voltage
IMP21_**I123**_AnIn_	3phase current	Input for 3-phase current

The applied analogue connectors must be identical to the analogue input type (i.e. voltage to voltage input etc.), Invalid connections are not allowed.

2.2.2 Analogue outputs

The function has no analogue outputs.

2.2.3 Binary input signals (graphed output statuses)

The conditions of the inputs are defined by the user, applying the graphic equation editor (logic editor). The part written in **bold** is seen on the function block in the logic editor.

Table 2-3 The binary input signals of the the impedance protection function

BINARY INPUT SIGNAL	EXPLANATION
IMP21_**Blk**_GrO_	Blocking of the impedance protection function
IMP21_**VTSBlk**_GrO_	Blocking of the impedance protection function from the VT supervision

2.2.4 Binary output signals (graphed input statuses)

The binary output status signals of the impedance protection function. Parts written in **bold** are seen on the function block in the logic editor.

Table 2-4 The binary output signals of the impedance protection function

BINARY OUTPUT SIGNAL	SIGNAL TITLE	EXPLANATION
IMP21_**GenSt**_Grl_	General Start	General Start signal of the function
IMP21_**StL1**_Grl_	Start L1	The impedance of phase L1 is within the characteristic
IMP21_**StL2**_Grl_	Start L2	The impedance of phase L2 is within the characteristic
IMP21_**StL3**_Grl_	Start L3	The impedance of phase L3 is within the characteristic
IMP21_**GenTr**_Grl_	General Trip	General trip signal of the function

2.2.5 On-line data

Visible values on the on-line data page:

Table 2-5 The displayed on-line data of the impedance protection function

SIGNAL TITLE	DIMENSION	EXPLANATION	IEC61850 DATA ATTRIBUTES
Direction	-	Direction setting when the function started	Z3PDIS1STStr$dirGeneral
Impedance Loop	-	Impedance loop of the fault was detected in	-
General Start	-	General Start signal of the function	Z3PDIS1STStr
Start L1	-	The impedance of phase L1 is within the characteristic	Z3PDIS1STStr$phsA
Start L2	-	The impedance of phase L2 is within the characteristic	Z3PDIS1STStr$phsB
Start L3	-	The impedance of phase L3 is within the characteristic	Z3PDIS1STStr$phsC
General Trip	-	General trip signal of the function	Z3PDIS1STOp
Voltage input assignment	-	*Status of the graphical analogue input (if exists) (Complete if OK, Missing if not connected)*	
Current input assignment	-	*Status of the graphical analogue input (if exists)*	

2.2.6 Events

The events in grey are not actually shown in the event list, but they are still accessible in IEC61850 reporting. See the On-Line data chapter above for them.

Table 2-6 Events of the impedance protection function

EVENT	VALUE	EXPLANATION	IEC61850 DATA ATTRIBUTES
Direction	-	Direction setting when it started	Z3PDIS1STStr$dirGeneral
Start L1	-	The impedance of phase L1 is within the characteristic	Z3PDIS1STStr$phsA
Start L2	-	The impedance of phase L2 is within the characteristic	Z3PDIS1STStr$phsB
Start L3	-	The impedance of phase L3 is within the characteristic	Z3PDIS1STStr$phsC
Neutral Start	-	The zero-sequence current condition for ground loops is fulfilled	Z3PDIS1STStr$neut
General Start	-	General Start signal of the function	Z3PDIS1STStr
General Trip	-	General trip signal of the function	Z3PDIS1STOp

2.2.7 Indication of the fault direction and loop

There are internal status variables created to indicate the direction and the fault loop. These variables are defined as integer statuses, which can be browsed in the EuroCAP program to have them displayed.

Table 2-7 Indication of the fault loop and direction of the impedance protection function

INTEGER STATUS	TITLE	VALUE	EXPLANATION
IMP21_Dir_ISt_	Direction	0: unknown 1: forward 2: backward	Direction setting when it started
IMP21_Loop_ISt_	Impedance Loop	0: N/A 1: L1-N 2: L2-N 3: L3-N 4: L1-L2 5: L2-L3 6: L3-L1 7: L1-L2-L3	Indication of the impedance loop of the fault was detected in

2.3 Technical data

The technical data are based on the function block testing according to the directives of the **IEC 60255-121:2014** standard.

Table 2-8 Technical data of the impedance protection function

FUNCTION	VALUE
Rated current (In)	1/5A, parameter setting
Rated voltage (Un)	100/200V phase to phase, parameter setting
Operating range - current	20 – 2000% of In
Operating range - voltage	3-110 % of Un
Impedance effective range In=1A In=5A	 0.1 – 200 Ω Ohm 0.1 – 40 Ω
Zone static accuracy	48 Hz – 52 Hz 49.5 Hz – 50.5 Hz
Zone angular accuracy	±3 °
Operate time	Typically 55 ms ±3 ms
Minimum operation time	<60 ms @ f nominal < 100 ms @ 48-52 Hz
Reset time	30-55 ms
Reset ratio	1.1

2.3.1 Notes for testing

Normally in the EuroProt+ devices the trip contacts are assigned to the Trip Logic function block, and not to the protection function blocks. Because of this the testing personnel must make sure that the Trip Logic is switched on (‘Operation’ parameter is set to other than ‘Off’) before starting the testing, otherwise there will be no physical trip on the relay.

Additional notes for Graphic Analogue inputs *(only from firmware version 2.10.2.3010 and up):*

Starting from the firmware version **2.10.2.3010**, the majority of the function blocks can be updated to be equipped with graphic analogue inputs which **allow the user to assign the functions’ analogue inputs by applying the graphic equation editor**.

The analogue connections of these functions can be checked by examining the source that is connected to their inputs (just like examining the source of a logic signal).

These functions must be placed in the Logic Editor and their graphic analogue inputs must be connected to make them operate. If a connection is intact, the online status of the corresponding analogue input will show “Complete”. If it is missing, the status will be “Missing” and the function will not operate.

Note that these graphical inputs do not exist in the earlier firmware/function versions (2.8.x.xxxx)! Checking and modifying the analogue assignments in these cases are done by using the EuroCAP Software Configuration menu.