ABB Network Partner AB

Transformer differential protection RADSB

User´s Guide
1MRK 504 002-UEN

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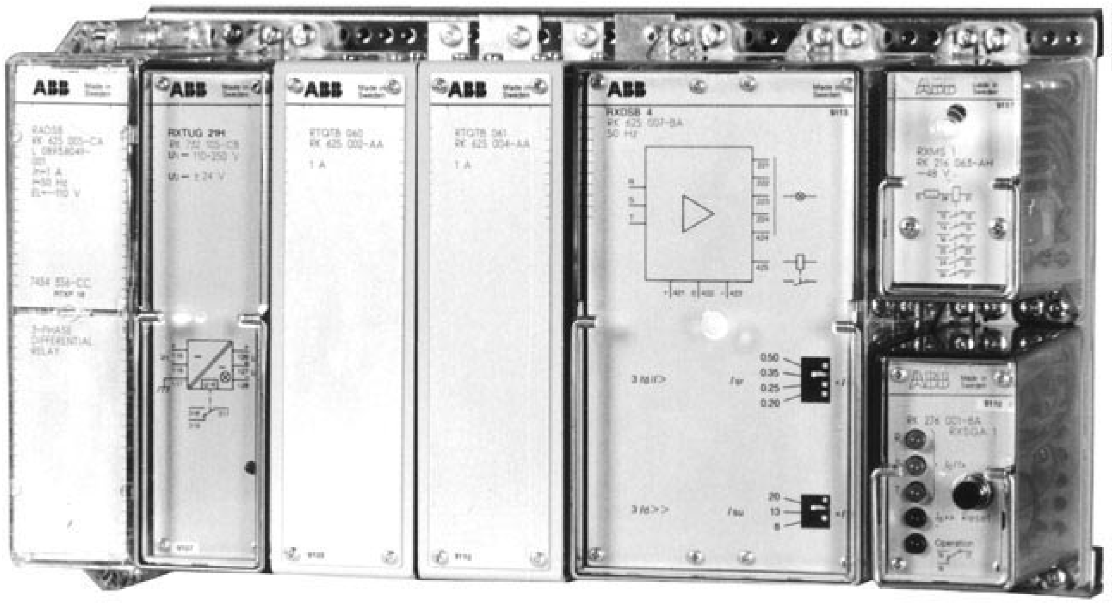


Features

- Three-phase differential protection with two, three, five or six through-current restraint inputs
- Complete phase and earth-fault protection
- Static measuring circuits with active filters for optimum utilization of harmonics in the current circuits
- A high voltage cable, length up to about 2 km, can be included in the differential zone
- Harmonic restrained operate time about 30 ms at 3 times pick-up current
- Unrestrained operate time 10-20 ms at 2 times pick-up current with minimum impulse time of 3 ms
- Variable percentage restraint for external fault security
- Second harmonic restraint from all three phases for inrush security
- Fifth harmonic restraint from all three phases for overexcitation security
- Sensitivity can be set to 20, 25, 35, or 50 % of rated current
- Unrestrained operation settable to 8, 13 or 20 times relay rated current
- Provided with separate interposing CT´s for ratio and phase angle matching and equalizing of zero sequence current
- Long CT secondary leads are feasible with 1 A relay
- Built-in trip relay, indicator and test switch

Type SLCE interposing current transformers:

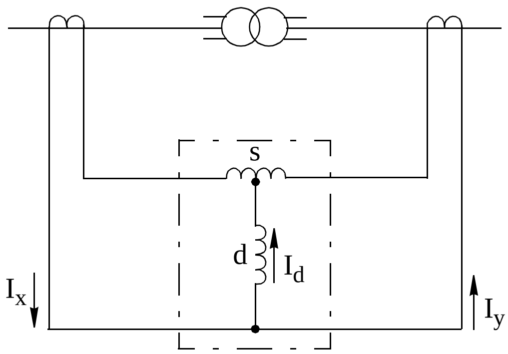
- Secondary current 1 A or 5 A
- Three different ranges of ratios reconnectible in steps of 4 to 6 %:
  0,65-2,60/1 A; 2,55-10,1/1 A; 2,85-11,2/5 A
- Fixed ratio with or without equalizing winding available on request
- Available as single-phase units and three-phase sets

List of contents

1 General

A transformer differential relay is connected so that it is supplied with currents proportional to the current in to the power transformer and to the current out from the transformer, see Fig. 1.

The relay is connected to line CTs and possible interposing CTs. The ratios and connections of the CTs should be selected with consideration taken to the ratio and connection of the power transformer and in principle so that the differential currents will be zero during normal operation. For power transformers with tap-changers for voltage control, the average ratio of the taps should be used for calculation.



s = restraint circuitry
d = differential circuitry

Fig. 1 The schematic principle for a transformer differential relay.

1.1 Normal operation

During normal conditions, a small current flows through the differential circuit of the relay. This current corresponds to the excitation current of the power transformer and to a current depending on the ratio error of the CTs. Normally, these two currents, amounts to just a small percentage of the rated current. However, it is possible, with power transformers with tap-changers, at rated load and with the tap-changers in one end-position, to obtain a current in the differential circuit, which can be up to 20% of the rated current, depending on the tap-changer regulating range.

1.2 Internal faults

The duty of the transformer differential relay is to detect internal faults (that is faults within the power transformer or on the connecting lines, for example feeding cables) and then rapidly initiate disconnection of the supply to the power transformer. Then damages, as well as non-selective tripping of other protective relays, are prevented. The internal electrical faults that can occur are:

- Short circuits
- Earth faults
- Turn-to-turn faults

1.3 External faults

When faults arise outside the CTs, the differential circuit of the relay may be supplied with a relatively large current, which can be caused by ratio errors in the CTs, or by the tap-changer not being in the center-tap position. If the tap-changer is in a position 20% from the center-tap position, and the short-circuit current is 10 times the rated current, a differential current of twice the rated current is obtained. The differential relay shall not operate for this differential current. In order to make an operate value setting for such high overcurrent unnecessary, the differential relay is provided with a through-fault restraint with restraining circuits according to Fig. 1. The relay will then not react for the absolute value of the differential current, but for an adaptive percentage differential current related to the current through the power transformer.

1.4 Energization of the power transformer

When energizing a power transformer, it is possible to obtain a large inrush current in the exciting winding and then proportionally large currents in the differential circuits of the relay. The magnitude and duration of the inrush current depend on the instant of switching in the power transformer (the point on wave), the power transformer remanence, the design of the power transformer, the type of transformer connection, the neutral point connection, the fault MVA rating of the power system, and power transformers connected in parallel. In modern power transformers the current can be 5-10 times the rated current when switching in to the high voltage side, and 10-20 times the rated current when switching in to the low voltage side.

To prevent the relay to operate when energizing a power transformer, it is not possible, as a rule, to delay the operation during such a long time as required. Thus, an instantaneous relay must have a magnetizing inrush restraint and thereby utilize a certain characteristic difference between the inrush current and the fault current.

1.5 Overvoltage

Occasionally, short duration voltage increases may arise during abnormal system conditions. This is a characteristic of generator-transformer units especially. Power transformers with grain-oriented steel cores usually have a high magnetic flux density at rated voltage, but in spite of this, the excitation current is small. However, during voltage increases, the excitation current will increase considerably and may be larger than the set operate value of the differential relay. The relay should therefore be equipped with some sort of restraint, or blocking, function to prevent unnecessary operation.

2 Application

The RADSB is a three-phase transformer-differential relay intended for all types of auto-transformers and multiple winding transformers. RADSB is available with up to six restraint inputs. The relay is also well suited for generator and step-up transformer overall protection, often including the auxiliary transformer in the protected zone.

The non-linear percentage restraint characteristic provides the required restraint for external faults. This makes the relay suitable for use with multi-winding transformers, auto-transformers or in a system where one transformer winding is directly connected to two or more breakers. The characteristics are designed to provide excellent internal fault sensitivity.

The RADSB relay also has an unrestrained instantaneous circuit which responds to the total differential current (less any dc component). This circuit will provide redundant operation for severe internal faults.

The second and fifth harmonic restraint voltages for each phase are paralleled and used for harmonic restraint for each phase.

The polyphase harmonic restraint circuitry prevents the relay from operating on inrush currents yet has a minimum effect on relay sensitivity if an internal fault occurs during energization. The fifth harmonic is used to prevent operation of the relay due to possible overexcitation of the transformer. Overexcitation protection should be provided by a V/Hz relay (for example type RALK which has several different inverse time characteristics and definite time delay).

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

Three examples of application are shown in Fig. 2. The third example shows recommended connection in 1 1/2-breaker and double breaker stations. Each set of CTs is connected to a restraint input of the relay. Through-fault current restraint is thus obtained, also when the current passes the CTs from one busbar to the other.

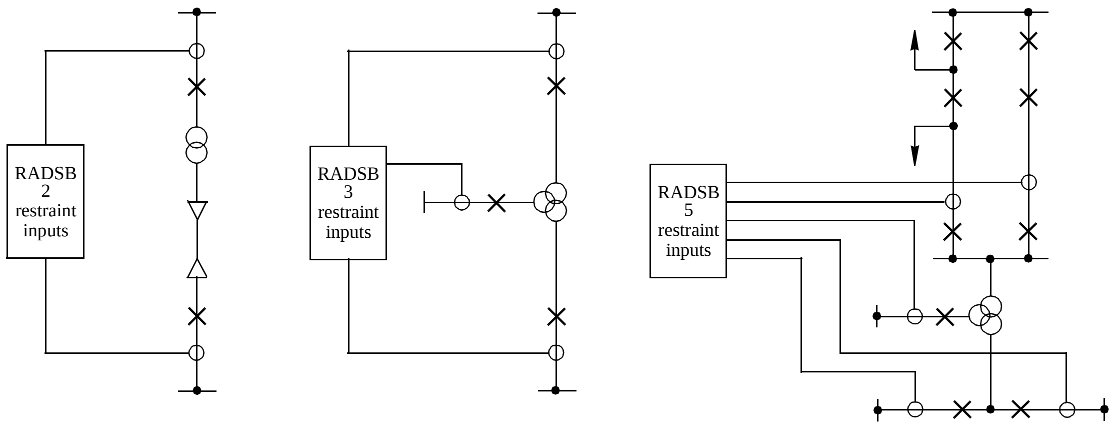


Fig. 2 Application examples for type RADSB.

2.1 Calculation of current ratio

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

The transformer differential relays type RADSB have the rated current 1 or 5 A (in the following denoted I_n). The restrained operation is set to 20, 25, 35 or 50% of I_n.

When the main CTs are not matched to a certain degree to the rated load of the power transformer, the secondary currents can deviate considerably from I_n. Then it is necessary to connect interposing CTs. If the ratio of the main CTs is such that the secondary current at rated load is for example only 65% of I_n, the real operate current of the differential relay will be about 1,5 times the set value. Interposing CTs should therefore always be used when there is a lower secondary rated current. Otherwise the sensitivity (calculated in per cent of the rated current of the power transformer) of the transformer differential relay can reach unacceptable values.

The secondary circuits are normally arranged so that the currents to the differential relay will be approximately 1 or 5 A at rated load of the power transformer. This adaptation is done with a set of interposing CTs for each transformer winding according to Fig. 9-17.

One set of interposing CTs can sometimes be omitted. See Fig. 10, 11, 12, 14 and 16 where a Yy-connected auxiliary current transformer set is dotted. However, if all the windings of the power transformer are provided with interposing CTs, the best stability is obtained during external faults.

Especially when there are large through-fault currents with a long dc time constant, it is suitable to use interposing CTs for all the windings of the power transformer. In such case there is no risk for unwanted operation due to CT saturation.

Fig. 9 to 17 show some standard connections for power transformers with two or three windings and different types of connections.

The secondary circuits can also be arranged in other ways, but as a rule, the Y-connected main CT should supply Y-connected windings of the interposing CTs so that correct operation is obtained for both internal and external earth faults in networks with large earth fault currents.

In addition, it should be noted that in the case of Yy-connected power transformers, the neutral of the differential relay should not be connected to the neutral of the main CTs. During external faults, fault currents can otherwise pass through the differential circuit of the relay and cause maloperation.

2.1.1 Yy-connected power transformer with two windings

The rated currents I_{n1} and I_{n2} of the power transformer are calculated based on given transformer data. 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_{nl} and i_{n2}.

When defining the current ratios of the interposing CTs, the ones for the primary side should be defined first, that means $i_{n\ prim}/i_{n\ sec}$. Corresponding marking is P_1-P_2/S_1-S_2. The current ratio has been given for each transformer set in Fig. 3 to 7.

The calculation of i_{n1} and i_{n2} is done according to the formulas 1 and 2.

$$i_{n1} = \frac{Sn}{U_1 \cdot \sqrt{3}} \cdot \frac{i_1}{I_1} \quad ....(1)$$

$$i_{n2} = \frac{Sn}{U_2 \cdot \sqrt{3}} \cdot \frac{i_2}{I_2} \quad ....(2)$$

S_n = the rated power of the power transformer.

The formulas are exactly valid for power transformers with fixed ratio, that means without regulating possibilities with for example tap changers. When there are power transformers with voltage regulation and with ratio

$$U_1 / (U_2 {}^{+p1}_{+p2} \%)$$

the “average voltage”

$$U'_2 = U_2\left(1 + \frac{p1 + p2}{200}\right)$$

is calculated for the secondary side. This forms the base for the calculation of the primary and secondary currents.

One set of interposing CTs
Each individual CT should be ordered for the ratio i_{n2}/i_{n1} (see Fig. 3) for the three-phase interposing CT set.

The D-connected equalizing windings of the interposing CTs are used to eliminate possible zero sequence currents in case of external earth faults and could always be arranged for rated current 1 A.

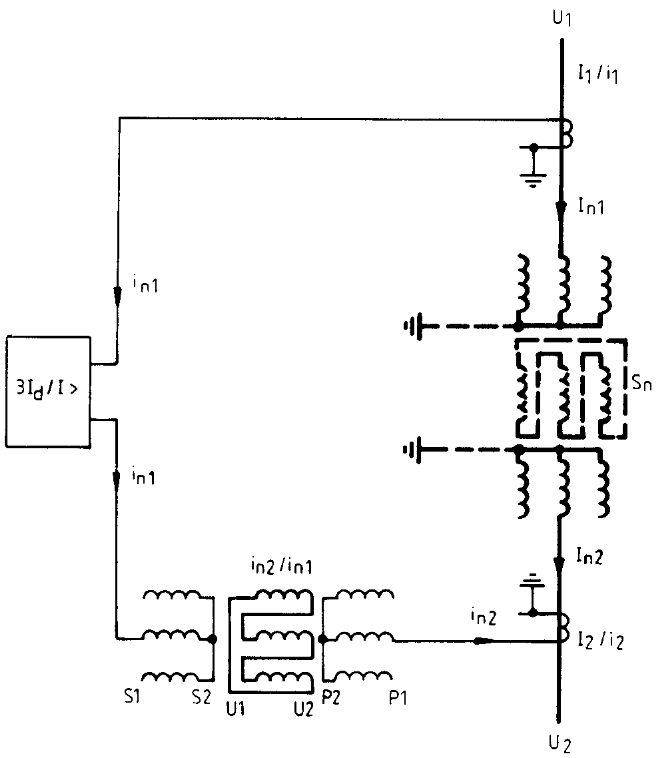


Fig. 3 One set of interposing CTs with equalizing (D) winding.

