

B R O W N B O V E R I

D I S T A N C E R E L A Y S

Types LZ3, LZ31 and LZ 32

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I. MAIN CHARACTERISTICS AND PRINCIPLE OF OPERATION

(The information given in this section is dealt with in more detail on the page indicated between brackets.)

1. The distance relays type LZ3, LZ31 and LZ32 are primarily intended for the protection of lines in medium and high -voltage systems in which the reactance is greater than the resistance.

These relays can detect interphase and three-phase short-circuits and

- a) in systems with solidly earthed neutral: single and poly-phase earth-faults or
- b) in systems with insulated neutral or impedance earthing: double earth faults.

The relay is started by measuring the impedance or summation current.

2. Depending on the type of fault, the associated values of voltage and current are fed into the M+PU measurement system (Sk2-6899) by means of the contactors CR, CS and CT through the 3 impedance starting relays ZR, ZS and ZT (see page 8).

The impedance pick-up value of these relays is infinitely variable within wide ranges and independent of the current at values exceeding $3.5 \times I_n$. In order to increase the range of the protection at low currents, the Z relays are designed so that the pick-up impedance at low currents is higher than the preset value (see page 10). When the voltage falls to zero, they act as current relays with a pick-up value of $0.25 \times I_n$.

During earth faults the earth-fault relay IE (see page 11) picks up and changes over the voltage circuit of the impedance relays as well as the fault voltage for the distance-measurement system M+PU to the phase voltage by means of the auxiliary contactor CE. At the same time it adds k_0 -times the summation current, to the phase current through the replica impedance M; k_0 having to be adjusted in accordance with the impedance of the loop between line and earth.

3. Both the distance and the direction are determined in one unit, which comprises the replica impedance M, the phase-comparison relay PU (with the phase shifter $R_D + C_D$) and the matching transformer HG8. This assembly is referred to below as the M+PU measurement system (see page 13).

This system enables circles to be obtained as tripping characteristics in the R-X diagrams, the centre points and radii depending on the type of fault and the impedance of the supply, but they are hardly affected by the size of the fault current. An explanation of exactly how these circles are derived is contained in another publications, which is available on request.

A change in the mains frequency has no effect on the measurement.

The positive-sequence phase impedance of the line is always measured, irrespective of the type fault and possible transient or service currents which may be superposed. The phase comparison relay is also practically unaffected by hunting. Even in the event of evolving faults, short-circuits between the halves of a two-circuit line and faults involving star-delta transformers, the measuring system M+PU operates selectively.

The voltage drop across an arc, if this should occur, or across a moderately high earth-fault resistance does not influence the distance measurement or if it does, then only insignificantly.

4. The distance-time characteristic is stepped throughout, which ensures the shortest tripping times for faults at any distance.

The operating characteristic has four time steps, of which the last is non-directional. Every step can be infinitely varied between 0.1 and 5 s, one independently of the other (see page 28). The measuring distance of the individual steps can be finely adjusted within wide limits (see page 25).

5. The shortest operating time is 40 ± 5 ms.
6. The LZ3, LZ31 and LZ32 relays are also suitable for systems with auto-reclosure.

The reclosing command after tripping by the distance relay must be given by the breaker control unit or by a separate auto-reclosure system.

To ensure rapid disconnection at both ends of the fault in the case of lines with double infeed, the following methods can be adopted (see page 55):

- a) Overlap (without signal connection between the stations at the two ends of the line (see page 55).
- b) Carrier transfer (transmission of the tripping command to the station at the other end of the line via an h.f. channel (see page 58).
- c) Follow-through connection (as soon as the distance relay has picked up, the range of the first step of the relay in the other station is increased by carrier transfer or pilot cable (see page 61).
- d) Pilot-wire coupling for releasing the tripping command (see page 62).

The following programmes are available for auto-reclosure (see page 53):

1. Single and three-phase reclosure (page 55)
 2. Three-phase reclosure only (page 55)
 3. Single-phase reclosure only (page 54)
 4. Triple-pole lockout only
-
7. The relay types LZ31 and LZ32 are equipped with compounding chokes for the starting relays. This is specially useful for the protection of long lines (page 38).
 8. The distance relays LZ3, LZ31 and LZ32 can be augmented with an L6f unit which is able to trip in one cycle.
 9. Contacts "without potential" of starting, earth-fault, step and reclosing contactors are brought out to terminals, a facility which proves useful for analyzing faults and for carrying out functional tests, etc.

"Without potential" means in this case that the contacts are completely isolated from all relay circuits, even from the auxiliary supply.
 10. The built-in testing terminals allow the distance relay to be easily disconnected from the mains instrument transformers and the breaker tripping circuit, so that it can be tested in situ with the aid of the special Brown Boveri test set. (This set is not supplied with the distance relay but has to be ordered separately.)
 11. All moving-coil relays, which form part of the starting relay Z, the earth-fault relay I and the phase relay PU, are of the plug-in type and, except for the one belonging to the phase relay PU, are interchangeable.

12. All elements are mounted on a hinged frame, making them readily accessible for inspection; the frame is enclosed in a dust-tight casing with a glass front.

11. THE MAJOR TECHNICAL DATA

Rated voltage U_n or variant for	100 - 110 V 200 - 220 V
Rated current I_n	1, 2 or 5 A (variants)
Frequency	50 or 60c/s(variants)
Auxiliary d.c. supply	24-220 V d.c.(variants) Tolerance $\pm 10\%$

All the impedances quoted below in ohm are referred to the rated values for the relay $U_n = 110$ V and $I_n = 5$ A

Conversion for other values:

for $U_n = 200$ V the impedance values are doubled

for $I_n = 2$ A the values are 2.5 times the quoted values and

for $I_n = 1$ A the values are 5 times the quoted ones.

Impedance relay type Z:

Starting impedance adjustable
between:

1 - 7 Ω /phase
(at $I > 3.5 \times I_n$)

At $0.65 \times I_n$ the starting impedance is 30% higher than the preset value: for values in between see the curve on page 10.

At over $1 \times I_n$ drop-out ratio 103%

At $U = 0$: pick-up current $0.25 \times I_n$
drop-out current $0.2 \times I_n$

Earth-fault relay IE:

Pick-up current adjustable
between:

0.2 and $2 \times I_n$
93%

Drop-out ratio:

Back-up earth-fault relay IB:
(only for type LZ32)

Pick-up current adjustable
between:

0.1 and $1 \times I_n$
93%

Drop-out ratio:

Distance-measuring system M+PU:

Minimum setting for measured
reactance:

$WL_{min} = 0.075 \Omega/\text{phase}$

(can also be supplied for LZ31 and LZ32 on request.)

The relays type LZ31 and LZ32
(with compounding) are normally
designed for:

$WL_{min} = 0.2 \Omega/\text{phase}$

Directional sensitivity: (For definition see page 23)

For triple-pole short-circuit: 0.1 V (at $I > 0.75 \times I_n$)

For double-pole short-circuit,
double and single earth faults: unlimited

Power factor of replica impedance: 0.1 to 0.8 adjustable

Summation-current coefficient

k_0 adjustable (in steps) of: 0, 0.1, 0.2, 0.3, 0.5, 0.6,
0.7, 0.8, 0.9, 1.0, 1.5

Number of steps in tripping
characteristic (of which 4th is
non-directional):

4

Time of steps (independently
adjustable):

0.1 to 5 s

Compounding impedance X (only for LZ31 and LZ32) adjustable
in steps, each of 0.4 Ω/ph between 0 and 5.2 Ω/ph .

Tripping times:

Minimum tripping time for earth
fault and double-pole short-
circuit:

$40 \pm 5 \text{ ms}$

For triple-pole dead short-
circuit at location of relay
when $U = 0$:

120 ms
(less if reference voltage
is not exactly zero)

Overcurrents:

Permissible sustained current: $2 \times I_n$

Permissible current during 5 s: $30 \times I_n$
for 1 s: $60 \times I_n$

Consumption of relay: (per phase, referred to U_n and I_n):

	LZ3	LZ31 and LZ32
Current circuit:		X choke set to 5.2 Ω/ph
during normal operation	0.9 VA	6 VA
during 2-phase short-circuit	1.0 VA	6.5 VA
during 1-phase earth fault	4.2 VA	16 VA

Voltage circuit:

(tapping on HGB)

with Z relay set to minimum im-
pedance during normal operation
during 2-phase short-circuit
during earth fault

	100%	200%
during normal operation	2.2 VA	2.2 VA
during 2-phase short-circuit	11.5 VA	23.0 VA
during earth fault	8.5 VA	9.0 VA

Auxiliary d.c. circuit:

During normal operation without
overlap:

0 W

During normal operation with
overlap:

2 W

During short-circuit, max. in
worst case:

110 W

Dimensions:

See dimensioned drawings
AK 420891/92 Amendt a

Weight:

44 kg (type LZ32)
= 97 lb

III. PURPOSE, DESIGN AND METHOD OF OPERATION OF THE INDIVIDUAL COMPONENTS

III.1. Minimum-impedance relay Z2

As starting element, the distance relay contains one minimum-impedance relay in each phase, i.e. three in all. When a fault occurs within the preset distance, these minimum-impedance relays detect the drop in impedance in the phases affected and hence the type of fault. Once they have picked up they also ensure that the associated auxiliary contactors CAR and / or CAS and/or CAT are energized, which then transmit the currents and voltages corresponding to the type of fault to the distance and direction-measuring system M+PU (for general diagram see Sk2-6899) and prepare the tripping circuits.

The voltage circuit of the Z relay is always connected during insulated faults between the phase by which it is designated and the phase which leads: e.g. ZAR between R and T. The phase current, e.g. I_R flows through the current circuit.

The main advantage offered by the impedance-relay starting system (as opposed to the simple current relay) lies in the fact that it can also detect faults with short-circuit currents, which are smaller than the maximum service current. In addition, unnecessary actuation of the relay is avoided during overload conditions without faults, when the voltage does not collapse.

The Z relay consists mainly of the current and voltage circuits, the rectifier circuit and a moving-coil system as sensing element. For the circuit diagram see Fig. 1 (page 9a).

The voltage circuit (C, D, E_u) produces a current proportional to the voltage, which when rectified has a blocking action on the moving-coil system (A).

Impedance relay Type Z2

Schematic diagram

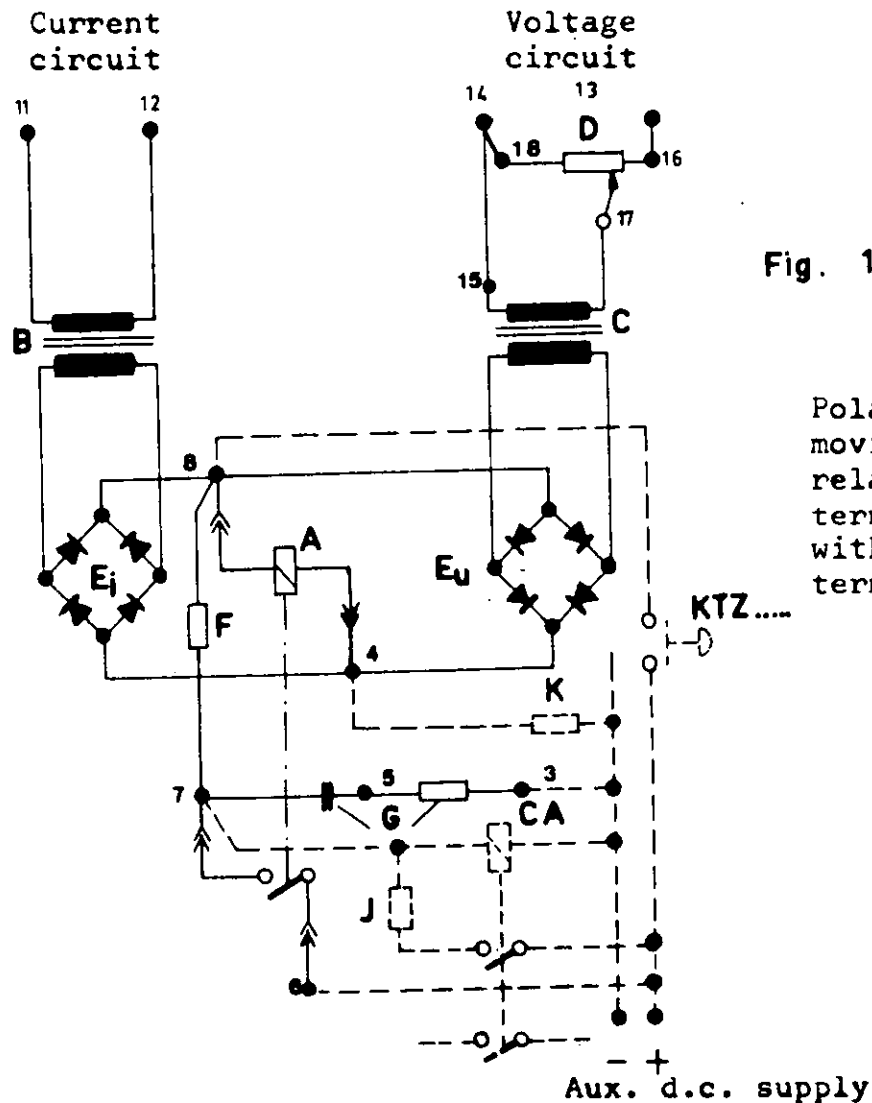


Fig. 1

Polarity causing moving coil relay to pick-up: term. 8 positive with respect to term. 4

- A Moving-coil relay (plug in)
- B Auxiliary current transformer
- C Auxiliary voltage transformer
- CA Pick-up auxiliary contactor CA
- D Potentiometer for setting pick-up value
- E_i, E_u Rectifier bridges
- F Resistor for increasing contact pressure
- G Spark suppression RC circuit
- J Auxiliary resistor to prevent chatter of CA
- K Resistor RKT for protecting test circuit
- KTZ Test button KTZ (on control panel of distance relay)

The terminal numbering corresponds with that of the Z relay. The connections and elements shown as dotted lines are located outside the Z relay.

