ASEA RELAYS

Type RADSS ultrahigh-speed bus differential relay
Single-phase version with summation auxiliary CT

A compact single-phase version of RADSS with one summation auxiliary CT for each 3-phase set of line CT's belonging to the bus is available (version D in B03-6010). The summation auxiliary CT enables the use of only one measuring relay to take care of all phase- and ground-faults, at a reduced cost compared to the three-phase design.

Operation of the single-phase version with summation auxiliary CT is the same as described in information RK 637-300 for the standard 3-phase RADSS. However since the turns ratio of the summation auxiliary CT is different in the phases some limitations will be introduced compared to the three-phase design.

The limitations are in practice normally accomodated without problems since internal busbar faults normally yield enough fault current for secure relay pick-up.

The limitations are:

1) Only one measuring circuit, which means that there is no internal back-up circuit in the case of 2-ph and 3-ph faults.

   In practice this means that the single-phase version stands for a lower redundancy in the measuring circuits compared to the three-phase version, however the rugged design of the restraint and operating circuits assures a correct and dependable operation under the most adverse conditions.

2) When a small internal ground fault occurs on one phase, the other two sound-phases may still carry a certain through-going load current. This load may cause a certain restraint on the operating quantity of the RADSS summation design.

   The <u>maximum</u> slope setting is therefore limited to S = 0.66 to prevent unneccessary restraining action.

   In practice this means that the largest and smallest line CT ratios may not differ by a factor of more than 5, e.g. 2500/5 A and 500/5 A, keeping the permissible main CT secondary loop resistance within reasonable values.

3) The primary operating current varies in the range 1:4 depending on type of fault, i.e. between most sensitive R-N ground fault and least sensitive R-S or S-T phase-phase fault.

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In practice this means that a single-phase RADSS with a stability slope of S = 0.5 and a differential relay pick-up of I_{d1min} = 0.2 A the percentage fault setting may vary from about 9 percent to 36 percent for internal busbar fault.

4) If one main CT secondary circuit is opened inadvertently the unbalance current in the differential circuit may become as high as 2.2 x the full load rating. A CT open-circuit alarm relay and a high-set starting relay (S_R) is, therefore, not normally used.

Auxiliary summation CT's types SLCE 16 or SLXE 4

A relatively large aux CT is required in order to provide adequate knee-point voltage and resonable copper-losses.

Two standard auxiliary summation CT's with type designations SLCE 16 and SLXE 4 are normally used.

For busbars where the max/min line CT ratio is $\leq$ 3 the SLCE 16 normally provides adequate knee-point voltage.

For busbars where the max/min line CT ratio is > 3 the requirement on increased knee point voltage will normally require the use of SLXE 4.

Both standard auxiliary summation CT's SLCE 16 and SLXE 4 are provided with three separate primary windings and one secondary winding. For three-phase balanced loads the typical current and turns ratios are:

Summation aux CT		SLCE 16	SLXE 4
5/1 A	terminals	P1-P2, P3-P4, P5-P6, S1-S2	P1-P2, P3-P4, P5-P6, S1-S2
	turns	60, 60, 120, 520	72, 72, 144, 625
	ordering nr	4785 040-BEG	4785 040-BEE
1/1 A	terminals	P1-P2, P3-P4, P5-P6, S1-S2	P1-P2, P3-P4, P5-P6, S1-S2
	turns	300, 300, 600, 520	360, 360, 720, 625
	ordering nr	4785 040-BEH	4785 040-BEF
Secondary knee-point voltage at 1.6 Tesla		270 V	412 V
Power Consumption		< 10 W	< 10 W