Two sets of interposing CTs
Connection according to Fig. 4 and 9.

When interposing CTs are used on both windings of the power transformer they should be Yd-connected. In that case there is no need for any D-connected equalizing winding. The ratios between the CTs in the separate sets will be according to Fig. 4. When all windings are equipped with interposing CTs, a differential relay with the rated current of 1 A is most suitable selected.

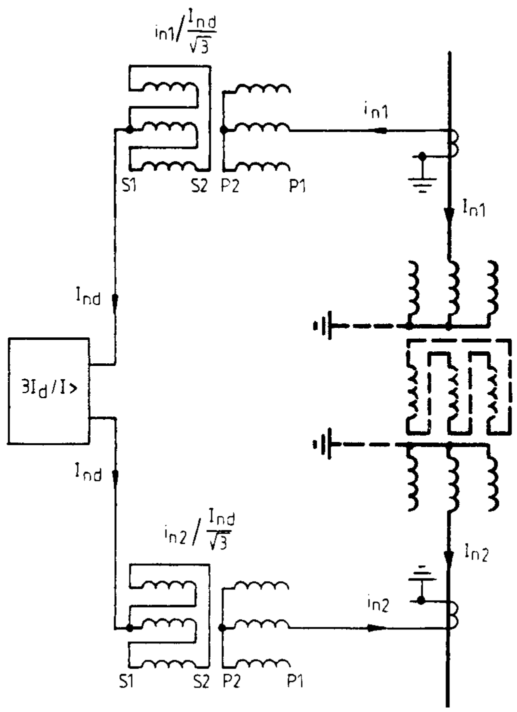


Fig. 4 Two sets of interposing CTs.

2.1.2 Dy-connected power transformer with two windings

One set of interposing CTs
Connection according to Fig. 5, 10 and 11.

The current ratio is the same as shown in Fig. 3, but with the difference that the rated current for the D-connected windings of the interposing CTs will be $i_{n1}/\sqrt{3}$.

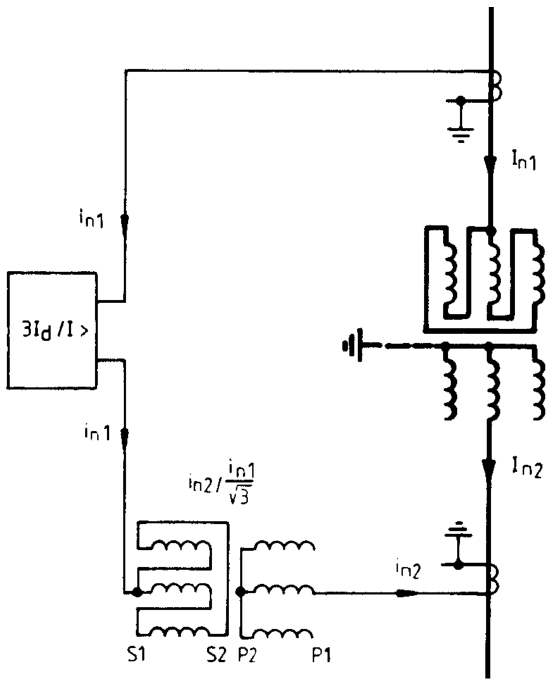


Fig. 5 One set of interposing CTs.

Two sets of interposing CTs

The ratio of the different sets will be i_{n1}/I_{nd} and $i_{n2}/\frac{I_{nd}}{\sqrt{3}}$ respectively.

2.1.3 Power transformers with three windings

Connections according to Fig. 6, 7, 13, 14, 15 or 16.

Power transformers with three windings often have different rated power S_{n1}, S_{n2} and S_{n3} of the windings.

When the ratios of the interposing CTs are calculated, the highest rated power is used for all the windings. To obtain the best adaptation of the different sets of interposing CTs with regard to external faults, there should not be any correction of the current ratios to the actual rated power of the winding. The current to the differential relay from one or more windings having lower rated power will then be lower at rated power than the rated current of the interposing CTs in proportion to the rated powers. See the following calculation example.

Two sets of interposing CTs

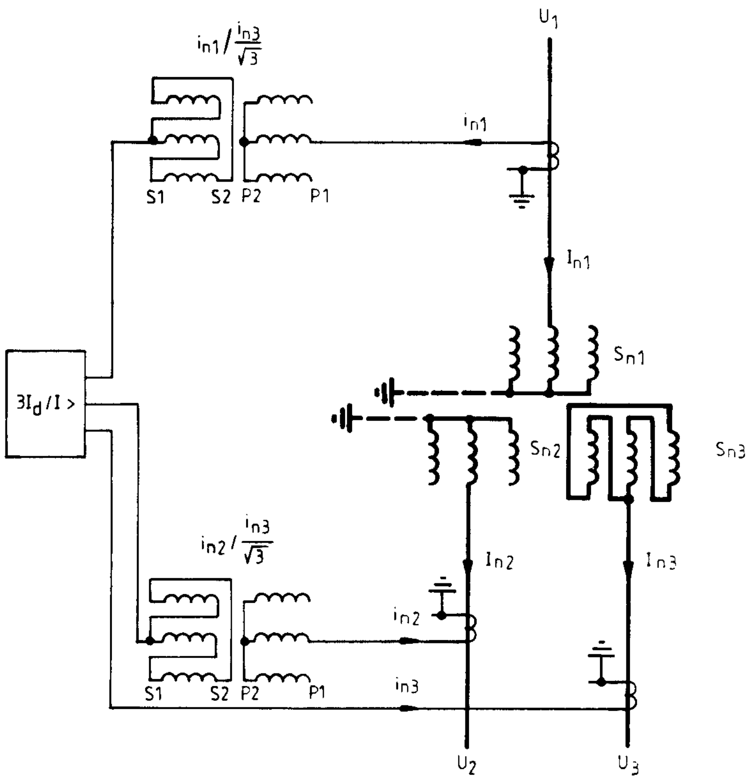


Fig. 6 Two sets of interposing CTs. One set left out.

Three sets of interposing CTs

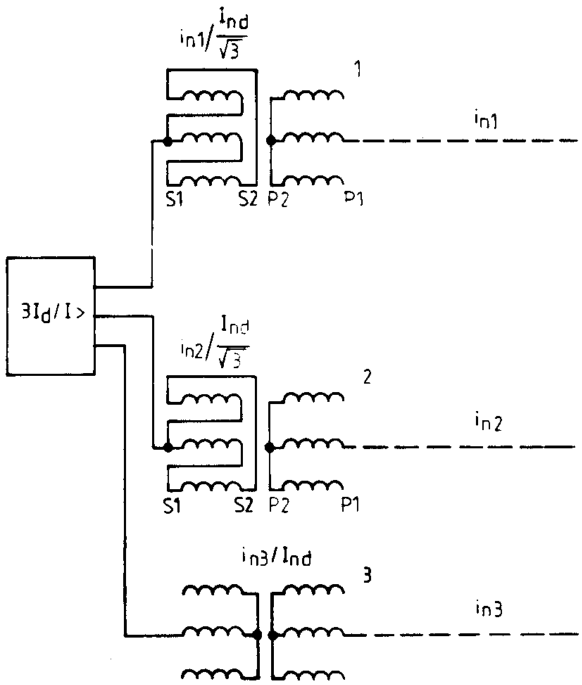


Fig. 7 Three sets of interposing CTs.

2.1.4 Calculation example for three sets of interposing CTs

(Fig. 7 and 14)

Power transformer:

$S_{n1}/S_{n2}/S_{n3}$ = 20/20/8 MVA

$U_1/U_2/U_3$ = 77 ±15%/21,5/11 kV

Connection = Yy0 d11 (Fig. 6)

Main CTs:

Position	77 kV	21,5 kV	11 kV
Current ratio	220/2 A	600/5 A	600/5 A
Connection	Y	Y	Y

Differential relay:

Type RADSB with rated current 1 A.

According to formulas 1 and 2 (see Yy-connected power transformer with two windings) the ratio will be for

a) the interposing CTs in set 1 connected Yd

$$i_{n1}/\frac{1}{\sqrt{3}} = \frac{20000}{77 \cdot \sqrt{3}} \cdot \frac{2}{200}/\frac{1}{\sqrt{3}} = 1.50/\frac{1}{\sqrt{3}}A(= 2.6/1A)$$

b) the interposing CTs in set 2 connected Yd

$$i_{n2} / \frac{1}{\sqrt{3}} = \frac{20000}{21.5 \cdot \sqrt{3}} \cdot \frac{5}{600} / \frac{1}{\sqrt{3}} = 4.48 / \frac{1}{\sqrt{3}} A (= 7.76 / 1A)$$

c) the interposing CTs in set 3 connected Yy

$$i_{n3} / 1 = \frac{20000}{11 \cdot \sqrt{3}} \cdot \frac{5}{600} / 1 = 8.7 / 1A$$

The primary and secondary currents at the rated power will be

$$8.7 \times \frac{8}{20} / 1 \times \frac{8}{20} = 3.5 / 0.4A$$

SLCE 12 according to order number 4785 040 - VR, see Table 2, can in this case be used for all three sets. They are connected in different manner.

It may happen that the ratio for the tertiary side falls outside the reconnection range. If it is calculated to for instance 20A/1A one can order interposing CTs with one fixed order-specific ratio e.g. 10A/0,5A.

2.1.5 CT requirements

The main CTs and the interposing CTs should have current factors that satisfy the requirements below:

To avoid maloperation on energization of the power transformer and in connection with fault current that passes through the power transformer, the equivalent secondary accuracy limiting voltage, U_{alc}, according to IEC 185 and IEC 44-6 should satisfy requirements (a) or (b) below:

$$U_{\mathrm{alc}} \geq 30 \cdot \mathrm{i}_{nt} \cdot (\mathrm{R}_{ct} + 2 \cdot \mathrm{R}_{l} + \mathrm{R}_{t} + \mathrm{Z}_{r}) \quad \text{(a)}$$

$$U_{\mathrm{alc}} \geq 20 \cdot \mathrm{i}_{nt} \cdot (\mathrm{R}_{ct} + 2 \cdot \mathrm{R}_{l} + \mathrm{R}_{t} + \mathrm{Z}_{r}) \quad \text{(b)}$$

Here i_{nt} is the main CT secondary current corresponding to <u>rated</u> primary current of the power transformer, R_{ct} is the secondary resistance of the main CT, R_l is the resistance of a single secondary wire from the main CTs to the interposing CTs (when used) or the relay (when interposing CT are not used), R_t is the burden of the interposing CTs (when used), and Z_r is the reflected burden of the relay and the loop resistance of the wires from the interposing CT (when used) to the relay as seen from the secondary side of the main CTs.

Requirement (a) applies to CTs with high (>0.5 T) remanence (e.g. type P, TPS or TPX) and requirement (b) to CTs with low (< 0.2 T) remanence (e.g. type TPY).

To avoid maloperation in connection with fault current that passes through the power transformer, the equivalent secondary accuracy limiting voltage, U_{alc}, according to IEC 185 and IEC 44-6 should also satisfy requirement (c) below:

$$U_{\mathrm{alc}} \geq 2 \cdot \mathrm{i}_{tf} \cdot (\mathrm{R}_{ct} + 2 \cdot \mathrm{R}_{l} + \mathrm{R}_{t} + \mathrm{Z}_{r}) \quad \text{(c)}$$

Here i_{tf} is the maximum secondary side fault current that pass two main CTs and the power transformer. Requirement (c) relates to the case when the transformation ratios are unequal and the case when the magnetisation characteristics are not equal. Requirement (c) applies to CTs with high (> 0.5 T) remanence (e.g. type P, TPS or TPX) and to CTs with low (< 0.2 T) remanence (e.g. type TPY) as well.

In substations with breaker-and-a-half or double-busbar double-breaker arrangement, the fault current may pass two main CTs for the transformer differential protection without passing the power transformer. In such cases, the CTs must satisfy the requirement below:

$$U_{\mathrm{alc}} \geq i_f \cdot (R_{ct} + 2 \cdot R_l + R_t + Z_r) \qquad \text{(d)}$$

Here i_f is the maximum secondary side fault current that passes two main CTs without passing the power transformer. Requirement (d) applies to the case when both main CTs have equal transformation ratio and magnetisation characteristics. Requirement (d) applies to CTs with high (>0.5 T) remanence (e.g. type P, TPS or TPX) and to CTs with low (< 0.2 T) remanence (e.g. type TPY) as well.

2.1.6 Choice 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. These interposing CTs can also be used when a secondary current less than 1 A or 5 A, alternatively, is requested. This can be the case when, for example, interposing CTs in a three-phase group should be D-connected and the desired secondary current is $1/\sqrt{3}$ A, or $5/\sqrt{3}$ A, respectively.

The SLCE 12 interposing CTs are available as loose single-phase units and as three-phase sets mounted on an apparatus plate with connection terminals. Ordering information is given in the Buyer’s Guide. Dimensions are found in section “Design” below.

It is an advantage that the interposing CTs are located close to the differential relay so they can get as high current factor as possible. The current 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 to 3 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 relay)

Table 1: 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

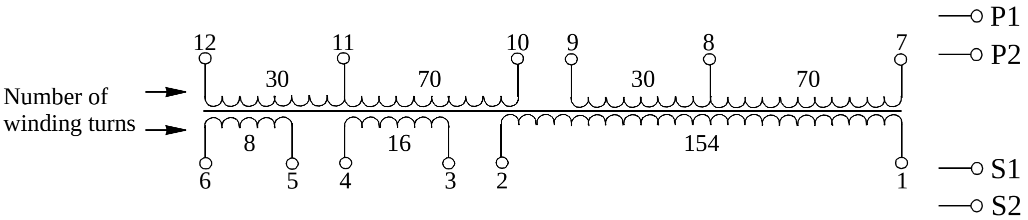


**Table 2: Transformer SLCE 12 for I_p = 2,55-10,1 A, I_s = 1 A
Ordering number 4785 040-VR**

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

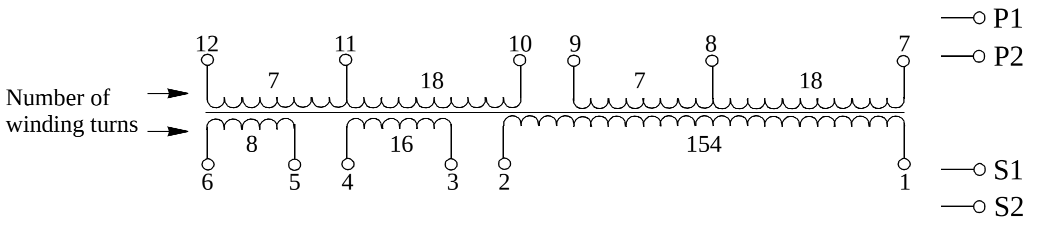
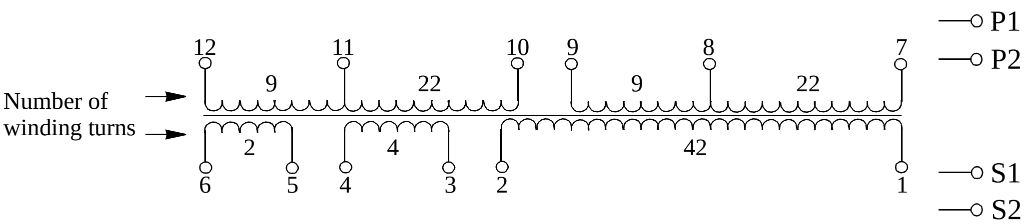


**Table 3: Transformer SLCE 12 for I_p = 2,85-11,2 A, I_s = 5 A
Ordering number 4785 040-VS**

Primary current between terminals A	Turn ratio	Connections on primary side between terminals	Connections on secondary side	a Ω	b Ω	Power consumption at I_s= 5 A 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



The rated primary current multiplied by the calculated current 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 current factor.

