RADSC
Multi-purpose current
differential protection

ABB Network Partner AB

User's Guide

1MRK 509 016-UEN

Version 1
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General

A differential protection is used to protect different major power system components from damage due to shunt faults (short circuit and earth faults). The major advantage with differential protections is their inherent selectivity of operation, i.e. only faults within the protected section are to be recognized and selectively disconnected by circuit breakers isolating the fault from the power system. The differential protection does not have any back-up elements for faults external to the protective section.

A differential protection is a unit protection, and it compare currents proportional to the inflowing current to the protected section to the outflowing current out from the same section, see Fig. 1.
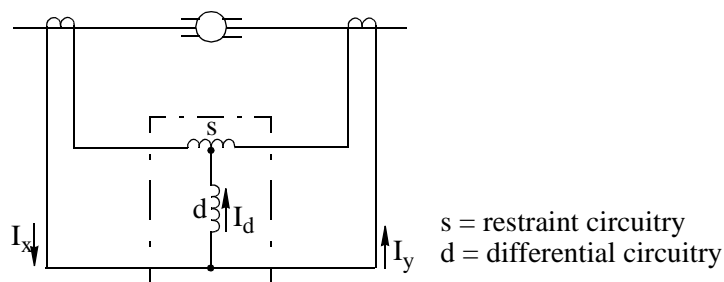

s = restraint circuitry
d = differential circuitry

Fig. 1   The schematic principle for a current differential relay

The protection is connected to the main current transformers, CTs, and possible interposing CTs. The ratios and connections of the interposing CTs should be selected with consideration taken to the ratio and connection of the main CT´s, in principle so that the differential currents will be zero during normal operation.

List of contents

1 Normal operation

During normal conditions however, a small current may flow through the differential circuit of the protection. This current normally corresponds to the ratio error of the CTs. Normally, this is only a small percentage of the rated current. If the protected object is a cable or a short line, a charge or leakage current could be of some significant value, e.g. 20% of the rated current.

1.1 Internal faults

The duty of the differential protection is to detect internal electrical faults (that is faults within the protected object or on the connecting lines, for example feeding cables included in the protected section) and then rapidly initiate tripping of the breakers associated with the protected section so as to prevent possible system instability due to the fault current. Fault damages, as well as non-selective tripping of other protective protections, are thereby prevented.

1.2 External faults

When faults arise outside the protected section, the differential circuit of the protection may be supplied with a relatively large current, which may be caused by ratio errors in the CTs. The differential protection must be designed not to operate for this differential current which could become very large. The differential protection is provided with a percentage through-fault current restraint. Therefor it does not operate for a constant value of the differential current, but for an adaptive percentage differential current related to the current through the protected object. This avoids having to set very high overcurrent operating levels in order not to operate during external faults leading to high protection spill currents.

2 Application

The RADSC is a three-phase differential protection intended for all types of power system components except full winding power transformers. Autotransformers may be protected if CT´s are included for each winding at the neutral end and no separate (tertiary) winding is available. To protect power transformers, magnetizing inrush current restraint is needed. Transformer differential protection, RADSB, is such a protection. See Buyer's Guide 1MRK 504 002-BEN

The RADSC is available with up to six restraint inputs. This protection is well suited for generators and motors, short cables or lines, reactors and capacitors.

The non-linear percentage restraint characteristic provides the required restraint for external faults. The characteristics are designed to provide excellent internal fault sensitivity. No through current restraint is applied until rated current is achieved, an advatage by design, that increases the sensitivity for internal faults during normal load conditions.

The RADSC protection also has an unrestrained instantaneous function which responds to the total differential current (less any dc component). This will provide faster and redundant operation for severe internal faults.

Interposing CTs are used to balance the currents to the protection. In addition interposing CTs may be used to reduce the effective burden of long secondary wires. The protected section of the protection can indude up to about two kilometers of high voltage cable since adequate filtering provides security against high current oscillations.

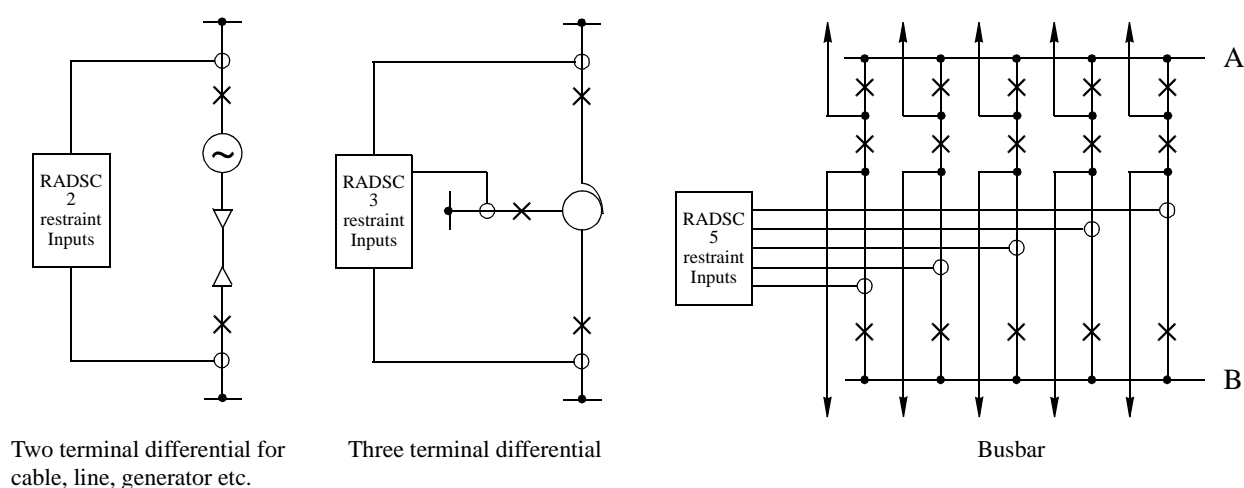Examples of application are shown in Fig. 2.

Two terminal differential for cable, line, generator etc.

Three terminal differential

Busbar

Fig. 2   Application examples for type RADSC

2.1 Calculation of current ratio

One or several sets of single-phase interposing CTs may be used to balance the differential protection, that means to match the protection inputs to the rated current of the protection. The interposing CT's have a connection and a turn ratio that in each individual case is adapted to the connection and rated data of the power transformer and to the ratios of the main CTs.

The differential protection type RADSC has the rated current 1 or 5 A (in the following denoted I_r). The restrained operation is set to 15, 20, 25 or 30 % of I_r.

When the main CTs are not matched to a certain degree to the rated load of the protected object, the secondary currents may deviate considerably from I_r. Then it is necessary to use interposing CTs. If the ratio of the main CTs is such that the secondary current at rated load only is for example 65 % of I_r, the real operate current of the differential protection will be about 1.5 times the set value. Interposing CTs should therefor be used to compensate for the lower secondary rated current, otherwise the sensitivity (calculated in per cent of the rated current of the power transformer) of the differential protection may become unacceptably low. The secondary circuits are normally arranged so that the currents to the differential protection will be approximately 1 or 5 A at rated load.

- Interposing CTs may be omitted if the input CT's are balanced, i.e. the ratios are the same.
- Normally Y-connected main CT should be used supplying Y-connected windings of the interposing CTs.
- The current ratios of the main CTs, I_1/i_1 and I_2/i_2, are used for calculations of the secondary currents i_{n1} and i_{n2}.
- When defining the current ratios of the interposing CTs, the primary side should be defined first, that means $i_{n\ prim} / i_{n\ sec}$. The corresponding marking of the interposing CT primary and secondary winding terminals are P_1 - P_2 / S_1 - S_2.

2.2 Selection of interposing CTs

As a standard the reconnectible multi-tapped interposing current transformer type SLCE 12 should be used. This CT is available in three versions with the current ratios 0.65-2.60/1 A, 2.55-10.1/1 A and 2.85-11.2/5 A, see Tables 1 to 3. The interposing CT can be connected in such way that the secondary current in an unloaded condition deviates maximum ±3 % from the rated value for a current within the range of the interposing CT.

The SLCE 12 interposing CTs are available as loose single-phase units or as complete three-phase assemblies on an apparatus plate with connection screw-terminal blocks. Ordering information is given in the Buyer's Guide. Dimensions are found in section "Design" below.
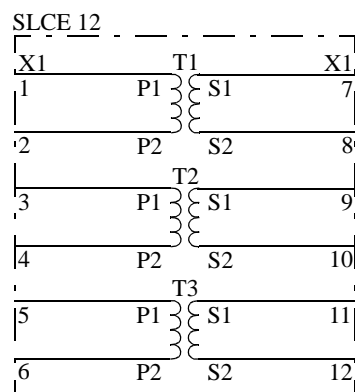
Fig. 3   Terminal diagram for three-phase CT assembly

It is an advantage that the interposing CTs are located close to the differential protection so they can get a saturation factor as high as possible. The saturation factor (n) can be calculated according to following formula:

$$n = \frac{a}{b + Z}$$

where

a =   a constant (ohms), which depends on the design of the current transformer and the frequency of the network. It is given in Table 1 at 50 Hz. The value is 20% higher at 60 Hz.

b =   the impedance of the secondary winding

Z =   the impedance of the burden (wires and the differential protection). See table 2 to 4.

The rated primary current multiplied by the calculated saturation factor gives the rated primary current at which the composite error is about 10%. This is valid when the primary current is sinusoidal. At asymmetrical transient currents, the dc component of the current strives to saturate the core at a lower current than the one stated by the saturation factor.

The main CTs and the interposing CTs should have saturation factors that correspond to the maximum through-fault current. In case of a 1arge through-fault current with a superimposed dc-component with a large time constant, it can be difficult to avoid saturation of the interposing CTs. In such cases it is recommended that interposing CTs of the same type are used for all input circuits to avoid the risk of unwanted operation at external faults. To obtain the best possible saturation factor, interposing CTs and the differential protection should be selected for 1 A rated current.