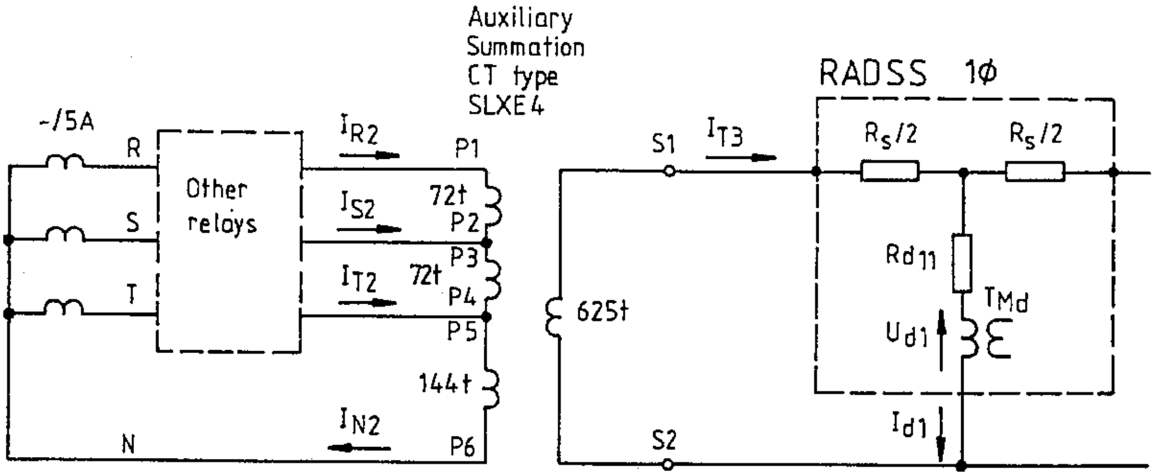
Summation CT connections

The auxiliary CT may be connected to the main CT's as (1) end connection or as (2) series connection.

Depending on the type of connection different relay pick-up values and permissible main CT secondary loop resistance is obtained.

Below follows an example for a single-phase RADSS with stability slope S = 0.5 and using auxiliary summation CT type SLXE 4 with 5 A primary.

1) End connection



The minimum relay operating current is given by $I_{T3} = I_{d1min}$

In the case of R-N fault, the operating current is obtained from:

$I_{R2} = \frac{625}{288} \quad I_{d1min} = 2.17\ I_{d1min}$

For an R-S faults: $I_{R2} = -I_{S2}$

$72\ I_{R2} = 625\ I_{d1min}$

$I_{R2} = 8.7\ I_{d1min}$

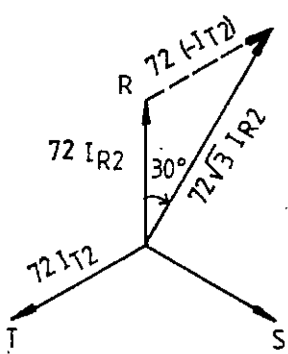
R-S-T fault vectors: $I_{R2} + I_{S2} + I_{T2} = 0$

The summation-CT primary amp-turns:

$72\ I_{R2} + 72\ (-I_{T2}) = 72\ \sqrt{3}\ I_{R2}\ \angle -30^o$

$72\ \sqrt{3}\ I_{R2} = 625\ I_{d1min}$

$I_{R2} = \frac{625}{72\ \sqrt{3}} \quad I_{d1min} = 5.0\ I_{d1min}$



Example: If S = 0.5 and $I_{d1min} = 0.2$ A

Hence R-N fault, $I_{R2} = 2.17 \times 0.2 = 0.43$ A

Hence R-S fault, $I_{R2} = -I_{S2} = 8.7 \times 0.2 = 1.74$ A

Hence R-S-T fault, $I_{R2} = 5.0 \times 0.2 = 1$ A

When based on 5 A rated current the percentage fault settings becomes approximately (neglecting magnetizing currents):

$\frac{0.43}{5}$ x 100 = <u>9 per cent</u> (R-N)

$\frac{1.74}{5}$ x 100 = <u>36 per cent</u> (R-S)

$\frac{1.0}{5}$ x 100 = <u>20 per cent</u> (R-S-T)

The corresponding primary fault settings may increase 10-30 per cent depending on the CT magnetizing currents and number of lines connected to the bus differential zone.