In case of a large 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 windings of the power transformer to avoid the risk of unnecessary operation at external faults. To obtain the best possible current factor, interposing CTs and the transformer differential relay should be selected for 1 A rated current.

Interposing CTs type SLCE 12 with fixed ratio, that are calculated and manufactured for specific applications, should be used when the interposing CTs should have an extra winding for the D-connected equalizing winding. Type SLCE 12/200 is used for secondary current 1 A and $1/\sqrt{3}A$. Type SLCE 12/270 is used for 5 A and $5/\sqrt{3}A$. The ratio and number of turns of the equalizing winding is without importance. In the standard design it is made with 180 turns. (SLCE 12 is the core size and 200 and 270 the number of ampere turns.)

When the differential relay 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 protection also includes a long supply cable for the power transformer. These interposing CTs are selected with a low secondary current to reduce the burden on the main CTs to an acceptable value. The suitable secondary rated current is 0,4 A. See Table 4. In such case, a set of interposing CTs type SLCE 16/350 are used and they should be located at the main CTs. Another set of interposing CTs type SLCE 12/200 with a secondary current of 1 A or 5 A, alternatively, are used and located close to the differential relay. In order to minimize the influence of the capacitance of the pilot wires, type SLCE 16/350 should then be Yy-connected.

Table 4

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 such quality or they are located in such way that there is risk for interruptions, non-linear protective resistors should be connected to the wires. The protective resistors are allowed to consume maximum 5 % of the current which flows in the pilot wires during maximum through-fault current and should be designed according to the characteristics in Fig. 8. Open secondary circuits may give destruction of the main CTs as well as the interposing CTs.

Information about the non-linear resistors are found in the User's Guide of RADHA High impedance differential relay.

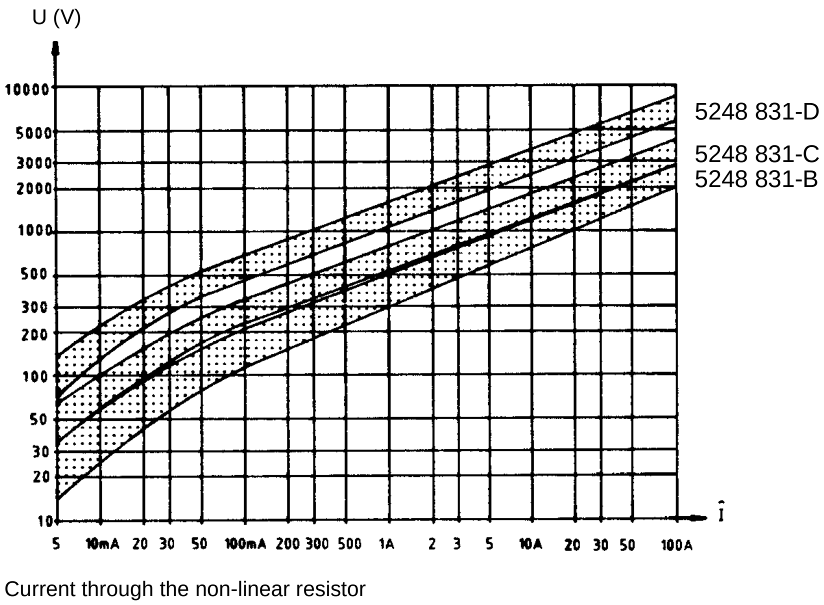


Fig. 8 Current voltage characteristics for the non-linear resistor.

2.2 Connection diagrams

Power transformer connection	Interposing current transformer in			Connection according to Fig.
	Winding 1	Winding 2	Winding 3	
Yy0	Yd	Yd		9
Dy11	(Yy)	Yd		10
Yd5	Yd	(Yy)		11
Dd0	(Yy)	Yy		12
Yyy	Yd	Yd	Yd	13
Yyd	Yd	Yd	(Yy)	14
Yyd with artificial neutral	Yd	Yd	Ydy	15
Yyd with artificial neutral	Yd	Yd	Yd (Yy)	16
Yz11	Yd	Ydy		17

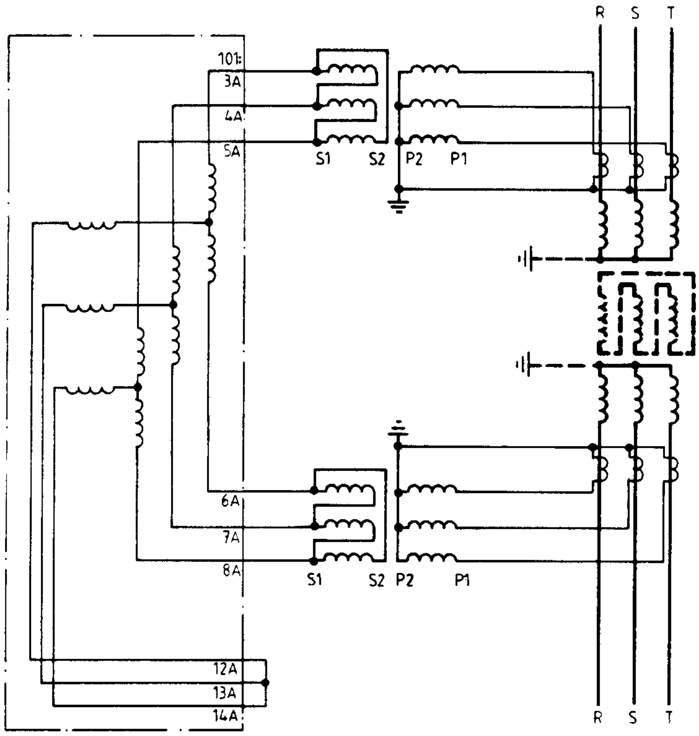


Fig. 9 Connection of RADSB at power transformer connection Yy 0.

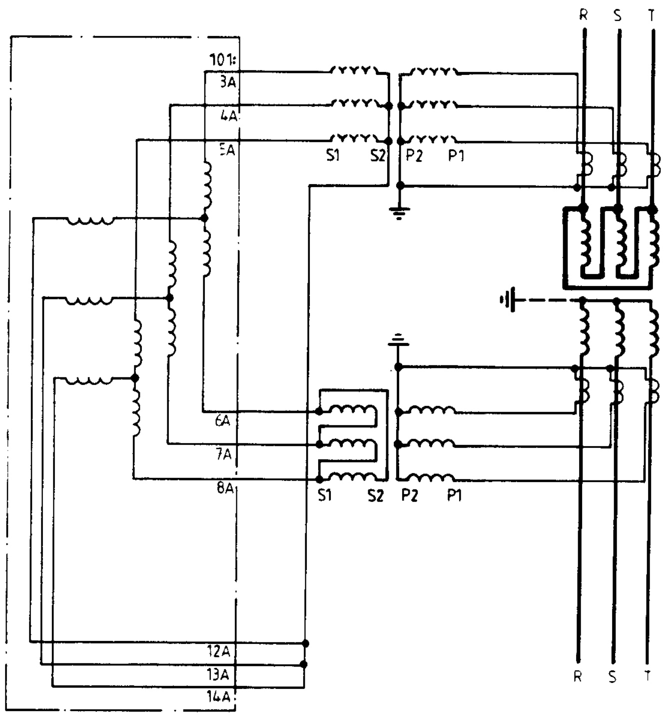


Fig. 10 Connection of RADSB at power transformer connection Dy 11.

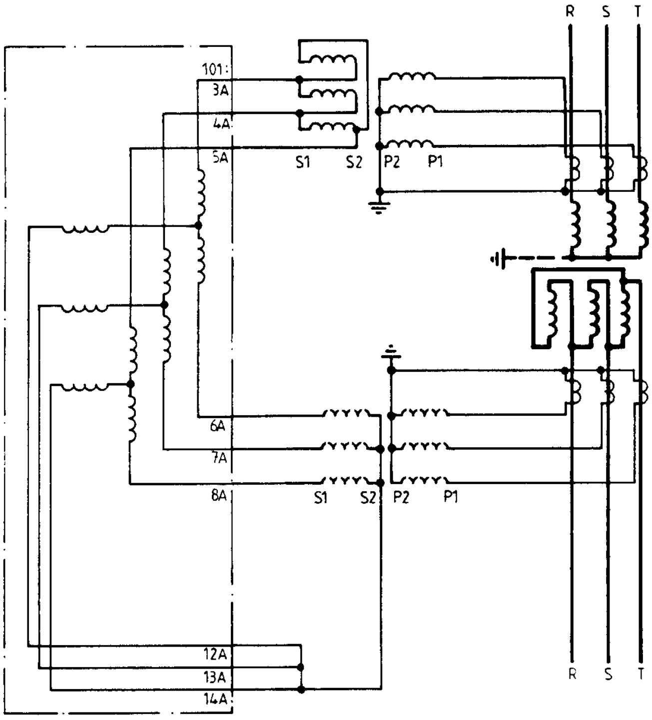


Fig. 11 Connection of RADSB at power transformer connection Yd 5,

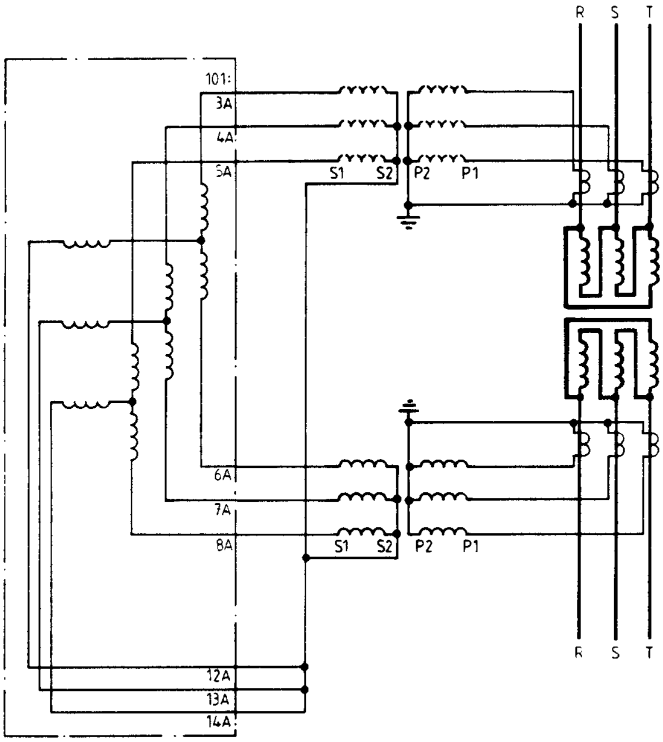


Fig. 12 Connection of RADSB at power transformer connection Dd 0.

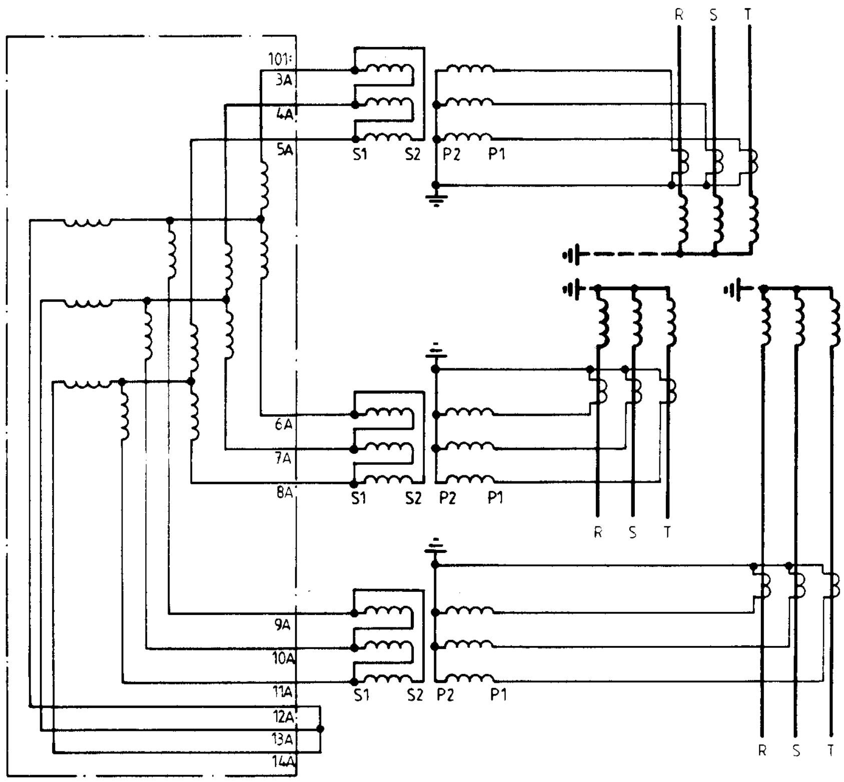


Fig. 13 Connection of RADSB at power transformer connection Yyy.

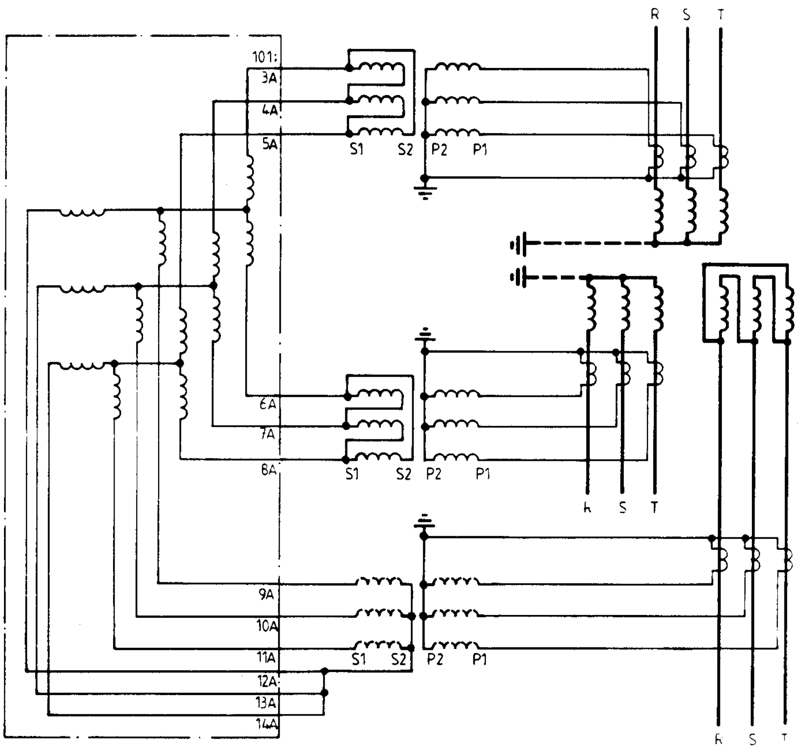


Fig. 14 Connection of RADSB at power transformer connection Yyd.

