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ABB Relays

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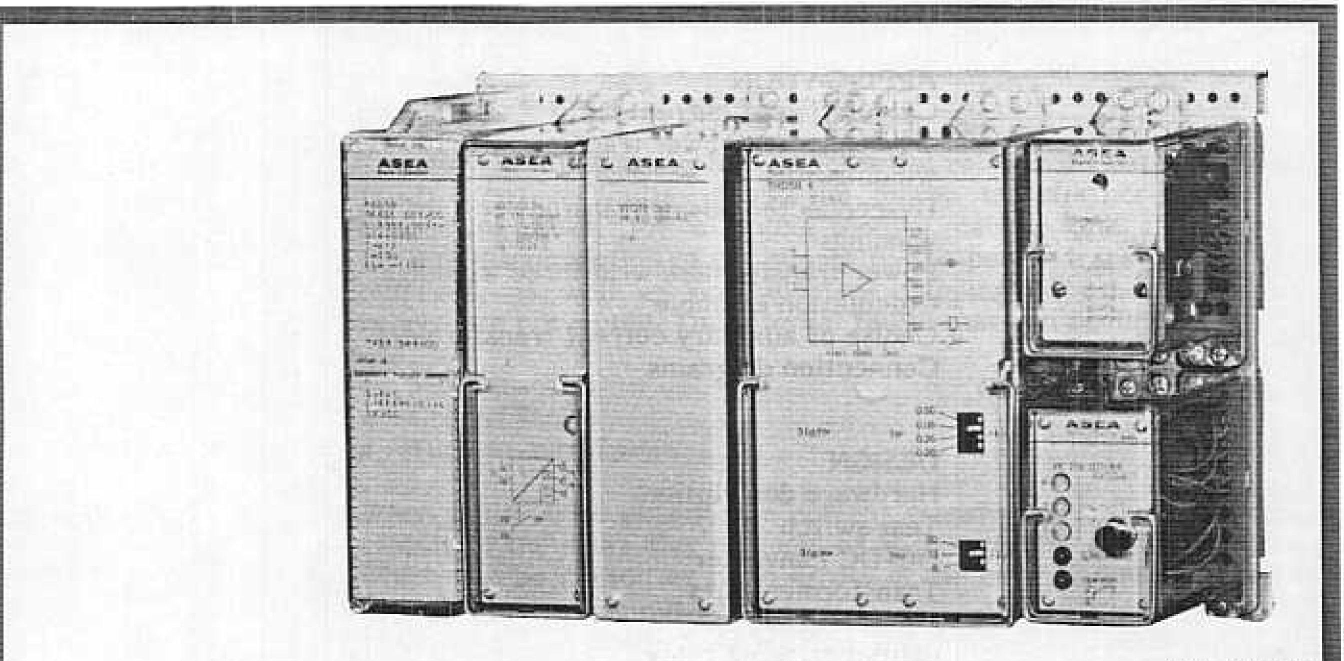
Type RADSB
Transformer differential relay



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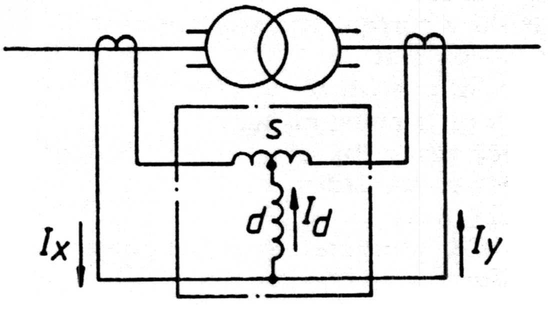
GENERAL

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 current transformers and possible auxiliary current transformers. The ratios and connections of the current transformers 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

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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 current transformers. Normally, these two currents only comprise a small percentage of the rated current. However, it is possible, with power transformers with tap-changers, at rated load and with the tap-changer 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.

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 faults that can occur are:

- Short circuits
- Ground faults
- Turn-to-turn faults

External faults

When faults arise outside the current transformers, the differential circuit of the relay may be supplied with a relatively large current, which can be caused by ratio errors in the current transformers, or by the tap-changer not being in the centre-tap position. If the tap-changer is in a position 20 % from the centre-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 a certain percentage differential current related to the current through the power transformer.

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), power transformer remanance, the design of the power transformer, the type of transformer connection, the method of neutral grounding, 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.

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.

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; RADSB is virtually unaffected by load restraint.

The RADSB relay also has an unrestrained instantaneous module which responds to the total differential current (less any dc component). This module 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 (preferably type RATUB which has an inverse-time operate characteristic).

Auxiliary CT's are used to balance the currents to the relay. In addition auxiliary CT's may be used to reduce the effective lead burden of long secondary leads. The differential zone of the relay can include up to three kilometer of high voltage cable since adequate filtering provides sequrity against high current oscillations.

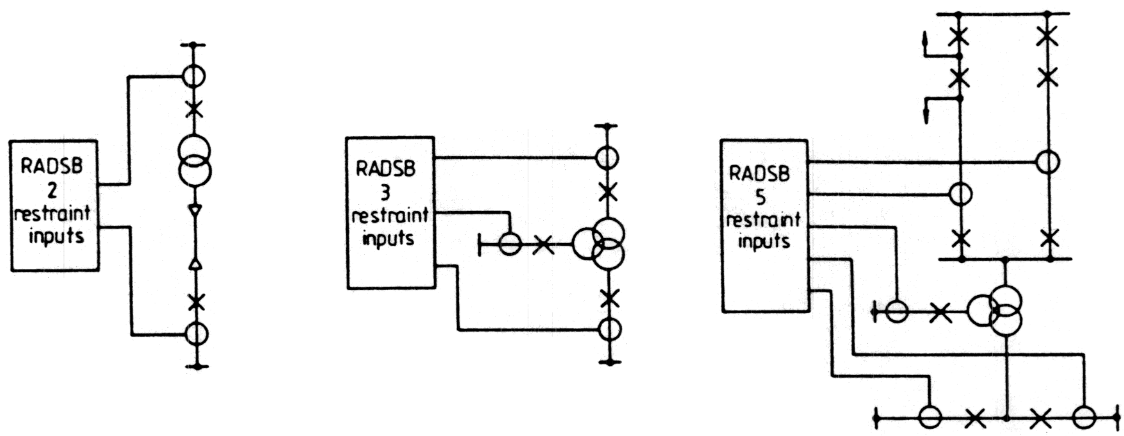


Fig. 2 Application examples for type RADSB.

Calculation of current ratio

One or several sets of single-phase auxiliary current transformers are used to balance the differential relay, that means to match the relay inputs to rated current of the relay. The auxiliary 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 current transformers.

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 current transformers 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 in auxiliary current transformers. If the ratio of the main current transformers is such that the secondary current at rated load only is for example 65 % of I_n, the real sensitivity of the differential relay will be 50 % lower than the set value. Auxiliary current transformers should therefore always be used when there is a lower secondary rated current. Otherwise the sensitivity (calculated in % 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 auxiliary current transformers for each transformer winding according to Figures 9-17.

One set of auxiliary current transformers can sometimes be omitted. See Figures 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 auxiliary current transformers, the best stability is obtained during external faults.

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

Figures 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 current transformer should supply Y-connected windings of the auxiliary current transformers so that correct operation is obtained for both internal and external ground-faults in networks with a large ground-fault current.

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 current transformers. During external faults, fault currents can otherwise pass through the differential circuit of the relay and cause maloperation.

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 current transformers, 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 auxiliary current transformers, 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 Figures 3-7.

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

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

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

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" $U'_2 = U_2\,(1 + \frac{p1 - p2}{200})$ is calcualted for the secondary side. This forms the base for the calculation of the primary and secondary currents.

One set of auxiliary current transformers

Each individual CT should be ordered for the ratio i_{n2}/i_{n1} (see fig. 3) for the three-phase auxiliary current transformer set.

The D-connected equalizing windings of the auxiliary current transformers are used to eliminate possible zero sequence currents in case of external ground-faults and should always be arranged for rated current 1 A.

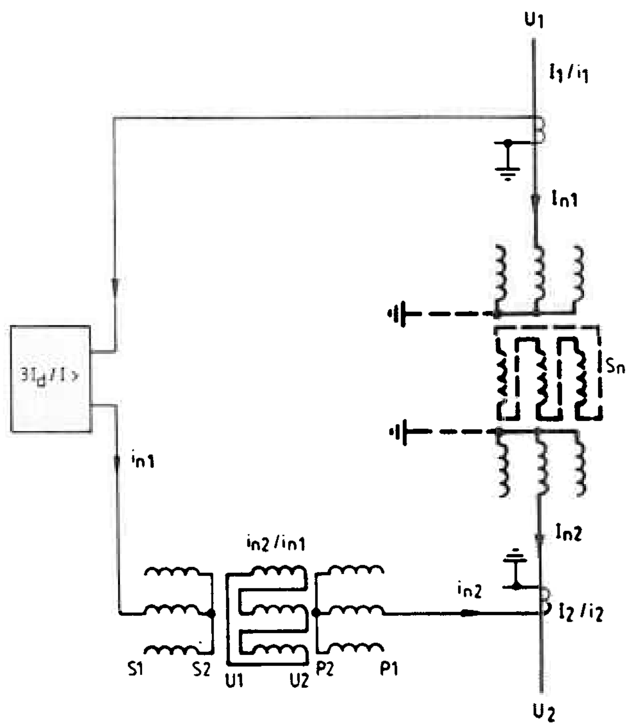


Fig 3

Two sets of auxiliary current transformers

Connection according to Fig. 4 and 9.

When auxiliary current transformers 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 current transformers in the separate sets will be according to Fig. 4. When all windings are equipped with auxiliary current transformers, a differential relay with the rated current of 1 A is most suitable selected.

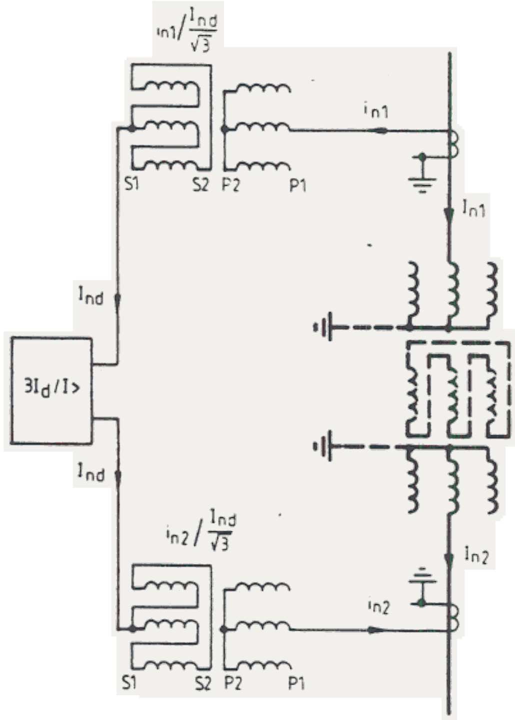


Fig 4

Dy-connected power transformer with two windings

<u>One set of auxiliary current transformers</u>

Connection according to Figures 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 auxiliary current transformers will be $i_{n1}/\sqrt{3}$.

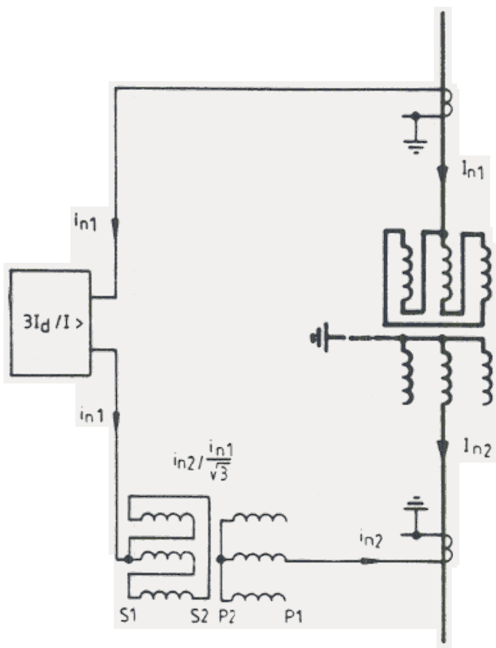


Fig 5

Two sets of auxiliary current transformers

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

Power transformers with three windings

Connections according to Figures 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 auxiliary current transformers are calculated, the highest rated power is used for all the windings. To obtain the best adaptation of the different sets of auxiliary current transformers 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 auxiliary current transformers in proportion to the rated powers. See the following calculation example.