When the differential protection is located at a large distance from the main CTs, it may be necessary to locate an extra set of interposing CTs close to the main CTs. This is specifically the case when the differential zone also includes a long supply cable.

These interposing CTs are selected with a low secondary current to reduce the burden on the main CTs to an acceptable value. A suitable secondary rated current is 0.4 A. See Table 1. In such case, a set of interposing CTs type SLCE 16/350 are used at the main CTs. Another set of interposing CTs type SLCE 12/200 with a secondary current of 1 A or 5 A, depending on selected protection, are used and located close to the differential protection. In order to minimize the influence of the capacitance of the pilot wires, type SLCE 16/350 should then be wye-wye-connected.

Table 1:

Type	Current ratio A/A	U_s V	a ohm	b ohm	S VA	Ordering number 4785 040-
SLCE 16/350	1/0,4	500	1200	10	3	-AUA
SLCE 16/350	5/0,4	500	1200	10	3	-ATL
SLCE 12/200	0,4/1	90	90	0,7	1,3	-AUB
SLCE 12/200	0,4/5	18	3,5	0,03	1,3	on request

If the wires between the CTs, i.e. the pilot wires, have poor insulation or there is risk for interruptions, non-linear protective resistors may be connected to the wires. The protective resistors may consume a maximum of about 5 % of the maximum through-fault current that may flow in the pilot wires. The protective resistors are available in three versions having the voltage dependent characteristics shown in Fig. 4. Open secondary circuits may otherwise be destructive to the main CTs as well as the interposing CTs

U (V)

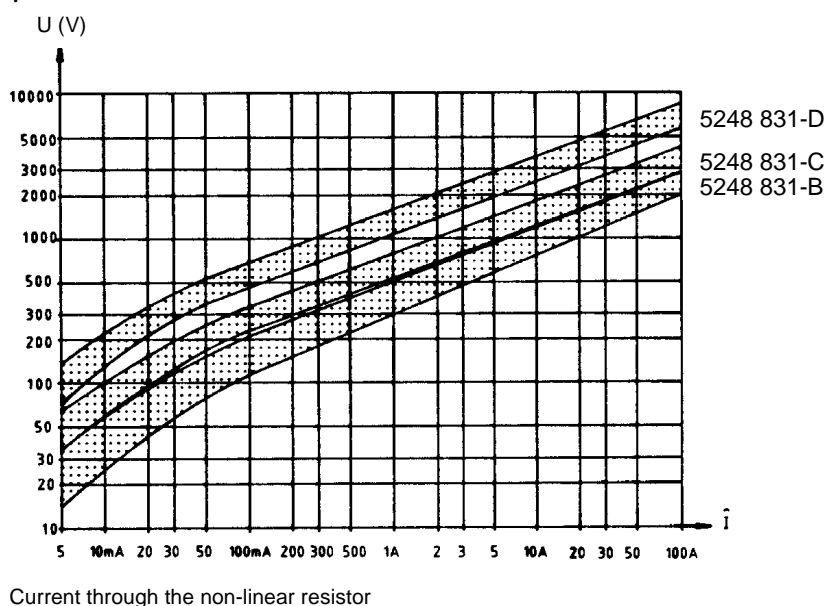Current through the non-linear resistor

Fig. 4   Current voltage characteristics for the non-linear resistor.

Information about the non-linear resistors are found in the User's Guide for the type RADHA High impedance differential protection.
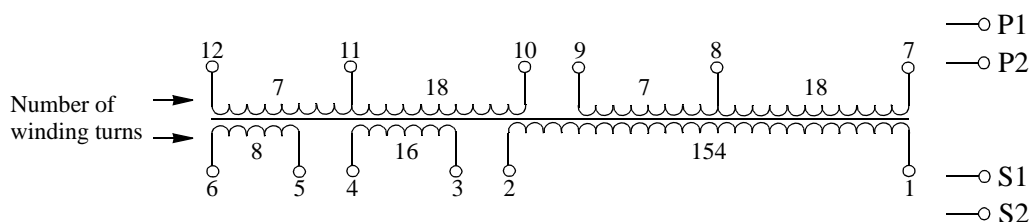
Table 2: Transformer SLCE 12 for I_p = 0.65-2.60 A, I_S = 1 A
Ordering number 4785 040-VP

Primary current A	Turn ratio	Connections on primary side between terminals	Connections on secondary side between terminals	a Ω	b Ω	Power consumption at I_S=1 A VA
0,650-0,670	200/130	P1-7, 9-10, 12-P2	S1-1, 2-6, 4-5, 3-S2	56	0,47	1,0
0,671-0,710	200/138		S1-1, 2-4, 3-S2	60	0,44	1,0
0,711-0,750	200/146		S1-1, 2-6, 5-S2	63	0,42	1,0
0,751-0,790	200/154		S1-1, 2-S2	67	0,39	1,0
0,791-0,830	200/162		S1-1, 2-5, 6-S2	70	0,42	1,1
0,831-0,870	200/170		S1-1, 2-3, 4-S2	74	0,44	1,2
0,871-0,900	200/178		S1-1, 2-3, 4-5, 6-S2	77	0,47	1,2
0,901-0,930	170/154	P1-7, 9-10, 11-P2	S1-1, 2-S2	67	0,39	1,2
0,931-0,980	170/162		S1-1, 2-5, 6-S2	70	0,42	1,2
0,981-1,02	170/170		S1-1, 2-3, 4-S2	74	0,44	1,4
1,03-1,07	170/178		S1-1, 2-3, 4-5, 6-S2	77	0,47	1,4
1,08-1,12	140/154	P1-7, 8-10, 11-P2	S1-1, 2-S2	67	0,39	1,4
1,13-1,18	140/162		S1-1, 2-5, 6-S2	70	0,42	1,4
1,19-1,24	140/170		S1-1, 2-3, 4-S2	74	0,44	1,6
1,25-1,28	140/178		S1-1, 2-3, 4-5, 6-S2	77	0,47	1,6
1,29-1,34	100/130	P1-7, P1-10, 9-P2	S1-1, 2-6, 4-5, 3-S2	56	0,47	1,0
1,35-1,42	100/138	and 12-P2	S1-1, 2-4, 3-S2	60	0,44	1,0
1,43-1,50	100/146		S1-1, 2-6, 5-S2	63	0,42	1,0
1,51-1,58	100/154		S1-1, 2-S2	67	0,39	1,0
1,59-1,66	100/162		S1-1, 2-5, 6-S2	70	0,42	1,2
1,67-1,74	100/170		S1-1, 2-3, 4-S2	74	0,44	1,2
1,75-1,81	100/178		S1-1, 2-3, 4-5, 6-S2	77	0,47	1,4
1,82-1,91	70/130	P1-7, P1-10, 8-P2	S1-1, 2-6, 4-5, 3-S2	56	0,47	1,2
1,92-2,01	70/138	and 11-P2	S1-1, 2-4, 3-S2	60	0,44	1,2
2,02-2,14	70/146		S1-1, 2-6, 5-S2	63	0,42	1,2
2,15-2,25	70/154		S1-1, 2-S2	67	0,39	1,4
2,26-2,37	70/162		S1-1, 2-5, 6-S2	70	0,42	1,4
2,38-2,48	70/170		S1-1, 2-3, 4-S2	74	0,44	1,6
2,49-2,60	70/178		S1-1, 2-3, 4-5, 6-S2	77	0,47	1,6

Multi-purpose current differential protection
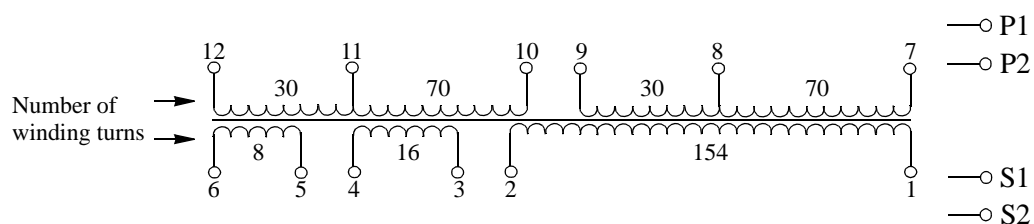
**Table 3: Transformer SLCE 12 for I_p = 2.55-10.1 A, I_s = 1 A**
Ordering number 4785 040 - VR

Primary current between terminals A	Turn ratio	Connections on primary side between terminals	Connections on secondary side	a Ω	b Ω	Power consumption at I_s=1 A VA
2,55-2,67	50/130	P1-7, 9-10, 12-P2	S1-1, 2-6, 4-5, 3-S2	56	0,47	1,2
2,68-2,84	50/138		S1-1, 2-4, 3-S2	60	0,44	1,2
2,85-3,00	50/146		S1-1, 2-6, 5-S2	63	0,42	1,2
3,01-3,16	50/154		S1-1, 2-S2	67	0,39	1,2
3,17-3,32	50/162		S1-1, 2-5, 6-S2	70	0,42	1,4
3,33-3,48	50/170		S1-1, 2-3, 4-S2	74	0,44	1,4
3,49-3,66	50/178		S1-1, 2-3, 4-5, 6-S2	77	0,47	1,6
3,67-3,86	43/162	P1-7, 9-10, 11-P2	S1-1, 2-5, 6-S2	70	0,42	1,4
3,87,4,04	43/170		S1-1, 2-3, 6-S2	74	0,44	1,6
4,05-4,21	43/178		S1-1, 2-3, 4-5, 6-S2	77	0,47	1,6
4,22-4,38	36/154	P1-7, 8-10, 11-P2	S1-1, 2-S2	67	0,39	1,6
4,39-4,61	36/162		S1-1, 2-5, 6-S2	70	0,42	1,6
4,62-4,83	36/170		S1-1, 2-3, 4-S2	74	0,44	1,8
4,84-5,07	36/178		S1-1, 2-3, 4-5, 6-S2	77	0,47	1,8
5,08-5,35	25/130	P1-7, P1-10, 9-P2	S1-1, 2-6, 4-5, 3-S2	56	0,47	1,2
5,36-5,67	25/138	and 12-P2	S1-1, 2-4, 3-S2	60	0,44	1,2
5,68-5,99	25/146		S1-1, 2-6, 5-S2	63	0,42	1,4
6,00-6,31	25/154		S1-1, 2-S2	67	0,39	1,4
6,32-6,64	25/162		S1-1, 2-5, 6-S2	70	0,42	1,4
6,65-6,95	25/170		S1-1, 2-3, 4-S2	74	0,44	1,6
6,96-7,17	25/178		S1-1, 2-3, 4-5, 6-S2	77	0,47	1,8
7,18-7,44	18/130	P1-7, P1-10, 8-P2	S1-1, 2-6, 4-5, 3-S2	56	0,47	1,4
7,45-7,88	18/138	and 11-P2	S1-1, 2-4, 3-S2	60	0,44	1,6
7,89-8,33	18/146		S1-1, 2-6, 5-S2	63	0,42	1,6
8,34-8,77	18/154		S1-1, 2-S2	67	0,39	1,8
8,78-9,21	18/162		S1-1, 2-5, 6-S2	70	0,42	1,8
9,22-9,60	18/170		S1-1, 2-3, 4-S2	74	0,44	2,0
9,61-10,1	18/178		S1-1, 2-3, 4-5, 6-S2	77	0,47	2,2