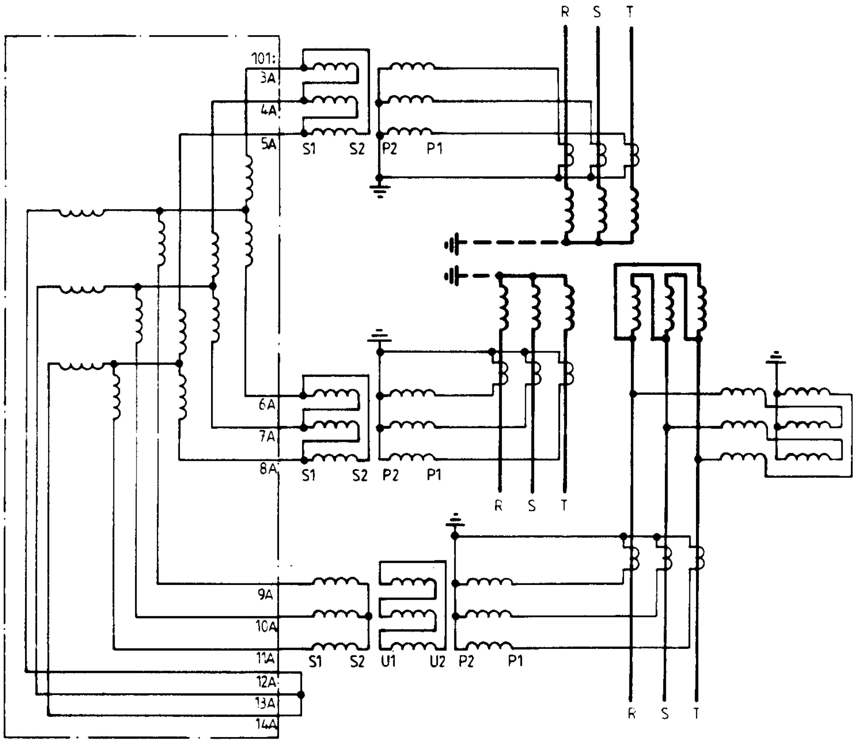


Fig. 15 *Connection of RADSB at power transformer connection Yyd with artificial neutral. Alternative 1.*

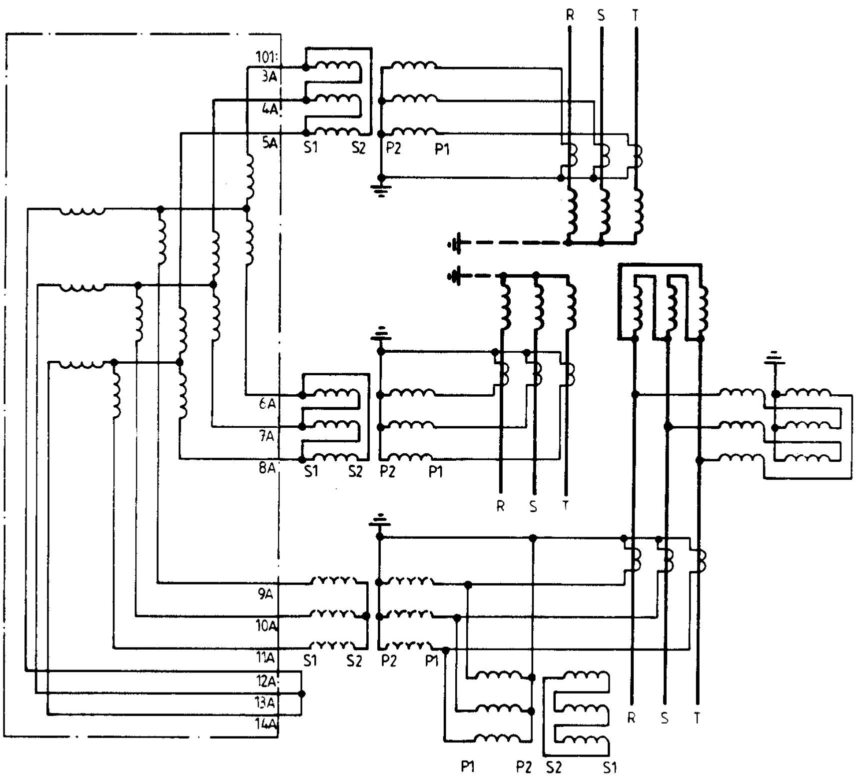


Fig. 16 *Connection of RADSB at power transformer connection Yyd with artificial neutral. Alternative 2.*

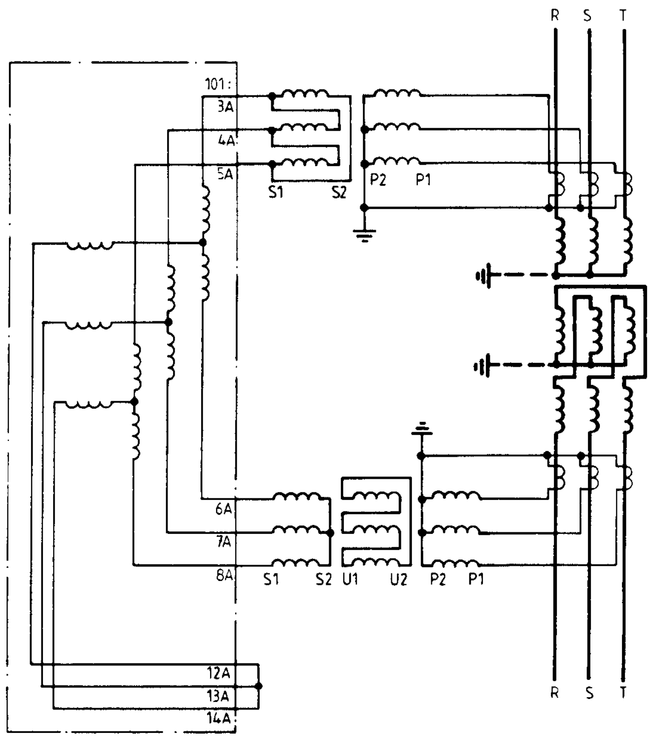


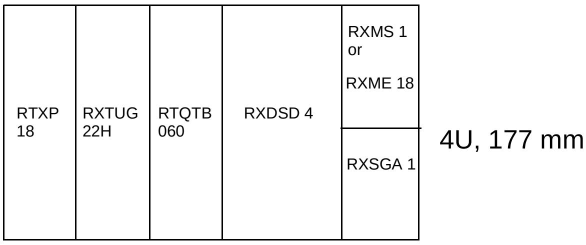
Fig. 17 Connection of RADSB at power transformer connection Yz 11.

3 Design

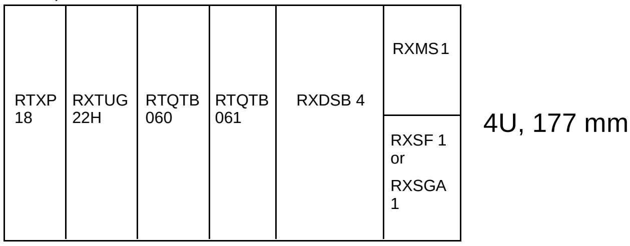
3.1 Hardware description

The relay 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 plug indication relay type RXSF 1.

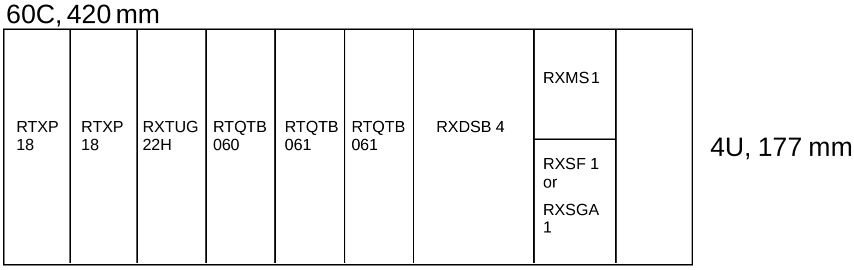
Two restraint circuits:
36C, 252mm



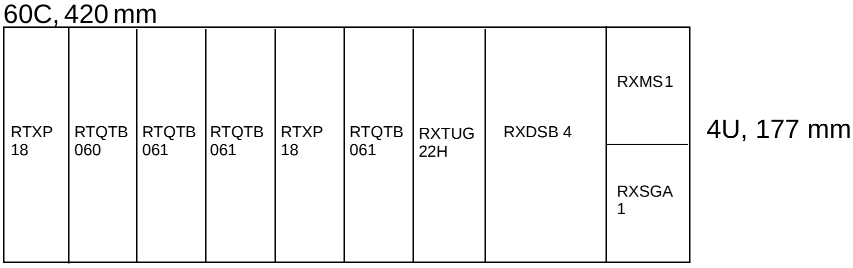
Three restraint input circuits:
42C, 294 mm



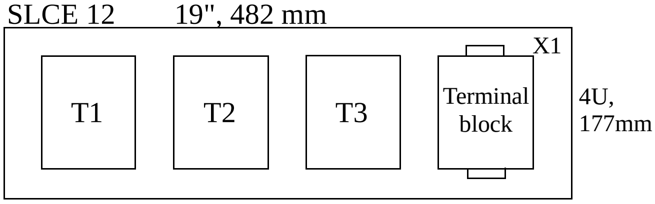
Five restraint input circuits:
60C, 420 mm



Six restraint input circuits:
60C, 420 mm



SLCE 12 19", 482 mm



The RADSB-units are:

RTXP 18	Test switch
RXTUG 22H	DC-DC converter
RTQTB 060, RTQTB 061	Transformer units
RXDSB 4	Measuring unit
RXMS 1, RXME 18	Tripping relay
RXSGA 1	Phase indicator
RXSF 1	Signal relay

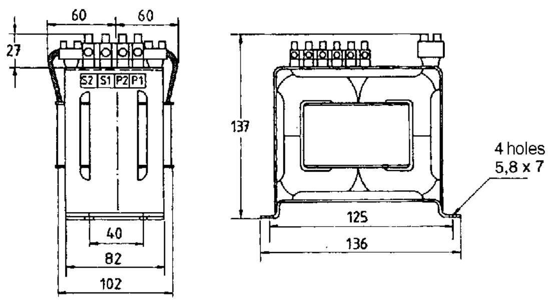


Fig. 18 Physical positions of the units in the RADSB versions, and dimensions of interposing CTs SLCE 12.

3.1.1 Test switch

The test switch type RTXP 18 is included in the testing system COMBITEST. A complete secondary testing of the protection can be performed by using a test-plug handle 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 currents can be measured during operation with a test plug type RTXM connected to an ammeter. The tripping circuits can be blocked with trip-block plug type RTXB. The 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.

Connections to CTs and the tripping circuits are done on the rear of the test switch and when the protection is installed. Connections of the auxiliary voltage or to contacts providing signal at operation or at loss of auxiliary supply is done directly on the terminal bases.

3.1.2 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 (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 LED for supervision of the output voltage.

3.1.3 Transformer units

The transformer units are connected to the test switch via the 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.

3.1.4 Measuring unit

The measuring unit type RXDSB 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, inrush, and over-excitation restraints 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 relay. 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.

3.1.5 Tripping relay

The auxiliary relay type RXMS 1 is used as an output relay. Depending on the version of the differential relay it has four or six make contacts. The operate time is approximately 5 ms.

The auxiliary relay type RXME 18 can be used as an output and 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 relay. The operate time is approximately 30 ms.

3.1.6 Phase indicator

The phase indicator type RXSGA 1 indicates with the aid of a signal relay and five LEDs, the operation of the transformer differential relay. 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.

The phase indicator is included as a standard in some of the variants. However, it can be included as an additional item in some of the other variants if these variants are supplemented with the necessary connections.

3.1.7 Flag indication relay

The flag indication relay type RXSF 1 is an electro-mechanical relay with two make contacts, one break contact and a red flag. The flag will be visible when the armature picks up, and is manually reset with a know in the front of the relay. The operate time is 20-25 ms.

3.2 Operate value settings

The two operate values of the differential relay - the restraint operate value I_{sr} (0,20, 0,25, 0,35 and 0,50 times the rated current) and the unrestrained value I_{su} (8, 13 and 20 times the rated current) - are set with switches on the front of the measuring unit RXDSB 4. The switches are accessible after the cover of the unit has been removed, thus preventing unwanted changes of the operate value settings. The operate value I_{sr} for the restraint operation is generally set at 0,35 x I_n. For power transformers with fixed ratio a setting of 0,20 or 0,25 x I_n can be used. Should the CTs on both sides of the power transformer be unsatisfactory matched, the setting may be required to be one setting step higher than the values recommended above.

The operate value I_{su} for the unrestrained operation, is determined by the magnitude of the inrush current to the power transformer and is thus affected by the rating and the connection of the power transformer. Table 5 indicates recommended value of settings of the unrestrained operate value I_{su}.

Table 5

Power transformer connection [1)]	**Rated power**	**Recommended value of I_{su} when energizing from the:**	
		High voltage side	**Low voltage side**
-	< 10 MVA	20x	20x
Yy	10-100 MVA	13x	13x
Yy	> 100 MVA	8x	8x
Yd	-	13x	13x
Dy	< 100 MVA	13x	20x
Dy	> 100 MVA	8x	13x

[1)] The primary side is anticipated to be high voltage side.

For transformers with low leakage reactance and high inrush current, a higher setting may be necessary.