Two sets of auxiliary current transformers

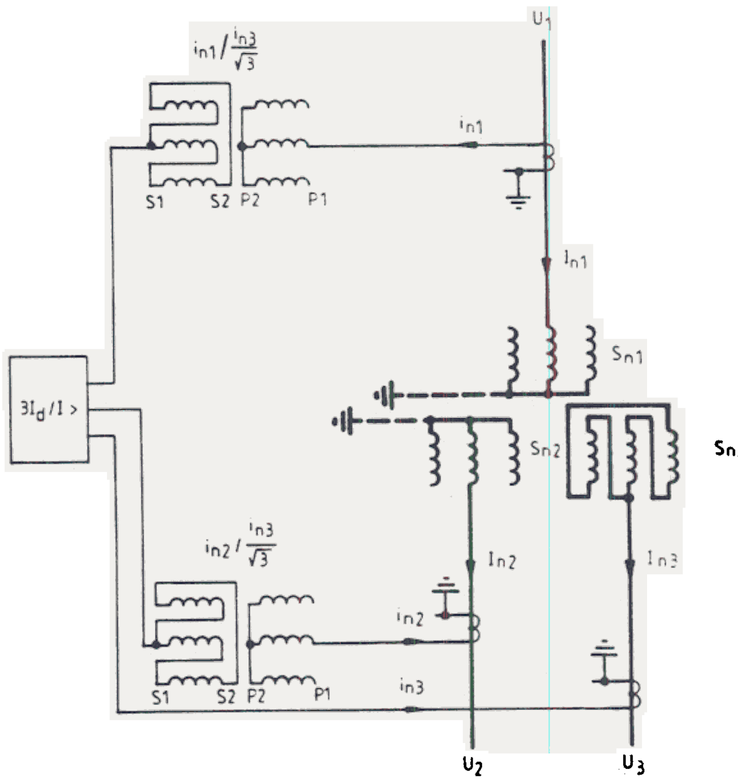


Fig 6

Three sets of auxiliary current transformers

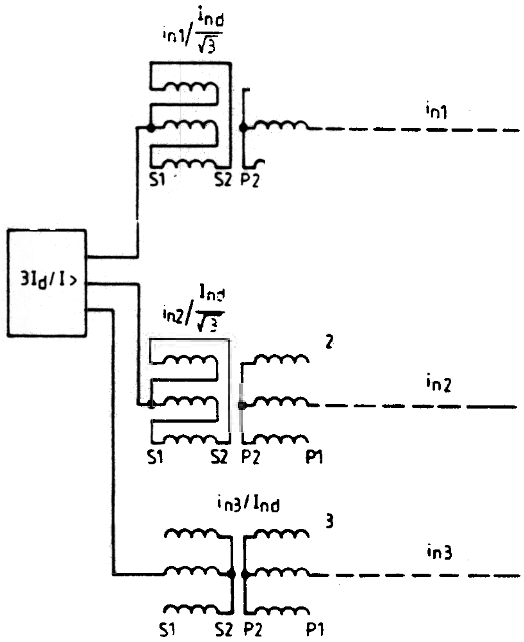


Fig 7

Calculation example for three sets of auxiliary current transformers

(Figures 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 currrent transformers:

Position	77 kV	21.5 kV	11 kV
Current ratio	200/2 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 auxiliary current transformers in set connected Yd

$$i_{n1}/\frac{1}{\sqrt{3}} = \frac{20000}{77 \times \sqrt{3}} \times \frac{2}{200} / \frac{1}{\sqrt{3}} = 1{,}50/\frac{1}{\sqrt{3}} \text{ A}$$

b) the auxiliary current transformers in set 2 connected Yd

$$i_{n2}/\frac{1}{\sqrt{3}} = \frac{20000}{21.5 \times \sqrt{3}} \times \frac{5}{600} / \frac{1}{\sqrt{3}} = 4.48/\frac{1}{\sqrt{3}} \text{ A}$$

c) the auxiliary current transformers in set 3 connected Yy

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

The primary and secondary currents at the rated power will be

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

Choice of auxiliary current transformers

As a standard the reconnectible multi-tapped auxiliary current transformer type SLCE 12 should be used, see B03-9280E. 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 auxiliary 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 auxiliary CT. These auxiliary current transformers can be used even when a secondary current less than 1 A or 5 A, alternatively, is requested. This can be the case when, for example, auxiliary current transformers 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.

It is an advantage that the auxiliary current transformers are located close to the differential relay so they can get as high saturation factor 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 relay).

Table

Transformer SLCE 12 for I_p = 0,65 - 2,60 A, I_s = 1 A

Ordering number 4785 040-VP

Primary current	Turn ratio	Connections on primary side between terminals	Connections on secondary side between terminals	a	b	Power Consumption at I_s=1 A
A				ohm	ohm	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, -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 and 12-P2	S1-1, 2-6, 4-5, 3-S2	56	0,47	1,0
1,35-1,42	100/138		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 and 11-P2	S1-1, 2-6, 4-5, 3-S2	56	0,47	1,2
1,92-2,01	70/138		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, A, I_s = 1 A

Ordering number 4785 040-VR

Primary current A	Turn ratio	Connections on primary side between terminals	Connections on secondary side between terminals	a ohm	b ohm	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, 1-P2	S1-1, 2-5, 6-S2	70	0,42	1,4
3,87-4,04	43/170		S1-1, 2-3, 4-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 and 12-P2	S1-1, 2-6, 4-5, 3-S2	56	0,47	1,2
5,36-5,67	25/138		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 and 11-P2	S1-1, 2-6, 4-5, 3-S2	56	0,47	1,4
7,45-7,88	18/138		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 $I_p = 2{,}85 - 1{,}2$ A, $I_s = 5$ A

Ordering number 4785 040-VS

Primary current A	Turn ratio	Connections on primary side between terminals	Connections on secondary side between terminals	a ohm	b ohm	Power Consumption at I_s=1 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 and 12-P2	S1-1, 2-6, 4-5, 3-S2	3,1	0,046	2,0
5,97-6,28	31/38		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 and 11-P2	S1-1, 2-6, 4-5, 3-S2	3,1	0,046	2,2
8,41-8,85	22/38		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, 2-5, 6-S2	3,8	0,040	2,6
10,21-10,7	22/46		S1-1, 2-3, 4-S2	4,0	0,041	2,8
10,71-11,2	22/48		S1-1, 2-3, 4-5, 6-S2	4,2	0,046	2,8

Table 4

Type	Current ratio	U_s	a	b	S
	A/A	V	ohm	ohm	VA
SLCE 16/350	1/0,4	500	1200	10	3
SLCE 16/350	5/0,4	500	1200	10	3
SLCE 12/200	0.4/1	90	90	0.7	1.3
SLCE 12/200	0.4/5	18	3.5	0.03	1.3

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 current transformers and the auxiliary current transformers should have saturation factors that correspond to the maximum through-fault current. With regard to the magnetizing inrush current, the saturation factor ought to be at least 20 for transformers with low (< 0.2 T) remanence and 30 with high (> 0.5 T) remanence. 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 auxiliary current transformers. In such cases it is recommended that auxiliary CT's 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 saturation factor, the auxiliay current transformers and the transformer saturation differential relay should be selected for 1 A rated current.

Auxiliary CT's type SLCE 12 with fixed ratio, that are calculated and manufactured for specific applications, should be used when the auxiliary current transformers 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 equalizing windings should always have the rated current 1 A.

When the differential relay is located at a large distance from the main current transformers, it may be necessary to locate an extra set of auxiliary current transformers close to the main current transformers. This is specifically the case when the differential protection also includes a long supply cable for the power transformer. These auxiliary current transformers are selected with a low secondary current to reduce the burden on the main current transformers to an acceptable value. The suitable secondary rated current is 0.4 A. In such case, a set of auxiliary current transformers type SLCE 16/350 are used and they should be located at the main current transformers. Another set of auxiliary current transformers 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.

If the wires between the current transformers, 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 current transformers as well as the auxiliary current transformers.

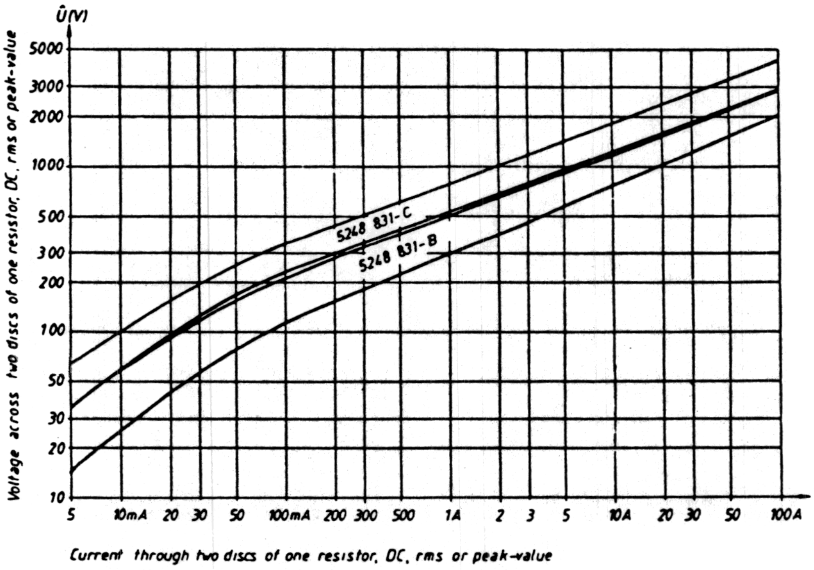


Fig. 8 Current voltage characteristics for the non-linear resistor

Connection diagrams

Power transformer connection	Auxiliary current transformer in			Connection according to Figure
	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

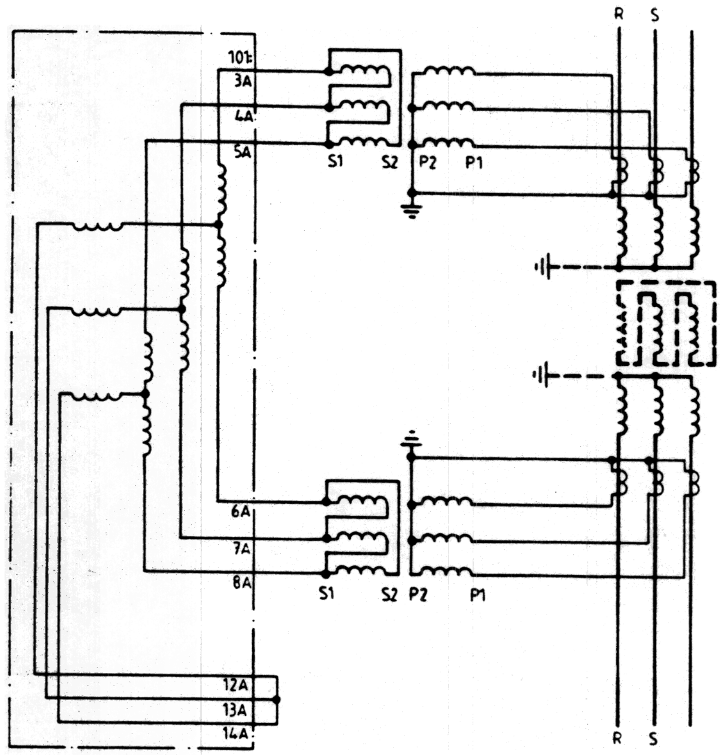


Fig. 9 Connection of RADSB at power transformer connection Yy 0.