The current measurand is rectified as well, its polarity acting in pick-up direction on the moving-coil relay.

The difference in the currents fed in by the two measurement circuits flows through the moving-coil relay, the polarity of the resultant current value determining the operation of the relay.

If the impedance of the circuit being monitored is greater than the preset minimum value, the voltage system predominates, and keeps the moving-coil relay into the rest position.

If however the impedance falls below the preset minimum value, the action of the current circuit predominates (B, E_i) and the moving-coil system closes its contacts (6 - 7).

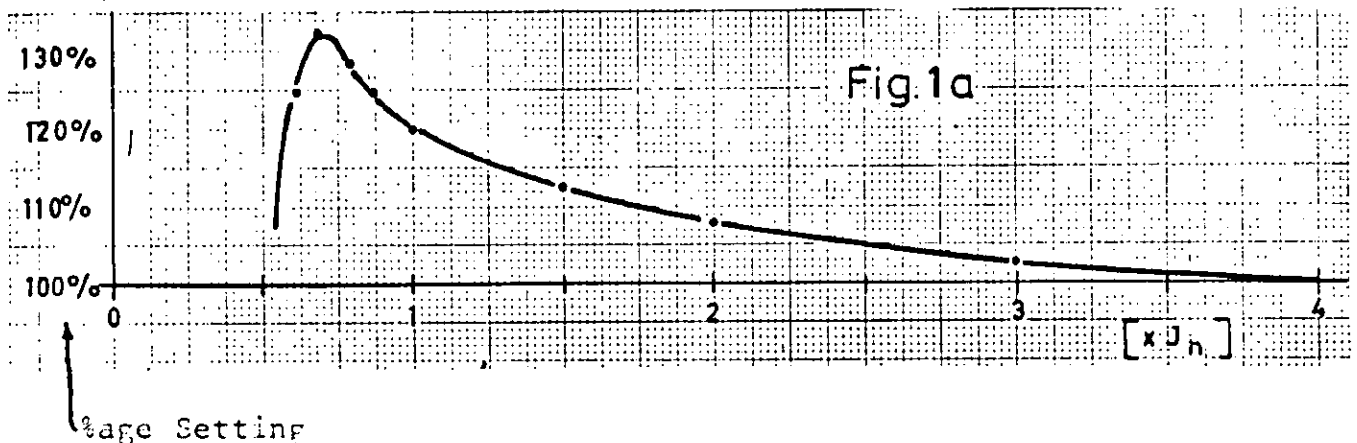
If the voltage at the input terminals of the voltage circuit is zero, the Z relay operates as a pure current relay, which picks up at $0,25 \times I_n$ and falls back at $0,2 \times I_n$.

A potentiometer(D) is provided in the voltage circuit with which the required pick-up impedance can be adjusted within the following ranges :

for relay design for :		
Z = Ohm/Ph	I_n	U_n
5 - 35	1 A	100 V
2,5-17.5	2 A	
1 - 7	5 A	
10 - 70	1 A	200 V
5 - 35	2 A	
2 - 14	5 A	

The pick-up value of the type Z2 relay is virtually independent of the phase angle between current and voltage, and also the direction of the energy flow: the pick-up characteristic therefore appears as a circle in the R-X plane with its centre at the origin. This circle can be displaced by compounding (see page 38).

If the fault is associated with rather small overcurrents, i.e. $I_k < 3.5I_n$, it is desirable that the range of the protection should be widened. For this reason the Z2 relay is designed so that at $I < 3.5I_n$ the pick-up value is greater than the preset one by the percentages shown in the curve below (due to bending of the characteristic of the diodes E_i).



Impedance relay Z2: Pick-up curve as a function of multiples of the rated current

Referred to the pick-up value, the reset impedance is 103%, which at values exceeding $1xI_n$ becomes slightly dependent on the current.

The moment the contacts (6 - 7) close, the contact pressure reinforcement (F, K) comes into action, so that chatter is prevented during unfavourable phase angles.

The RC circuit (G) serves as spark-suppressor for the contacts of the moving-coil relay.

The moving-coil relays of the three Z relays, as also those of the earth-fault relays IE and IB are interchangeable, since they are adjusted to the same pick-up current. (The moving-coil relay of the PU is however adjusted to very different values.)

IMPORTANT

When testing, the contacts of the moving-coil relay may only be closed by pressing the relevant test button (KTZ) on the control panel of the distance relay. (The auxiliary d.c. supply must then be switched on.) Attempts to operate the contacts mechanically could result in damage to the delicate measuring system.

The auxiliary contactors CR, CS and CT each have a contact "without potential" which is brought out to terminals for signalling purposes.

III.2. The earth-fault relay IE

The earth-fault relay IE (type I2) is used to change over both the impedance relay Z and the measuring system M+PU from the phase-to-phase voltages to the phase voltages whenever a summation current (zero-sequence current), which is greater than the preset limit, occurs, i.e. an earth fault (general diagram Sk2-6899). The actual changeover is carried out by the auxiliary contactor CE.

The earth-fault current relay mainly consists of the setting and rectifier systems together with a moving-coil system as the sensing element (circuit diagram in Fig. 2).

The required starting value can be adjusted on the potentiometer (B) within the range 0.2 to $2 \times I_n$.

The current measurand is rectified and acts on the moving-coil system (E), which is held in the rest position by a spring, when no current is being fed to it. As soon as the electrodynamic torque overcomes the spring, the contact 6 - 7 closes.

The current relay drops out at 93% of the pick-up value.

The setting of the earth-fault relay IE should never be less than $0.5 \times I_n$ for the following reasons:

- a) To prevent undesirable picking up when in case of a heavy short-circuit (interphase short-circuit or triple-pole fault), and, due to unequal transformer errors, the distance relay is fed with a small summation current which is not really flowing in the h.v. circuit.
- b) Or that the relay IE should reset in the dead time during auto-reclosure, although the service currents in the healthy phases appear in the summation circuit.

The device for increasing contact pressure, the spark suppression and the test circuit operate in exactly the same manner as for the impedance relay Z2 (described under III.1 above).

The same also applies with regard to interchangeability of the moving-coil relays.

The auxiliary contactor CE is equipped with a "without potential" contact, which is brought out to terminals for signalling purposes. The coil connection 1 is taken to terminal 40 (of the distance relay); auxiliary contactors with maximum coil capacities of 3 W can be connected between this terminal and terminal 35 (of the distance relay).

III.2a Back-up earth-fault relay IB

(only fitted into distance relay type LZ32)

The back-up relay IB is incorporated in order to detect true earth faults with a small summation current, to which the relay IE does not respond (especially earth faults at the busbar of the opposite station or at the end of fairly long lines).

Overcurrent relay Type I₂

Schematic diagram

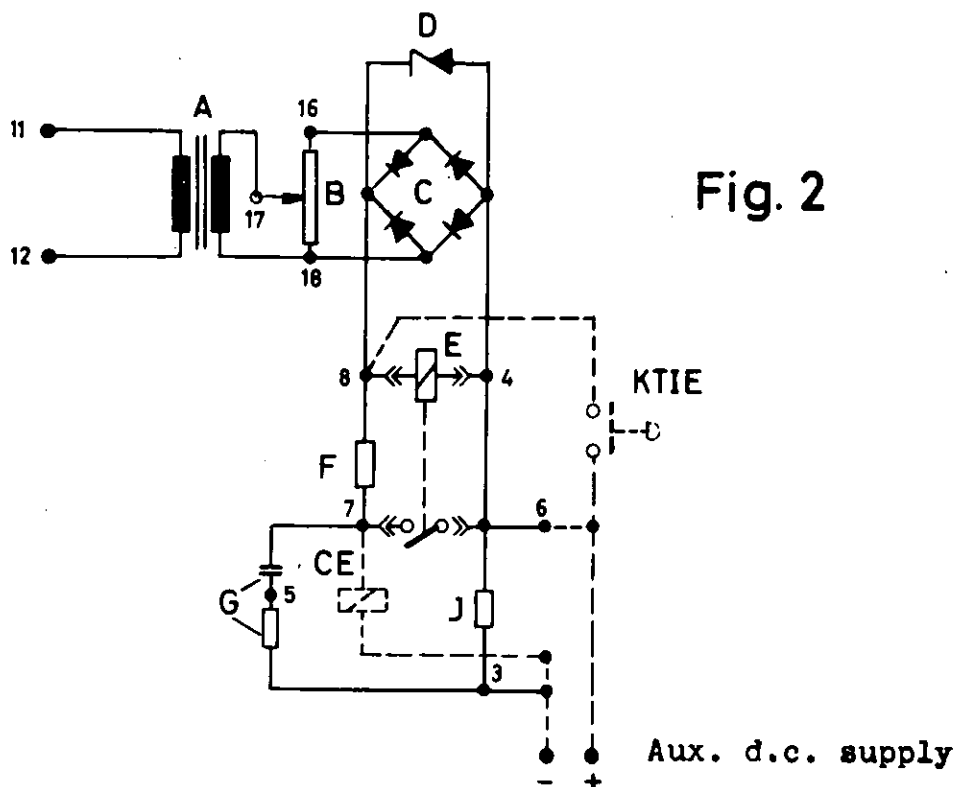


Fig. 2

- A Auxiliary current transformer
- B Potentiometer for setting pick-up value
- C Rectifier bridge
- CE Auxiliary contactor for relay IE (or aux. contactor PTaE for relay IB)
- D Overvoltage protection
- E Moving-coil relay (plug-in)
- F Resistor for increasing contact pressure
- G Spark-suppression RC circuit
- J Protective resistor for test circuit
- KTIE Test button for relay IE (or KTIB for relay IB)

The dotted connections and elements are located outside the I₂ relay (this applies both to the earth-fault relay IE and the auxiliary relay IB)

With the exception of the setting range, the relay IB is identical to the IE described under III.2.

Its setting range is between 0.1 and $1 \times I_n$.

When the back-up relay picks up, it energizes a delayed auxiliary contactor PTaE, the time-lag of which is normally set to 2s. This in turn is connected to the auxiliary contactor CE, which is dealt with under III.2 and on page 67

During the delay of the PTaE the distance relay can clear the heavy-current short-circuit, condition a) above and prevent unnecessary operation by CE (see above b)).

If the small summation current persists for longer than 2 s (without the distance relay starting), this can only be due to a remote earth fault. The PTaE then operates, whereupon the CE switches the impedance relays Z to phase voltage: these can be expected to pick up, since the phase current in the earth faults in question are usually larger than the summation current.

III.3. Distance and directional measuring system M+PU

a. Measurement principle

The system makes use of the well-proven Brown Boveri distance and directional measuring principle, in which a replica impedance M and a phase-measuring relay PU constitute the actual measuring system.

The basic operation is as follows (see Fig. 3 below):

Initially an interphase fault is assumed between the phases S and T: the relevant starting relays Z have picked up and have energized their CA contactors.

The section of line being protected [A-D] has an impedance of \bar{Z}_D per phase.

(\bar{Z} and \bar{I} represent vectorial quantities)

The impedance of the generator involved together with that of the line upto the point A, where the relay is located, adds to \bar{Z}_{sp} per phase.

The phase-to-phase service voltage of the generator is \bar{U}_{sp} .