Table 4: Transformer SLCE 12 for I_p = 2.85-11.2 A, I_S = 5 A
Ordering number 4785 040 - VS

| Primary current between terminals A	Turn ratio	Connections on primary side between terminals	Connections on secondary side	a	b	Power consumption at I_S= 5 A
				Ω	Ω	VA
2,85-2,98	62/36	P1-7, 9-10, 12-P2	S1-1, 2-6, 4-5, 3-S2	3,1	0,046	1,8
2,99-3,14	62/38		S1-1, 2-4, 3-S2	3,3	0,041	1,8
3,15-3,30	62/40		S1-1, 2-6, 5-S2	3,5	0,040	1,8
3,31-3,46	62/42		S1-1, 2-S2	3,6	0,035	1,8
3,47-3,62	62/44		S1-1, 2-5, 6-S2	3,8	0,040	2,0
3,63-3,78	62/46		S1-1, 2-3, 4-S2	4,0	0,041	2,2
3,79-3,91	62/48		S1-1, 2-3, 4-5, 6-S2	4,2	0,046	2,4
3,92-4,05	53/42	P1-7, 9-10, 11-P2	S1-1, 2-S2	3,6	0,035	2,2
4,06-4,24	53/44		S1-1, 2-5, 6-S2	3,8	0,040	2,2
4,25-4,43	53/46		S1-1, 2-3, 4-S2	4,0	0,041	2,4
4,44-4,65	53/48		S1-1, 2-3, 4-5, 6-S2	4,2	0,046	2,6
4,66-4,87	44/42	P1-7, 8-10, 11-P2	S1-1, 2-S2	3,6	0,035	2,2
4,88-5,11	44/44		S1-1, 2-5, 6-S2	3,8	0,040	2,4
5,12-5,34	44/46		S1-1, 2-3, 4-S2	4,0	0,041	2,6
5,35-5,62	44/48		S1-1, 2-3, 4-5, 6-S2	4,2	0,046	2,8
5,63-5,96	31/36	P1-7, P1-10, 9-P2	S1-1, 2-6, 4-5, 3-S2	3,1	0,046	2,0
5,97-6,28	31/38	and 12-P2	S1-1, 2-4, 3-S2	3,3	0,041	2,0
6,29-6,61	31/40		S1-1, 2-6, 5-S2	3,5	0,040	2,0
6,62-6,93	31/42		S1-1, 2-S2	3,6	0,035	2,0
6,94-7,25	31/44		S1-1, 2-5, 6-S2	3,8	0,040	2,2
7,26-7,57	31/46		S1-1, 2-3, 4-S2	4,0	0,041	2,2
7,58-7,95	31/48		S1-1, 2-3, 4-5, 6-S2	4,2	0,046	2,4
7,96-8,40	22/36	P1-7, P1-10, 8-P2	S1-1, 2-6, 4-5, 3-S2	3,1	0,046	2,2
8,41-8,85	22/38	and 11-P2	S1-1, 2-4, 3-S2	3,3	0,041	2,2
8,86-9,31	22/40		S1-1, 2-6, 5-S2	3,5	0,040	2,4
9,32-9,70	22/42		S1-1, 2-S2	3,6	0,035	2,4
9,71-10,2	22/44		S1-1, 2-S2	3,8	0,040	2,6
10,21-10,7	22/46		S1-1, 2-5, 6-S2	4,0	0,041	2,8
10,71-11,2	22/48		S1-1, 2-3, 4-S2	4,2	0,046	2,8
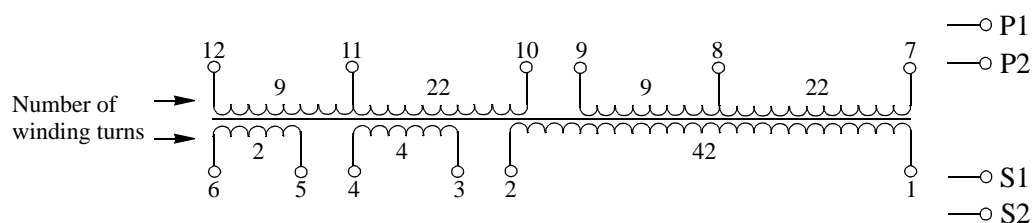
3 Design

3.1 Hardware description

The protection can be obtained in a number of variants; with output tripping relay type RXMS 1 or RXME 18 and with or without either phase indicator type RXSGA 1 or flag indication relay type RXSF 1.
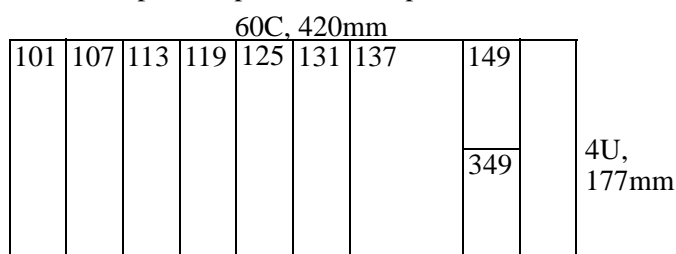
Two three-phase input restraint circuits

36C

101	107	113	119		131
					331	4U
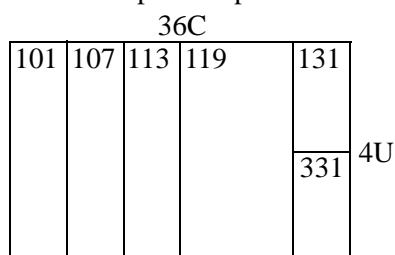
101	RTXP 18	Test switch
107	RXTUG 22H	DC/DC converter
113	RTQTB 060	Transformer unit
119	RXDSC 4	Measuring unit
131	RXMS 1 or RXME 18	Tripping relays
331	RXSGA 1	Phase indicator

Three three-phase input restraint input circuits

42C, 294mm

101	107	113	119	125		137
						337	4U, 177mm
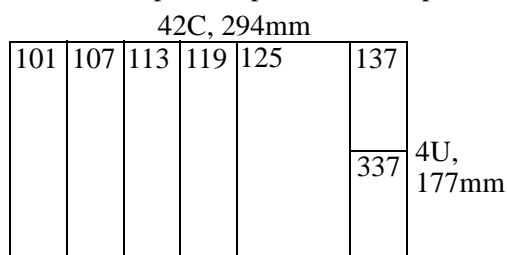
101	RTXP 18	Test switch
107	RXTUG 22H	DC/DC converter
113	RTQTB 060	Transformer unit
119	RTQTB 061	Transformer unit
125	RXDSC 4	Measuring unit
137	RXMS 1	Tripping relay
337	RXSGA 1	Phase indicator

Five three-phase input restraint input circuits

60C, 420mm

101	107	113	119	125	131	137		149	
								349		4U, 177mm

101 107	RTXP 18	Test switches
113	RXTUG 22H	DC/DC converter
119	RTQTB 060	Transformer unit
125 131	RTQTB 061	Transformer units
137	RXDSC 4	Measuring unit
149	RXMS 1	Tripping relay
349	RXSGA 1	Phase indicator

Six three-phase input restraint input curcuits

60C, 420mm

101	107	113	119	125	131	137	143		155
									355	4U, 177mm
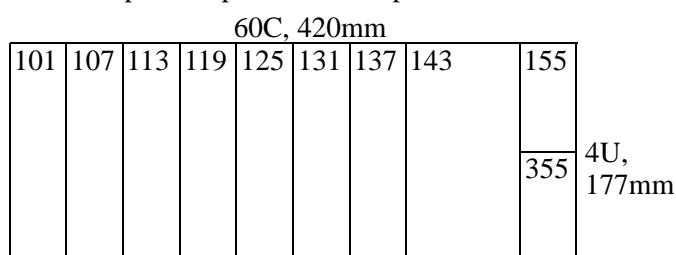
101 125	RTXP 18	Test switch
107	RTQTB 060	Transformer unit
113 119 131	RTQTB 061	Transformer units
137	RXTUG 22H	DC/DC converter
143	RXDSC 4	Measuring unit
155	RXMS 1	Tripping relay
355	RXSGA 1	Phase indicator

Fig. 5   Physical positions of the units in the RADSC versions
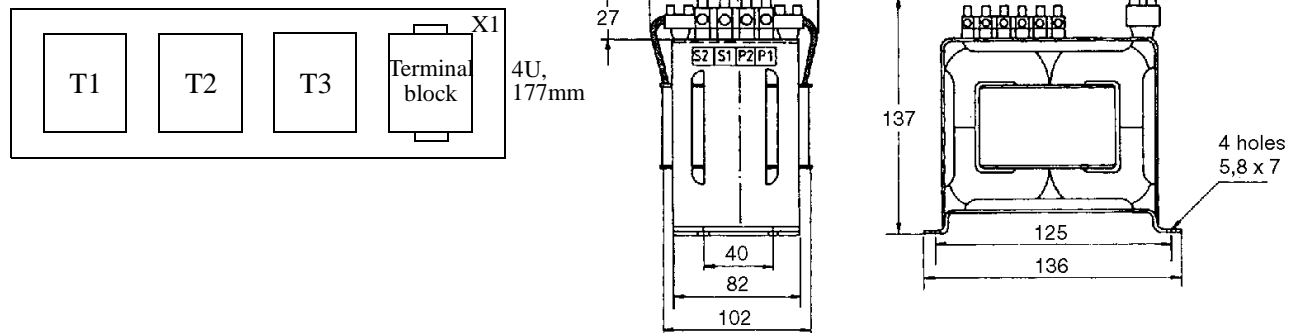
SLCE 12 19", 482 mm

Fig. 6   Dimensions of interposing CTs SLCE 12

3.2 Test switch

The test switch type RTXP 18 is included in the testing system COMBIT-EST. A complete secondary testing of the protection can be performed with 1 or 2 test-plug handles type RTXH 18 connected to a test set. When the test plug handle is inserted in the test switch, the tripping circuits are first opened and then the current transformer circuits are short circuited.