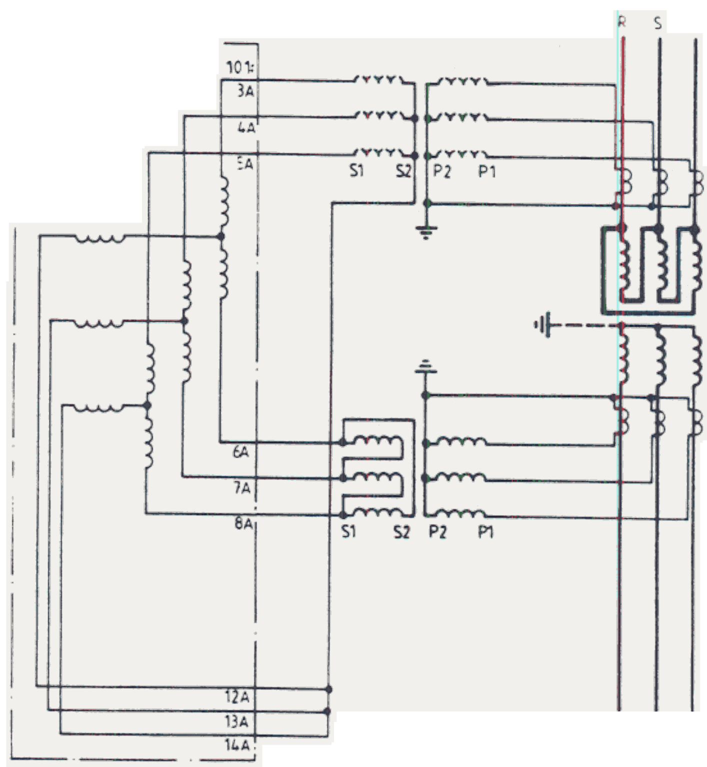


Fig. 10 Connection of RADSB at power transformer connection Dy 11.

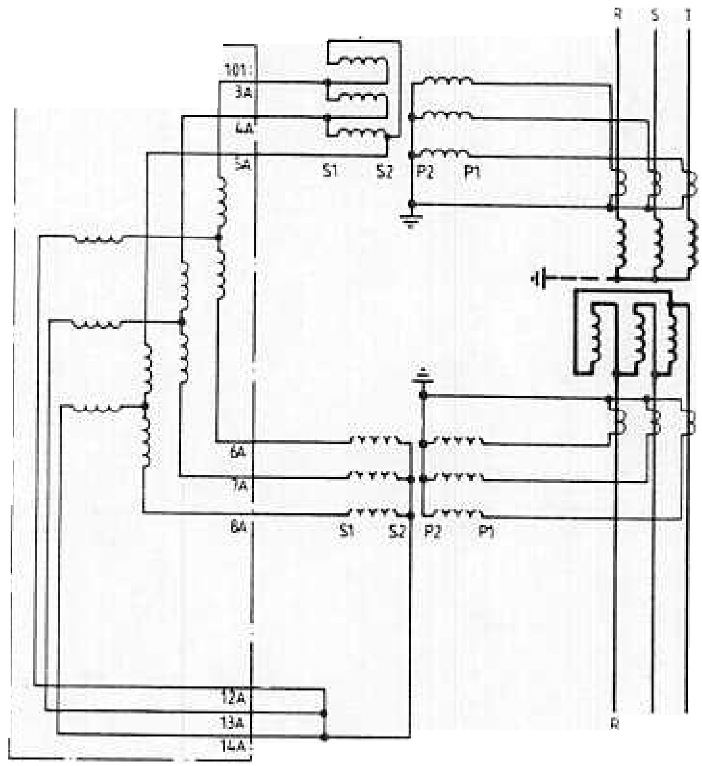


Fig. 11 Connection of RADSB at power transformer connection Yd 5.

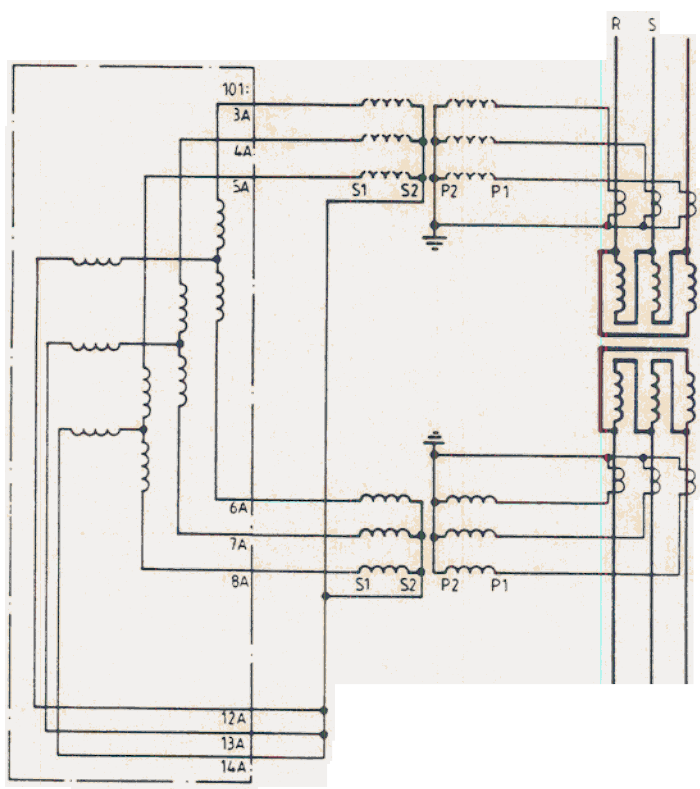


Fig. 12 Connection of RADSB at transformer connection Dd 0.

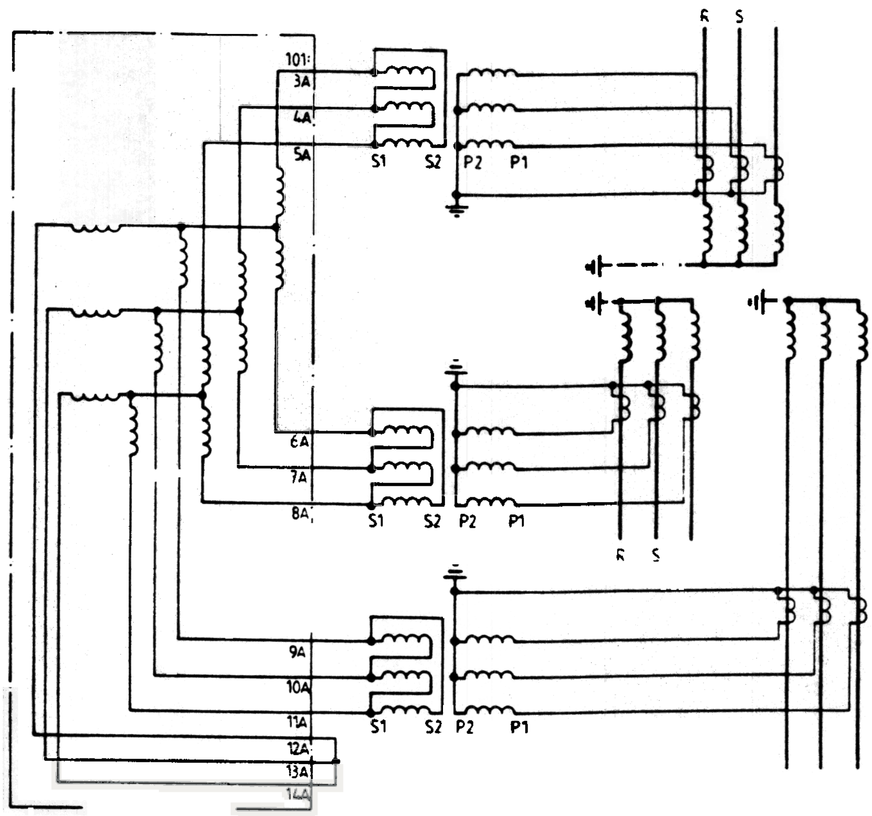


Fig. 13 Connection of RADSB at transformer connection Yyy.

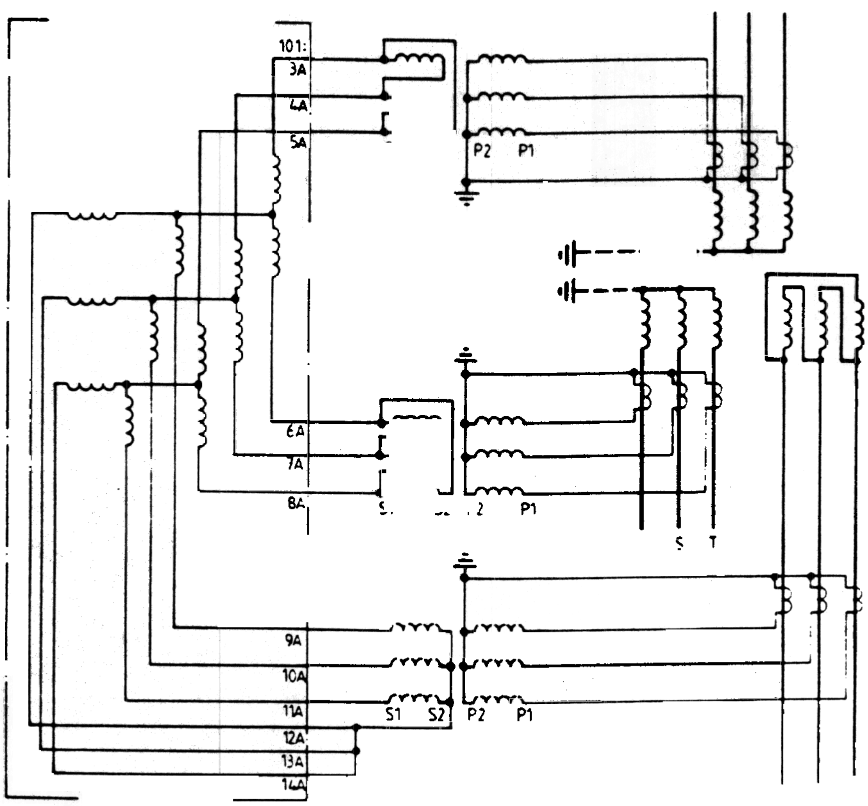


Fig. 14 Connection of RADSB at transformer connection Yyd

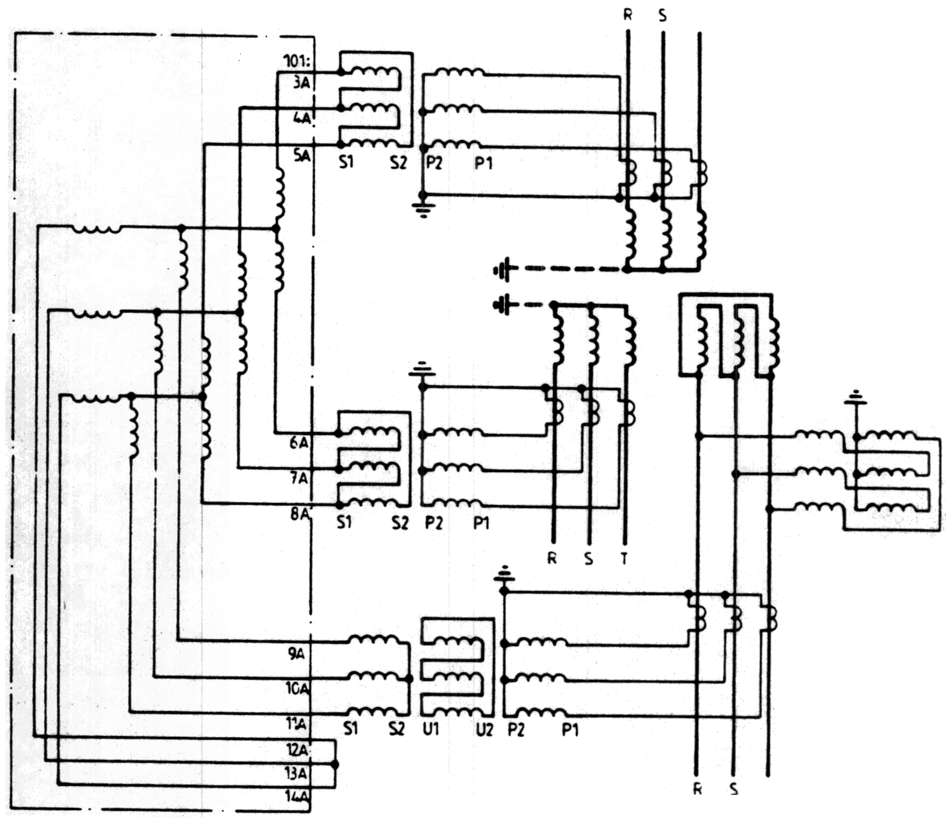


Fig. 5 Connection of RADSB at transformer connection Yyd with artificial neutral. Alternative 1.