Assuming a short-circuit at the end D, the short-circuit current is:

$$\bar{I}_K = \frac{\bar{U}_{sp}}{2(\bar{Z}_{sp} + \bar{Z}_D)} \quad (1)$$

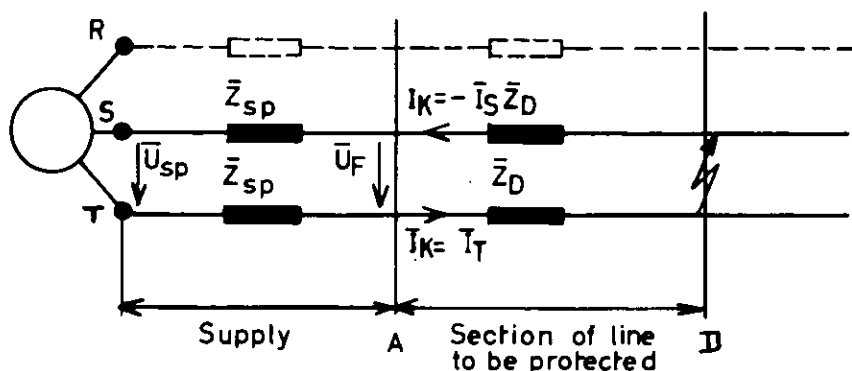
having the same amplitude but in opposite directions in the phases R and T:

$$-\bar{I}_S = \bar{I}_T = \bar{I}_K \quad (1a)$$

The phase-to-phase voltage between the affected phases at A is \bar{U}_F , which is referred to as the fault voltage: this is

$$\bar{U}_F = \bar{I}_K \cdot 2 \bar{Z}_D \quad (2)$$

Fig. 3



Explanation of the terms supply impedance Z_{sp} and impedance Z_D of the protected line

The current \bar{I}_K flows through the current transformers W_{IS} and W_{IT} with transformation ratios of I/i (Fig. 5a and 5c).

The phase angle φ_M of the replica impedance M is chosen so that it is the same as the phase angle φ_D of the line being protected in the case of metallic short-circuits. The composite secondary current $\bar{I}_M = \bar{I}_T - \bar{I}_S$ produces the voltage drop $\bar{Z}_M \cdot \bar{I}_M = \bar{U}_M$ on this impedance.

A certain percentage of the fault voltage \bar{U}_F , i.e. $\% \bar{U}_F$ is connected in opposition to the voltage drop \bar{U}_M in the distance relay.

If the transformation ratio U/u of the matching transformer HG8 (in the distance relay) is so chosen, that the following applies in the case of a short-circuit at the end D of the line section A-D being protected:

$$\bar{U}_D = \bar{Z}_M \cdot \bar{I}_M - \bar{U}_F \cdot u/U = 0 \text{ (with } \bar{U}_F \cdot u/U = \% \bar{U}_F \text{)} \quad (3)$$

then the distance relay is set so that it reacts to short circuits along the line section A-D.

The equation (3) represents voltage relationships in the "difference-circuit" within the measuring system.

If the short-circuit occurs at a point other than at D, then the expression (3) $\neq 0$ and hence $\bar{U}_D \neq 0$.

If the short-circuit is located closer to the relay than D, the fault impedance Z_F is $< Z_D$. As a result \bar{U}_F falls and \bar{I}_K rises, so that in accordance with (3) \bar{U}_D becomes positive (with respect to \bar{U}_F): the relay must then trip (Fig. 5c).

If the short-circuit is further away from the relay than point D, then $\bar{Z}_F > \bar{Z}_D$, so that \bar{U}_F in (2) increases and \bar{I}_K falls: \bar{U}_d becomes negative with respect to \bar{U}_F (from (3)) and the relay does not trip.

With infeeds at both ends of the line, the above-mentioned applies as well. It is also possible for the short-circuit to occur to the left of point A at the back of the relay. The short-circuit current then flows in the opposite direction compared with the cases above, so that \bar{I}_M in (3) is always negative and hence \bar{U}_d as well: the relay does not trip.

The direction of \bar{U}_d with respect to \bar{U}_F is therefore always an indication of the distance to the fault and its direction. The sign of \bar{U}_d is determined in the phase relay PU by comparing the direction of \bar{U}_d and that of the reference voltage \bar{U}_r .

As explained below, however, in the LZ3... the voltage U_r is used to give the reference direction and not the voltage U_F .

Depending on the type of fault (single-pole, double-pole, etc.) this reference voltage \bar{U}_r is automatically selected by the starting relays Z and IE in the distance relay, so that a correct measurement of distance is achieved together with the maximum possible torque in the moving-coil relay. At the same time a voltage drop across a possible arc or an earth fault resistance has practically no effect on the measurement due to the fact that \bar{U}_r is so chosen, that the vector is as nearly parallel as possible to the drop across the arc.

During all asymmetrical faults, these requirements are best satisfied by the healthy phase-to-phase voltage \bar{U}_r , which leads the affected voltage. In the case of single-pole earth faults this phase-to-phase voltage U_r could also be referred to as the one perpendicular to the affected one. This choice of U_r brings with it the advantage that it never falls to zero, even during an almost dead short circuit, so that the directional

sensitivity remains good, irrespective of possible spurious voltages in the circuits of the mains voltage transformers.

The main advantages of the Brown Boveri measurement principle using a replica impedance M include:

As implied by the name "replica impedance", M (when $\varphi_M = \varphi_D$) is an exact replica of the impedance of the line being protected, so that the voltage at the terminals of M faithfully represents the voltage drop across the impedance of the protected line. The measurement therefore remains correct, even if:

- the frequency changes,
- harmonics occur, as long as these actually exist in the fault circuit and are not produced from the voltage or current-transformer circuits, thus creating a false impression,
- the alternating current contains a d.c. component (assuming that the current transformer transmits the d.c. component G at all), which occurs at the beginning of the short-circuit at voltage zero (e.g. should a circuit-breaker be closed when an earthing switch is inadvertently left in, etc.).

This is based on the physical fact that in the same way as

- a) every L-R series impedance connected to a sinusoidal voltage at voltage zero produces a current displaced by the decreasing component G
- b) conversely, the imposition of such an asymmetrical current on a L-R series impedance results in a symmetrical sinusoidal voltage at the terminals of the impedance.

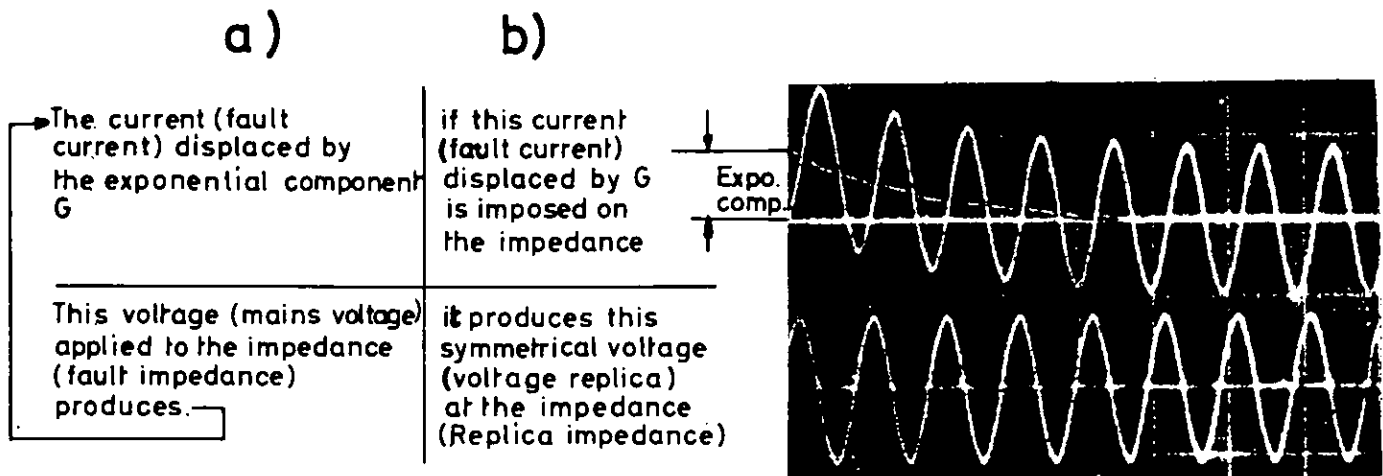


Fig. 5/1

III.3b Description and principle

Together with the matching transformer HG8 and the replica impedance M , the phase relay PU makes up the required directional and impedance-measuring system for the distance protection. For the distance relay type LZ3 in question, the PU relay must be complemented with a phase shifter C_b and R_b in order to be able to make use of the above-mentioned phase angle of the reference voltage U_r (see diagrams 4 and 5). M and HG8 constitute the difference circuit.

The PU relay mainly comprises: two practically identical voltage circuits (of which one, known as g , acts in the tripping direction on the moving-coil relay whereas the other, m , has a blocking action on it) and the moving-coil relay a .

The device for increasing contact pressure, spark suppression and the test circuit are similar to those described for the impedance relay.

The auxiliary tripping circuit (resistors, diode and capacitor n) only comes into action during three-phase short-circuits, when all three starting contactors are attracted simultaneously. It feeds a small auxiliary voltage to the moving-coil relay in the

tripping direction; this ensures that tripping still takes place, even if the mains voltage disappears completely due to a very close dead fault ($U = 0$).

III.3c The operation of the system can now be explained, using the example of a short-circuit between the phases S and T (Fig. 5):

If the impedance in the protected line sinks below the value preset in the Z relay, then one or two Z relays (not shown) in the affected phases pick up (for details see V.1). These feed a given selection of voltages and currents - determined by the type of fault - to the phase measuring system via the associated auxiliary contactors CA (not shown). This choice for different types of fault is clearly represented in 5k2-6899.

Fig. 5 shows a considerably simplified representation of the connections between the phase measuring system and both the mains-current and mains-voltage transformers (through the auxiliary instrument transformers built into distance relay and the contacts of the starting contactors) during the fault in question (interphase fault ST).

All components not vital for the understanding of the operation (e.g. mains voltage transformers, auxiliary transformers in the distance relay, contacts of the starting contactors, auxiliary tripping circuit, etc.) or which play no part in the chosen example (e.g. the current transformer in phase R, etc.) have been omitted for the sake of clarity.

The arrows \longrightarrow in Fig. 5a indicate the arbitrarily chosen positive sense of currents and voltages. The currents and voltages are actually directed in the sense of these arrows when the projection of the vectors in the vector diagrams Fig. 5c, d and e on the clockwise rotating time-base t is positive.

To facilitate understanding still further, an instantaneous picture at the time "t" of the voltage and current directions of the positive electricity are included in Fig. 5a. The actual directions of the current and voltage, which at the instant "t" produce negative projections on the time baset in Fig. 5c, d and e, act against the above-mentioned arrows and are therefore indicated with the triangular arrow head \longleftrightarrow in Fig. 5a.

Vector references: e.g.

U_{SR} indicates a vector with end at S and point at R, i.e. a vector which points from S to R.

Similarly U_{RO} : end at R, point at O

U_{OR} : end at O, point at R.

The infeed point in Fig. 5a and 5b is on the left-hand side.

It is also assumed that, as is normal, the replica impedance is matched to the section of line being protected, i.e.

$$\varphi_M = \varphi_D$$

The two current transformers W_{IS} and W_{IT} are connected in antiparallel on the secondary side, so that they drive $\bar{I}_T - \bar{I}_S = \bar{I}_M$ through the replica impedance.

Incidentally: When all the contactors are in the rest position $\bar{I}_T - \bar{I}_S$ is already connected to M, although this has no effects. In the example S-T chosen at random, $\bar{I}_T - \bar{I}_S$ is also connected to M, when CAT is attracted, this does not alter any current connections to M. This only applies, however, for the short-circuit TS.

A voltage drop then occurs at the terminals of M:

$\bar{I}_M \cdot \bar{Z}_M = \bar{U}_M$, the "replica voltage", which in accordance with the assumptions $\varphi_M = \varphi_D$ has the same direction as the affected voltage \bar{U}_F , which is also known as the fault voltage and drives the fault current.

If a certain percentage of the fault voltage $\% \bar{u}_f$ is deducted from \bar{u}_M , the direction of the resulting difference voltage \bar{u}_d will either be the same or opposite to that of the fault voltage, depending as to whether $\% \bar{u}_f$ is greater or smaller than \bar{u}_M .

This is represented in Fig. 5b:

If the fault is displaced along the line being protected, assuming a constant fault current \bar{I}_K , then \bar{u}_M will always have the same size: this is represented by the horizontal straight line \bar{u}_M . The voltage $\bar{U}_F = \bar{I}_F \cdot \bar{Z}_F$ on the other hand does change, in fact proportionally to $\% \bar{u}_f$ at the location of the relay and as a function of the distance to the fault: the further the fault is away, the greater the impedance \bar{Z}_F of the line upto the fault and hence \bar{U}_F as well. This is represented by the straight line $\% \bar{u}_f$ falling from 0.

The difference $\bar{u}_d = \bar{u}_M - \% \bar{u}_f$ can therefore be represented by an inclined straight line, which begins with the value \bar{u}_M at the location of the relay and passes through zero at the point D, where $\% \bar{u}_f$ is equal to \bar{u}_M . This also determines the range of the measuring system M+PU.