Permissible CT secondary resistance

The main CT secondary winding resistance plus the one way pilot-wire resistance up to the aux CT, the ohmic burden of other relays and also the resistance of the neutral return wire can be denoted R_{X2}.

It can be shown that this resistance value must be less than the following expression in order to maintain stability:

$R_{X2} = R_{LX} (\frac{144}{625})^2$ for 5/1 A sum-CT

Similary, for other summation-CT ratios, the last factor is given by the square of the turns ratio found between terminals: P5-P6/S1-S2.

RADSS settings

The typical settings are:

S = 0.5 (Max S = 0.66)

$R_{d11} = 0$ or $R_{d11} = 136$ ohms and

$R_{dT} = nd^2R_{d3} + R_{Md} + R_{d11}$

Consider $R_{dT} = 110 + 35 + 136 = 281$ ohm

with S = 0.5 the max permissible loop resistance becomes:

$R_{LX} = \frac{0.5}{1-0.5}$ 281 = 281 ohms (using S = 0.66 gives 545 ohms)

Hence, when a standard 5/1 A summation aux CT is used, the max permissible main CT loop-resistance becomes:

$R_{X2} = 281 (\frac{144}{625})^2 = 14.9$ ohms (using S = 0.66 gives 28.9 ohms)

If the largest and smallest line CT ratios are:

n_A = 2000/5 A and n_X = 500/5 A

the corresponding summation-CT current and turns ratios are:

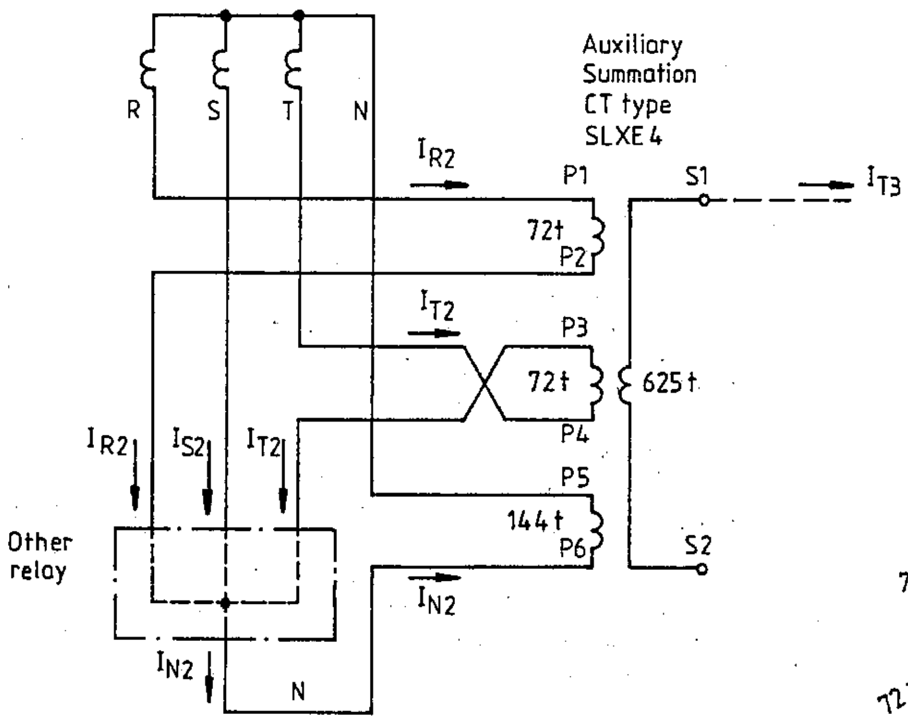
n_{MA} = 5/1 A and n_{MX} = 5/0.25 A

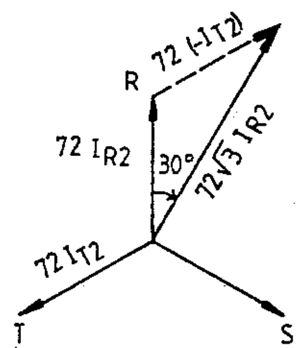
72-72-144/625 t and 18-18-36/625 t

In this case the 500/5 A CT can tolerate a max loop-resistance of:

$R_{X2} = 281\ (\frac{36}{625})^2 = 0.9$ ohm (Using S = 0.66 gives 1.8 ohms)

2) Series connection





For 3-phase fault, the summation-CT primary amp-turns:

$72 I_{R2} + 72\,(-I_{T2}) = 72\sqrt{3}\, I_{R2}\ \angle{-30^\circ}$

Minimum operating current $I_{T3} = I_{d1min}$

Hence, for 3-phase fault $I_{R2} = \frac{625}{72\sqrt{3}}\ I_{d1min} = 5.0\ I_{d1min}$

For R-N fault $I_{R2} = \frac{625}{72}\ I_{d1min} = 8.7\ I_{d1min}$

For S-N fault $I_{S2} = \frac{625}{144}\ I_{d1min} = 4.35\ I_{d1min}$

For T-N fault $I_{T2} = \frac{625}{216}\ I_{d1min} = 2.9\ I_{d1min}$

For R-S and S-T fault

$I_{R2} = I_{T2} = \frac{625}{72}\ I_{d1min} = 8.7\ I_{d1min}$

For R-T fault $I_{R2} = \frac{625}{144}\ I_{d1min} = 4.35\ I_{d1min}$

When based on 5 A main CT secondary rating and relay setting $S = 0.5$, and $I_{d1min} = 0.2$ A, the percentage fault settings becomes:

R-S-T fault,	$\frac{5.0 \times 0.2}{5} \times 100$	= 20 per cent
R-N fault,	$\frac{8.7 \times 0.2}{5} \times 100$	= 35 per cent
S-N fault,	$\frac{4.35 \times 0.2}{5} \times 100$	= 17 per cent
T-N fault,	$\frac{2.9 \times 0.2}{5} \times 100$	= 12 per cent
R-S/S-T fault,	$\frac{8.7 \times 0.2}{5} \times 100$	= 35 per cent
R-T fault,	$\frac{4.35 \times 0.2}{5} \times 100$	= 17 per cent

It can be shown that in order to have full stability the main CT secondary loop-resistance (R_{X2}) must be less than:

$R_{X2} = R_{LX} \left(\frac{72}{625} \right)^2$ for 5/1 A summation-CT

i.e. if $R_{LX} = 281$ ohms, $S = 0.5$

$R_{X2} = 281 \left(\frac{72}{625} \right)^2 = 3.7$ ohms (Using $S = 0.66$ gives 7.2 ohms)

which is four times less than in the case with end-connected summation-CT. In the above equation the last factor is based on the square of the turns-ratio found between terminals: P1-P2/S1-S2.

Example:

If the largest and smallest line CT ratios are:

$n_A = 2000/5$ A and $n_X = 500/5$ A

the corresponding summation-CT current and turns ratio are:

$n_{MA} = 5/1$ A and $n_{MX} = 5/0.25$ A

72-72-144/625 t and 18-18-36/625 t

In this case the 500/5 A CT can tolerate a max secondary loop-resistance of:

$R_{X2} = 281 \left(\frac{18}{625} \right)^2 = 0.23$ ohm (Using $S = 0.66$ gives 0.45 ohms)

Note: In this case the loop-resistance R_{X2} should include the main CT winding resistance of say R-phase, the pilot-wire resistance up to the summation-CT, the return wire resistance and, also, the main CT winding resistance of say S-phase. Hence, the value of R_{X2} may become twice as large as in the case with end-connected summation-CT.