When the differential relay is applied also to provide bus protection, the setting 20 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 and mounting details

4.1 Technical data

Energizing quantities, rated values and limits

Rated current I_n	1 or 5 A	
Rated frequency	50 or 60 Hz	
Operate values: I_{sr} restraint I_{su} unrestrained	 Settable 0,20, 0,25, 0,35, and 0,5 times I_n (Operation occurs at appr. 1,5 times the set value at three-phase energizing) Settable 8, 13 and 20 times I_n (Operation occurs at appr. 0,8 times the set value at three-phase energizing)	
Reset ratios: Restrained operation Unrestrained operation	 > 60% 100% (pulse > 150 ms)	
Operate times with output relays type RXMS 1 and type RXME 18, respectively:	**RXMS 1**	**RXME 18**
$I_d = 3 \times I_{sr}$	appr. 32 ms	appr. 60 ms
$I_d = 10 \times I_{sr}$	appr. 29 ms	appr. 60 ms
$I_d = 2 \times I_{su}$	10-20 ms	40-50 ms
Impulse limit times: Restrained operation Unrestrained operation	 > 20 ms at $I = 3 \times I_{sr}$ Appr. 3 ms at $I = 3 \times I_{su}$	
Transient overreach	< 5%	
Overload capacity: 1 A version 5 A version	 10 A continuously 100 A during 1 s 20 A continuously 250 A during 1 s	
Restraining limit values at: Energization Overvoltage External faults	 2:nd harmonic = 15 % of the fundamental 5:th harmonic = 38% of the fundamental Acc. to the curves in Fig. 21	
Permitted ambient temperature range	-25°C to +55°C	
Auxiliary voltage EL	24-36, 48-60 or 110-250 V dc	
Permitted auxiliary voltage variation	-20% to +10% of the nominal value	

Power consumption

Restraint circuitry	Approx. 0,025 VA/phase at I_n = 1 A Approx. 0,25 VA/phase at I_n = 5 A
Differential circuitry	Approx. 0,025 VA/phase at I_n = 1 A Approx. 0,25 VA/phase at I_n = 5 A
Auxiliary voltage circuitry normal service operation	 Approx. 7 W Approx. 11 W

Insulation tests

Dielectric tests (IEC 60255-5) current circuits other circuits	 50 Hz, 2,5 kV, 1 min 50 Hz, 2,0 kV, 1 min
Impulse voltage test (IEC 60255-5)	5 kV, 1,2/50 µs, 0,5 J

Electromagnetic compatibility tests

Power frequency test (SS 436 15 03)	500V, class PL4
Fast transient test (SS 436 15 03)	4-8 kV, class PL4
1 MHz burst test (IEC 60255-22-1)	2,5 kV, class III
Electrostatic discharge test (IEC 60255-22-2)	8kV, class III
Radiated electromagnetic field test (IEC 60255-22-3)	10 V/m, 27-500 MHz
Fast transient test (IEC 60255-22-4)	4 kV, class IV

Mass

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

Contacts

	RXMS 1 4 or 6 make contacts	RXME 18 2 make contacts	RXTUG 22H RXSGA 1 1 two-way contact	RXSF 1 2 make and 1 break contact
Maximum voltage between the lines dc/ac	300/250 V	450/400 V	250/250 V	300/250 V
Current carrying capacity: Continuously 1 s 10 ms	 4 A 20 A 100 A	 6 A 30 A	 5 A 15 A	 5 A 50 A
Making and conducting capacity during 200 ms	30 A	30 A	30 A	30 A
Breaking capacity: ac, P.F. >0,4 max 250 V dc, L/R <40 ms max 48 V 110 V 125 V 220 V 250 V	 10 A 1,2 A 0,3 A 0,25 A 0,15 A 0,12 A	 20 A 18 A 3 A 2,5 A 1 A 0,8 A	 8 A 1,0 A 0,4 A 0,3 A 0,2 A 0,15 A	 10 A 1,5 A 0,4 A 0,3 A 0,2 A 0,15 A

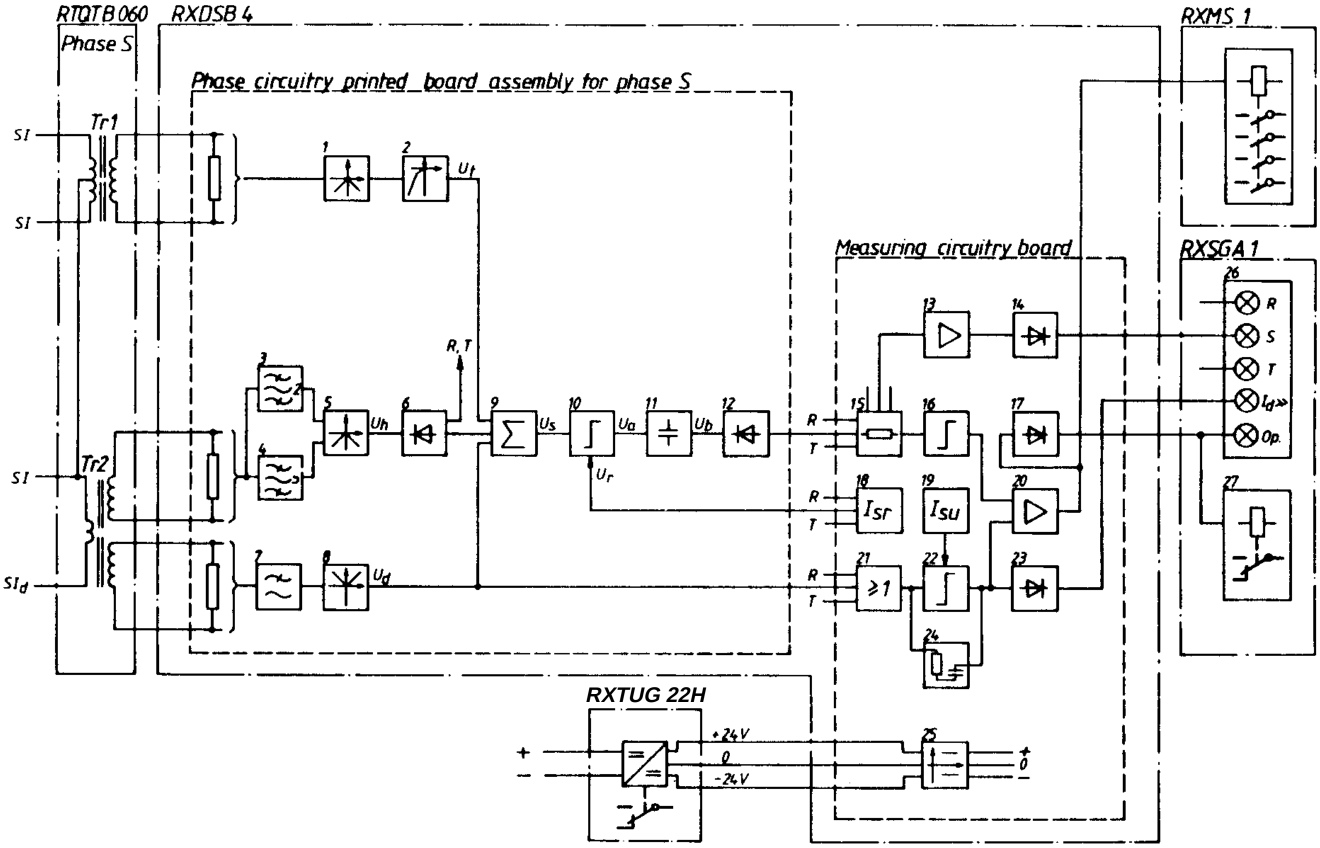
Interposing CTs SLCE 12 and SLCE 16

Overload capacity: Continuously 10 s 1 s	 2,5 x I_n 15 x I_n 75 x I_n
Max external conductor area	10 mm^2
Remanence	< 0,2 T
Mass: SLCE 16 SLCE 12	 5,4 kg 3,6 kg

4.2 Mounting details

The RADSB 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 type RHGX 12 or 20 case for panel mounting. (See Buyer’s Guide catalogue for COMBIFLEX connection and installation components.)

5 Operation



1 Rectifier
2 Non-linear circuit
3 Second harmonic filter
4 Fifth harmonic filter
5 Rectifier
6 Diode circuit
7 Low-pass filter
8 Rectifier
9 Summation circuit
10 Level detector
11 Integration circuit
12 Diode circuit
13 Amplifier
14 Diode circuit
15 Resistor circuit
16 Level detector
17 Diode circuit
18 Setting device
19 Setting device
20 Relay driver stage
21 OR-circuit
22 Level detector
23 Diode circuit
24 Feed-back circuit
25 Stabilizing circuit
26 LED-indicators
27 Signal relay

Fig. 19 Block diagram for phase S of the transformer differential relay type RADSB.

The input transformers of phase S, Tr1 and Tr2, are mounted in the transformer unit RTQTB 060 and connected to the line current transformer, as illustrated in Fig. 20, possibly via interposing CTs.

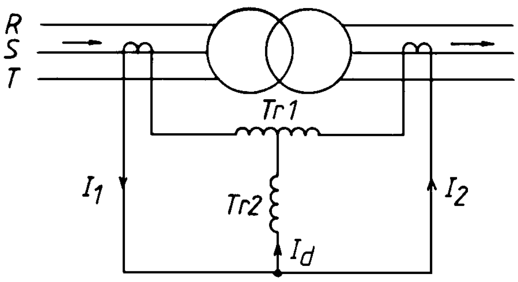


Fig. 20 Principle connection of the input transformers Tr1 and Tr2.

The transformers Tr1 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 Tr1. The voltage is rectified (1), see Fig. 19, and via a nonlinear circuit (2), containing regulating diodes and resistors, a negative voltage U_t is obtained. This voltage provides the differential relay with a variable through-fault restraint. The restraint is small at small through currents and large at large through currents when saturation can cause large differential currents $I_d = I_1 - I_2$. The operation of the differential relay is blocked up to a certain differential current. This is illustrated in Fig. 21 which show the differential current as a function of the through current.

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

$I_x = I_1$ and $I_y = I_2$ when connected to two transformer windings. When connected to three windings I_x = the largest input current and I_y = the largest output current.

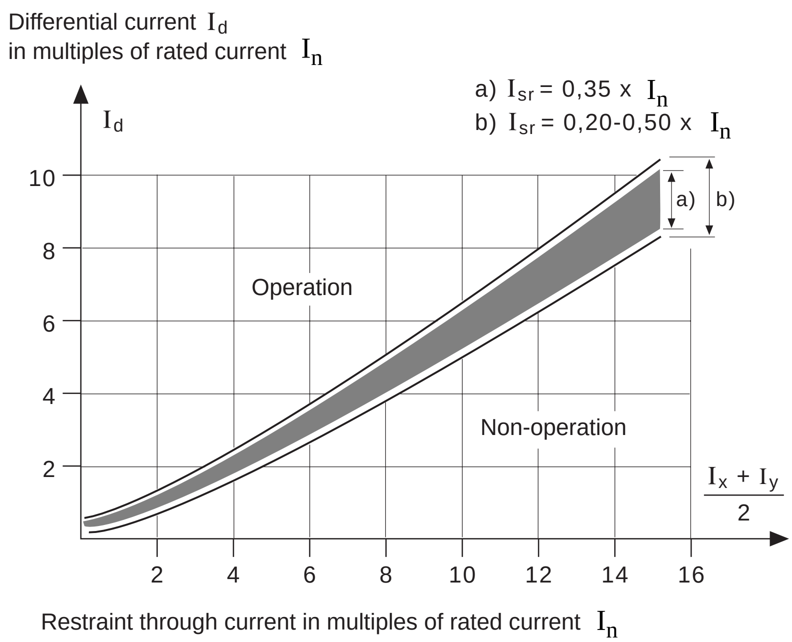


Fig. 21 Restraint characteristic at through currents

At a small through current the stabilising slope is small, but increases to about 60% at 10 times rated current.

When an internal fault occurs, the differential current will be

$$I_d / \frac{I_x + I_y}{2} = 200\ \%$$

of the through current at single end supply, and much larger at supply from both sides. Thus, operation will be obtained with a satisfactory safety margin.

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 has two secondary windings with suitably adapted load resistors. One of the windings provides the voltage that initiates operation at internal faults. The voltage passes through a low-pass filter (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 (8) composed by operational amplifiers and the positive voltage U_d is obtained.

The other winding of Tr2 provides voltages to two band-pass filters (3 and 4). The filters are active filters tuned for the second and fifth harmonics and provide after an ideal rectifier (5) a negative voltage U_h. This voltage is used to restrain the differential relay for inrush currents and at large no-load currents caused by high voltages, respectively, the last being the over-excitation restrained. The voltage U_h is obtained from all three phases via a diode circuit (6). The phase having the largest second or fifth harmonic current in a certain moment, will thus provide a restrained voltage to all three phases.

The harmonic voltage U_h is opposite to the voltage U_d and prevents operation if the second or fifth harmonic current is more than 15 and 38%, respectively, of the fundamental current.The feature having the output voltages connected together from the harmonic restrained circuits of the three phases results in that the restrained can be made weaker corresponding to what otherwise should have been required to provide correct restrained operation of the differential relay during unfavourable instances when switching in the power transformer when it has maximum remanence.

The voltage U_h will be low for the third harmonic and the differential relay will therefore operate for third harmonic currents, which is important with consideration taken to the security of operation for large internal faults with saturated CTs when the content of the third harmonics can be up to approximately 60% of the fundamental.

The rectified, but unsmoothed, voltages U_t, U_d, and U_h are summed (9) and supplied to a level detector (10). The resultant voltage U_s, which is a pulsating dc voltage, is compared with a reference dc voltage U_r. The voltage U_r can be controlled with a switch on the measuring circuitry board providing settings of the restrained operate value I_{sr} (0,20, 0,25, 0,35, or 0,50 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 (11) and connected via a diode circuit (12) 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 cycle, that means 4,1 ms per 10 ms, the integrated voltage U_b will exceed a permanently set reference value U_z of the level detector (16). The relay driver stage (20) will then operate and the output tripping relay type RXMS 1 (or type RXME 18) will pick up. A signal will then simultaneously be provided via a diode circuit (17) to an input of the phase indicator unit type RXSGA 1. A LED marked “Operation” (26) will then be lit and the relay (27) will pick up (or, in versions with signal relay RXSF 1, that relay will pick up).

Fig. 22 shows the various voltages when Us is larger than Ur during approximately 50% of the cycle, that means that the conditions for operation are satisfied.

Fig. 22 Wave shapes and pulse width integrating action required to develop trip signals.

When the level detector (16) operates, a current will flow through a resistor circuit (15). The voltage across the resistors will be amplified (13) and connected via a diode circuit (14) 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 (21) to a level detector (22) having a reference value regulated by a switch for setting of the unrestrained operate value I_{su} (19). When the set operate value has been exceeded, an output voltage is obtained which is fed back via an RC-circuit (24) to provide the voltage with a sufficient duration. The voltage triggers a relay driver stage (20) and is supplied via a diode circuit (23) to an input of the phase indicator unit. The output relay operates and a LED marked “I_d>>” will be lit (or, in versions with target relay, that relay will pick up).

The unrestrained operate value circuit can be set for operation at 8, 13 or 20 times the rated current, and provides fast tripping for large differential currents. The circuit has very short impulse limit time, less than 3 ms, thus operation will be obtained even if the CTs will be saturated. 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 with trip relay type RXMS 1 as an output relay are illustrated in Fig. 23. The operate time will be approximately 25 ms longer if the trip relay type RXME 18 is used as an output tripping relay.