If the percentage of the fault voltage $\% \bar{u}_f$ is altered by choosing other tapplings at the transformer HGB, (this voltage being deducted from \bar{u}_M), the slope of the line $\% \bar{u}_f$ is modified; the point D is now displaced to a place where $\bar{u}_d = 0$. A basic conclusion can therefore be drawn, that the protected distance (expressed as an impedance) $Z_S = \text{const.}/N \%$, in which $N\%$ is the percentage tapped off at HGB (the exact relationship is contained in the setting instructions on page 109).

To determine whether the direction of \bar{u}_d is the same or opposite to that of \bar{u}_r , the direction of \bar{u}_d is compared with that of the reference voltage \bar{u}_r in the phase relay PU.

The healthy voltage \bar{U}_{SR} , which is shifted forwards by 90° by means of the $C_b + R_b$ is used here as \bar{u}_r , this former voltage

being approximately parallel to the fault current; in this manner the influence of the arc voltage is kept to a minimum.

The two circuits in PU, namely g and m, only differ in the fact that in the instrument transformer m the two primary windings are connected in the same direction (both winding ends E to terminal 11), whereas in the transformer g they are connected in opposite directions.

As shown in Fig. 5a and 5d, in this case, \bar{u}_r acts in the instrument transformer m against the positive arrows, so that the voltage \bar{u}_m at the centre tapping of the winding becomes smaller than the voltage \bar{u}_g at the corresponding winding of transformer g, where the voltages \bar{u}_r and \bar{u}_d act in the same directions.

If the currents in the secondary windings of the instrument transformer m and g are rectified, their mean values can be compared. The comparison of directions between \bar{u}_r and \bar{u}_d is transformed by this way into an amplitude comparison between $|\bar{u}_m|$ and $|\bar{u}_g|$. The polarities of the rectifier diodes and of the moving-coil relay are so chosen, that when the current from the transformer g predominates, the moving-coil relay picks up: terminal 8 is then positive with respect to terminal 4.

For a fault located to the right of the protected zone, $\% \bar{u}_f$ will be $> u_m$ so that the direction of u_d will be opposite to that shown in Fig. 5a. The corresponding vector diagram is shown in Fig. 5b from which it is clear that $|u_m| > |u_g|$; relay PU remains in the rest position or blocks and no tripping occurs.

The changeover of theappings at HG8 for producing the distance-time step characteristic is explained on pages 32 and 61.

All that has been said so far also applies if the distance relay is used in a line with infeed at both ends: in this case it is possible for the fault to occur to the left of the relay (at the back of it) as well. The currents I_s and I_r , therefore

also \bar{I}_M , will then flow in the opposite direction to that shown in Fig. 5a. Accordingly the voltage \bar{U}_M will also change direction and will be added to $\% \bar{U}_F$ (instead of being subtracted from it). A high value of voltage \bar{U}_D will therefore result in the blocking direction; herewith is demonstrated that the distance relay is directionally selective. This is shown in Fig. 5b to the left of A.

In the general case, however, the phase angle φ_F of the loop of line (including the arc resistance) could be such

that $\varphi_F \neq \varphi_D = \varphi_M$. This effect does not bring any basic alteration into the above-mentioned processes. As long as $\varphi_M = \varphi_D$ is chosen, it suffices to insert the line reactance in the calculation, since in high and very-high-voltage lines R is generally smaller than X , so that $Z \approx X$. In order to take a possible resistance at the point where the fault occurs into account more effectively, φ_M can be deliberately made smaller than φ_D . In this case it may also become necessary to bear the different sizes of the absolute values of the impedances \bar{Z}_L and the replica impedance \bar{Z}_M in mind when calculating the percentage tapping $\% \bar{U}_F$.

The M+PU measuring system always determines the positive sequence phase impedance independently of possible service and balancing currents since, as already shown, the phase-to-phase current and voltage is fed to it during interphase short-circuits (in the same way as during three-phase short-circuits). An example using other phases than those assumed previously could be: short-circuit RT, current $(\bar{I}_R - \bar{I}_T)$ and voltage \bar{U}_{RT} . It is fairly evident that the service current in the healthy phase S is divided into two equivalent inphase currents \bar{I}'_S in the affected phases on its return towards A. These currents add up to the short-circuit currents in R and T, but are cancelled out by the difference $\bar{I}_R - \bar{I}_T = (\bar{I}_R + \bar{I}'_S) - (\bar{I}_T + \bar{I}'_S)$.

Similar investigations can be carried out in the case of other faults (earth faults, etc.) as well (see also table Sk2-6899).

During interphase or single pole faults involving ground ~~both~~ the phase voltage and current plus the summation current $\times k_0$ are supplied to the measuring system M+PU, so that the relay also measures the phase impedance, irrespective of the earth impedance and the ratio of the summation current to the phase current.

During an earth fault (e.g. R0) in a system with an earthed neutral, the reference voltage (e.g. TS) (see Sk2-6899) lags further behind the fault current than during insulated short-circuits (Fig. 5). In order to make the distance measurement independent of a possible voltage drop across an arc or an earth fault in this case as well, part of the resistor R_b is shorted by the contact I2 of the earth-fault contactor CE, so that the reference voltage is advanced by about 12° more compared with the case dealt with above (see also page 58).

The coil of the moving-coil relay a is adjusted so that the relay picks up at a current of 50 μ A, when its own consumption is about 1.3 μ W. This gives the PU a very high measurement accuracy and - even during triple-pole faults - its directional sensitivity is virtually equivalent to that of a precision instrument operating on the nulling method.

During a triple-pole short-circuit with $2 \times I_n$ and at the tapping 100% of HG8, the directional sensitivity attains 0.1 V. If the fault voltage during a triple-pole short-circuit is still smaller, the auxiliary tripping circuit described on page 19 initiates selective tripping. The directional sensitivity in the case of all other faults is unlimited.

- a Moving-coil relay on plug-in socket
 C_b Capacitor of phase shifter
 HG8 Matching transformer
 KTPU Test button
 M Replica impedance
 n Elements auxiliary tripping circuit
 p Resistor for increasing contact pressure
 q Spark-suppression circuit
 RKT Resistor of test circuit
 g Mixing voltage transformer of g circuit
 m Mixing voltage transformer of m circuit
 R_b Resistor of phase-shifter for reference voltage
 X_b Auxiliary transformer of phase-shifting circuit
 i_M Current through replica impedance M (originates at current-selector contacts of auxiliary starting contactor)
 u_F Fault voltage (originates at fault-voltage selector contacts of auxiliary starting contactor)
 U_r Reference voltage (originates at reference-voltage selector contacts of auxiliary starting contactor)
 u_r U_r shifted to 90° leading
 u_M Voltage drop across M due to i_M
 u_d Difference voltage

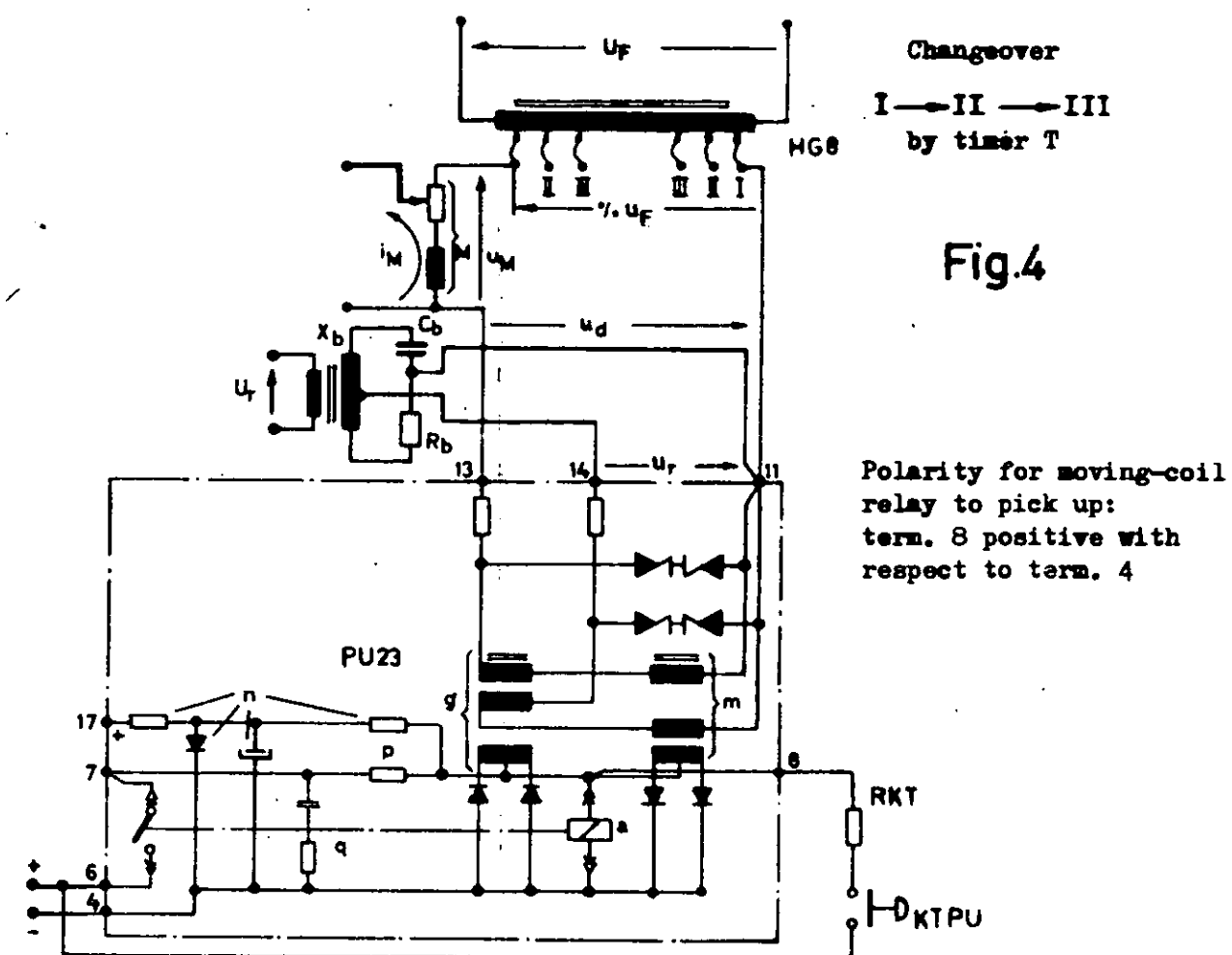


Fig. 4: Distance and direction measuring system with PU phase relay: complete schematic diagram

Fig. 5:

- 1 u_d has tripping action
- 2 u_d has blocking action
- A Station where distance relay is installed
- a Moving-coil relay on plug-in socket
- B Station at other end of line
- C_b Capacitor of phase shifter for reference voltage
- D Limit of preset protected distance
- F Location of fault
- HGB Matching transformer in distance relay
- M Replica impedance
- P Direction of energy flow to which distance relay is sensitive
- PU23 Phase relay
- QA Circuit-breaker in station A
- R_b Resistor of phase shifter for reference voltage
- St_A Busbars in station A
- St_B Busbars in station B
- W_g Mixing instrument transformer in circuit g
- W_m Mixing instrument transformer in circuit m
- X_b Auxiliary transformer of phase shifter for reference voltage
- Z_D Basic distance
- Z_F Distance to fault

For explanation of other notations see text III 3

Distance and directional measuring system M+PU

Graphic representation of range and vector diagram during interphase fault.