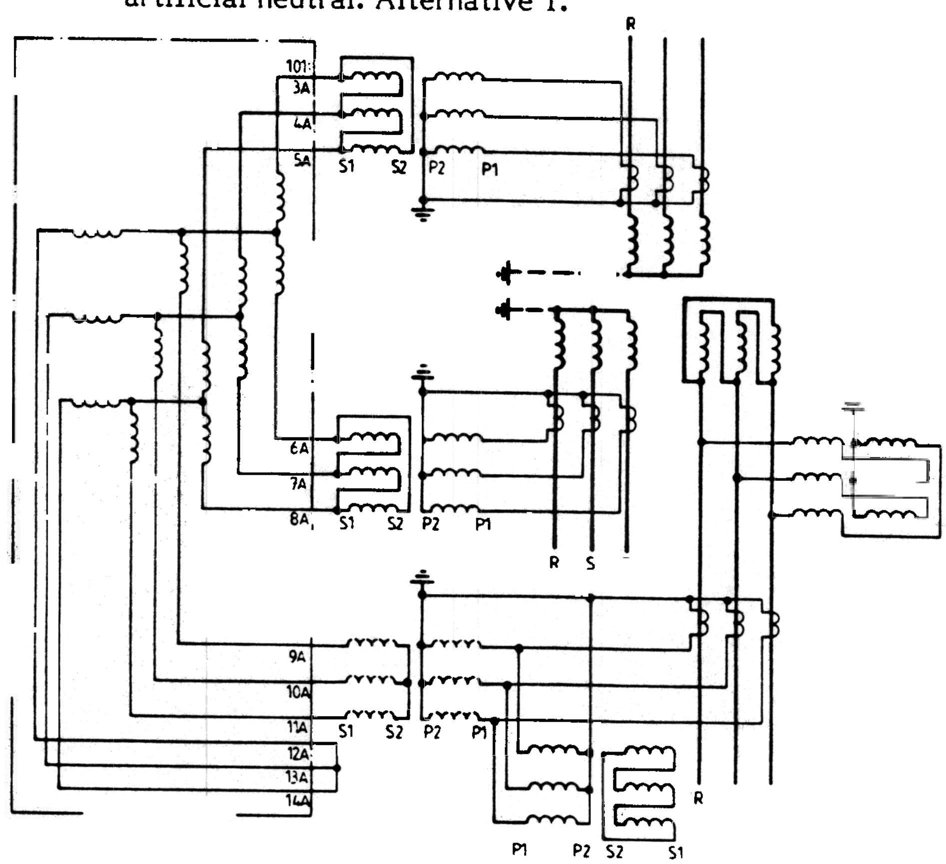


Fig. 16 Connection of RADSB at transformer connection Yyd with artificial neutral. Alternative 2.

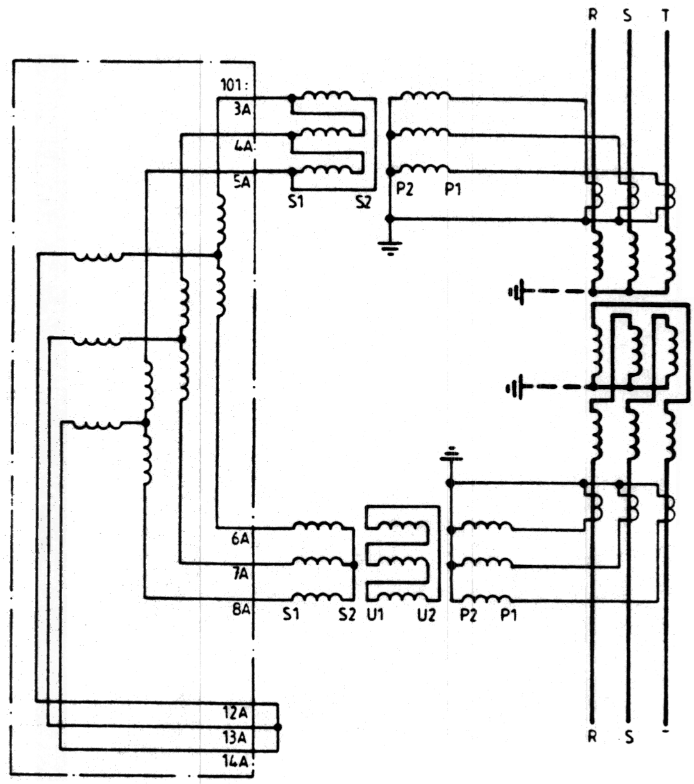


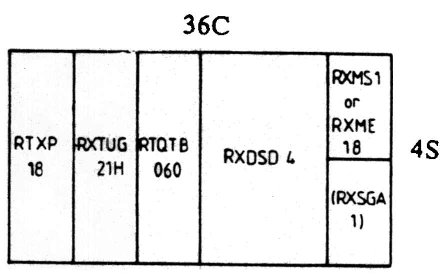
Fig. 17 Connection of RADSB at transformer connection Yz 11.

DESIGN

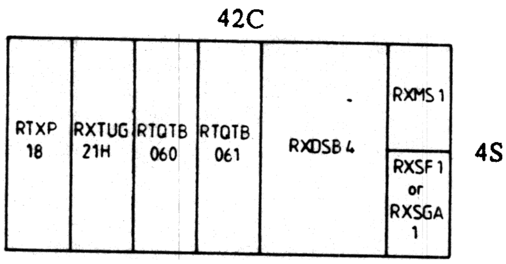
Hardware description

The relay can be obtained in a number of versions; with output tripping relay type RXMS 1 or RXME 18 and with or without either phase indicator unit type RXSGA 1 or target relay type RXSF 1.

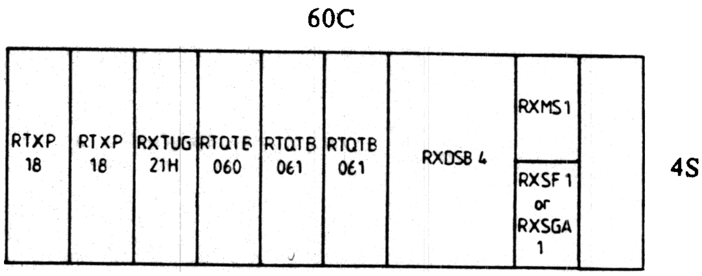
Two restraint input circuits



Three restraint input cicuits



Five restraint input circuits



Six restraint input circuits

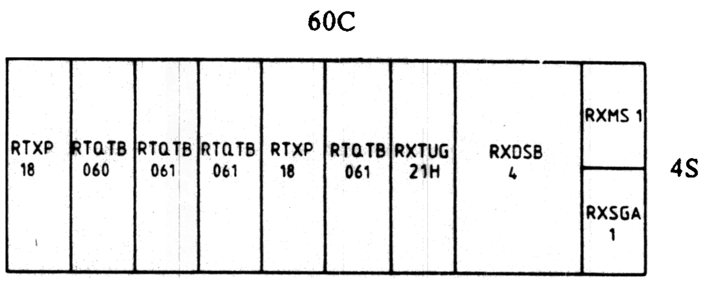


Fig. 18 Physical positions of the units in the RADSB versions.

The RADSB-units are:

RTXP 18 Test switch
RXTUG 21H DC-DC converter
RTQTB 060, RTQTB 061 Transformer units
RXDSB 4 Measuring unit
RXMS 1, RXME 18 Output tripping relay
RXSGA 1 Phase indicator unit
RXSF 1 Target relay

Test switch

The test switch type RTXP 18 is included in the testing system COMBITEST. A complete secondary testing of the relay 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 relay 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 current transformers and the tripping circuits are done on the rear of the test switch and when the differential relay is installed. Connection to contacts providing signal at operation or at loss of auxiliary supply is done directly on the terminal bases for the output tripping realys, the phase indicator unit (or the target relay) and the dc-dc converter.

DC-DC converter

The dc-dc converter type RXTUG 21H converts the supplied battery voltage to an alternating voltage which is then transformed, rectified, and smoothed 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 auxiliary relay for supervision of the output voltage.

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 the restraint circuit.

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 operating 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 current transformers or the input transformers. On the other hand, the ouput 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.

Output 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 is used as an output and tripping relay. It has two make contacts and a red target. The target 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.

Phase indicator unit

The phase indicator unit type RXSGA 1 indicates with the aid of an auxiliary 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 card. The unit also indicates if the operation occurs in the unrestraint circuitry, that means if the differential current has been larger than the unrestraint 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 auxiliary relay will reset automatically when the output signal from the measuring unit ceases.

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

Target relay

The target relay type RXSF 1 consists of two electromechanical relays with two make contacts, one break contact and a red target. The target 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 20-25 ms.

Setting mechanics

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 unrestraint value I_{su} (8, 13 and 20 times the rated current) - are set with switches on the front of the measuring unit type 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 current transformers 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 unrestraint 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 unrestraint 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 the high voltage side.

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 current transformers saturate.

Technical data

Rated current I_n	1 or 5 A
Rated frequency	50 or 60 Hz
Operate values:	
I_{sr} restraint	Settable 0.20, 0.25, 0.35, and 0.5 times I_n (Operation occurs at appr. 1.4 times the set value at three-phase energizing)
I_{su} unrestraint	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	> 60 %	
Unrestrained operation	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. 30 ms	appr. 60 ms
$I_d = 10 \times I_{sr}$	appr. 28 ms	appr. 60 ms
$I_d = 2 \times I_{su}$	10-20 ms	appr. 40 ms
Impulse limit times:		
Restrained operation	> 20 ms at $I = 3 \times I_{sr}$	
Unrestrained operation	Appr. 3 ms at $I = 3 \times I_{su}$	
Transient overreach	< 5 %	
Overload capacity:		
1 A version	10 A continuously 100 A during 1 s	
5 A version	20 A continuously 250 A during 1 s	
Restraining limit values at:		
Energization	2:nd harmonic = 17 % of the fundamental	
Overvoltage	5:th harmonic = 38 % of the fundamental	
External faults	Acc. to the curves in Fig. 22	
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:		
Totally at rated current	Appr. 0.02 VA/phase at $I_n = 1$ A Appr. 0.14 VA/phase at $I_n = 5$ A	
In the differential circuit at $0.25 \times I_n$	Appr. 0.003 VA/phase at $I_n = 1$ A Appr. 0.02 VA/phase at $I_n = 5$ A	
In the auxiliary voltage circuit,		
before operation	Appr. 6 W	
during operation	Appr. 10 W	
Dielectric test voltage:		
Current circuit	2500 V 50 Hz	
Voltage circuit	2000 V 50 Hz	
Impulse withstand test voltage	5 kV, 1.2/50 us, 0.5 J	
Disturbance test voltage:		
Common mode	2.5 kV, 1 MHz	
Transverse mode	2.5 kV, 1 MHz	

Mass:	
4S 36C	Appr. 6 kg
4S 42C	Appr. 9 kg
4S 60C	Appr. 11 kg

	RXMS 1	RXME 18	RXTUG 21H RXSGA 1	RXSF 1
Contacts	4 or 6 make contacts	2 make contacts	1 two-way contact	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	4 A	6 A	5 A	5 A
1 s	20 A	30 A	15 A	50 A
10 ms	100 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	10 A	20 A	8 A	10 A
dc, L/R < 40 ms, max 48 V	1.2 A	18 A	1.0 A	1.5 A
55 V	1 A	15 A	0.8 A	1 A
110 V	0.3 A	3 A	0.4 A	0.4 A
125 V	0.25 A	2.5 A	0.3 A	0.3 A
220 V	0.15 A	1 A	0.2 A	0.2 A
250 V	0.12 A	0.8 A	0.15 A	0.15 A

Auxiliary current transformers	SLCE 12 and SLCE 16
Overload capacity:	
Continuously	$2.5 \times I_n$
10 s	$15 \times I_n$
1 s	$75 \times I_n$
Max external conductor area	10 mm^2
Remanence	< 0.2 T
Mass:	
SLCE 16	5.4 kg
SLCE 12	3.6 kg

Mounting details

The RADSB is provided on apparatus bars. When additional mounting is required specify a 4S equipment frame for 19" rack mounting or a type RHGX 12 or 20 case for panel mounting.

OPERATION

The theory of operation of the transformer differential relay type RADSB is shown in a simplified form in the single-phase block diagram in fig. 19, which shows all units of the differential relay with two restraint input circuits with the exception of the test switch type RTXP 18.