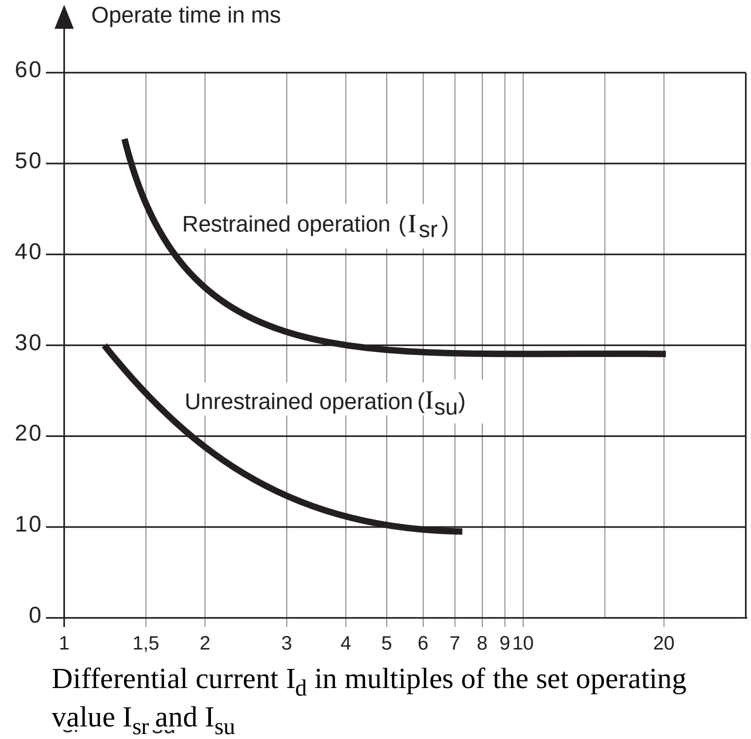


Fig. 23 Operate time-current characteristics

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 ranges. The measuring unit includes the stabilizing circuit (25) 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.

6 Testing

Before the final commissioning, the following tests should be carried out. Information 1MRK 504 002-WEN gives detailed information on testing of operating values, etc. Ratios and connections of interposing CTs for RADSB is described under “Calculation of current ratio”.

6.1 Receiving

Remove the relay from the transport case and make a visual inspection for possible transport damage. Check that all screws are firmly tightened and all relays and other elements are securely fastened.

Check that the delivered relays have correct rated data stamped on the rating plate which is located on the test switches RTXP 18, i.e. rated current, rated voltage, rated frequency, rated dc 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.

6.2 Storage

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

6.3 Installation

The relay 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 transformer differential relay is mounted an apparatus bars intended for mounting into an equipment frame with a support frame, or in a case type RHGX. The rear of the relay 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 relay covers should be properly fitted, otherwise there is a risk that dust, etc may enter the relays 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 relay.

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 relay with correct polarity.

6.4 Maintenance

All the apparatus in the transformer differential relay is robust and maintenance is therefore reduced to a minimum. Since the relay is only called upon to operate at very infrequent intervals, it will be of value to test the relay regularly, say every second 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 relay 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 1MRK 512 001-BEN.

The relays can be tested with the equipment in service. However, the protective relay cannot operate in its normal manner during the time the test is performed. Should a fault occur, a backup protective relay 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 relays, the auxiliary voltage should be connected to the protective relay at least ten minutes before the measurements start.

6.5 Test reports

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

- compare with preceding tests if there has been any change of the operation of the protective relay
- 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 protective relay has changed, for example, if some relay units have been exchanged
- see when and how the settings of the protective relay have been changed

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

6.6 General check

Before the tests, a check should be made that there is no interruptions in the current transformer circuits. First, for example, phase A (R) at a terminal board (before the relay 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 A (R) in series with the connection in parallel of the phases B (Y) and C (B) 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 B (Y), C (B) and the neutral. The resistance values should be low, for example not more than a few tens of ohms in a 1 A circuit.

6.7 Interposing current transformer test

Check the current of the CTs 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 + terminal 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.

6.8 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. After the testing the protective grounding connections should be restored immediately. There should be only one grounding connection in each current transformer circuit.

6.9 Check of the operating current

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

Insert the test handle in the testing device.

Interconnect terminals 12, 13 and 14 of the test handle. Connect terminal 12 of the RTXH 18 testing handle to the test set. Connect through an instrument one of the terminals 3, 4 and 5 to the test set and check the operate value for phase R.

Check the operate current consequently for phase S and T. 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. One may repeat by injection into terminals 6, 7 and 8.

6.10 Check of the tripping circuits

Pull out the testing handle completely. Check that the circuit breaker for the power transformer 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 relay is not allowed, the tripping circuit should be checked in another way.

6.11 Service test with primary current through the power transformer

A test with primary current through the power transformer constitutes a final check that the current circuits of the relay are correctly connected and balanced so that the currents in the differential circuits, in principles, are zero in the case of a fully operational power transformer.

The primary current can be a load current, or in some way injected, as indicated in section “Current sources during the primary current test”. With regard to three-winding transformers, see section “Three winding transformers” below.

The 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, a lower current, for example approx. 10 per cent, is, however, sufficient (for example for supply in accordance with alternative 2 or 3 in section “Current sources during the service tests” below). The currents do not need to be identical in the phases.

If there is an on-load or off-circuit tap changer, it should, during the test, be in a position, usually the central position, at which the protection is supposed to be fully balanced.

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 I, the current measuring plug type RTXM, to which an ammeter is connected, is inserted in the test device in contact blocks 3, 4 and 5 if the transformer is fed from winding 1. An instrument with low power consumption connected to the relay via the current measuring plug RTXM inserted in the contact blocks 12 (phase A (R)), 13 (phase B (Y)) and 14 (phase C (B)), should preferably be used for measuring the differential current.

The phase currents and the differential currents I_d should be read off for all the three phases.

If the relay is correctly connected, the differential current I_d should only amount to a few per cent of I. In case of faulty connections, differential currents are obtained, the size of which in different phases 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.

6.11.1 Three-winding transformers

Three-winding transformers are tested in accordance with instructions above, but only with two windings loaded at a time.
If a differential current is indicated only when a certain winding is loaded, the incorrect connection is probably in the current transformer circuit of that winding.

6.11.2 Examples of faulty connections

Approximately the same value for I_d in all the three phases probably means that the same incorrect connection is present in all phases.

If the differential currents are relatively low, the tap changer is probably in the wrong position, or the current transformer ratio is incorrect. In the interposing CTs, primary and secondary windings may have been interchanged or connected for wrong ratio.

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

a) $I_d = 2\ I$

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

Alternative: A combination of incorrect connections according to b) and c) below.

b) $I_d = I$

In a (D/Y) - connected transformer, the delta connection of the L(interposing) CTs may be wrongly connected reversed) polarity compared to the delta connected of the power transformer.

Alternative: A combination of incorrect connections according to b) and c) or according to a) and c).

c) $I_d = \sqrt{3}\ I$

Permutation of the phases, that is connection of phase A (R) from the one side together with, for example, phase B (Y) on the other, and B (Y) together with C (B) and C (B) together with A (R).

Alternative: A combination of incorrect connections according to a) and b).

Complete 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: $I_d = \sqrt{3}\ I$ in two phases, $I_d = 0$ in one phase. Two phases have been interchanged (that is, A (R) on the one side has been connected together with B (Y) on the other, and B (Y) together with A (R).

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

6.11.3 Current sources during the primary current test

One of the following alternatives is normally used.

Alternative 1; Test with a generator
Supply from a separate generator and with a three-phase short circuit applied to the high-voltage side of the power transformer outside the CTs. This method is the obvious one for generator-transformer units. 50-100 % of the rated current is obtained with hardly any excitation.

Alternative 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, through the power transformer towards an applied three-phase short-circuit outside the CTs.

Assume that the transformer, which is to be tested, has, for the side supplied, rated data of U kV and I A and a fault MVA impedance of Z_k per cent and that the local transformer has on the low-voltage side U_1 kV and I_1 A. The current will then be

$$\frac{100}{Z_k} \cdot \frac{U_1}{U} \cdot I$$

In accordance with the above, the current should be at least 10 per cent of I but at the same time not more than I_1 in order that the local transformer should not be overloaded. If U_1 = 380 V and U = 11000 V and Z_k = 10 %, the current will be approx. 0,35 x I and the rated output power of the local transformer need only to be approx. 1 % of that of the test transformer.

Alternative 3; Test on a loaded transformer

The simplest method is to connect the transformer to the network and load it. However, the condition here is that the circuit breaker and the switchgear can be taken into use and that a sufficient load can be achieved. In addition, other protective relays, primarily the gas-operated relay (the Buchholz relay) and the over-current protection, should be connected and ready for service. The over-current relays should, during the test, be set at approx. 30 % above the rated current and with a short operating time (after the transformer has been connected in at, the shortest time setting) and for instantaneous tripping upon the presence of a high current.

6.12 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.

6.13 Test with energization of the power transformer

The operating value is set at the appropriate value. The transformer should be switched in a few times to the network at full service voltage. If the networks of both the high-voltage side and the low-voltage side have low source impedance (high fault MVA level), the transformer should be switched in and energized from both sides. Magnetizing inrush currents should not cause operation of the protection. Repeated relay operations when switching in the transformer to the networks may be caused by a fault in the transformer, which will probably result in development of gas which can be observed at the gas-operated relay (the Buchholz relay).

7 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 relay is correctly set
- the indications have been reset

8 Circuit diagrams

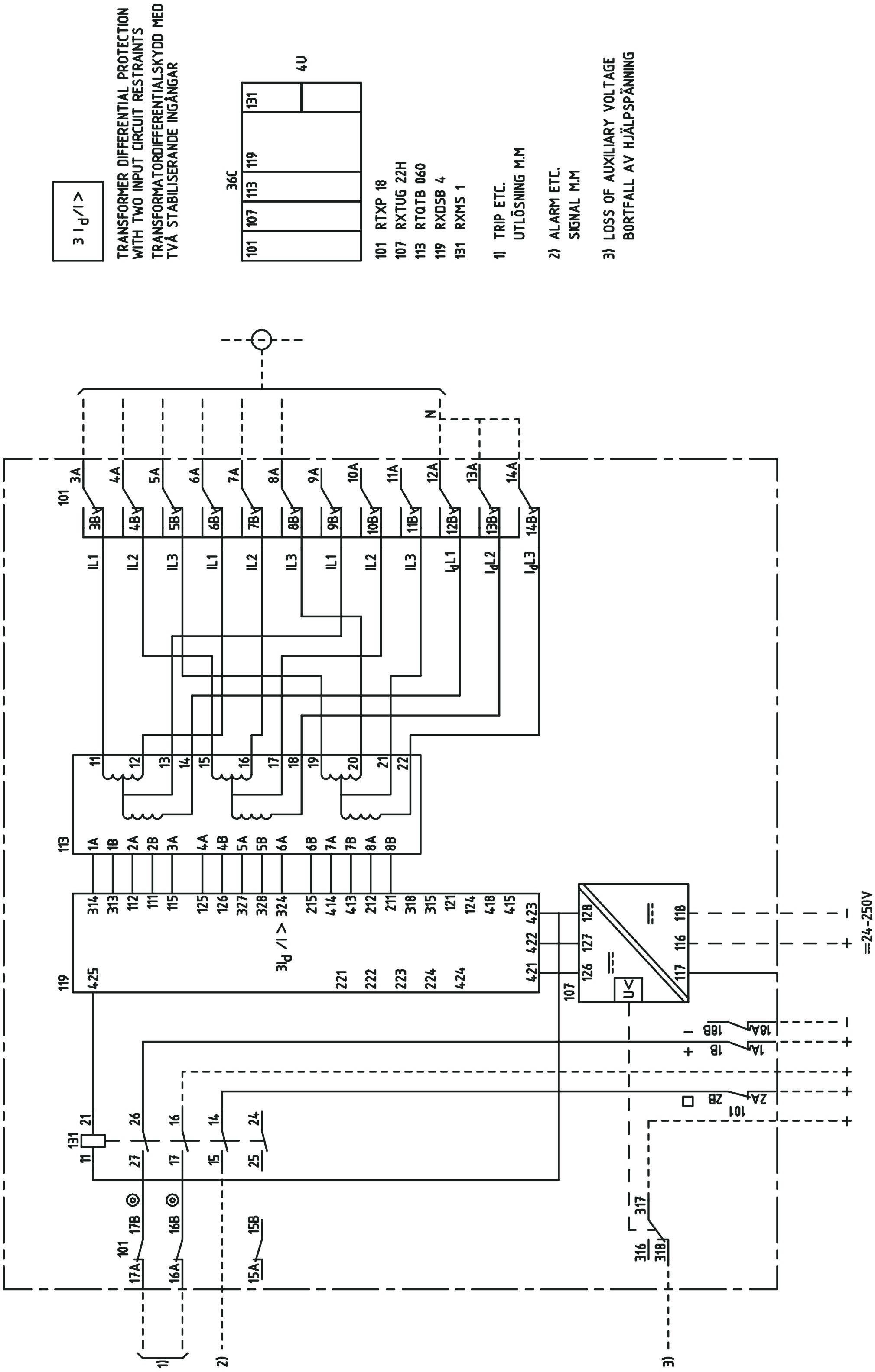


Fig. 24 *Ordering No. RK 625 001-AC,*
Circuit diagram 7454 344-AE (Terminal diagram 7454 344-ADA).