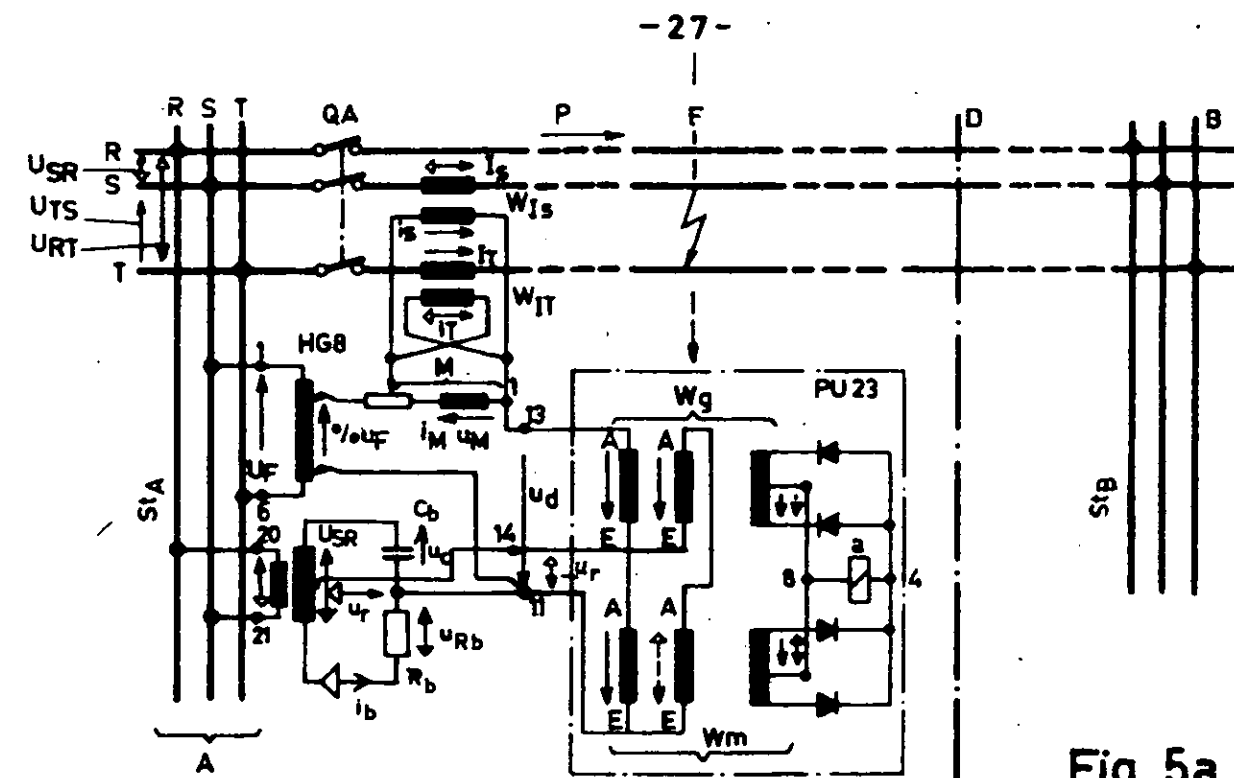


Fig. 5a

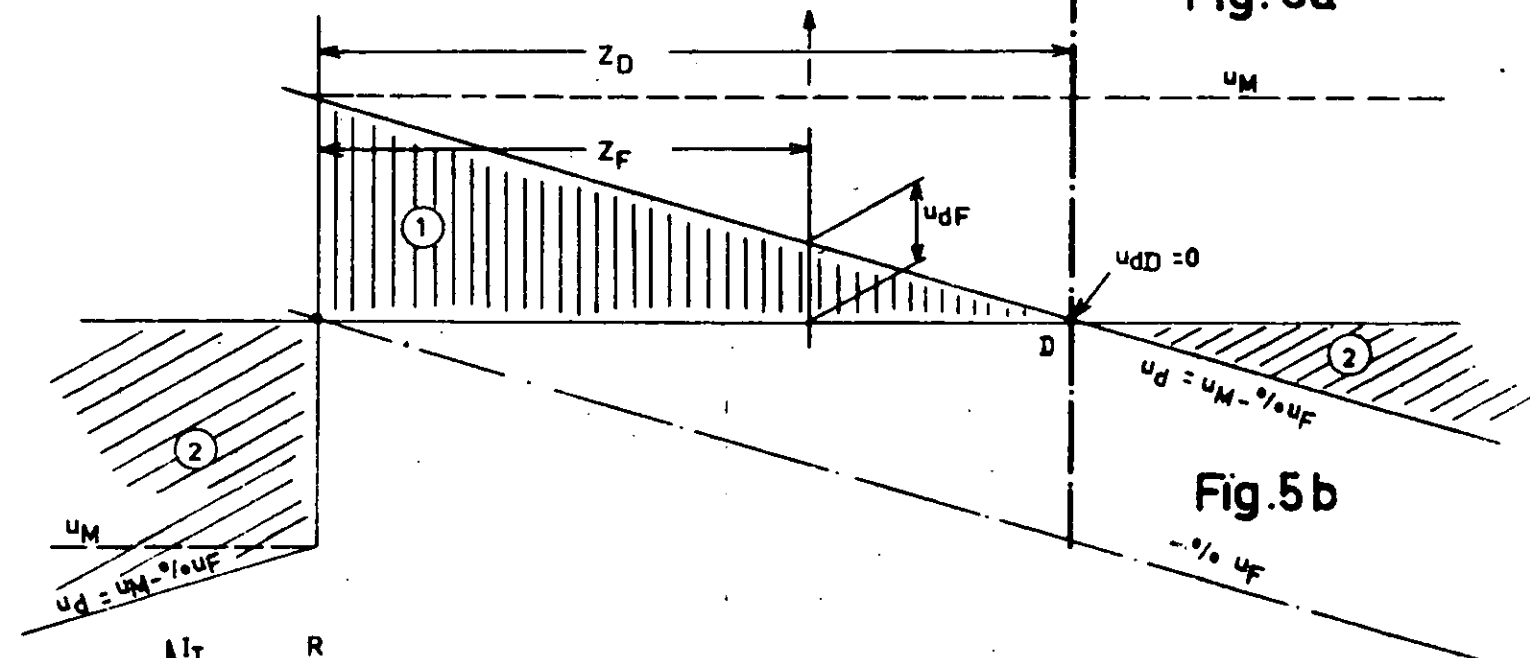


Fig. 5b

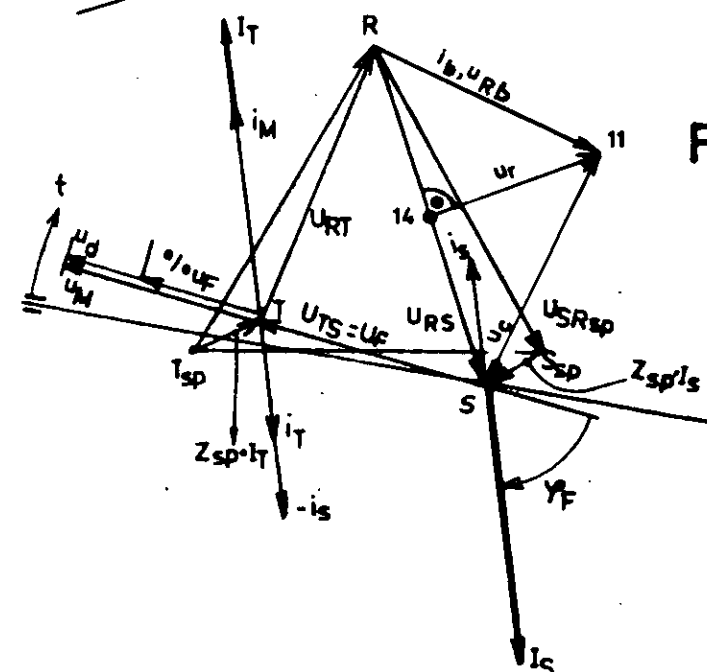


Fig. 5c

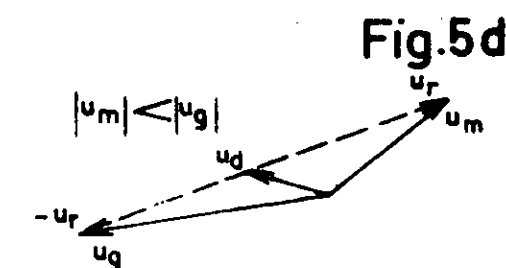


Fig. 5d

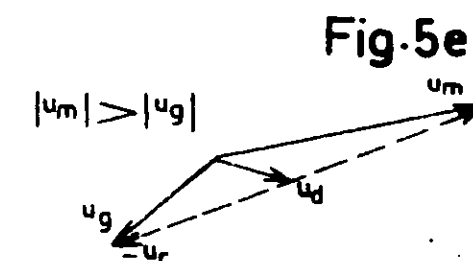


Fig. 5e

The characteristic "directional sensitivity" in the case of triple-pole faults can be explained as follows:

Let us assume that a triple-pole symmetrical fault occurs at the back of the distance relay (i.e. to the left of A in Fig.5a) so that $0,75 \times$ the rated current flows through the distance relay.

If the fault is some distance away, the PU is definitely drawn into the rest position, since both the reference and the difference voltages have appreciable values. Because of the triple-pole symmetry of the fault, the reference and fault voltages are equal.

Imagining that the fault is gradually coming closer, the voltages at the location of the relay fall, i.e. the reference voltage in the relay drops in proportion and the fault voltage decreases at the same rate. Since the current is assumed to be constant, however, u_d cannot become smaller than u_M ($\bar{u}_d = \bar{u}_M - \% \bar{u}_F$: see page 22 ff).

The fault finally reaches a point at which the reference voltage is so small that the effect of the difference and the reference voltages on the PU can still just prevent it from picking up, which the auxiliary tripping circuit wants to carry out. This limit defines the directional sensitivity, which is designated by the corresponding value of the reference voltage: in the case of LZ3...: 0.1 V.

This definition also means that in the case of triple-pole faults the circular locus in the R-X diagram just encompasses the point where the relay is fitted.

During all asymmetrical faults, however, even when these occur at the place where the relay is fitted, the reference value retains a considerable value, at least U_{ph-0} ; this is due to the fact that the leading healthy voltage is used as a reference;

u_d can once again not fall below u_M .

If the fault is now imagined as passing through the location of the relay, then the direction of the short-circuit current suddenly reverses and hence also the replica voltage u_M . The PU can therefore clearly recognize the direction of the fault, even if this were at the actual primary terminals of the main current transformer. The PU blocks if the fault is at the terminal K and trips if it lies at terminal L.

The auxiliary tripping circuit is not used during asymmetric faults.

This degree of directional sensitivity is referred to as "unlimited".

(The moving-coil relay in the PU cannot be interchanged with those in the Z, IE or IB relays, since these are adjusted quite differently.)

III.4 Current transformer SH1

The three built-in current transformers SH1 are used to supply the replica impedance M, for which purpose they:

- a. Step down to light secondary rated currents (to ensure small power consumption in current-measuring circuit and the possibility of changing over by means of light-current contacts).
- b. Create the required combination of currents (Sk2-6899) for correct measurement of distance, which necessitates isolating the secondary sides from one another.
- c. Introduce the summation current, as necessary.
- d. Are equipped with secondary tapplings to vary the transformation ratio so that the minimum measurement reactance w_L can be selected.

Each transformer comprises:

- 1 main primary winding (term. 3 + 4) for phase currents
- 1 main primary winding (term. 1 + 2), by means of which the position of the summation current on the phase current is excented during earth faults, which is essential for correct distance measurement.

Tappings enable the factor k_o to be chosen, which gives a numerical value to the amount by which the summation current is superimposed.

The k_o factor is calculated as follows:

$$k_o = \frac{1}{3} \cdot \left(\frac{X_o}{X} - 1 \right) = \frac{X_m}{X}$$

in which: X_o = Zero-sequence reactance

X = Positive-sequence reactance per phase

X_m = Mutual impedance between the two loops line-earth

The following values of k_o can be selected at the instrument transformer SH1:

0, 0.1, 0.2, 0.3, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0 and 1.5

The two cable shoes marked + and - are to be connected to the 5 tapping terminals, so that the difference of the terminal values produce the required k_o values:

e.g. cable shoe + to term 0.8 } $k_o = 0.7$
cable shoe - to term 0.1 }

- 1 secondary winding (term. 5 + 6) for feeding the replica impedance M. This winding has tappings, with which in the case of the LZ3 the minimum preset measurement reactance ωL (referred to briefly as the "measurement reactance") of the system M+PU can be selected referred to: $U_n = 100$ V and the 100% tapping at HG8, as follows:

Rated relay current	Measurement reactance	Terminal marking at SH1 $\omega L =$
5 A	0.15 Ω /ph	0.15
	0.2 Ω /ph	0.2
	0.4 Ω /ph	0.4
1 A	0.75 Ω /ph	0.75
	1.0 Ω /ph	1.0
	2.0 Ω /ph	2.0

At $I_n = 2$ A the reactances are half those at $I_n = 1$ A.

At $U_n = 200$ V the measurement reactances and values for ωL are doubled (for a definition of "measurement reactance" see also VII.e on page 110).

In the case of the relays LZ31 and LZ32, which are intended for particularly long lines or those carrying a very high load, which necessitates compounding chokes in the relays, the SH1 transformers normally have the following tapplings:

Rated relay current	Measurement reactance	Terminal marking $\omega L =$
5 A	0.4 Ω/ph	0.4
	0.8 Ω/ph	0.8
1 A	2 Ω/ph	2
	4 Ω/ph	4

When $U_n = 220$ V or $I_n = 2$ A the foot notes below the upper table apply.

Nevertheless, the designs in the first table can be built in LZ31 or 32 if required.

All the measurement reactances quoted can also be halved by means of a special connection at the HGB transformer (see page 33 and section VII.e).

III.5 Replica impedance M

The replica impedance produces a voltage \bar{u}_M proportional to the fault current and leading it by φ_M (normally $\varphi_M = \varphi_D$ is set).

The replica impedance consists of a choke with gap in the iron core with an absolute value of 40 Ω (at 50 c/s) in series with a sliding resistance, which enables the phase angle of the total impedance M to be varied infinitely between $\cos\varphi$ 0.1 and 0.8, so that it can be matched to the line being protected.