Relay operating voltage

The minimum relay operating voltage is obtained from

$U_{T3}(dR) = I_{d1min}(R_{dT} + 28) + n_d V_{D3}$

In the case of S = 0.5 and $I_{d1min} = 0.2$ A we obtain

$U_{T3}(dR) = 0.2(281 + 28) + 20 = 82$ V (Using S = 0.66 and $I_{d1min} = 0.3$ A gives 113 V)

In the event of a small internal ground fault occuring on one phase, it is possible that a certain load current may still be fed out via the two sound-phases. This will cause a certain restraint on the RADSS operation. The magnitude of this restraint is difficult to establish because it is affected by the different number of turns in the summation-CT and the phase relation between the operating and restraining quantities.

To simplify the calculations and to assume a certain theoretical absolute worst case consider that the outgoing relay current $I_L = 1$ A is in-phase with the differential current I_{d1}.

The equation for relay operation is obtained from:

$I_{d1} = S\, I_{T3} + K$

Consider S = 0.5 and $I_{T3} = I_{d1} + I_L$;K = 0.1

The operating current then becomes:

$I_{d1} = 0.5(I_{d1} + 1) + 0.1$

$I_{d1} = \frac{0.6}{0.5} = 1.2$ A

Total input, $I_{T3} = I_{d1} + I_L = 1.2 + 1.0 = 2.2$ A

Also, $U_{T3}(dR) = 1.2(281 + 28) + 20 = 391$ V

In this example the fault current is $\frac{1.2}{2.2} \times 100 = 55$ per cent of the total input current.

A relatively high operating voltage must therefore be expected when:

1) The percentage value of fault current is only slighly higher than the percentage slope setting.

2) The internal fault current and the load current is assumed to be in-phase.

The restraining quantities cannot be ignored nor should they be exaggerated. The RADSS summation design was tested in 1970 at KEMA, Holland, to the full satisfaction of all the visiting engineers. Since then a large number of relays have been in actual service.

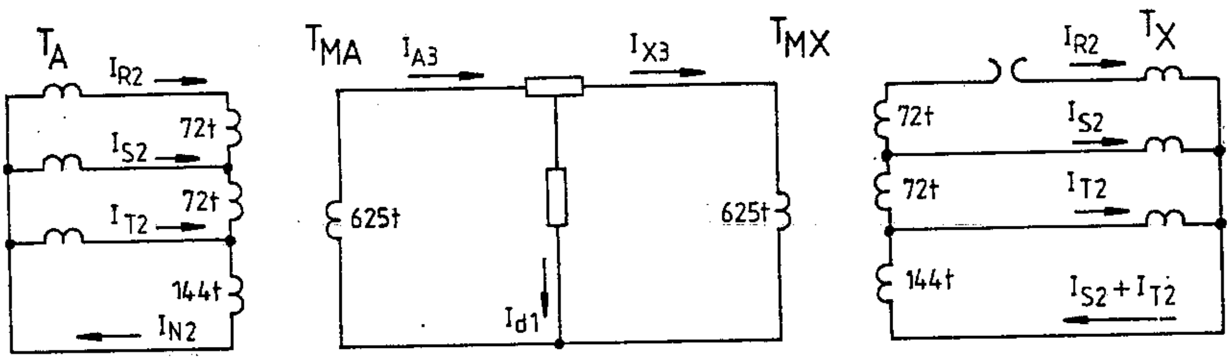
The practical experience with the single-phase RADSS has shown during the years that there has never been any maloperation in the case of external faults or a failure to operate on internal faults.

In the event of internal bus faults it can be argued that the fault impedance of an arc is very small and, also, that the steel structure in a station is securely connected to the earthing-system. The percentage value of a fault current will, therefore, in practice be much larger than the percentage slope setting. Decisive operation will therefore be obtained with internal faults.