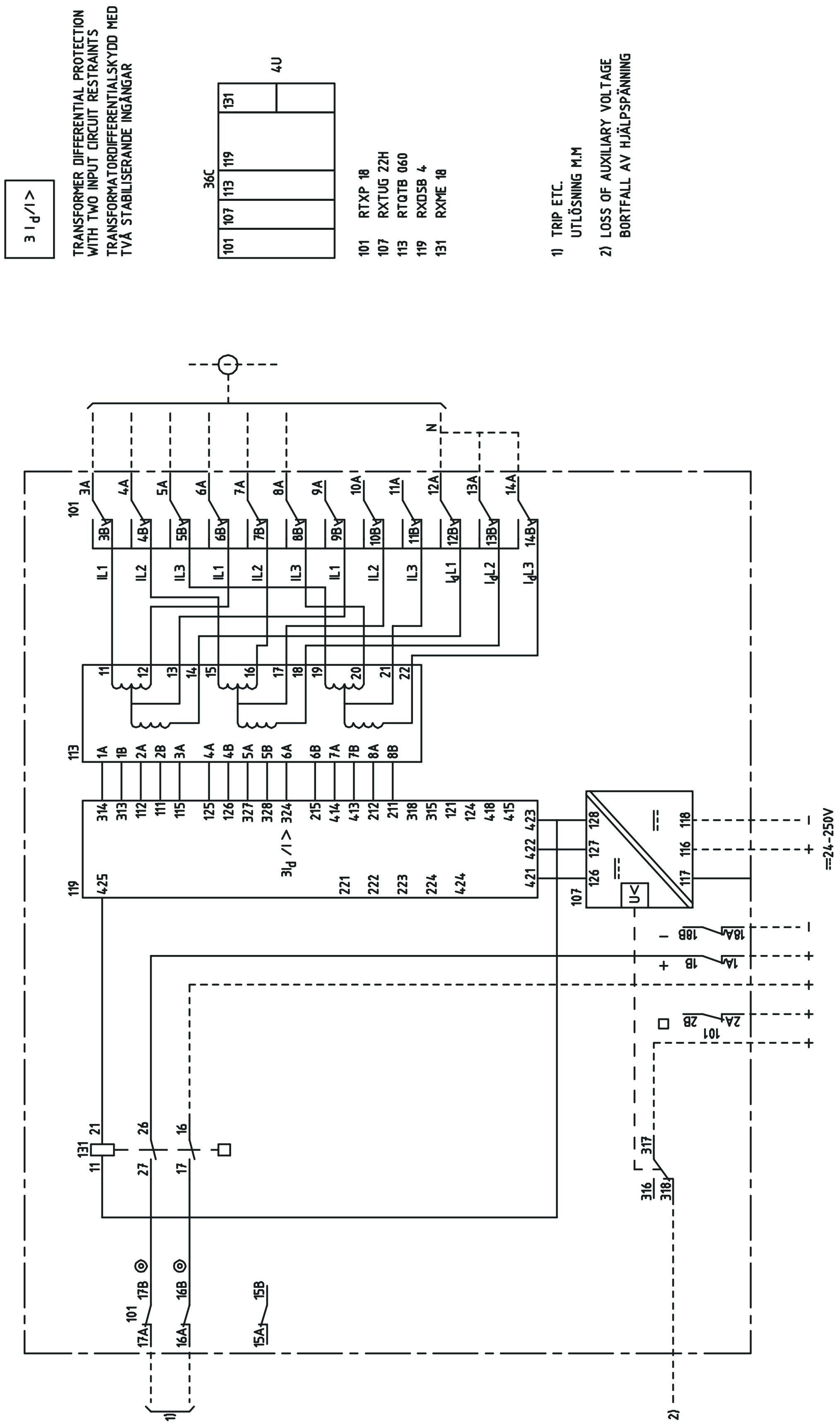


Fig. 25 RADSB, Ordering No. RK 625 001-BC, Circuit diagram 7454 344-BE (Terminal diagram 7454 344-BDA).

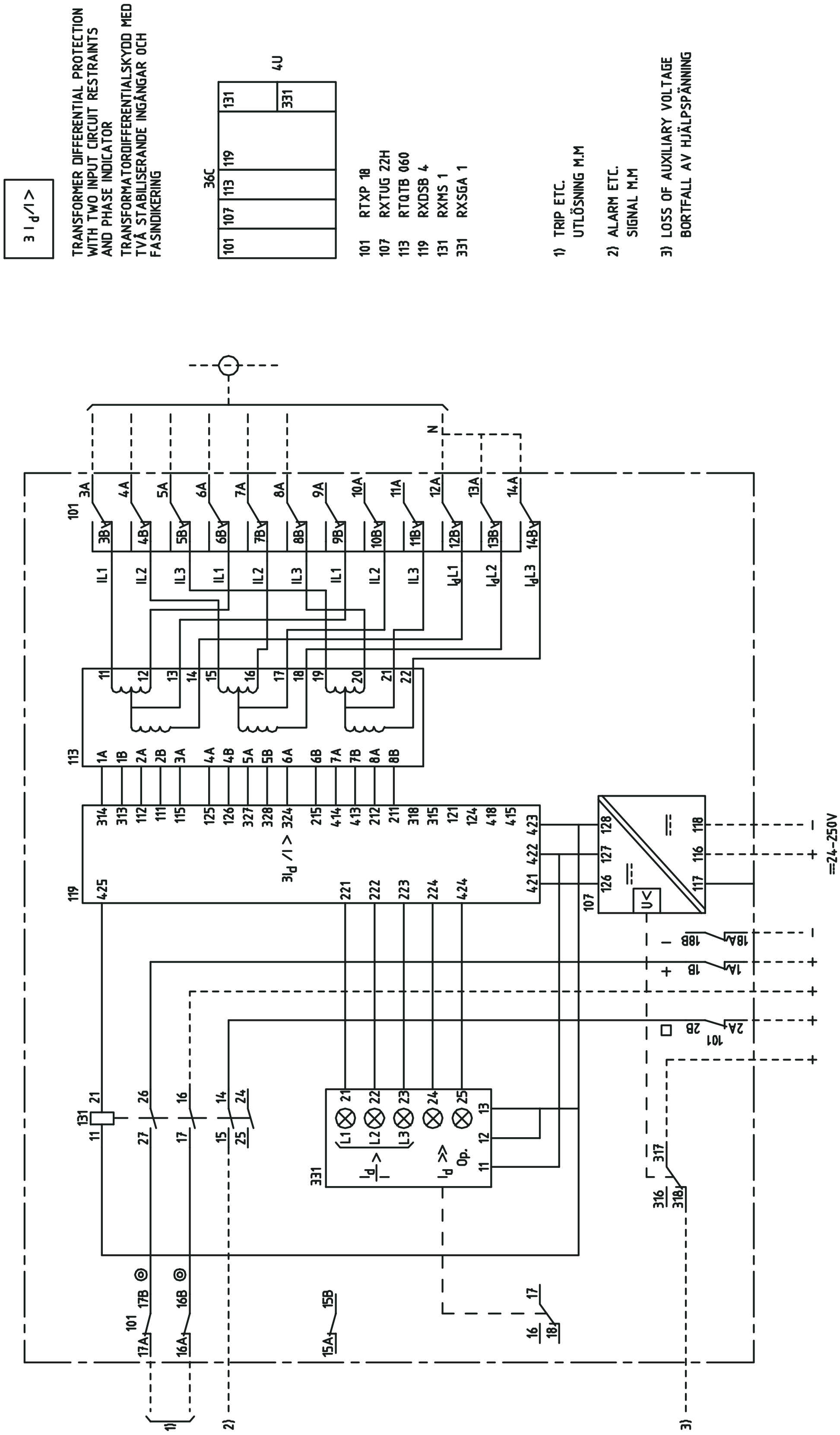


Fig. 26 RADSB, Ordering No. RK 625 001-CC, Circuit diagram 7454 344-CE (Terminal diagram 7454 344-ADA).

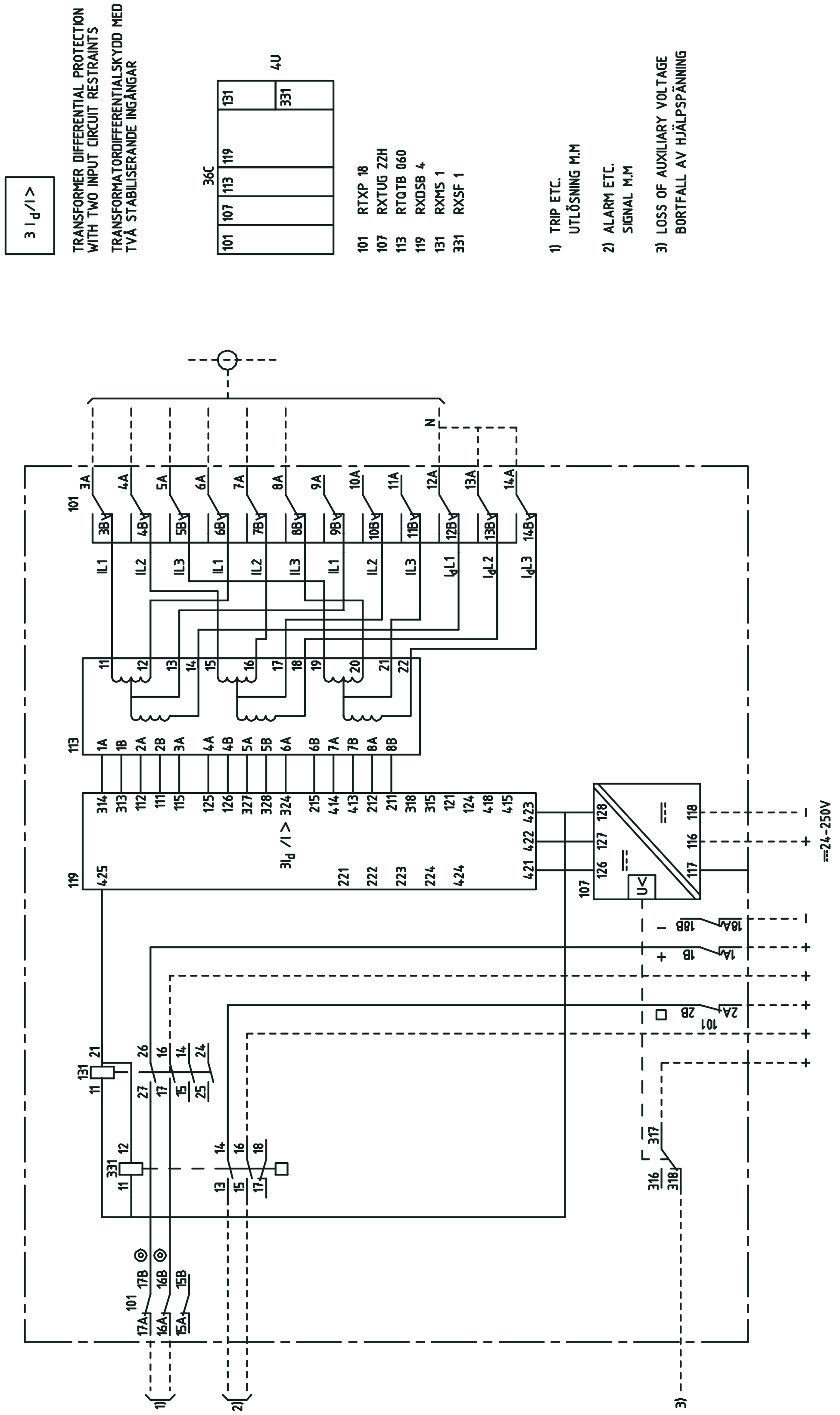


*Fig. 27 RADSB, Ordering No. RK 625 001-EA,
Circuit diagram 7454 344-EB (Terminal diagram 7454 344-EAA).*

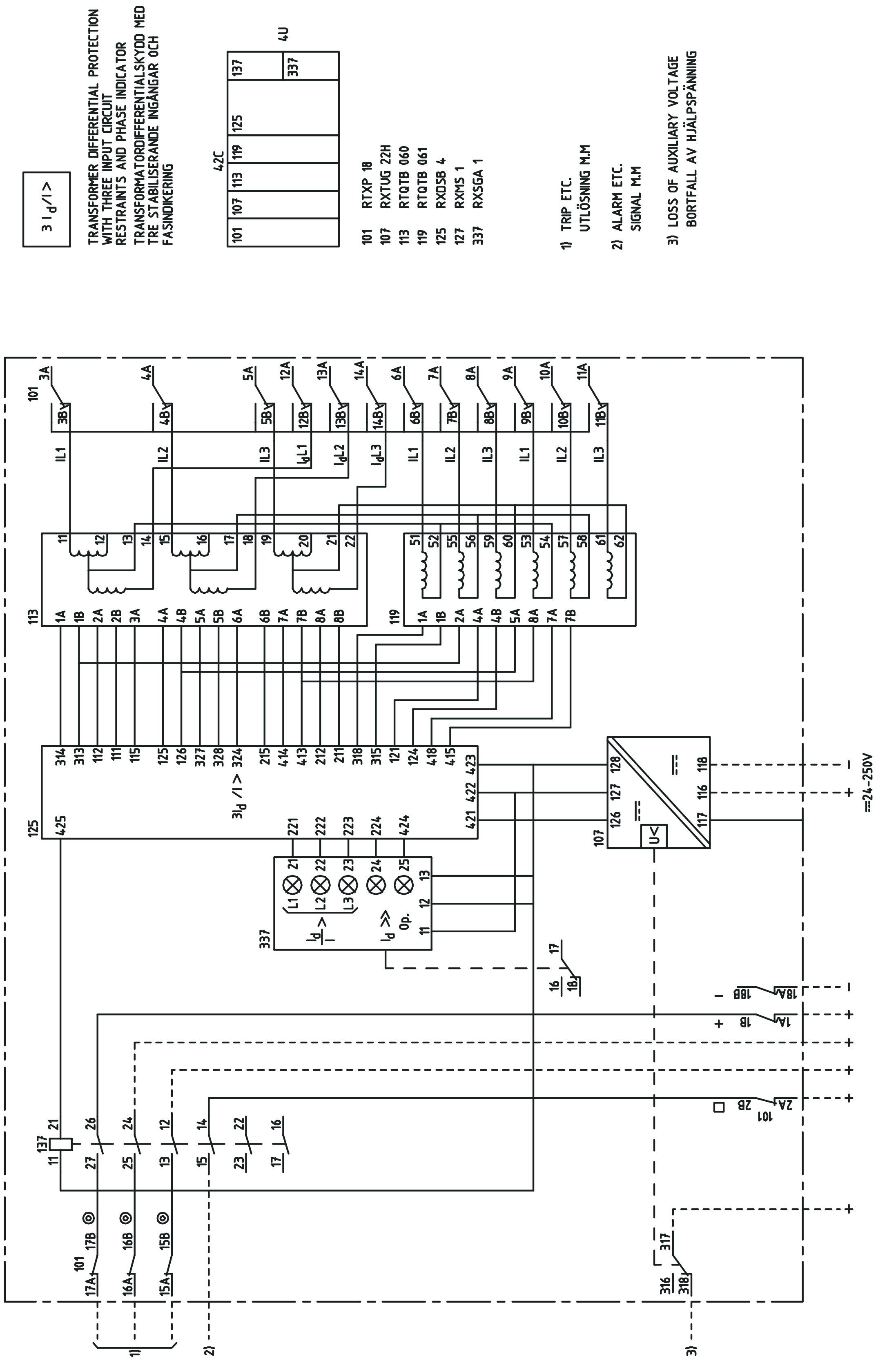


Fig. 28 RADSB, Ordering No. RK 625 005-CA, Circuit diagram 7454 356-CC (Terminal diagram 7454 356-DBA).