The choke has a linear characteristic, which it retains even with very heavy currents.

Because of the increased risk of earth faults in solidly earthed systems it may be found useful to set two different values of $\cos\phi$ at the replica impedance for interphase faults and faults involving earth. This is done by disconnecting the yellow link between terminals 2 and 4, whereupon the latter is connected to the setting attachment of the sliding resistance. This setting attachment is then adjusted to the required value of $\cos\phi$ during earth faults in accordance with the special instructions.

III.6. Matching transformer HG8


(For its purpose see under V.2)

Any percentage of the fault voltage U_f between 0.5% and 200% can be obtained from the matching transformer HG8 (see also page 22). These percentages are used to set the distance being protected by the measuring system M+PU.

The matching transformer HG8 is equipped with 4 + 4 flexible leads with shoes (4 for the unit percentages and 4 for the decade percentages) corresponding to the 3 distance steps of the characteristic and the possibility of an overlap connection (see page 72). Each pair of unit and decade leads is marked with coloured sleeves to indicate that they belong together, as follows:

white	:	step I
yellow	:	step II
red	:	step III
green	:	overlap A

These cables shoes are to be connected to the percentage tapping terminals of the matching transformer HGB, which correspond to the required distance steps (for the calculation of the required values see page 109). The additional cable shoe identified by a black sleeve is connected to the terminal $c = 1$ (normal), the percentages indicated next to the transformer terminals 0 - 90% and 0 - 9% apply, the minimum step being 1%.

Example A: Marked with  along the sketch below

To be set: 64%

Connections: Unit cable to 4%, tens cable to 60%

Percentages between 110 and 200% in steps of 10% are set by connecting the one-percent cable shoes of the relevant step to the terminal 110% and the ten-percent shoe to the terminal, whose marking plus 110 produces the required percentage.

Example B: Marked with 

To be set: 160%.

Connections: ten-percent shoe to $160 - 110 = 50\%$

one-percent shoe to 110%

cable with black sleeve to $c = 1$

If all required percentages are smaller than 50%, the smallest step can be set to 0.5% by connecting the "black" cable shoe to the terminal $c = 0.5$. The percentages marked at the transformer terminals then only apply at half-value.

Example C: Marked with 

To be set: 43.5%

Connections: one-percent cable to 7% and the ten-percent cable to 80% so that

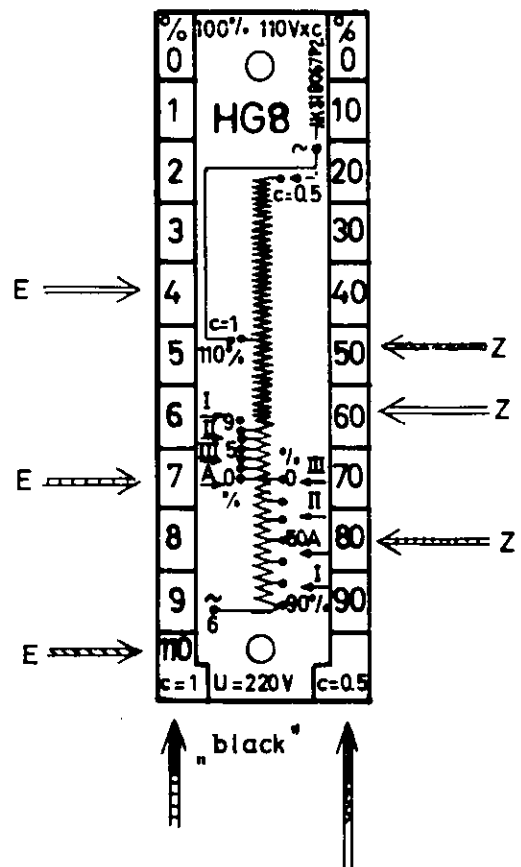
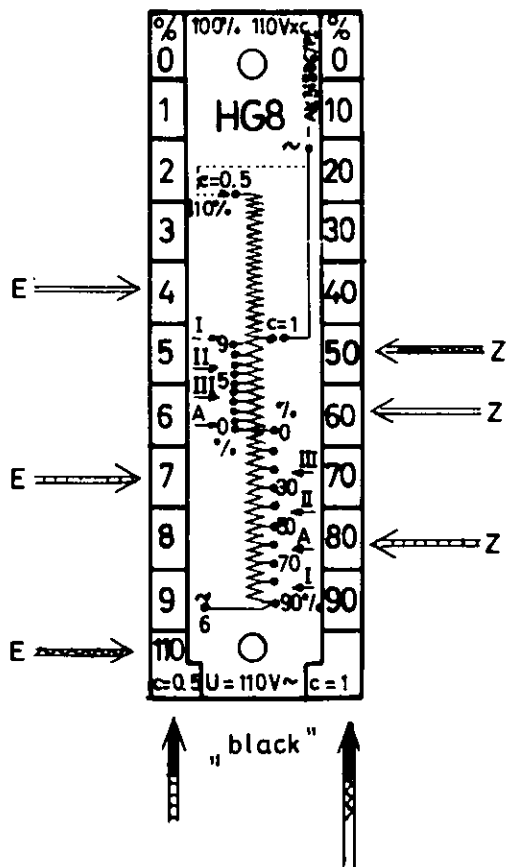
$$\frac{80+7}{2} = 43.5\%$$

Cable with "black" sleeve to $c = 0.5$.

Warning: If $U_n = 220 \text{ V}$, no other cable than that with the black sleeve may be connected to the terminal $c = 0.5$.

$E = \text{One-percent cable}$
 $Z = \text{Ten-percent cable}$

} of the step in question



(see also section VII.e)

Tapping for given percentages at the matching transformer HG8.

III.7. Time-step relay I (complete type designation Taj)
(for purpose see under V.2 below)

The time-step relay comes into action as soon as one or more impedance starting relays Z have picked up.

The relay I is used to feed the percentages of the fault voltage corresponding to the distance steps obtained at the tapplings of the matching transformer HG8 (see page 32) in the correct timing sequence - which is adjustable - to the difference circuit (see page 22) of the distance measuring system M+PU. In this way the range is increased in accordance with the stepped characteristic.

At the start a d.c. solenoid is energized, which releases a tensioned spring driving the camshaft, whose rotation is regulated by a mechanism running in dust-proof bearings. This spring drive ensures that the time measurement is independent of fluctuations in the auxiliary voltage.

As soon as the fault disappears, causing the Z relays to reset, the cams immediately return to their original positions. By loosening the large knurled nut at the right-hand end, the five cams can be adjusted independently. A scale marked in steps of 0.1 s can be found on each cam. By looking horizontally through the transparent strip in front of the cam edges and aligning the black line on the transparent strip with the line on the metal mirror the scale indicates when the associated contacts change over after the beginning of the fault (1 make and 1 break contact). The cam I is normally set so that its contacts are always closed, which ensures that the relay trips in case of faults within the first distance step in the shortest possible time. In special cases the basic time (step I) can also be extended.

On actuation of the sets of contacts II and III, they energize the auxiliary contactors CS II and CS III, which initiate the changeover of the tappings I, II and III selected at the transformer HG8.

The cam IV is normally set to 0.3 s, as explained on page 70 , section V.3.b, para. 5 and V.3.c.1, last paragraph.

The so-called non directional time limit is set on cam V: this time depends on conditions in the network, but in any case it is longer than any of the other time steps. When actuated, the set of contacts V gives the tripping command to the circuit-breaker, irrespective of the direction of the sustained fault within the pick-up range of the impedance relays.

With regard to the duty cycle of the coil in the relay T, reference should be made to III.13.b below.

III.8. Selector switches W and Wa

The selector switch W is used to set the type of operation of the auto-reclosure device. The following programmes are available:

Position 1: Indication: 1+3 ph



Single and three-phase auto-reclosure. During single-phase faults, i.e. earth faults, only the breaker pole in the affected phase is opened and reclosed. If the fault affects two or three phases, all three breakers perform the switching sequence.

Position 2: Indication: 3 ph



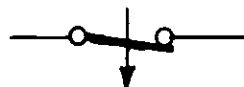
Three-phase auto-reclosure. All faults cause the three breaker poles to open and reclose.

Position 3: Indication: 1 ph



Earth faults result in an off-on sequence of the breaker pole in the affected phase, whereas 2 and 3-phase short-circuits always cause the breakers to lock out in all three phases.

Position 4: Indication: 3 ph



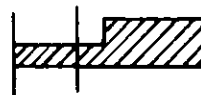
No auto-reclosure

Any fault causes all three phases of breaker to lock out.

Positions 1 and 3 are only to be used together with systems having a solidly earthed neutral.

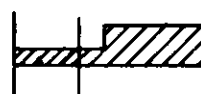
The changeover switch Wa controls the overlap circuit (see Page 72) and has the following two positions:

Position A : Indication:



Overlap circuit in action, coil of CSA contactor switched in; the distance selected by means of the "green" cable shoe "A" at the transformer HG8 represents the basic distance, except during the blocking time (i.e. a few, usually 4 s after the "first" tripping of a breaker equipped with auto-reclosure). The percentage picked off with the "white" cable shoes "I" applies to the first step (for details see page 72).

Position I : Indication:



No overlap. As soon as the fault appears the first distance step comes into action in accordance with tapping I at the transformer HG8.

If no overlap mode is needed, the selector switch Wa can be used for other purposes: if the wire AK 43-44 is removed and the input of an h.f. or wire coupling is connected to AK 44,

a follow-up circuit results, which can be switched in or out with the selector W_a (see V.3c.3). Similarly, after removal of AK 43-44 a command can be fed in from the outside on terminal AK 44, which enables the range of the basic time to be changed over to suit changing system conditions, e.g. variations associated with the time of day (see V.3f, page 101).

III.9. Compounding the impedance starting relay Z

(chokes built into types LZ31 and LZ32)

When protecting long lines, the required setting value for the impedance relay Z can be very close to the minimum service impedance; under certain circumstances the minimum service impedance could in fact be smaller than the starting impedance to be set in order to obtain the required range of protection (absolute values). This would lead to tripping when no fault is present.

The two conditions: heavy load and short-circuit differ with regard to the phase angle between current and voltage. This fact is exploited by compounding, which gives the Z relay a greater range during short-circuits.

A compounding choke X_R , X_S and X_T (for short: X_{ph}) is fitted in each phase, the corresponding phase currents flowing through the primary windings of the chokes. These chokes have an air-gap in the iron core.

In the path of the summation current there is an identical choke X_o .

In their secondary windings these chokes X_{ph} produce a voltage \bar{U}_X whose amplitude is proportional to the amplitude of the primary current \bar{I}_{ph} . The phase of \bar{U}_X leads \bar{I}_{ph} by a given phase angle φ_X , which is matched to the protected line. This is achieved by connecting a fixed resistor in parallel to the secondary winding or a part of it (Fig. 6 and 7).

This voltage \bar{U}_X is connected in series with the corresponding voltage of the associated starting relay Z , so that \bar{U}_X opposes the phase voltage \bar{U}_{ph} when a fault occurs. As a result, during two and three-phase short-circuits the impedance Z_c is simulated to the impedance relay giving it the impression of a value which is smaller than the actual impedance U_{SR}/I by:

$$Z_X = \left| \frac{\bar{U}_{XR}}{I} \right| + \left| \frac{\bar{U}_{XS}}{I} \right|$$

Hence the point at which the measurement takes place is advanced electrically along the line by Z_X . If $\varphi_X = \varphi_L$, the voltages U_X have the same direction as U_{SR} during short-circuits, so that direct algebraic subtraction is permissible and a simplified diagram can be drawn (Fig. 6, page 44).

(For the definition of the arrows and vectors see page 20 .)

As in Fig. 5, the same simplifying assumption of $I_K = \text{constant}$ and not affected by the distance to the fault is made, so that once again $\bar{U}_X = \text{const.}$ can be represented by a horizontal line. Moreover, $\bar{U}_{SR} = I_K \cdot Z_F$ is proportional to the distance to the fault. The line inclined upwards from A means that the voltage in A - supposing a fault at H - has a value represented by the distance between the 0 and \bar{U}_{SR} lines at the point H.

If the two lines \bar{U}_{SR} and \bar{U}_X are superimposed, \bar{U}_{CH} is obtained, which shows that the sign of this voltage changes in H. However, since the starting relay is non-directional, only the absolute value of \bar{U}_{CH} is significant.

The division of \bar{U}_{SR} by I_K produces the line Z_A , which in a similar manner to the line \bar{U}_{RS} indicates the impedance to be measured from A in the case of a fault whose position is imagined to be variable along the line.

The line broken at H for Z_{CH} represents the expression \bar{U}_{CH}/I_K , which also indicates an impedance measured by a relay, in this case that by the relay Z_R : the value is the vertical distance between the zero line and Z_{CH} .