All input, output and differential currents can be measured during operation with 1 or 2 ammeter test plugs type RTXM. The tripping circuits can be blocked with trip-block plug type RTXB. The differential protection can be totally blocked with a block-plug handle type RTXF 18.

When the block-plug handle is inserted in the test switch the current transformer circuits are short circuited and the tripping and signal circuits are disconnected , including the DC power supply.

Connections to CTs and the tripping circuits are done on the rear of the test switch and when the differential protection is installed. Connection to contacts providing signal at operation or at loss of auxiliary supply is done directly on the terminal bases for the tripping protections, the phase indicator (or the signal relay) and the DC-DC converter.

3.3 DC-DC converter

The DC-DC converter type RXTUG 22H converts the supplied battery voltage to an alternating voltage which is then transformed, rectified, smoothed and regulated to another direct voltage ($\pm$ 24 V). The available auxiliary voltage is in that way adapted to the measuring unit. In addition, the input and output voltages will be galvanically separated in the transformer unit which contributes to damping possible transients in the auxiliary voltage supply to the measuring unit. The converter has a built-in signal relay and a green light emitting diode (LED) for supervision of the output voltage.

3.4 Transformer units

The transformer units are connected to the test switch via their primary windings. The secondary windings are connected to the measuring unit.

The transformer unit type RTQTB 060 contains six input transformers, two for each phase of which one in the restraint circuit and the other in the differential circuit.

The transformer unit type RTQTB 061 contains six input transformers as well as diodes and resistors for two three-phase restraint circuits.

3.5 Measuring units

The measuring unit type RXDSC 4 contains four printed board assemblies, three of them phase circuitry printed board assemblies and one of them a measuring circuitry printed board assembly.

The phase circuitry boards contain circuits providing voltages for through-fault restraint as well as for operation. Additionally, the boards contain summing and integrating circuits as well as level detectors.

The measuring circuitry board contains two level detectors (restrained and unrestrained functions), and one relay driver as well as circuitries for stabilization of the auxiliary voltage, reference voltages and phase indication.

In addition, the board is equipped with two selector switches which make it possible to change the reference voltages and thus the operate values of the differential protection. The switches are accessible on the front of the measuring unit.

If required, the measuring unit can be removed from its terminal base, as it is of plug-in design, also during operation without any damages to the CTs or the input transformers. On the other hand, the output circuits must be blocked as there is a risk that a short-duration output impulse will be obtained depending on that terminal pins of the plug-in unit will not necessarily make or break the connections in the terminal base simultaneously when inserting or unplugging the unit.

3.6 Tripping relay

The auxiliary relay type RXMS 1 is used as an output tripping relay. Depending on the version of the differential protection it has four or six make contacts. The operate time is approximately four (4) ms.

The auxiliary relay type RXME 18 is used as an output tripping relay. It has two make contacts and a red flag. The flag will be visible when the armature picks up and is manually reset with a knob in the front of the protection. The operate time is approximately 30 ms.

3.7 Phase indicator

The phase indicator type RXSGA 1 indicates, with the aid of a signal relay and five LEDs, the operation of the differential protection. The unit gives information about which phase circuitry board that has provided operating voltage to the measuring circuitry board. The unit also indicates if the operation occurs in the unrestrained circuitry, that means if the differential current has been larger than the unrestrained operate value I_{su}.

The unit contains a printed circuit board with an operate and seal-in circuit for each LED. The LEDs, that provide phase indication with yellow light and operation indication with red light, are located in the front of the unit. The LED indication is reset by a push-button in the front of the unit. The signal relay will reset automatically when the output signal from the measuring unit ceases.

3.8 Operate value settings

The two operate values of the differential protection — the restraint operate value I_{sr} (0.15, 0.20, 0.25 and 0.30 times the rated current) and the unrestrained value I_{su} (5, 10 and 15 times the rated current) — are set with switches on the front of the measuring unit RXDSC 4. The switches are accessible after the cover of the unit has been removed, thus protecting the set operate value while in normal service. The operate value I_{sr} for the restraint operation is typically set at 0.25 x I_n.

The operate value Isu for the unrestrained high set instantaneous differential overcurrent operation, is determined by the magnitude of the maximum inrush through fault current and how good the ratios and saturation factors fo the CT´s are matched to each other.

When the differential protection is applied to provide bus protection, the setting 15 x should be chosen, as there may be very large through-fault currents when external faults occur. These currents can cause large differential currents if the CTs saturate.

4 Technical data

Energising quantities, rated values and limit

RADSC		
Rated current, I_r	1 or 5 A	
Rated frequency, f_r	50 and 60 Hz	
Restrained operate value, I_{sr}	Settable 0,15, 0,20, 0,25 and 0,3 times I_r	
Unrestrained high speed operate value, I_{su}	Settable 5, 10 and 15 times I_r	
Resetting ratios	> 85%	

Operate time:
   at $I_d = 3 \times I_{sr}$
   at $I_d = 3 \times I_{su}$
	approx. 20 ms
	approx. 15 ms	

Minimum impulse time	3 ms at $I_d = 3 \cdot I_{su}$	
Resetting time	< 50 ms	

Overload capacity:
   continuously
   for 1 s
	$I_r = 1$ A
	10 A
	100 A
		$I_r = 5$ A
		20 A
		250 A

Permitted ambient temperature	-25°C to +55°C	
Auxiliary voltage, EL	24-250 V dc +10%, -20%	

Power consumption:
Restraint circuitry
   $I_r = 1$ A
   $I_r = 5$ A
Differential circuitry
   $I_r = 1$ A
   $I_r = 5$ A
Auxiliary voltage circuitry
   normal service
   operation
	
	approx. 0,03 VA/phase
	approx. 0,3 VA/phase
	
	approx. 0,03 VA/phase
	approx. 0,3 VA/phase
	
	approx. 7 W
	approx. 11 W	

Insulation tests (IEC 255-5)

Dielectric tests
   current circuits
   other circuits
	
	50 Hz, 2,5 kV, 1 min
	50 Hz, 2,0 kV, 1 min

Impulse voltage test	1,2/50 µs, 5,0 kV, 0,5 J

Electromagnetic compatibility tes

Power frequency tes	(SS 436 15 03)	0,5 kV, class PL4
Fast transient test	(SS 436 15 03)	4-8 kV, class PL 4
1 MHz burst test	(IEC 255-22-1)	2,5 kV, class III

Electrostatic test
   contact discharge
   air discharge
	(IEC 255-22-2)	
		6 kV, class III
		8 kV, class III

Radiated electromagnetic field test	(IEC 1000-4-3)	10 V/m, 26 - 1000 MHz, class III
Conducted electromagnetic test	(IEC 1000-4-6)	10 V 0,15-80 MHz
Fast transient test	(IEC 255-22-4)	4 kV, class IV
Electromagnetic emission test	(EN 55 011)	0,15-100 MHz, class A

Mechanical tests

Vibration test
   Response test
   Endurance test
	(IEC 255-21-1)	
		0,035/0,5 g, 10-150 Hz, class I
		1 g, 10-150 HZ, 20 sweeps, class I

Shock tests
   Response test
   Withstand test
	(IEC 255-21-2)	
		5 g, 11 ms, 3 pulses, class I
		15 g, 11 ms, 3 pulses, class I

Bump test	(IEC 255-21-2)	10 g, 16 ms, 1000 pulses, class I

Mass

4U 36C	Appr. 6 kg
4U 42C	Appr. 9kg
4U 60C	Appr. 11-13 kg

Contacts

Relay	RXMS 1	RXTUG 21H RXSGA 1
Contacts	4 or 6 make contacts	1 change-over contact
Maximum voltage between the lines, DC/AC Current carrying capacity: Continuously 1 s 10 ms	300/250 V 4 A 20 A 100 A	250/250 V 5 A 15 A
Making and conducting capacity during 200 ms	30 A	
Breaking capacity: AC, P.F.> 0.4, max 250 V DC, L/R < 40 ms, max 48 V 110 V 125 V	10 A 1.2 A 0.3 A 0.25 A 0.15 A	30 A 8 A 1.0 A 0.4 A 0.3 A

Interposing CTs SLCE 12 and SLCE 16

Overload capacity Continuously 10 s 1 s	$2.5 \times I_n$ $15 \times I_n$ $75 \times I_n$
Maximum conductor size	10 mm^2
Dielectric tests	50 Hz, 2.5 kV, 1 min
Remanence	< 0.2 T
Weight: SLCE 16 SLCE 12	5.4 kg 3.6 kg

5 Mounting details

The RADSC is delivered mounted on apparatus bars. When additional mounting is required specify a 4U equipment frame with support frame for 19" rack mounting or a panel mounting case type RHGX 12 or 20 or RHGS 30 case . (See Buyer's Guide catalogue for COMBIFLEX connection and installation components.)