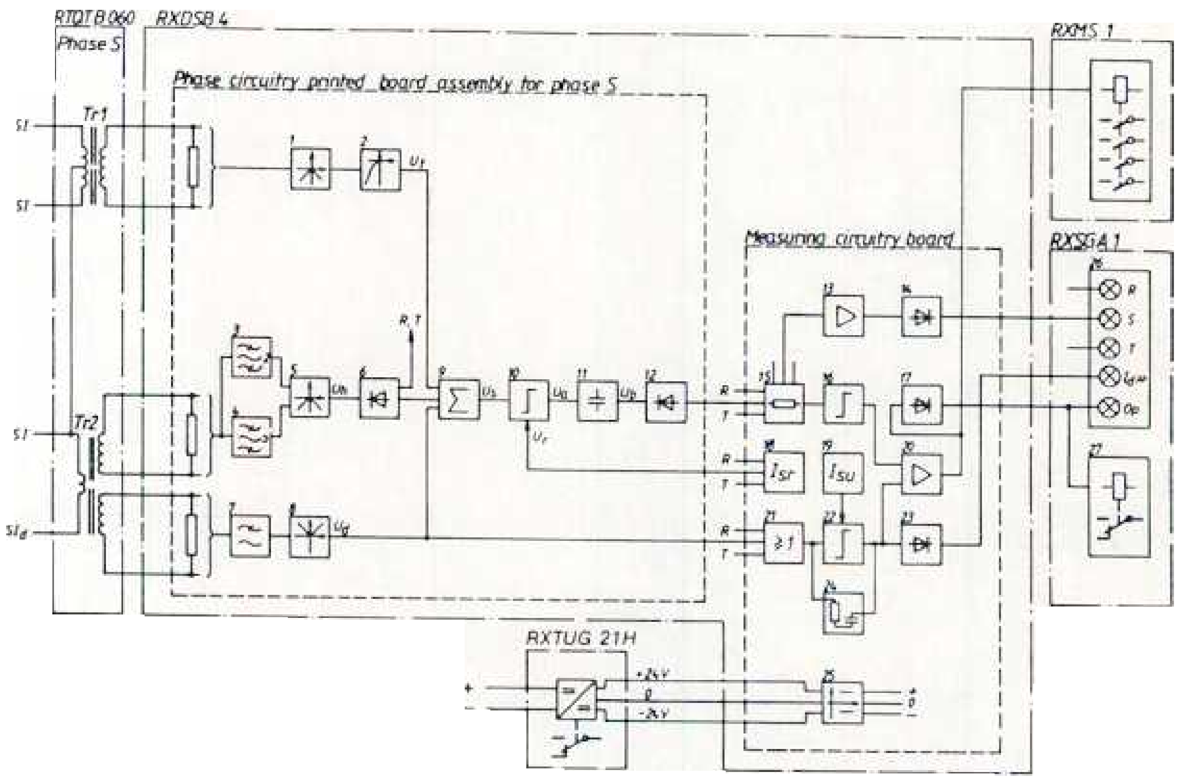


Fig 19 Block diagram for phase S of the transformer differential relay type RADSB.

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

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 auxiliary current transformers.

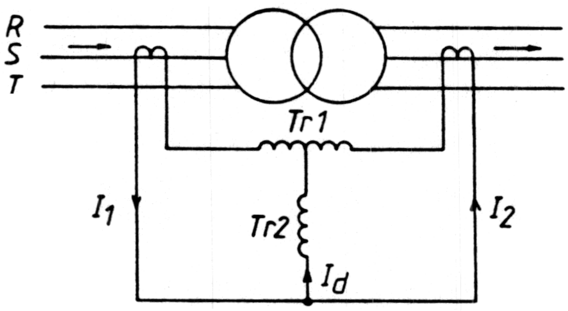


Fig. 20 Principle connection of the input transformers Tr1 and Tr2.

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's 21 and 22 which show the differential current as a function of the thorugh 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.

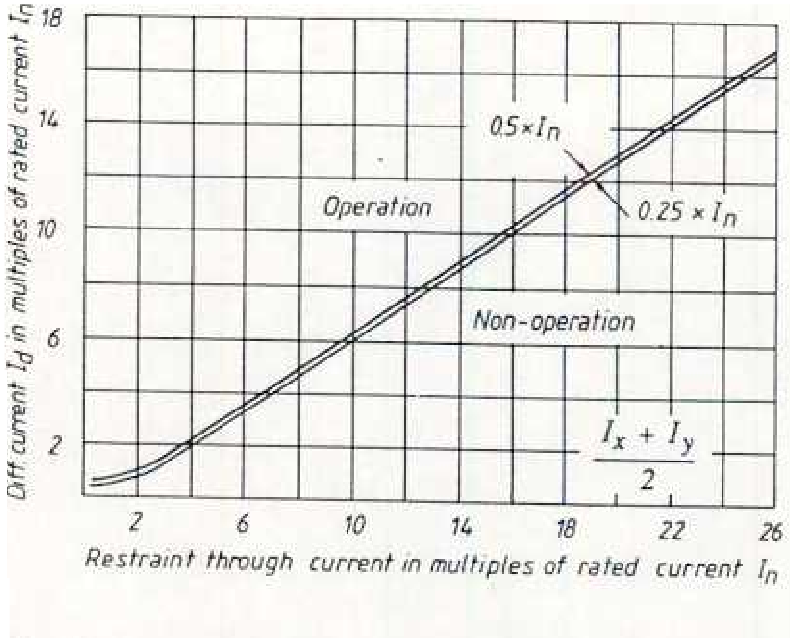


Fig. 21 Restraint characteristic at large through current values

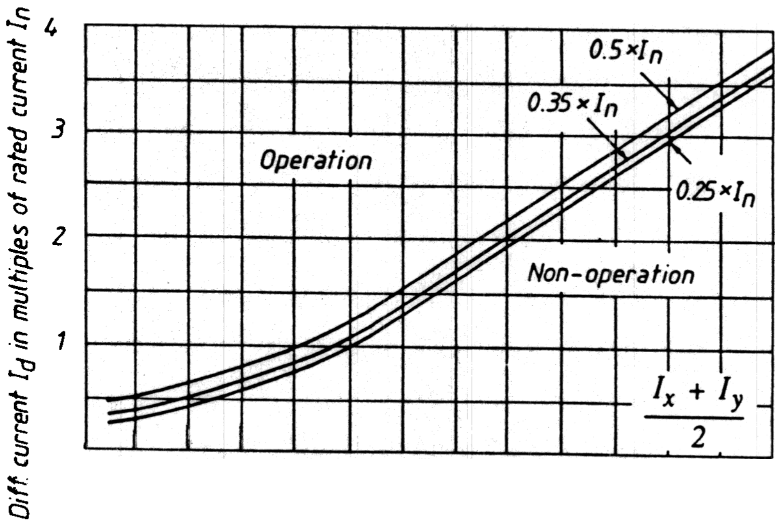


Fig. 22 Restraint characteristic at small through current values

The variable through-fault restraint at external faults is clearly illustrated if the restraining limit value of the differential current is expressed in percentage of the through current, as illustrated in fig. 23.

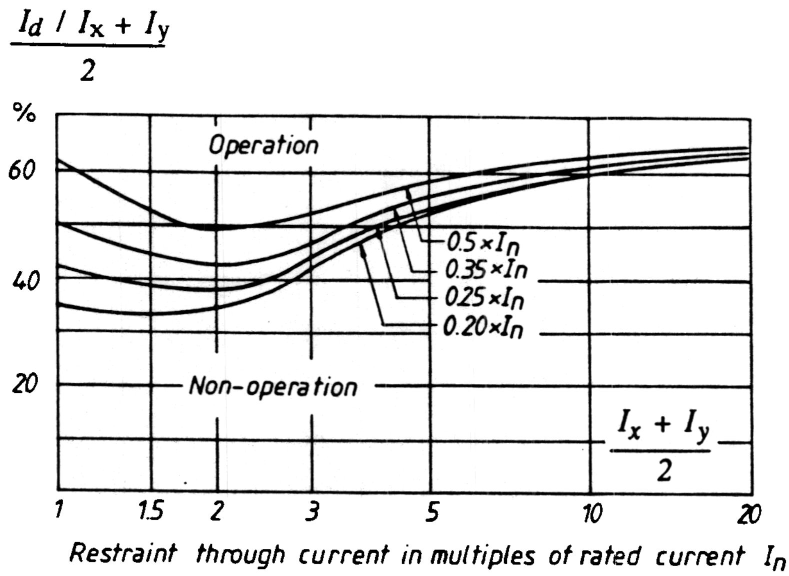


Fig. 23 Restraining limit values at external faults.

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 overexcitation restraint. 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 restraint 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 17 and 38 %, respectively, of the fundamental current.

The feature having the output voltages connected together from the harmonic restraint circuits of the three phases results in that the restraint can be made weaker corresponding to what otherwise should have been required to provide correct restraint operation of the differential relay during unfavourable instances when switching in the power transformer when it has maximum remanance.

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 current transformers 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 restraint 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 target relay RXSF 1, that relay will pick up).

Fig. 24 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 satisfied.

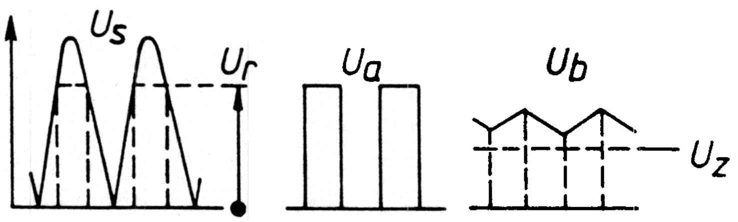


Fig 24. Wave shapes and pulse width integrating action required to develop trip signals.

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 unrestraint 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 out-put relay operates and a LED marked "I_d >> " will be lit (or, in versions with target relay, that relay will pick up).

The unrestraint 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, only approximately 3 ms, thus operation will be obtained even if the current transformers will be saturated. Operation is obtained at approximately 20 % below the set value for symmetrical three-phase currents.

The operate times of the restraint circuit and the unrestraint circuit with auxiliary relay type RXMS 1 as an ouput relay are illustrated in Fig. 25. The operate time will be approximately 25 ms longer if the auxiliary relay type RXME 18 is used as an ouput tripping relay.

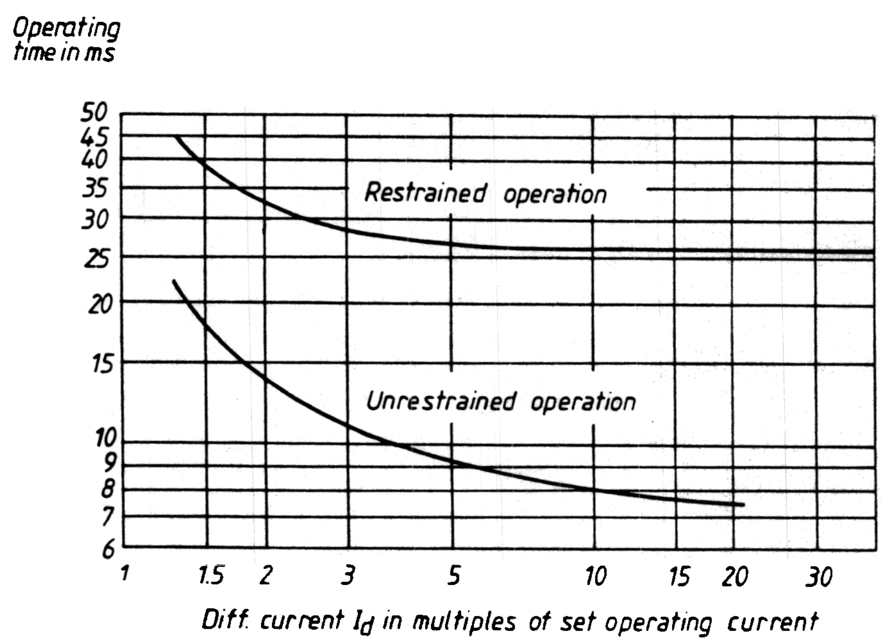


Fig. 25 Operate time-current characteristics for type RADSB.

The necessary auxiliary voltage required for operation is obtained from the dc-dc converter type RXTUG 21H which provides an output voltage ± 24 V dc for input voltages within the specified ranges. The measuring unit includes the stabilizing circuit (25) that stabilizes voltages to values suitable for the electronic circuits of the phase circuitry boards and the measuring circuitry board as well as for reference circuits.

TESTING

Before the final commissioning, the following tests should be carried out. Information RK 625-101E gives detailed information on testing of operating values, etc. Ratios and connections of auxiliary current transformers for RADSB is described under "Calculation of current ratio".