During normal operation and fault conditions the relay Z_R therefore measures to the right of H as though, from an electrical aspect, it were installed at H, although in fact it is located at A and is connected there.

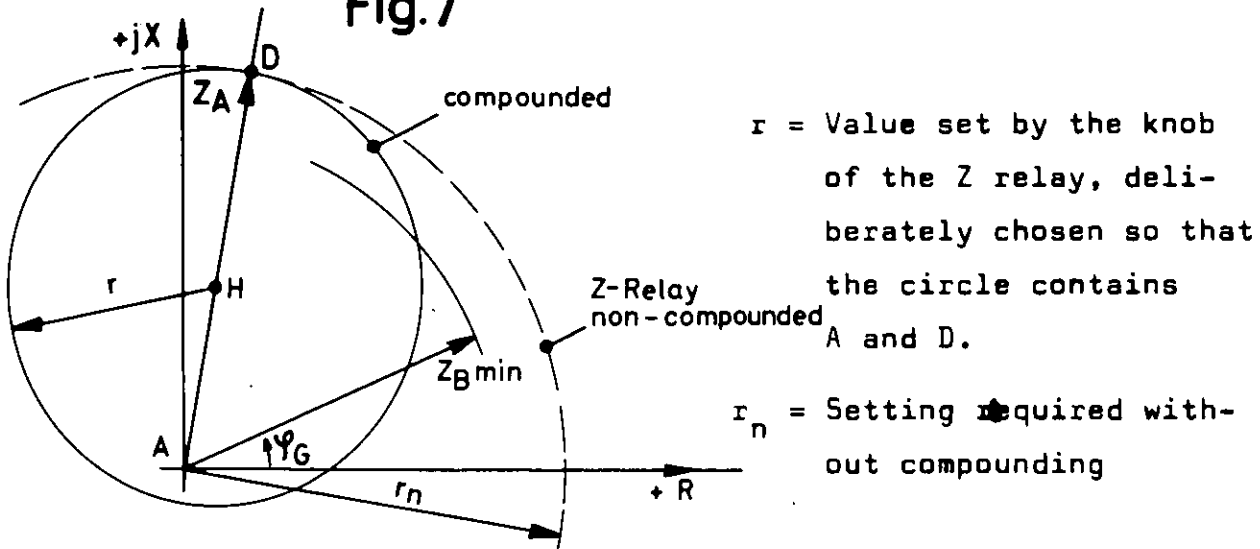
In the case of faults between A and H the impedance relay at A obtains a voltage, which is "imaginary" insofar as a relay actually located at H would not receive this imaginary voltage but - with unilateral infeed from A - only the voltage as at the place where the fault occurs (perhaps even 0) without current, so that it would not pick up. On the other hand, the imaginary voltage $U_{SR}-U_X$ together with the fault current at A ensures that the relay reacts correctly.

With infeed at both points of the line A and D, a second voltage distribution in the form of a mirror image to Fig. 6 takes place, so that the above logically applies to the relay at D as well.

To prevent the voltages U_X during heavy-current faults close to the relay from rising so much that the voltage influence predominates in the relay Z and thus prevents it picking up correctly, the design of the X chokes is specially adapted: they begin to saturate as U_X exceeds a given percentage of the phase voltage, i.e. U_X remains limited.

In the case of a relay Z compounded to simulate location at H, the R-X diagram is as follows:

Fig.7



Remaining designations as in Fig. 6

Since the subtraction is actually carried out vectorially, this facilitates the distinction between the service current (i.e. with consumer connected) - whose phase angle between the phase voltage and current is usually less than 26° (p.f. 0.9) - and the fault current as determined by the short-circuit phase angle between the line voltage and the current in the line (approx. 80° corresponding to a p.f. of 0.2).

This is demonstrated by the vector diagram in Fig. 8a drawn for the normal condition of the relay - subscript G - and for two-pole short-circuit not involving earth - subscript K - assuming $|\bar{I}_K| = |\bar{I}_G|$. (This assumption was chosen because it simplifies understanding, but it is certainly feasible.)

The principles of compounding apply of course under other conditions as well. The voltage circuit of the Z_G relay is fed by the phase-to-phase voltage U_{SR} . The vectorial subtraction:

$$\bar{U}_{SR} - \bar{U}_{XR} - \bar{U}_{XS} = \bar{U}_{CSR}$$

produces clearly differing values: $|\bar{U}_{CGSR}|$ and $|\bar{U}_{CKSP}|$ (Fig. 8b), in spite of the fact that $|\bar{I}_G| = |\bar{I}_K|$

If the service current I_G is purely resistive, the voltages U_X - which are virtually perpendicular to I_G - only cause a displacement of the phase-to-phase voltage for the Z relay (the change in value at $\varphi = 0$ is insignificant): the impedance value measured then is therefore not affected by resistive service currents.

In Fig. 8b a service current at a p.f. = 0.9 was assumed, resulting in a slight reduction of the phase-to-phase voltage due to the compounding at the impedance relay and hence also of the measured impedance (by about 20%).

In a similar manner the service current in the healthy phase, which completes the circuit through the two affected phases during an interphase fault, only causes a parallel displacement of the affected voltage for the Z relay; the measurement is therefore not influenced.

During earth faults, the current flows through the earthing impedance, for which reason a choke X_0 is provided in the path of the summation current. When CE is attracted, the secondary voltage of this choke then acts in a subtracting sense in the neutral conductor of the voltage circuit of the starting relays Z, thus achieving the same result as the X_{ph} chokes in the phases during the interphase faults of the example above.

During earth faults the summation current produces a secondary voltage in the choke X_0 , increasing the healthy voltages for the Z relay and protecting it still more against undesired operation.

The degree of compounding is set by means of tapplings at the primary winding, thus selecting the size of the secondary voltage in proportion to the primary current. This ratio is expressed in Ohm ($\frac{U}{I}$), so that the tapping terminals are designated directly in n/ph, i.e. by how many n/ph the electrical position of the impedance relay (only the starting relays and not the M+PU measuring system) is advanced along the line, so to speak.

As in the case of the X chokes in the phases, the X_0 choke has to be set according to conditions in the network, i.e. to $X_0 = k_0 X$ (where X is the compounding impedance (Ω/ph) set on the other X_{ph} chokes in the phases and k_0 the summation current factor set on the SH1 instrument transformers).

The phase angle between the primary current I_{ph} and the compounding voltage \bar{U}_X should be about the same as the angle φ_L of the object being protected. This is obtained with the aid of the resistor R built on to the choke, through this match does not have to be very precise. In many cases it is useful to set the compounding more inductive than φ_L .

The secondary winding has one tapping i.e. the terminal 4.

The power factor can be set to the following values:

p.f.	Connect R to terminals:	The primary Ω/ph values are to be multiplied with: (correction)
------	-------------------------	--

0.02	3 - 3 (R not effective)	1.0
0.2	3 - 4	0.95
0.35	3 - 5	0.88

The effect of the Ω/ph value set on the primary side can be reduced to 70% by means of the terminal 4 at the X chokes. This is done by changing the wire from terminal 5 to terminal 4.

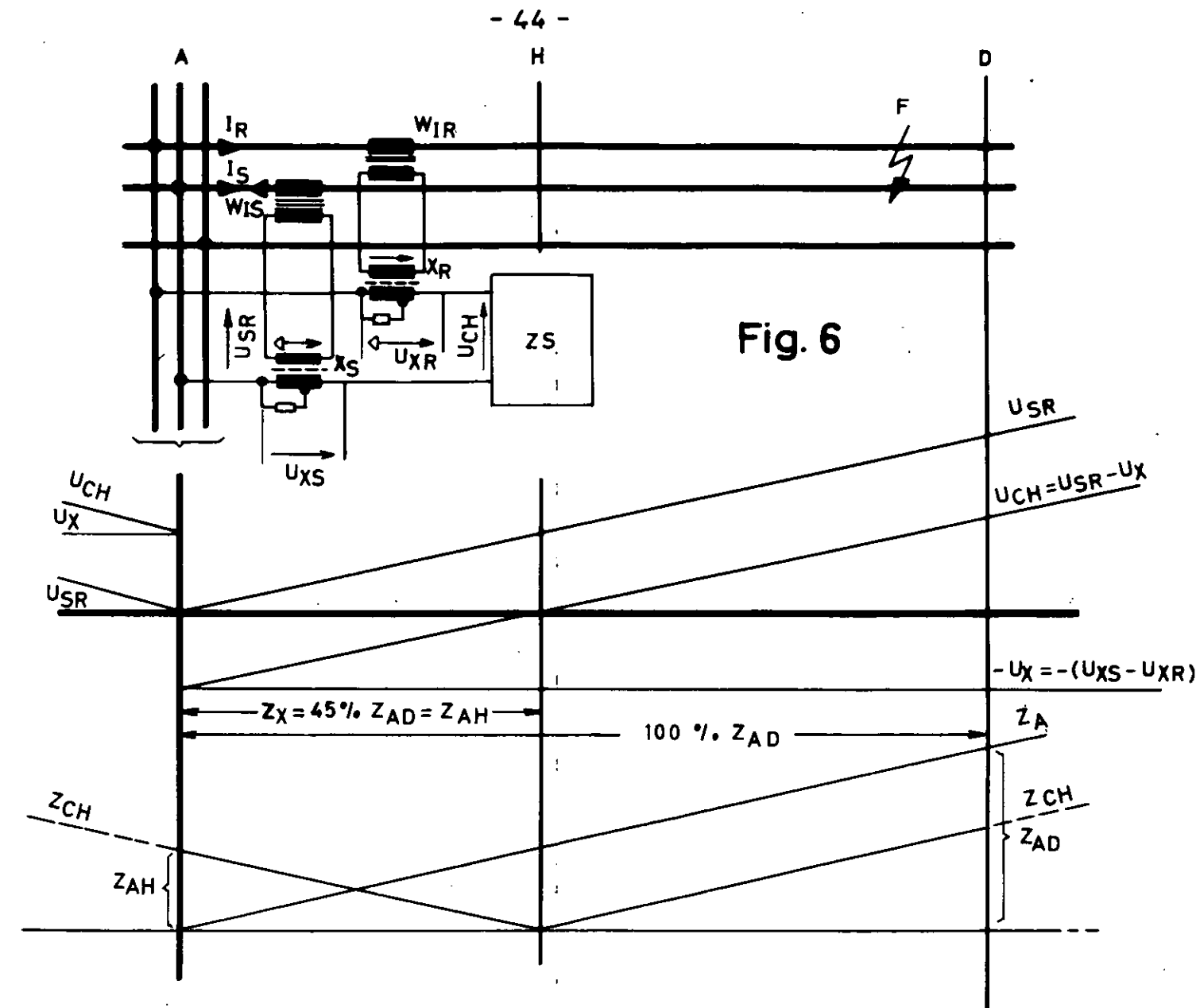
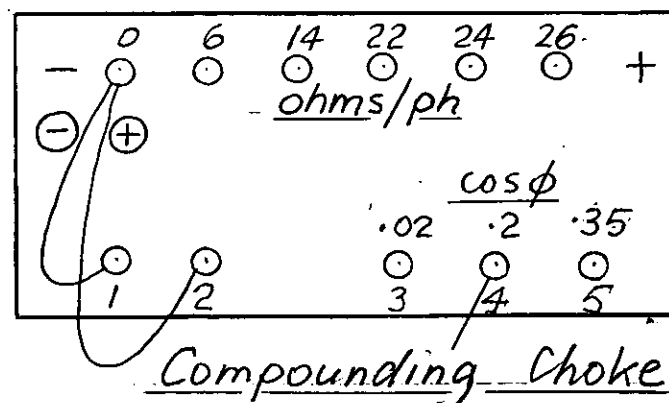
This is useful, especially in the case of the X_0 choke, since the earth-fault impedance is often smaller than the phase impedance. At $k_0 \sim 0.7$ the primary setting of all the X chokes can therefore be the same, the low value of the earth impedance being taken into account by the reconnecting of the wire from terminal 5 to terminal 4 at X_0 .