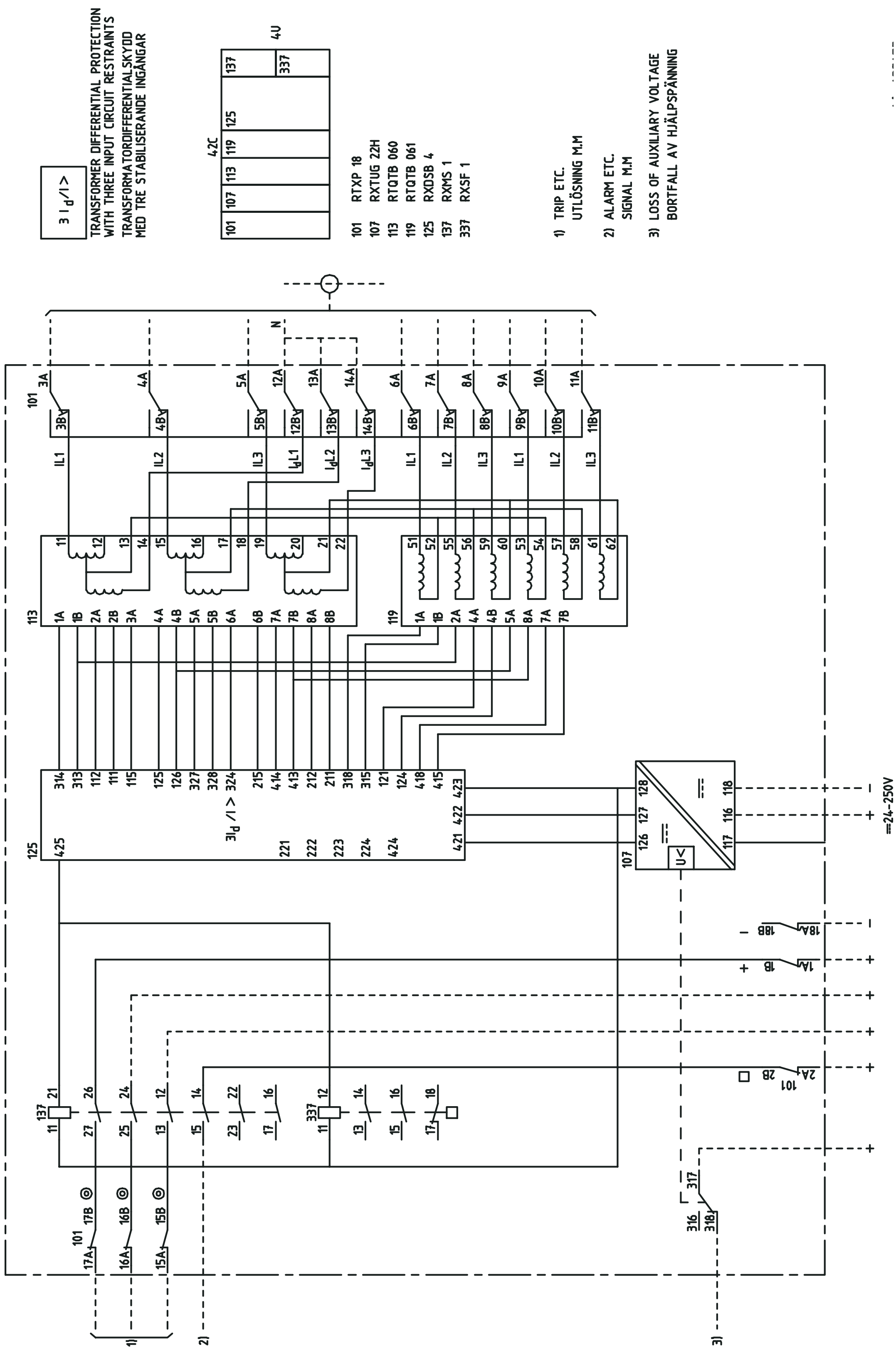


Fig. 29 *RADSB, Ordering No. RK 625 005-DA, Circuit diagram 7454 356-DC (Terminal diagram 7454 356-DBA).*

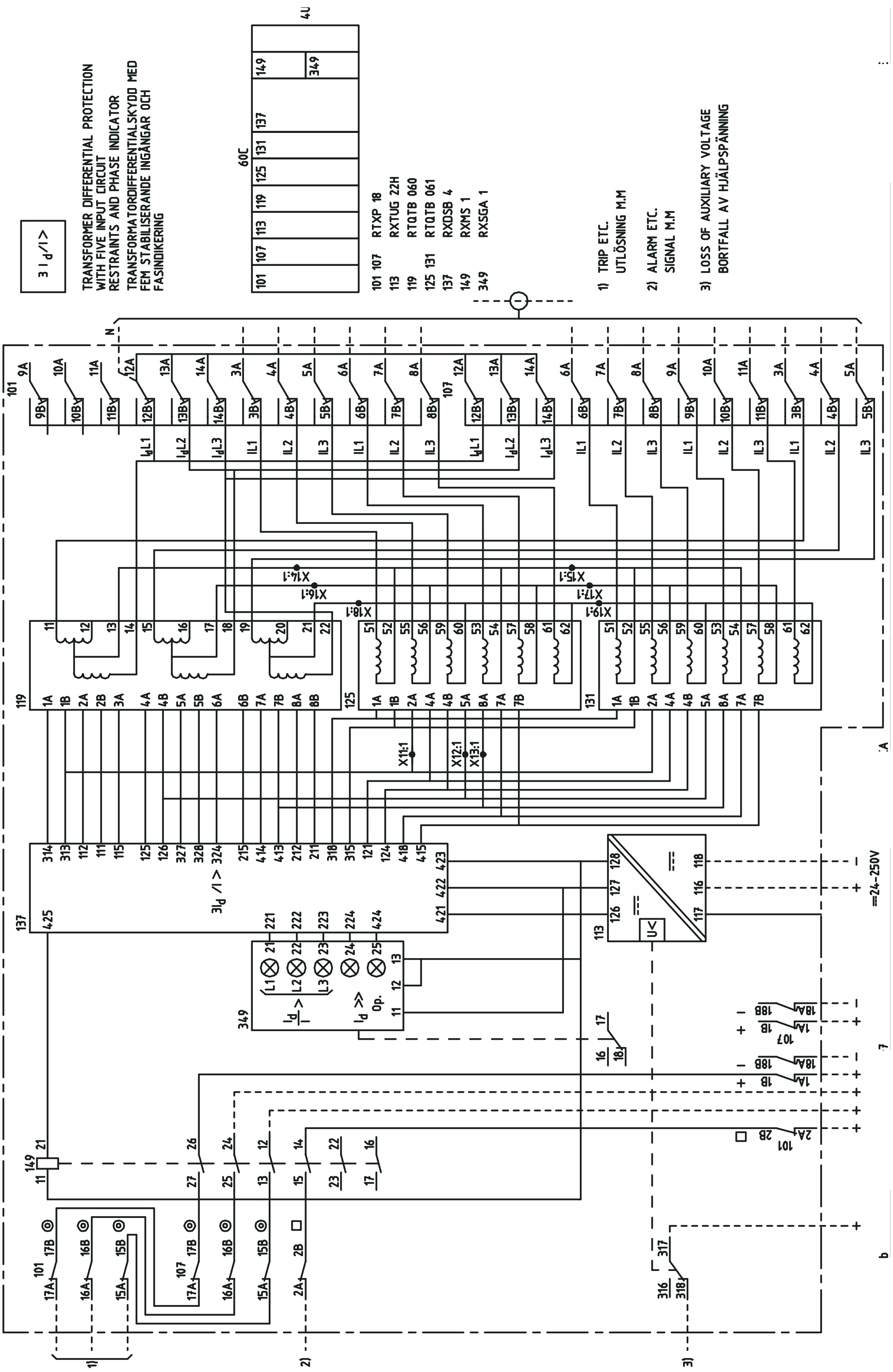


Fig. 30 RADSB, Ordering No. RK 625 006-CA,
Circuit diagram 7454 359-CC (Terminal diagram 7454 359-DBA).

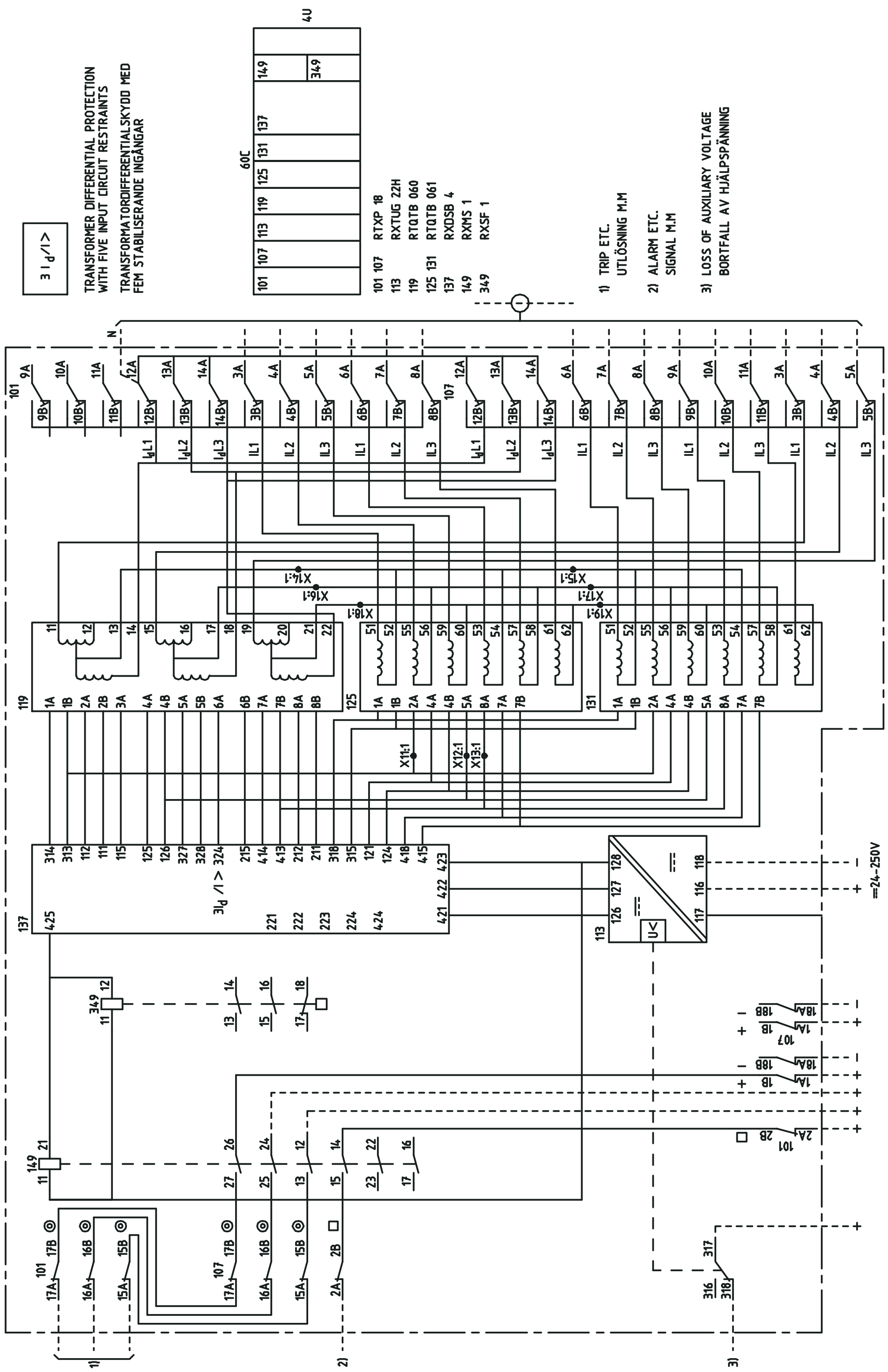


Fig. 31 *RADSB, Ordering No. RK 625 006-DA, Circuit diagram 7454 359-DC (Terminal diagram 7454 359-DBA).*

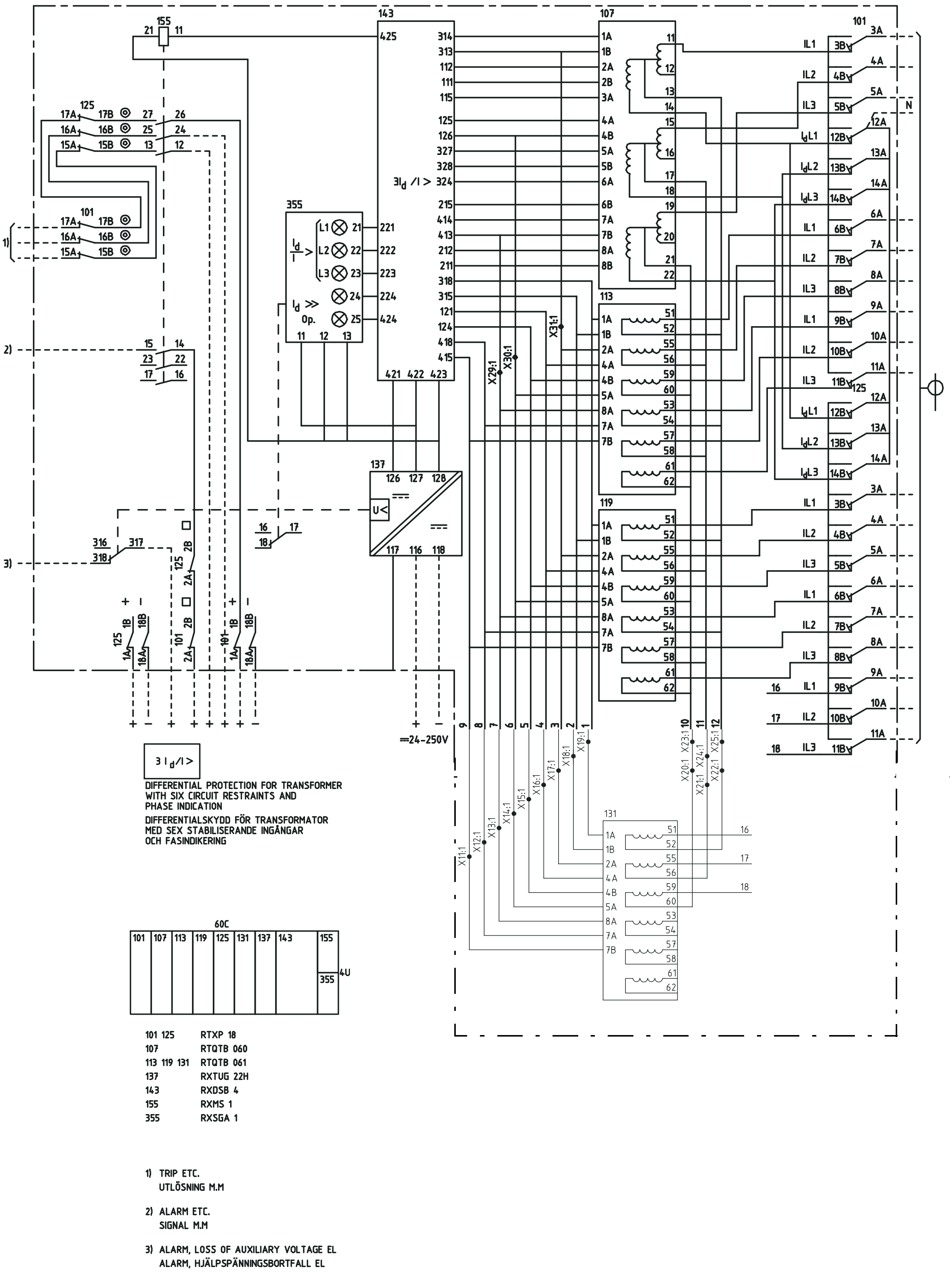


Fig. 32 *RADSB 1 Ordering No. RK 625 010-CA, Circuit diagram 7454 361-CB (Terminal diagram 7454 361-CBA).*

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