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 current transformers and auxiliary current transformers have the correct rated data.

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.

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 19" rack mounting system but is also suitable for conventional flush mounting on a panel. The COMBIFLEX system and the connection and installation parts are described in the Buyer's Guide section 93. The location and terminal marking system used is described in Buyer's Guide B03-9381E.

The transformer differential relay is mounted an apparatus bars intended for mounting into an equipment frame. 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.

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.

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 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 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 B03-9510E.

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.

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

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.

Auxiliary 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 + 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.

Insulation test

With an insulation test apparatus (megger), (or with an ac voltage of max. 1500 V) the insulation resistance to ground 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.

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.

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 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.

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 impulse should be connected so that it reaches the tripping coil of the circuit-breaker.

Service test with load current through the power transformer

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.

The test 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 principle, are zero in the case of a fully operational power transformer.

Several methods can be used to supply the power transformer, as indicated in section "Current sources during the service test". With regard to three-winding transformers, see section "Examples of faulty connections".

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 sercice tests" below). The curents 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.

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.

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.

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 auxiliary current transformers, 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) $I_d = 2$

Probably wrong polarity in one set of current transformers. In one set of (auxiliary) current transformers, 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 (auxiliary) current transformers may be wrongly connected (reversed) polarity compared to the delta connection 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 (auxiliary) current transformers should be easy to discover by directly checking the polarity and delta connection.

Current sources during the service test

One of the following alternatives is normally used.

Alternative 1

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

Alternative 2

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_l kV and I_l A. The current will then be

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

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_l in order that the local transformer should not be overloaded. If $U_l = 380$ V and $U = 11000$ V and $Z_k = 10$ per cent, the current will be approx. $0.35 \times I$ and the rated output power of the local transformer need only to be approx. 1 per cent of that of the test transformer.

Alternative 3

The simplest method is to connect in the transformer to the network and load it. However, the condition here is that the circuit-breaker and the isolator 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 per cent 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.

If the two methods described above cannot be used, another possibility is to supply the transformer, with all its three phases short circuited, from the low-voltage side of a local transformer.

Tripping test

In particular, a final tripping test should be carried out 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.

If the service test is carried out with supply as in "Alternative 1" or "Alternative 3" under "Current sources during the sercice test", a primary tripping test can also - if so required - be carried out in connection with it. The short circuit is then moved inside the current transformers. 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.

Test with energization of the power transformer

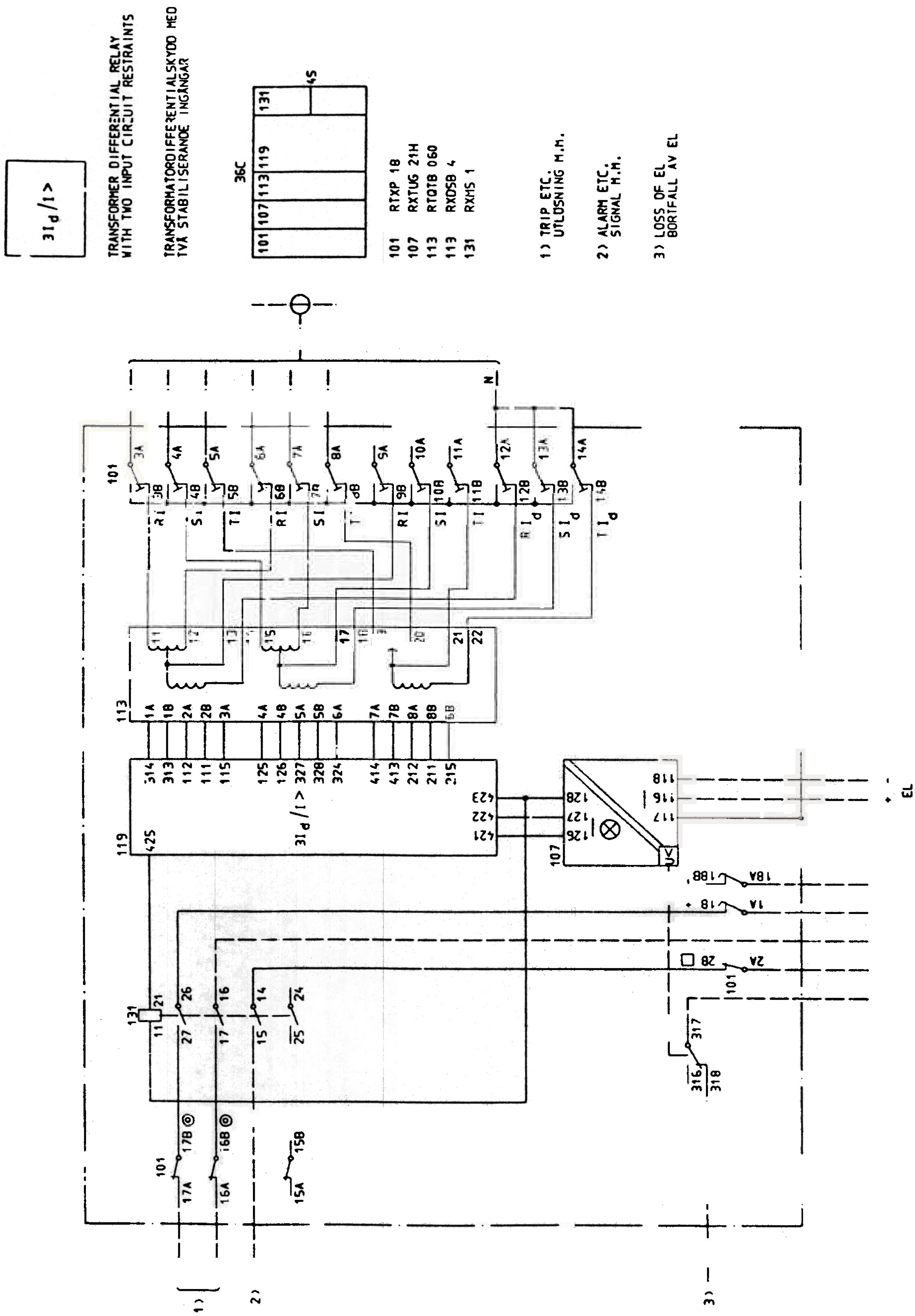
The operating value is set at the appropriate value (see Information RK 625-101E. The transformer should be switched in several times to the network at full service voltage. If the networks of both the high-voltage side and the low-voltage side have low source impedance (high fault MVA level), the transformer should be switched in and energized from both sides. Magnetizing inrush currents should not cause operation of the protection. Repeated operations when switching in the transformer to the networks may mean faults in the transformer, which will probably result in development of gas which can be observed at the gas-operated relay (the Buchholz relay)

COMMISSIONING

After tests have shown that the relay with its auxiliary current transformers and connections are correct, the relay 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

CIRCUIT DIAGRAMS



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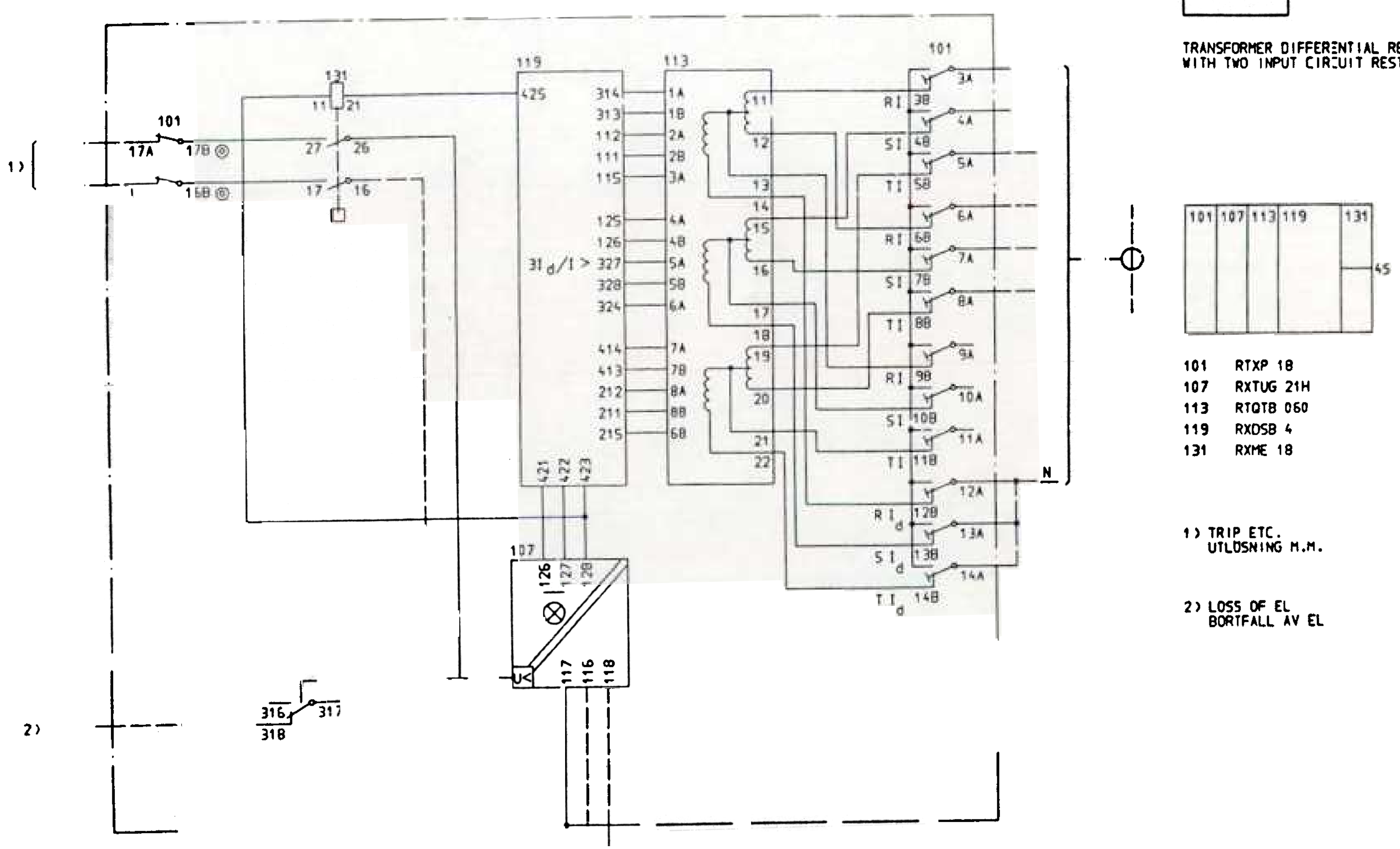
TRANSFORMER DIFFERENTIAL RELAY
WITH TWO INPUT CIRCUIT RESTRAINTS