6 Operation
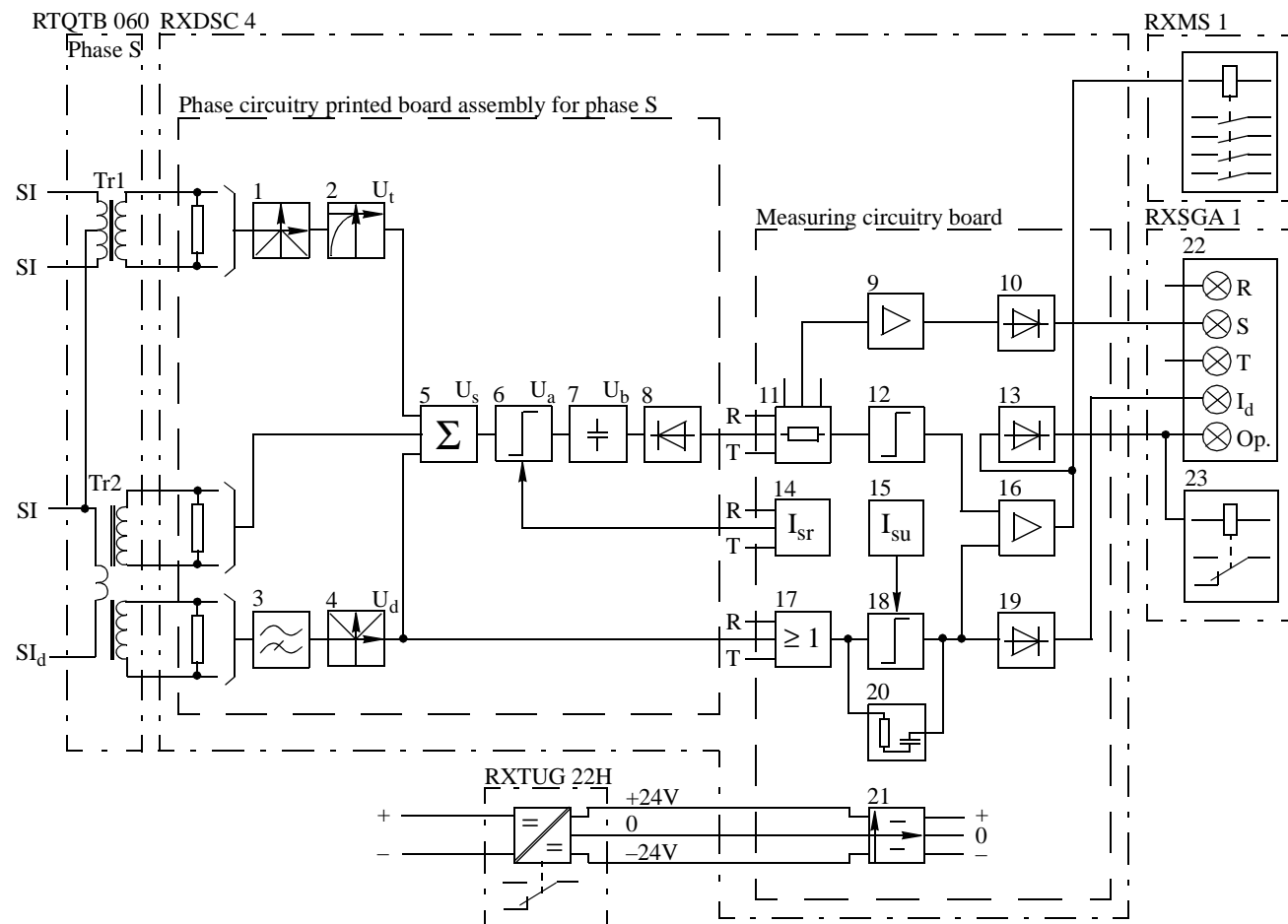
1 Rectifier
2 Non-linear circuit
3 Low-pass filter
4 Rectifier
5 Summation curcuit
6 Level detector
7 Integration curcuit
8 Diode cutcuit
9 Amplifirt
10 Diode curcuit
11 Resistor circuit
12 Level detector

13 Diode curcuit
14 Setting device
15 Setting device
16 protection driver stage
17 OR-curcuit
18 Level detector
19 Diode curcuit8 Diode cutcui
20 Feed-back curcuit
21 Stabilizing curcuit
22 LED-indicators
23 Signal protection

Fig. 7   Block Diagram for one phase element of RADSC

The two input transformers Tr1 and Tr2 of phase S are mounted in the transformer unit RTQTB 060 and connected to the line current transformer, as illustrated in Fig. 8, possibly via interposing CTs.
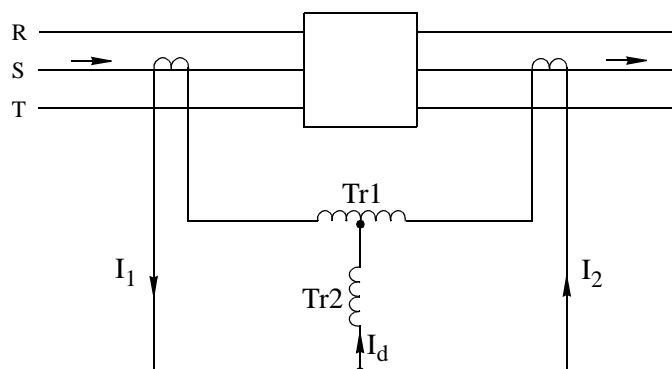

Fig. 8   Principle connection of the input transformers Tr1 and Tr2

The transformers Trl and Tr2, which have cores with air gaps, have secondary voltages proportional to the currents $I_1 + I_2$ and $I_d = I_1 - I_2$, respectively.

During normal service, $I_1 - I_2 \approx 0$ and output voltage is obtained only from Trl. The voltage is rectified (1), see Fig 19, and via a nonlinear circuit (2), containing regulating diodes and resistors, a negative voltage Ut is obtained. This voltage provides the differential protection with a variable through-fault restraint. The restraint is zero at through currents smaller or equal to rated current and large at large through currents when saturation can cause large differential currents $I_d = I_1 - I_2$. The operation of the differential protection is blocked up to a certain differential current. This is illustrated in figure 9, which shows the restraint chracteristic at thorough current

$$\frac{I_x + I_y}{2}$$

I_x and I_y are the largest currents in to and out from the protected section respectively.

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Differential current I_d
in multiples of rated current I_r

a) $I_{sr} = 0,35 \times I_r$
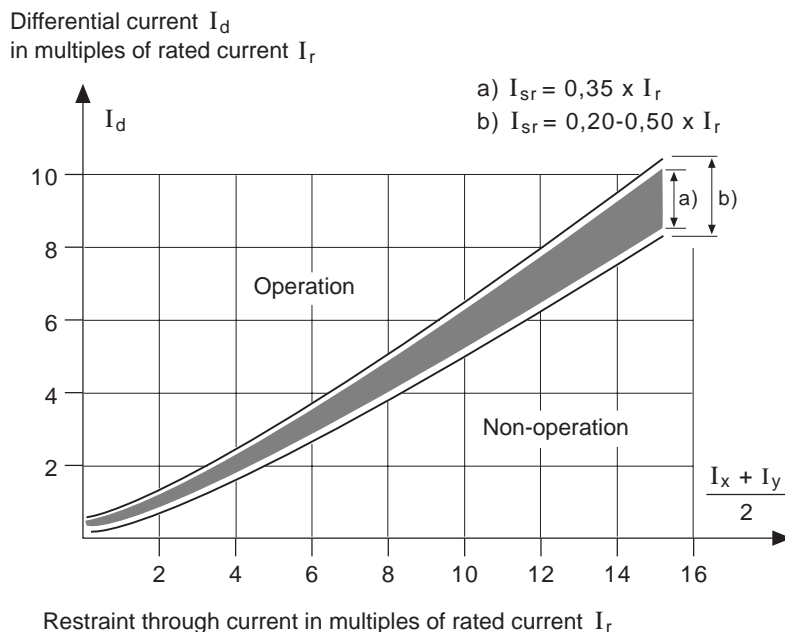b) $I_{sr} = 0,20\text{-}0,50 \times I_r$

Fig. 9   Restraint characteristic at through currents

The differential current I_d will flow through the primary winding of the transformer Tr2. Also this transformer has a core with air gap and a secondary winding with suitably adapted load resistor. The winding provides the operating voltage that initiates operation at internal faults. The voltage passes through a low-pass filter in (3 in Fig. 7), which suppresses the signals from high frequency differential currents, which e.g. can be developed during switching operations in faultless cable networks. The voltage is then rectified in an ideal rectifier (4) composed by operational amplifiers and the positive voltage U_d is obtained.

The rectified, but unsmoothed, voltages U_t, and U_d are summed (5) and supplied to a level detector (6). The resultant voltage U which is a pulsating DC voltage, is compared with a reference DC voltage Ur. The voltage Ur can be controlled with a switch on the measuring circuitry board providing settings of the restrained operate value I_{sr} (0.15, 0.20, 0,25 or 0.30 times the rated current). The level detector provides an output voltage U_a with a constant amplitude when the voltage U_s is larger than the reference voltage U_r. The duration of the output voltage is thus equal to the time when U_s is larger than U_r. The voltage pulses U_a are integrated (7) and connected via a diode circuit (8) to one for all three phases common measuring circuit on the measuring circuitry board.

When the duration of U_a is at least 41% of the power system period, that means 4.1 ms per 10 ms at 50Hz, the integrated voltage U_b will exceed a permanently set reference value U_z of the level detector (12). The protection driver stage (16) will then operate and the output tripping relay type RXMS 1 will pick up. A signal is simultaneously provided via a diode cir-

cuit (13) to an input of the phase indicator unit type RXSGA 1. A LED marked "Operation" (22) will then be lit and the auxiliary relay (23) in RXSGA 1 will pick up.