Main CT open circuits

In the case of double bus systems with switching of CT secondary circuits from one zone to the other, there is a risk that a CT open circuit can occur inadvertently. The resulting unbalance current will then find its way through the differential circuit.

Consider the circuit shown below with an open circuit in R-phase of T_X main CT's.



The input currents to T_{MA} are all correct and balanced. The primary Amp-turns are therefore:

$$A_{t(A)} = 72\, I_{R2} - 72\, I_{T2}$$

The T_{MX} output current are:

$$I_{S2} + I_{T2} = I_{N2}$$

and resulting Amp-turns:

$$AT_X = 72\, I_{S2} + 144\, (I_{S2} + I_{T2}) = 72\, I_{S2} - 144\, I_{R2}$$

The differential current is therefore:

$$I_{d1} = \frac{1}{625} \left[At_{(A)} - At_{(X)} \right]$$

$$I_{d1} = \frac{1}{625} \left[216\, I_{R2} - 72\, (I_{T2} + I_{S2}) \right] = \frac{288}{625}\; I_{R2}$$

If the R-phase is opened during rated load:

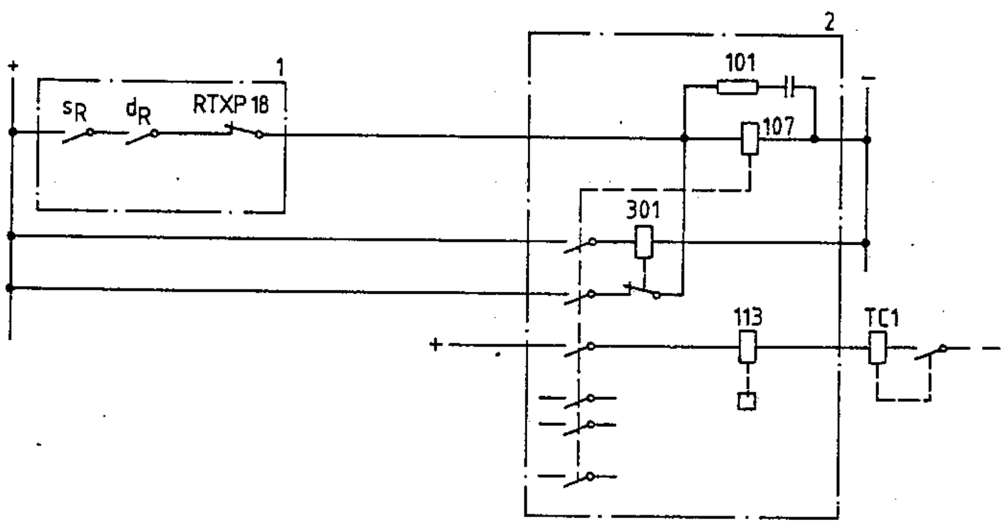
then $I_{R2} = 5$ A and

$$I_{d1} = \frac{288}{625} \times 5 = 2.3 \text{ A}$$

If, for example, the S_R-starting relay is set to operate at this value, instead of $I_{d1min} = 0.2$ A, the various primary current settings and, also, the relay operating voltage would increase by a factor of 11. This is of cource not acceptable.

In order to maintain a sensitive primary current setting and a reasonable relay operating voltage, S_R relay is normally set to operate at a value less than I_{d1min}. By maintaining a small relay operating voltage the physical size of the auxiliary summation CT can also be kept small.

Single-phase RADSS simplified dc circuit diagram



The single-phase RADSS for upto 12 circuits, has one measuring circuit and two standard output options, each with flag indication (113), impulse-storing unit (101) and RXMS 1 (107) high-speed medium-(trip-) duty output relay. One output option (1) has 5 normally open contacts available for tripping which automatically seal-in. This seal-in must be broken by an external contact. The other output option (2) has 4 normally open contacts available for tripping. An RXKE 1 timer (301) provides an adjustable trip pulse length from 20 ms to 99 s.