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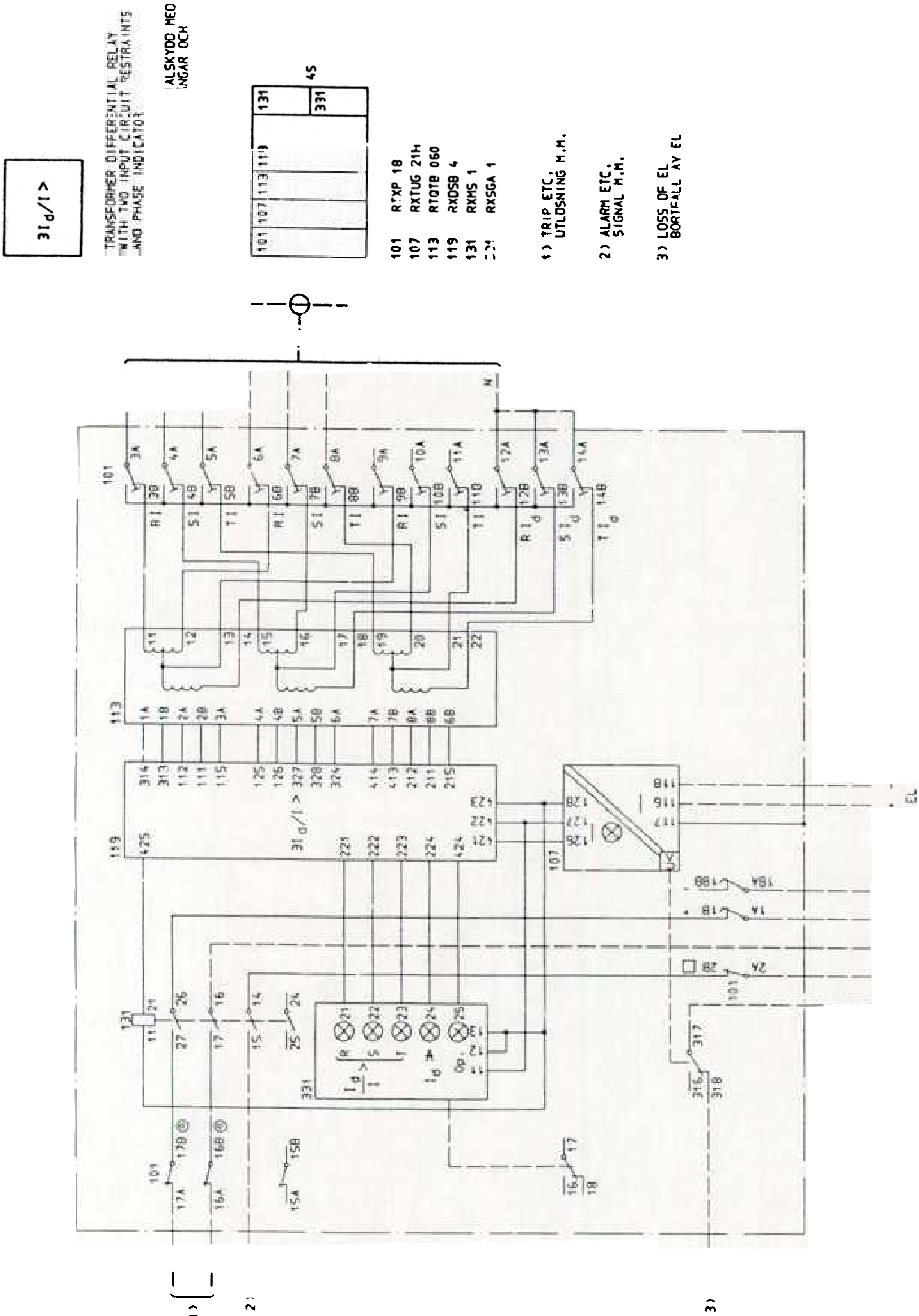
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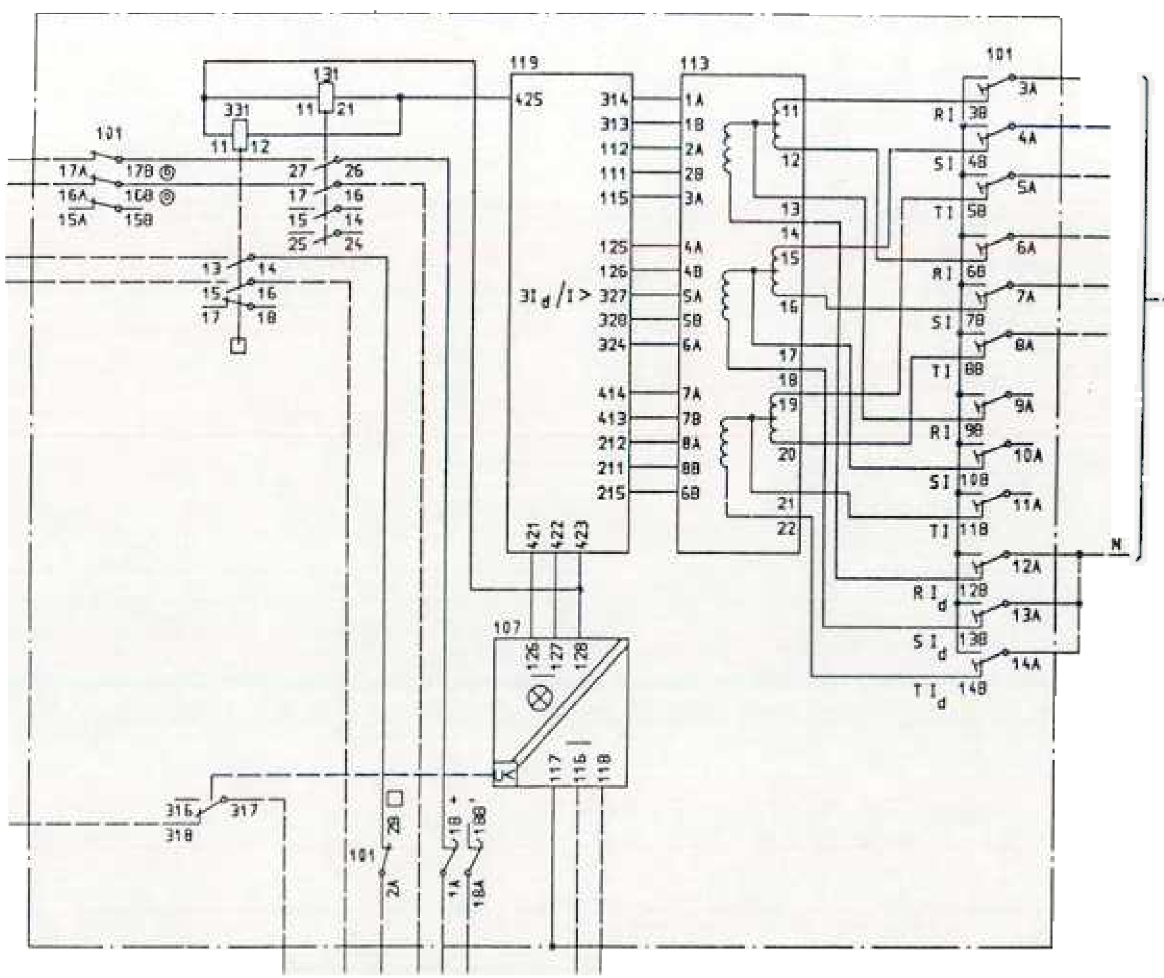

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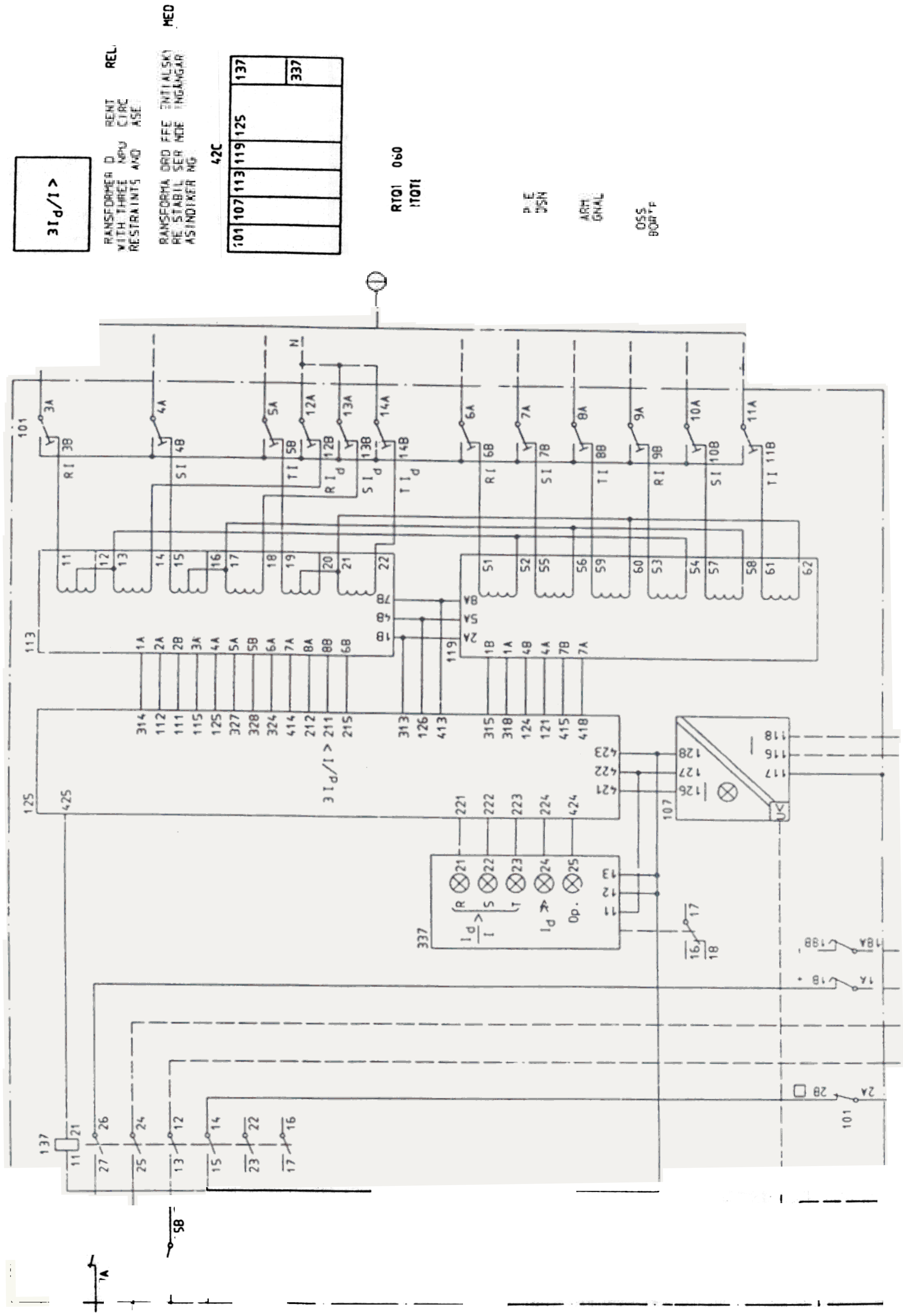