Fig. 10 shows the various voltages when U_s is larger than U_r during approximately 50% of the cycle, that means that the conditions for operation are fullfilled.
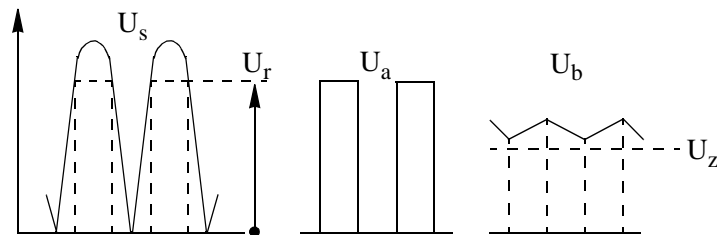

Fig. 10   Signal integration for operation

When the level detector (12) operates, a current will flow through a resistor circuit (11). The voltage across the resistors will be amplified (9) and connected via a diode circuit (10) to the phase indicator unit. This unit indicates with LEDs the particular phase or phases in which the differential current has exceeded the operate value.

The voltage U_d is also connected directly to the measuring circuitry board. It is supplied via an OR-circuit (17) to a level detector (18) having a reference value regulated by a switch for setting the unrestrained operate value I_{su} (15). When the set value is exceeded, an output voltage is obtained which is fed back via an RC-circuit (20) to provide an output of a sufficient duration. The voltage triggers a protection driver stage (16) and is supplied via a diode circuit (19) to an input to the phase indicator unit. The output protection operates and a LED marked "Id > > " will be lit.

The unrestrained operate value circuit can be set for operation at 5, 10 or 15 times the rated current, and provides fast tripping for large differential currents. The circuit has a very short impulse limit time of only approximately 3 ms. Thus operation will be obtained even if the CTs will become saturated during the event. Operation is obtained at approximately 20% below the set value for symmetrical three-phase currents.

The operate times of the restrained circuit and the unrestrained circuit including trip relay type RXMS 1 as an output protection are illustrated in Fig. 11.
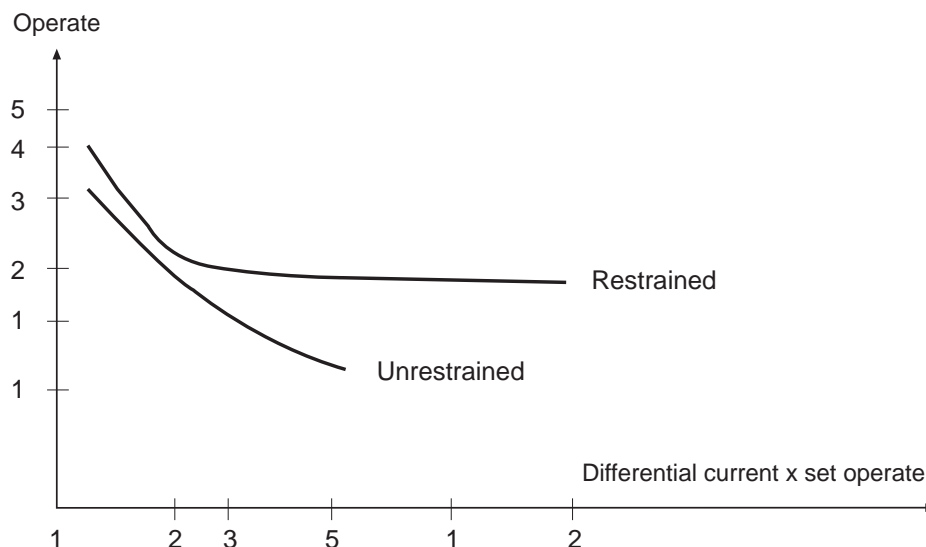
Fig. 11   Operate time-current characteristics for type RADSC

The necessary auxiliary voltage required for operation is obtained from the dc-dc converter type RXTUG 22H which provides an output voltage ± 24 V dc for input voltages within the specified range. The measuring unit includes the stabilizing circuit (21) that stabilises voltages to values suitable for the electronic circuits of the phase circuitry boards and the measuring circuitry board as well as for reference circuits.

7 Testing

Before the final commissioning, the following tests should be carried out. Ratios and connections of interposing CTs for RADSC is described under "Calculation of current ratio".

7.1 Receiving

Remove the protection from the packaging material and visually inspect for possible transportation damage. Check that all screws are firmly tightened and that all elements are securely fastened.

Check that the delivered protections have correct rated data stamped on the rating plate which is located on the test switch RTXP 18, i.e. ordering number, rated current, rated frequency and rated EL voltage. Check that all optional elements requested are included. Also check that all auxiliary relays, line CTs and interposing CTs have the correct rated data as ordered.

7.2 Storage

If the protection is to be stored before installation this must be in a dry and dust-free place, preferably in the original transport case.

7.3 Installation

The protection is built up of plug-in units according to ABB's mounting system COMBIFLEX. This system is mainly adapted for the international flush mounting on a panel. See the Buyer's Guide for the COMBIFLEX system and the connection and installation parts.

The differential protection is mounted an apparatus bars intended for mounting into a 19" equipment frame with a support frame, or in a case type RHGX or RHGS. The rear of the protection should be accessible for inspection and wiring work. Places which are dusty, moist or liable to rapid temperature variations or powerful vibration or shocks should be avoided. The individual protection covers should be properly fitted, otherwise there is a risk that dust, etc may enter the protections and elements. Before a cover is removed, it should be dusted well in advance so that any dust stirred up does not settle in the unit.

The external connections should be made according to the proper enclosed diagram with socket equipped leads of type COMBIFLEX. 20 A sockets shall be used for connection to the test switch RTXP 18 and 10 A sockets for connection directly to the sockets for plug-in modules. See the relevant circuit diagram.

The leads from the current and voltage transformers should be identified with regard to phase, phase sequence and polarity and connected to the correct terminals according to the external connection diagram.

Before starting the commissioning, check that the station auxiliary DC voltage is in accordance with the data stated on the rating plate, and that the auxiliary voltage is connected to the protection with correct polarity.

7.4 Maintenance

All the apparatus in the differential protection is robust and maintenance is therefore reduced to a minimum. Since the protection is only called upon to operate at very infrequent intervals, it will be of value to test the protection regularly, say once a year, by secondary injection. In severe environments, where problems with contacts may be experienced, more frequent checking may be required and therefore the testing should be adapted to the individual needs of each plant.

To simplify tests the protection is provided with a test switch type RTXP 18 which is a part of test system COMBITEST. The test system is described in Buyer's Guide lMRK 512 001-BEN.

The protections can be tested with the equipment in service. However, the protection cannot operate in its normal manner during the time the test is performed. Should a fault occur; a backup protection will operate instead. If the protected object can be taken out of service during the testing, this disadvantage can be avoided and it is then possible to test the complete circuit with all associated apparatus.

When testing static protections, the auxiliary voltage should be connected to the protection at least ten minutes before the measurements start.

7.5 Test reports

It is important to keep accurate equipment reports, test reports, and protection setting reports to be able to:

- compare with preceding tests if there has been any change of the operation of the protection
- observe how long a period of time has passed since the last testing and plan when the next testing should take place
- see if the protection has changed, for example, if some protection units have been exchanged
- see when and how the settings of the protection have been changed

After large service disturbances, these reports can be valuable when analysing the disturbances.

7.6 General check

Before the tests, a check should be made that there is no interruptions in the current transformer circuits. First, for example, phase L1 at a terminal board (before the protection test device) should be opened in each circuit. An ohm-meter or resistor bridge should be connected across the interruption and the resistance measured in the circuit (phase L1 in series with the connection in parallel of the phases L2 and L3 and any neutral). After this measurement the test handle is inserted in the test device and the resistance is measured once more to check that the test handle does not interrupt the current circuit. The measurements should then be carried out in the same way in the phases L2, L3 and the neutral. The resistance values should be low, for example not more than a few tens of ohms in a 1 A circuit.

7.7 Interposing current transformer test

Check the current of the CT's ratio by measuring the secondary current for a given supplied primary current. The polarity of the secondary terminals can be checked using a dc instrument of the moving coil type, the + terrninal of which is connected to S1 and other terminals to S2. If a pocket torch battery (approx. 4 V) has the plus pole connected to the primary terminal P1 and the minus pole is temporarily connected to P2, the instrument should show a positive reading, if the secondary terminals have the correct polarity.

7.8 Insulation test

With an insulation test apparatus (megger), (or with an ac voltage of max. 1500 V) the insulation resistance to earth of the current transformer circuits should be checked. The protective grounding should be disconnected and the megger connected in its place. The test should be carried out with the test handle inserted and with the handle fully withdrawn. Alter the testing the protective grounding connections should be restored immediately. There should be only one grounding connection in each current transformer circuit.

7.9 Check of the operating current

- The auxiliary voltage supply should be checked that it is correctly connected to the protection and it should also be measured.

- Insert the test handle in the testing device.

- Connect terminal 12 of the RTXH 18 testing handle to the test set with instrument. Connect the terminals 3, 4 and 5 to the test set and check the operate value for phase L1.

- Check the operate current consequently for phase L2 and L3. Maximum deviation from set value ±10 per cent if the current only contains sinusoidal current of fundamental frequency. Connect the voltmeter between terminal 17 (+) and 18 on the test handle for check of the operation.

7.10 Check of the tripping circuits

- Pull out the testing handle completely.

- Check that the circuit breaker for the protected object is tripped by manually actuating the armature of the tripping relay with a screw-driver through the hole in the cover.

If this type of manual operation of the tripping protection is not allowed, the tripping impulse should be connected so that it reaches the tripping coil of the circuit breaker.

7.11 Service test with primary current through the protected object

- A test with primary current through the protected object constitutes a final check that the current circuits of the protection are correctly connected and balanced, so that the three phase-currents in the differential circuits, in principle, all are zero in the case of full operating current conditions.