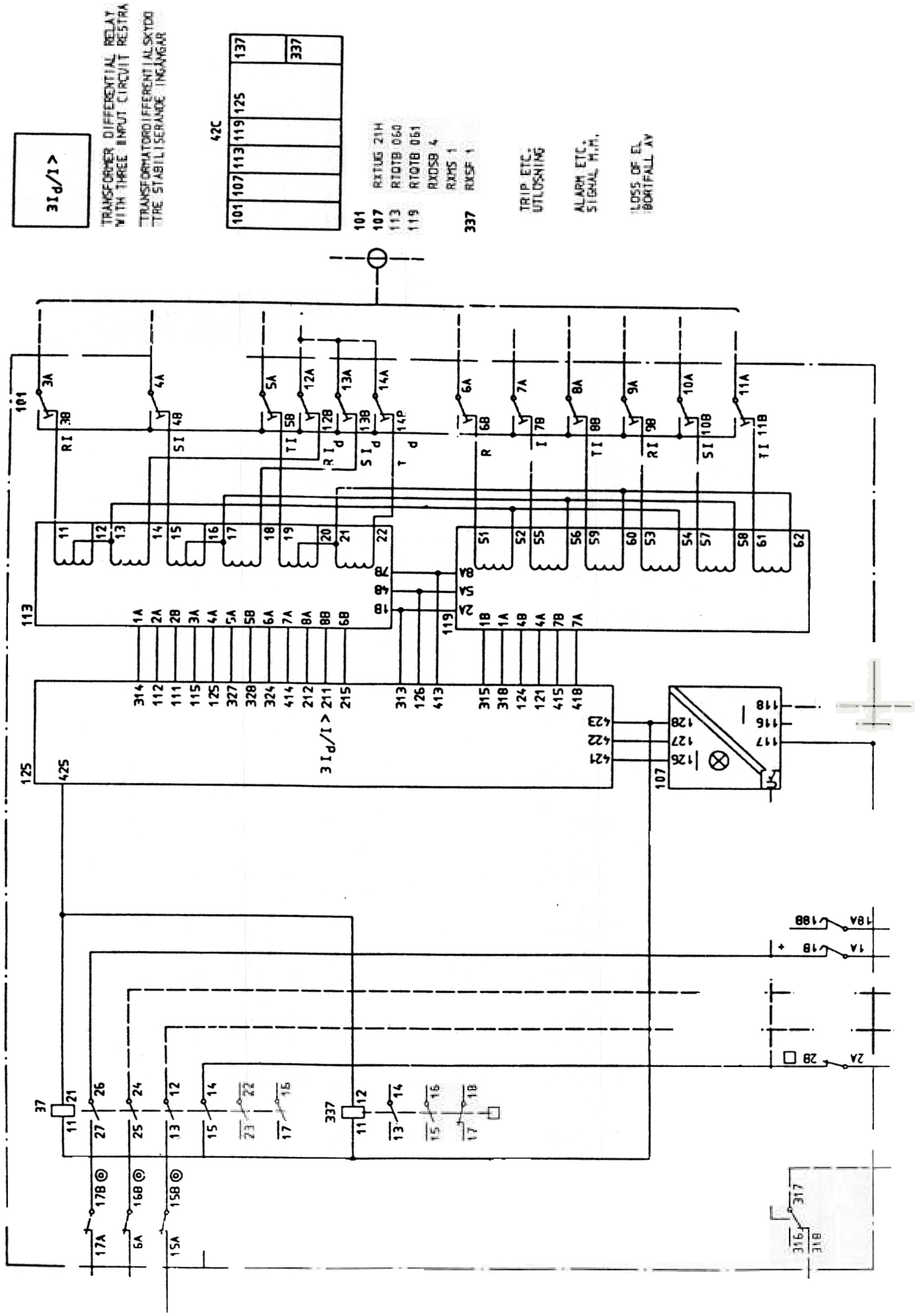
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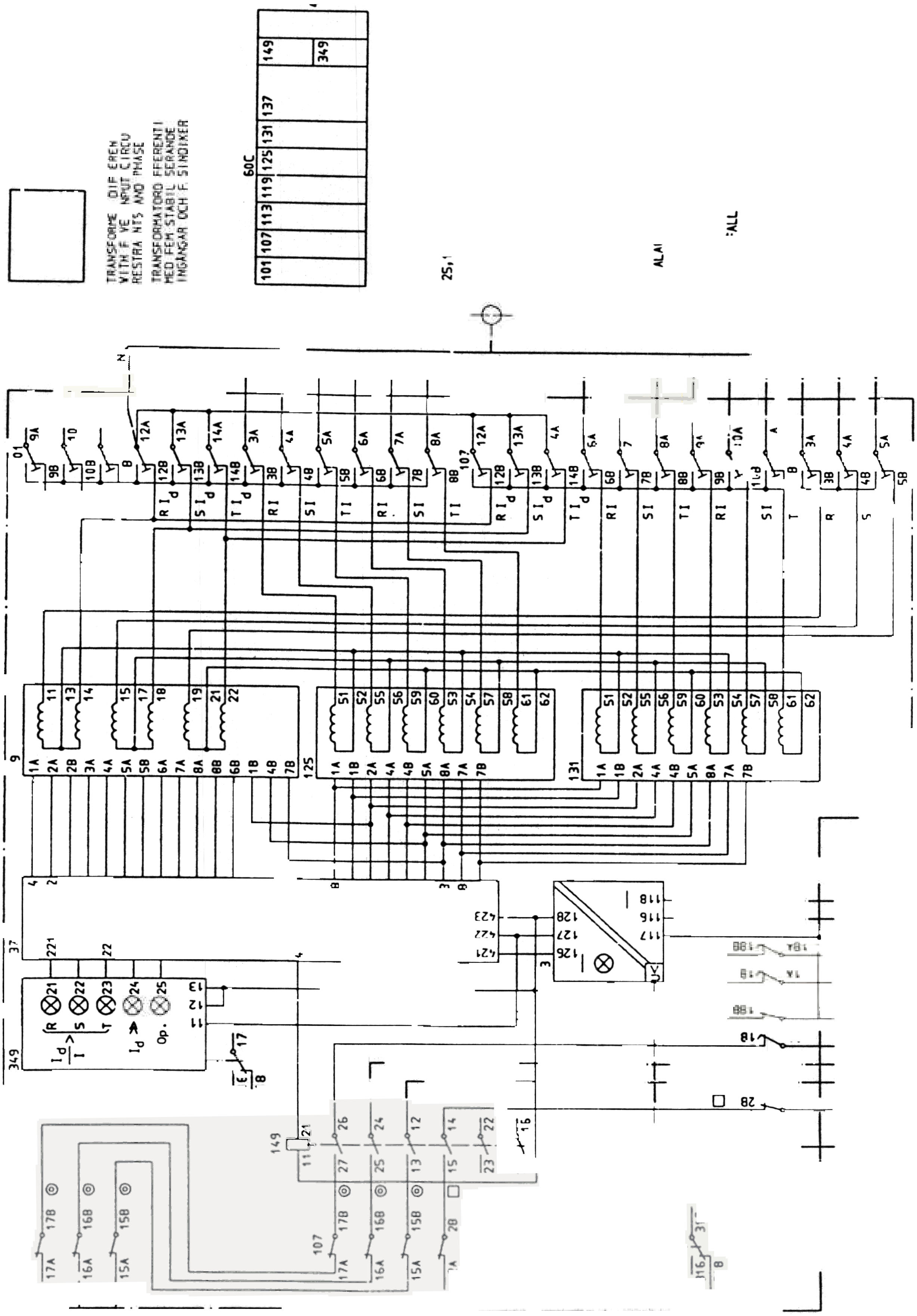
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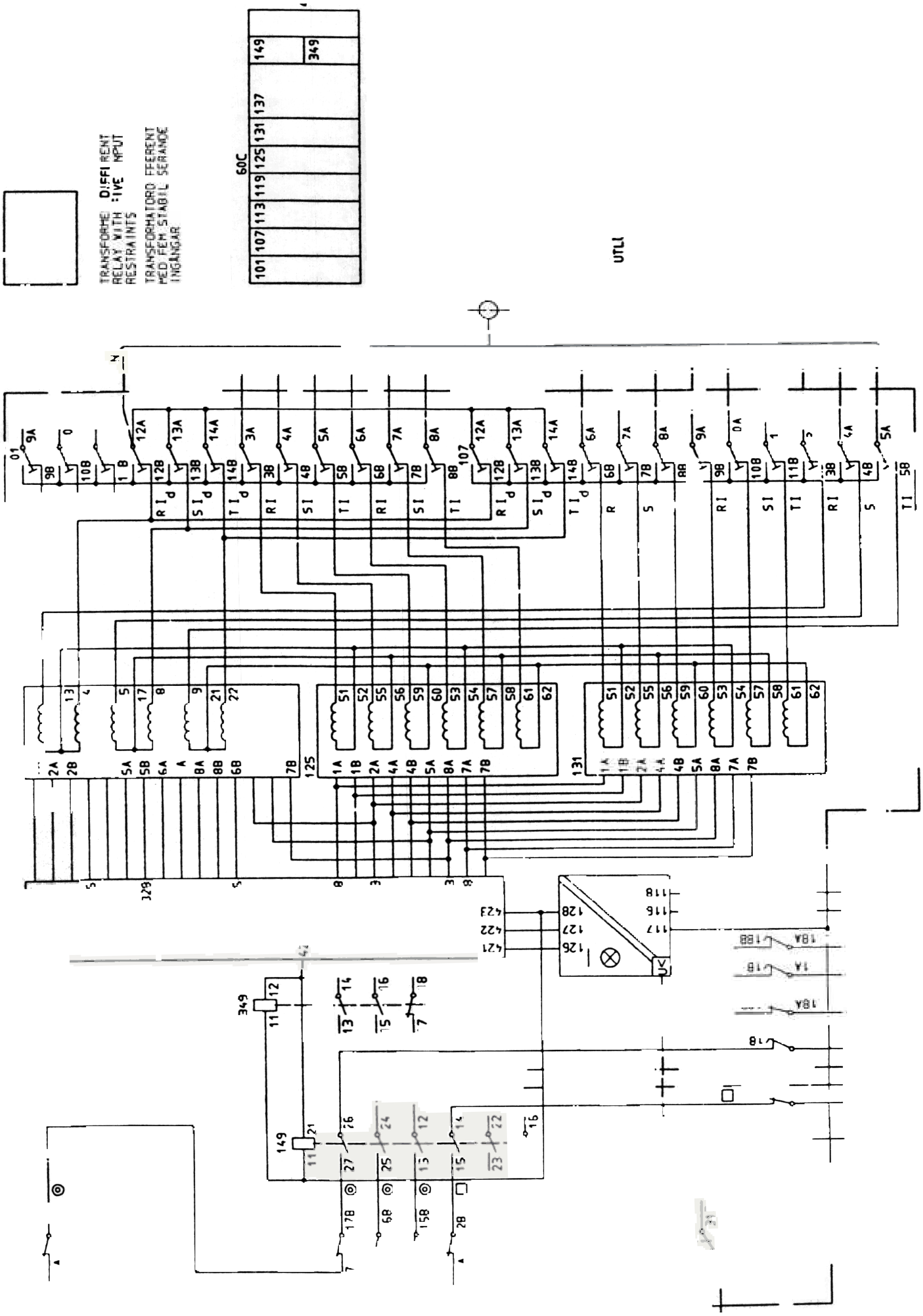
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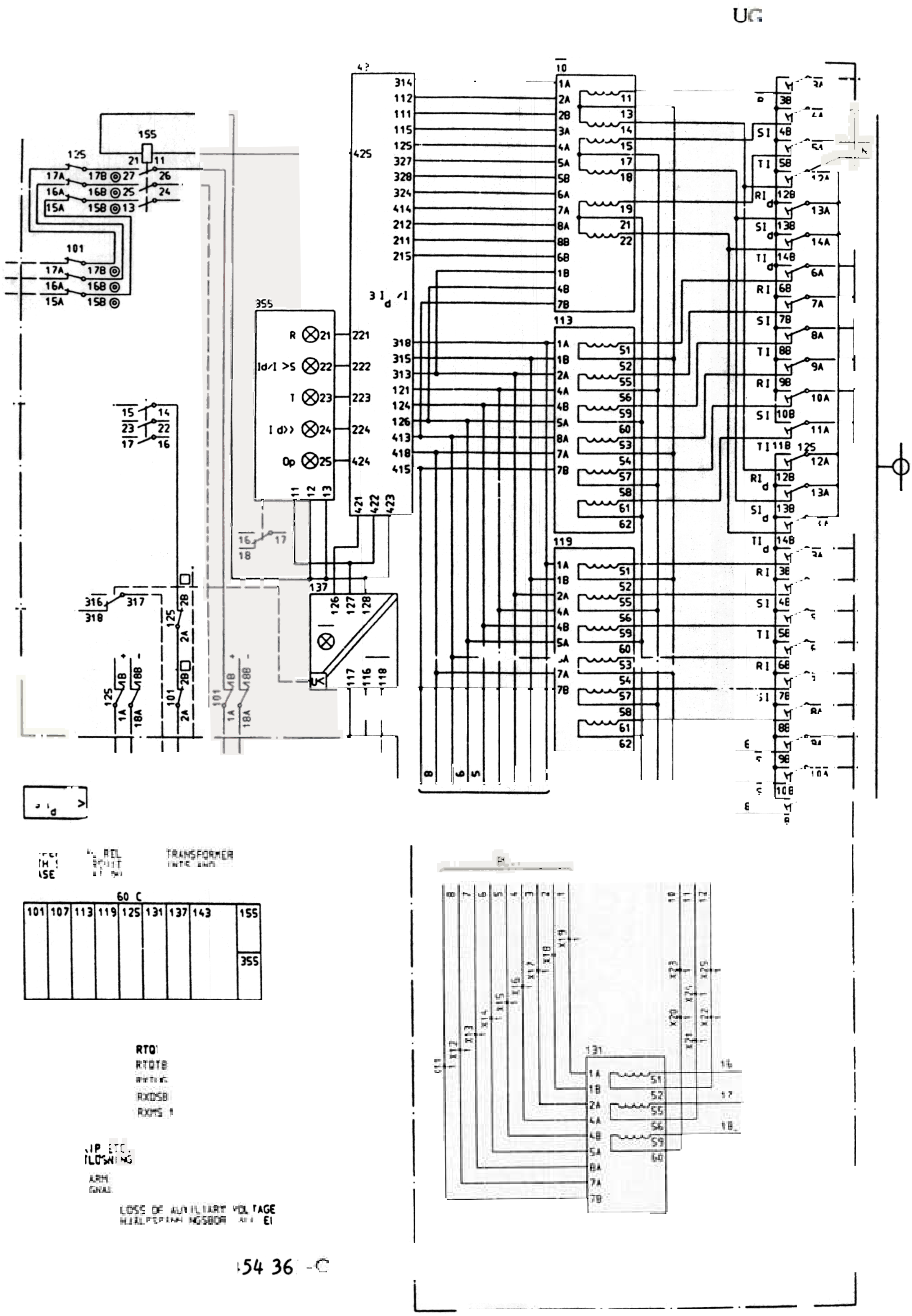

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