- The primary current can be a load current, or in some way injected, as indicated in section "Current sources during the primary current test".

- For the test, the current transformer should preferably be supplied with at least approx. 50 per cent of the rated current. In order to check that the current transformer circuits are correctly connected however, a lower current, for example 10 per cent is sufficient. The currents do not need to be identical in the three phases.

- Insert a blocking pin type RTXB (the red one) in the testing device in contact block 17, or if the two other tripping contacts of relay RXMS 1 are connected to the test device, insert a blocking pin also in blocks 15 and 16.

- In order to measure the through current, the current measuring plug type RTXM connected to an ammeter is used and inserted into the test device in contact blocks 3, 4 and 5, if the protection is fed from input 1.

- An ammeter with low power consumption connected to the protection via the current measuring plug RTXM inserted in the contact blocks 12 (phase L1), 13 (phase L2) and 14 (phase L3), should preferably be used for measuring the differential current.

- The phase currents and the differential currents Id should be noted for all three phases.

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- If the protection is correctly connected, the differential current Id should only amount to a few per cent of the input through-going load current. In case of faulty CT connections, differential currents are obtained. The magnitude depends on the type of faulty connection. Instructions will be given below for the most common cases of faulty connections. The blocking pin(s) and the current measuring plug are removed after executed tests.

7.12 Examples of faulty connections

- Approximately the same value for Id in all the three phases probably means that the type of incorrect connection has been made in all three phases.

- If the differential currents are relatively low a current transformer ratio may be incorrect. If interposing CTs are used, primary and secondary windings may have been interchanged or connected for the wrong over-all ratio.

- If the current in one of the differential circuits is high (Id > I), one of the incorrect connections below probably applies.

- I_d = 2 I. Probably wrong polarity in one set of CTs. In one set of (interposing) CTs, the polarity should then be changed in all three phases.

- I_d = √3 I. Permutation of the phases, that is connection of phase L1 from the one side together with, for example, phase L2 on the other, and L2 together with L3 and L3 together with L1.

- Alternative: A combination of incorrect connections above.

- Completely different values of I_d in different phases indicate asymmetric incorrect connections. They can be of many kinds. In certain cases the measured currents may indicate the fault directly.

Example: I_d = √3 I in two phases, I_d = 0 in one phase. Two phases have been interchanged (that is, L1 on the one side has been connected together with L2 on the other, and L2 together with L1.

- Asymmetries in the connection of the (interposing) CTs should be easy to discover by directly checking the polarity and delta connection.

7.13 Current sources during the primary current test

One of the following alternatives is normally used.

1. Test with a generator

Supply from a separate generator and with a three-phase short circuit applied outside the protected object (section). This method is the obvious one for generating stations. 50-100 per cent of the rated current is obtained with hardly any excitation of the generator.

2. Current supply from a transformer

If the above method is not applicable, the following could be an alternative. Inject three-phase current from the low voltage side of a local station service transformer.

7.14 Tripping test

A final tripping test should be carried out, in particular if reconnections have been made during previous tests. This can be done as described in section "Check of the tripping circuits", but including every phase.

It can also be made as a primary function test, if a method with injection towards an applied short-circuit is made at the primary current test, described above. The short circuit is then moved inside the CTs. Since the faults in a current transformer or interruptions and incorrect connections in the current transformer circuits should have been discovered in previous tests, a primary tripping test is usually not required.

7.15 Test with energization of the protected object

The operating value is set at the appropriate value. The protected object should be switched in a few times to the network at full service voltage without causing protection problems. In case of protection operation due to charging currents without any fault present, the settings may need to be changed or the wiring checked for correctness.

8 Commissioning

After tests have shown that the protection with its interposing CTs and connections are correct, the protection can be commissioned.

Check that:

- all provisional connections made during the tests are removed
- the tripping circuits of the circuit-breakers are connected
- the protection is correctly set
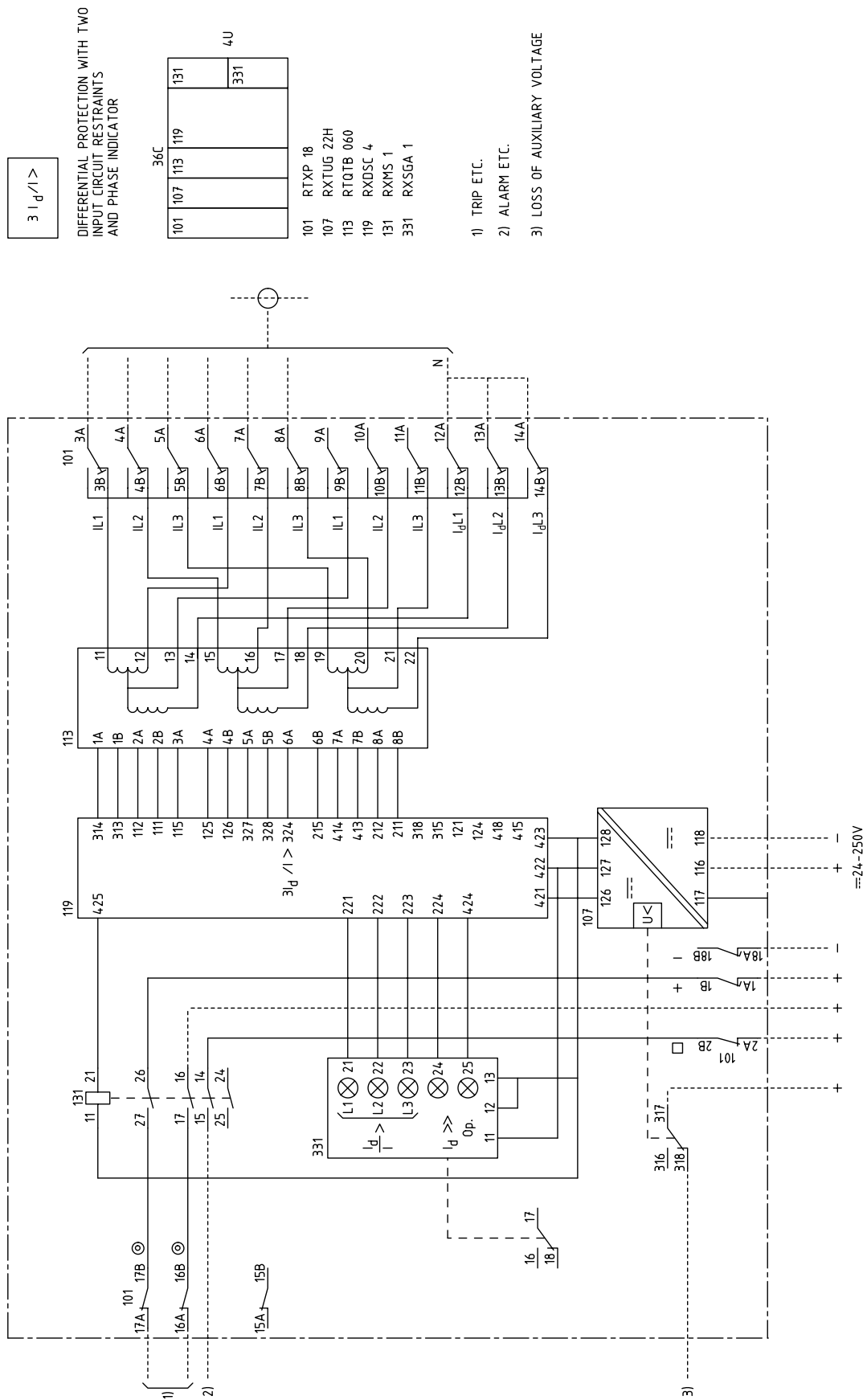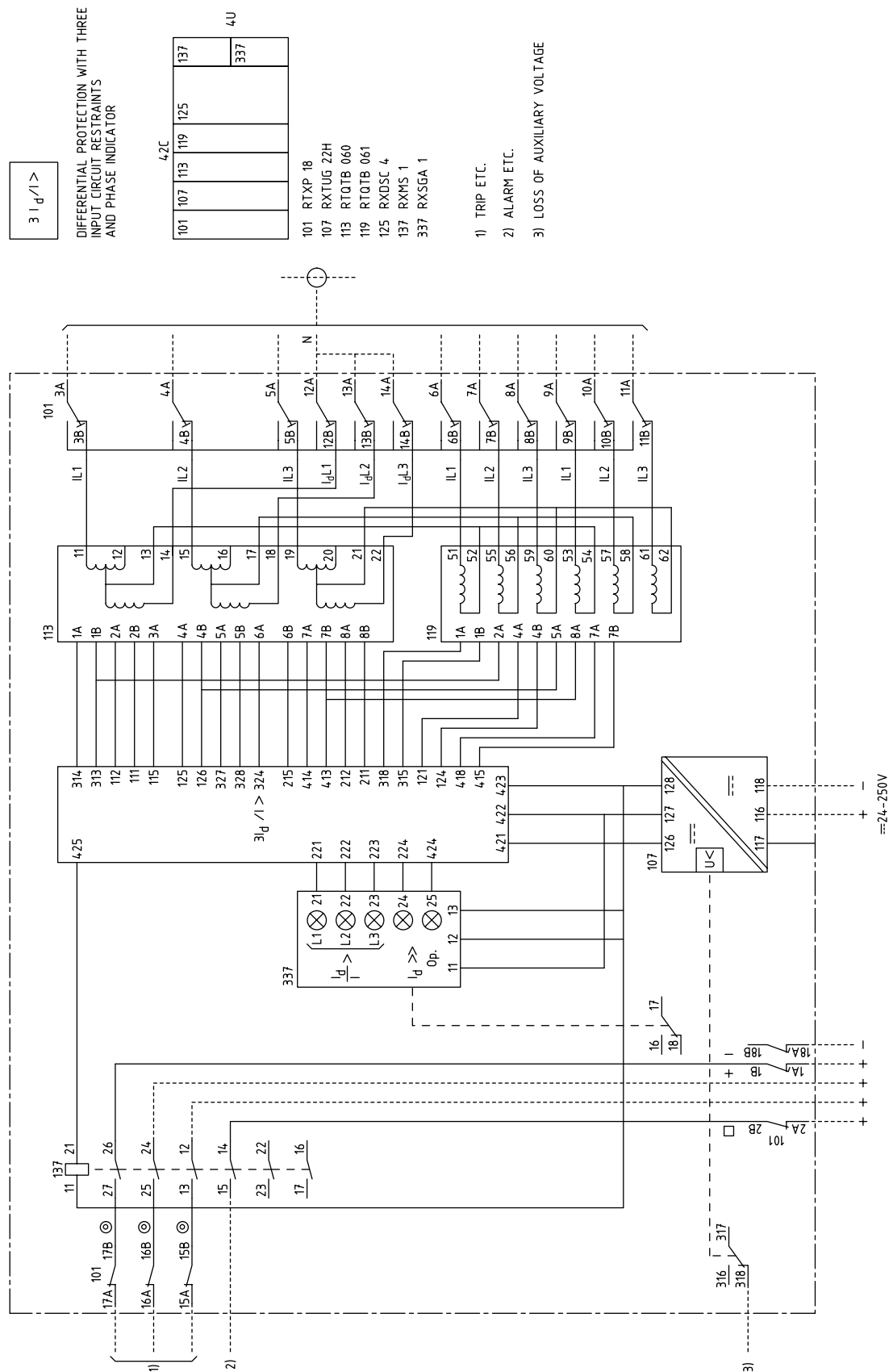- the indications have been reset

9 Circuit diagrams

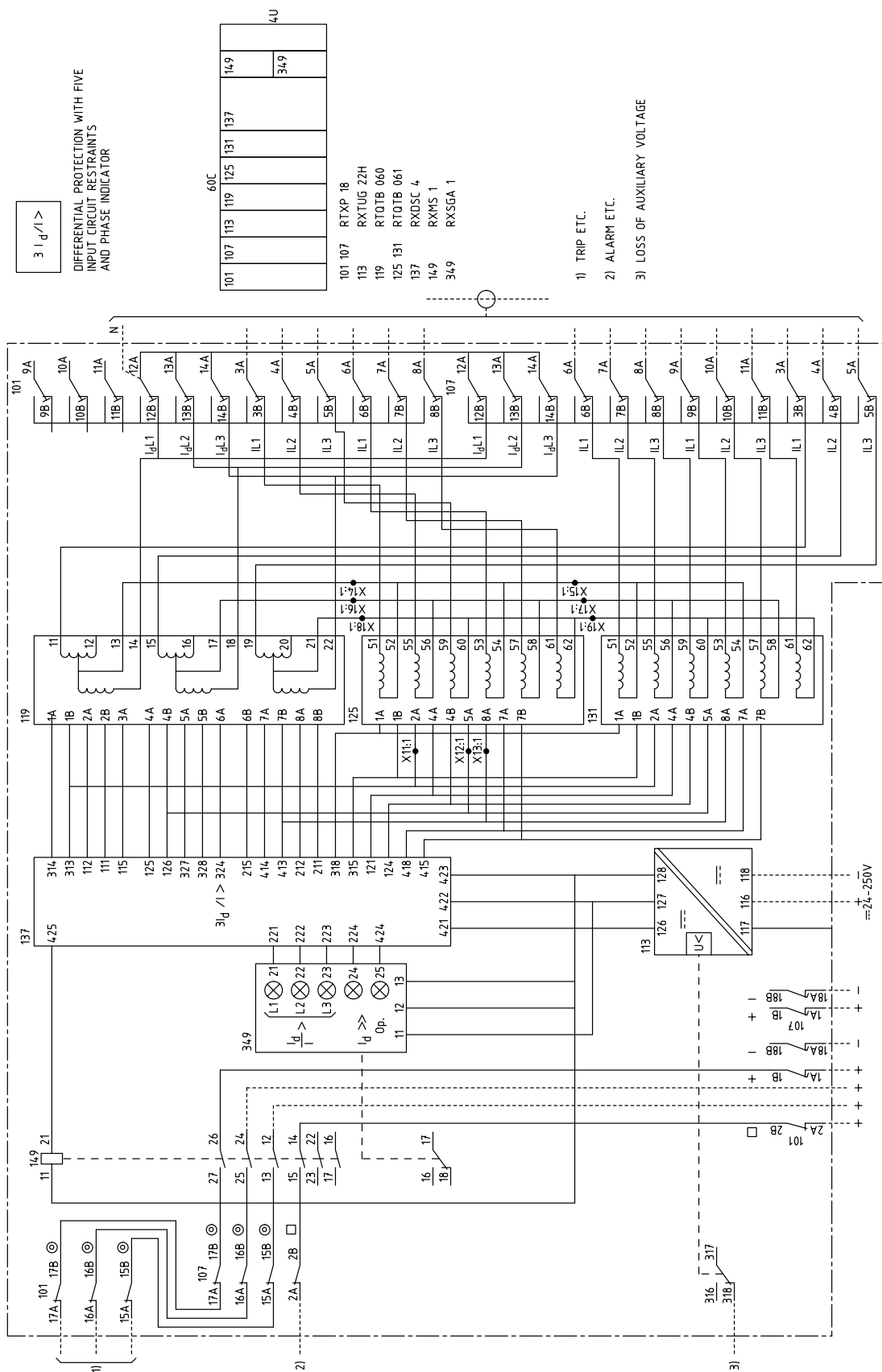*Fig. 12   Circuit diagram 1MRK 000 320-AA for RADSC, 1MRK 000 319-AA*

Fig. 13   Circuit diagram 1MRK 000 320-BA for RADSC, 1MRK 000 319-BA

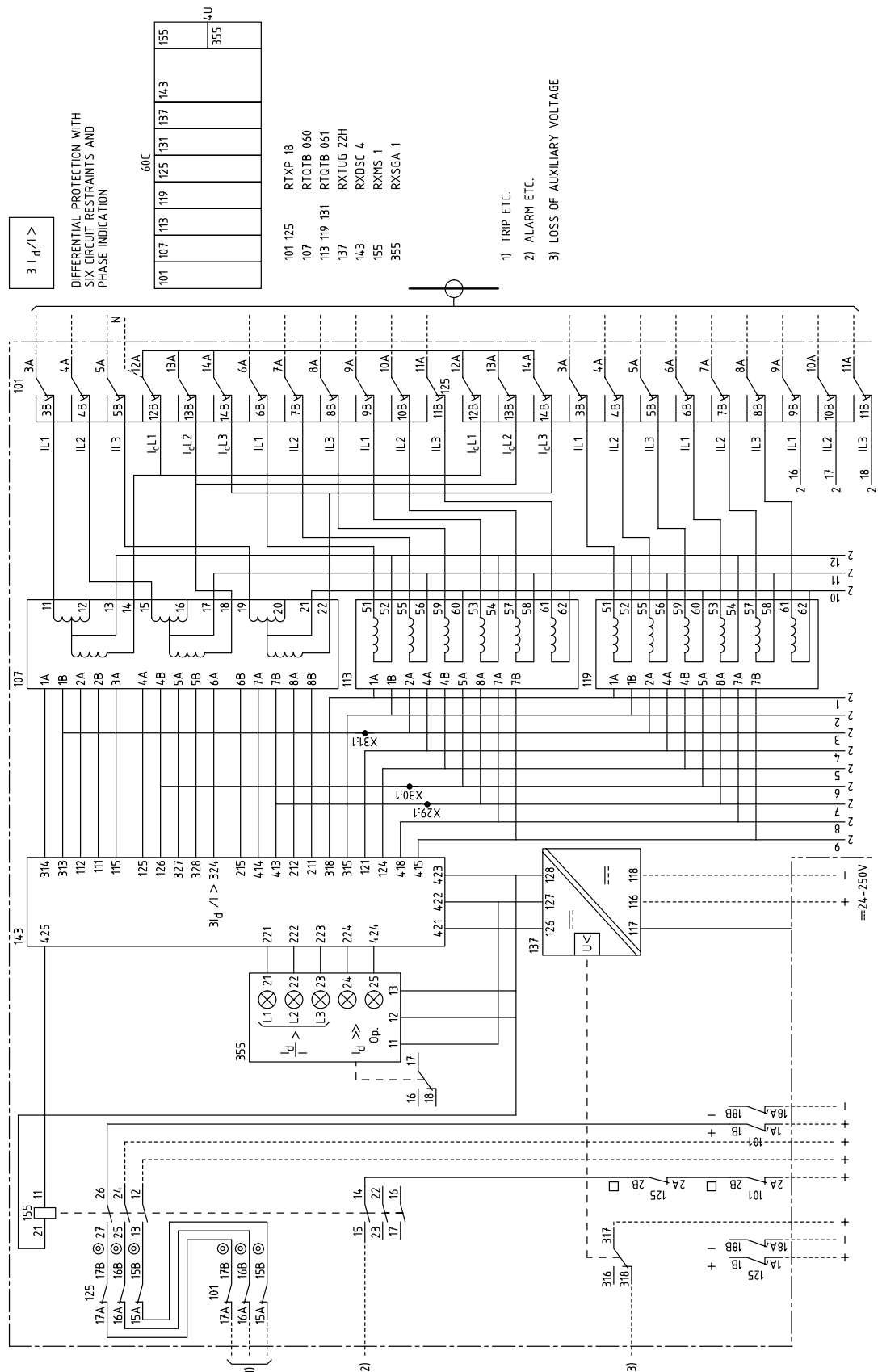*Fig. 14   Circuit diagram 1MRK 000 320-CA for RADSC, 1MRK 000 319-CA*

Fig. 15   Circuit diagram 1MRK 000 320-DA for RADSC, 1MRK 000 319-DA