Fig. 6:

Compounding of the Z starting relay

Simplified representation for $\varphi_K = \varphi_X$

A - D	Section of line to be protected by the range of the starting impedance relay Z
H	The compounding displaces the relay situated in A electrically to this point
X_R, X_S	Compounding chokes in phases R & T (X_T, X_O omitted)
W_{IR}, W_{IS}	Current transformers
ZR	Impedance starting relay in phase current S
I_R, I_S	Currents in phases R and S
U_{SR}	Fault voltage
U_{XR}, U_{XS}	Voltage at compounding chokes
$U_X = U_{XS} - U_{XR}$	
U_{CH}	Voltage at the terminals of the Z relay when compounded towards point H
Z_{AD}	Impedance of line section A - D
$Z_{CH} = U_{CH}/I$	Impedance measured from relay ZR when compounded towards point H
Z_{AH}	Impedance of line section A - H
Z_A	Impedance measured from point A without compounding
Z_X	Compounding impedance set at X_R and X_S



- Indicates the beginning of the winding (polarity marks) so that these two coils are therefore of opposite polarities
- AK1, AK2... etc. Terminals
- I Current in protected line
- \bar{U}_C "Imaginary" voltage at impedance relay due to compounding
- \bar{U}_X Compounding voltage at terminals 3-5 of X
- X_R, X_S, X_T Compounding chokes
- Z_R, Z_S, Z_T Starting impedance relays

Subscripts:

- G Normal condition
- K During interphase short-circuit
- R, S, T Phases

Example:

\bar{U}_{XRK} Voltage at compounding choke X_R due to phase current R during short-circuit

It can be seen that:

$$\bar{U}_{CK} < \bar{U}_{CG} \text{ and since } \bar{I}_K = \bar{I}_G \text{ also } \frac{\bar{U}_{CK}}{\bar{I}_u} = \bar{Z}_{CK} \quad \bar{Z}_{CG} = \frac{\bar{U}_{CG}}{\bar{I}_K}$$

which clearly reveals the difference between a short-circuit and a heavy load though without fault, although the absolute values for the currents are assumed to be the same.

Compounding the impedance starting relay Z

Example by way of comparison for $I_G = I_K$ and p.f._G = 0.9, $\varphi_K = 80^\circ$ during operation under heavy load and interphase fault.

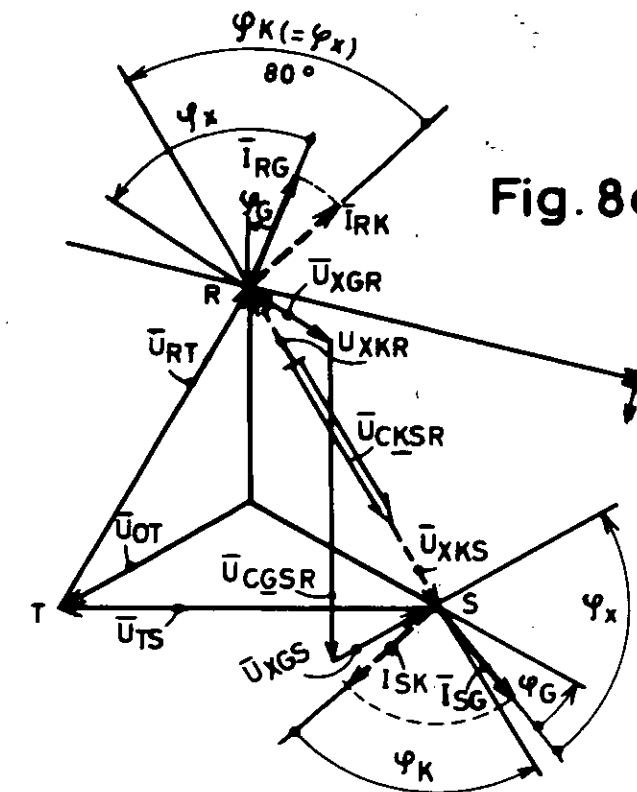


Fig. 8a

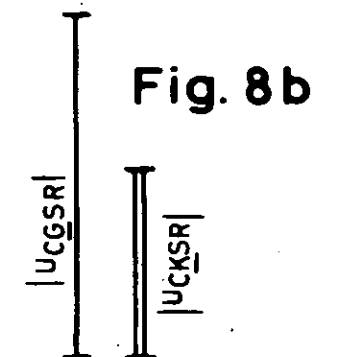


Fig. 8b

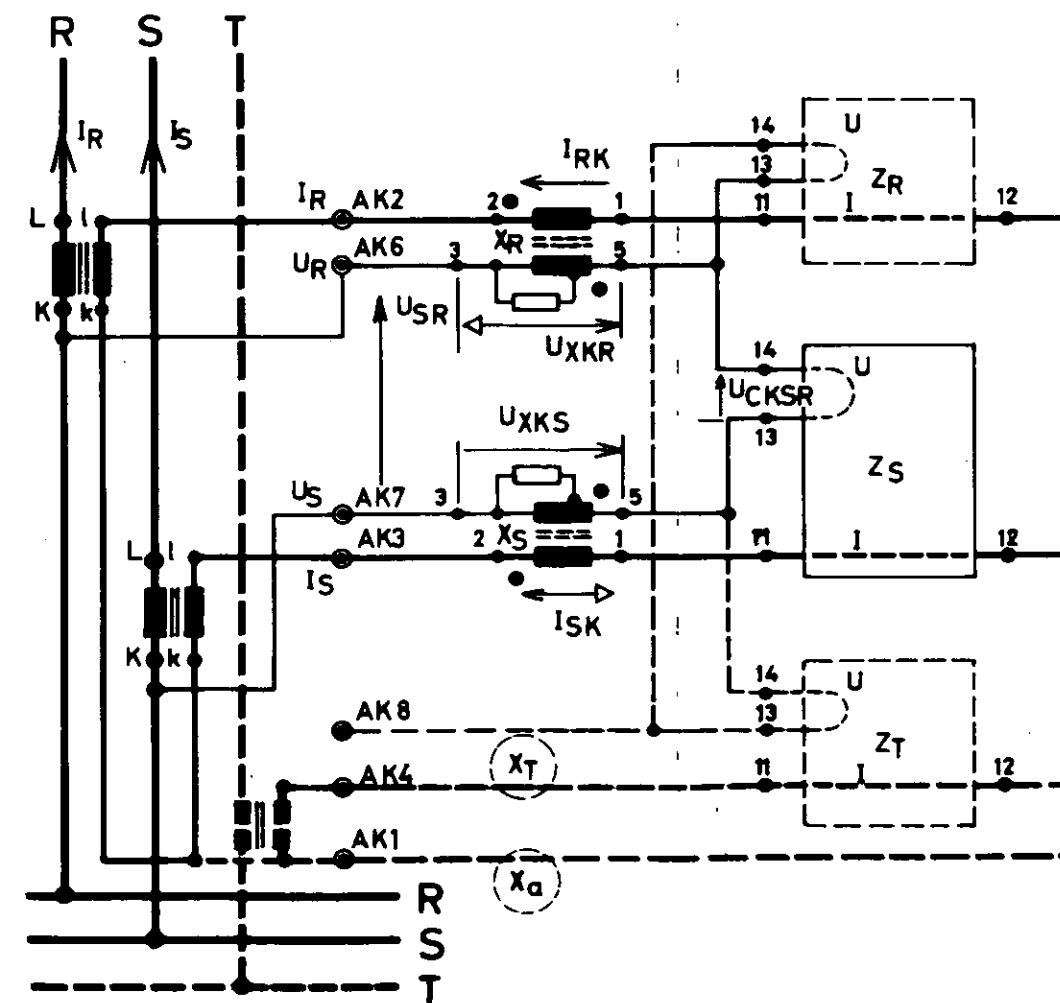
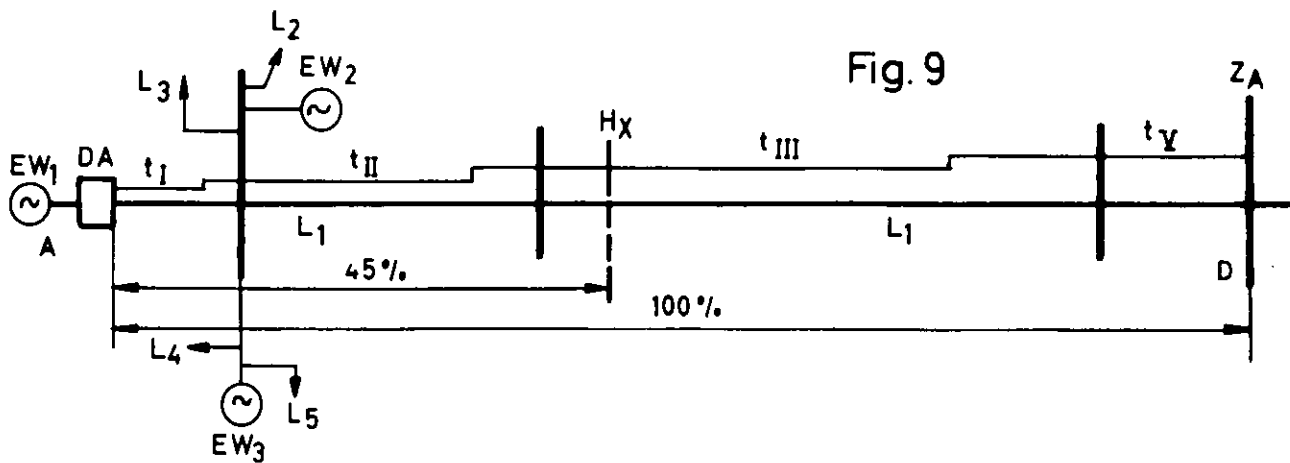


Fig. 8c

An interesting application: (Fig. 9)



The power station EW 1 supplies another station C via the short line A - C, the station C forming an energy centre, into which a few other stations feed, say EW 2 and EW 3, etc., some of which are at the end of long lines. The distance relay DA is to act as the back-up protection for the outgoing lines, e.g. L1 at the higher time steps or limit time.

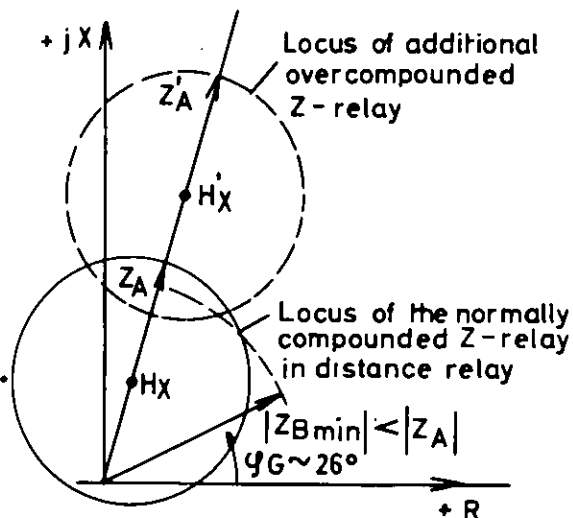
Seen from A, however, the starting impedance Z_A is greater than the minimum service impedance Z_B , which occurs if, for some reason, one or more of the other power stations are disconnected from the busbar C. This creates an overload condition for EW 1, due to the sum of the loads in the outgoing feeders $L_1 - L_5$, resulting in the small service impedance $Z_B < Z_A$. Accordingly the non-compounded Z relays in DA would pick up and undesired tripping could result.

This is all the more to be avoided, since it could cause a ~~break~~ break down of the system. It is preferable to continue the overload for EW 1, at least until such time when EW 2 and EW 3 can be synchronized again.

If DA is compounded to 45% of the distance A - D, i.e. so that electrically it would be located at about H_X , then the locus centre would be displaced towards H_X (as already shown in Fig. 7); the tip of the vector of the minimum service impedance $Z_{B_{min}}$ would now be outside the locus and the Z relay would not pick up, even though $|Z_{B_{min}}| < |Z_A|$, as shown in the diagram below.

Fig. 9a

If the starting reach Z_A' should extend still further, without a risk of tripping during overloads, then 3 additional impedance relays could be fitted outside the distance relay, each with 1 compounding choke. These chokes could be set in accordance with the dotted circle alongside, i.e. the measurement location compounded towards H_X' .



~~III.18. Rotating field indicator~~

~~The rotating-field indicator is incorporated for checking the mains voltage for failure or for correct phase sequence. This indicator comprises a combination of capacitors and resistors, which feed the pilot light RST in the control panel. During normal operation this light is bright. When the bulb stays dark or goes out altogether, the voltage circuits (AK 5, 6, 7 and 8) should be checked for phase sequence or for a drop in voltage below 0,7 U_n.~~

~~In the case of relays for auxiliary voltages of 110 - 220 V, the neon lamp (G.E. type NE 51) can be changed with that in the polarity indicator G for the auxiliary direct voltage, so that~~

~~it can be tested in this position. Since the lamp itself contains no series resistance, it must never be connected to the supply unless a resistance (approx. 50 k Ω) is in circuit.~~

III.11. Checking the auxiliary d.c. supply

The pilot lamp G in series with the diode G_p is provided to check whether the direct voltage is connected to the correct pole (AK 13 +, AK 14 -) or whether this voltage is available at all.

In the case of auxiliary voltages of 110 - 220 V the neon lamp (G.E. type NE 51) contains a lamp which is interchangeable with that of RST, so that it could be checked there. The required series resistor is included in the lampholder.

A filament lamp is provided for auxiliary voltages between 24 and 60 V.

III.12. Auxiliary contactors

The other individual components in the distance relay include:

a) Time-lag auxiliary contactors PTa and PTr (NEVER oil the delay mechanisms; for further information please refer to the particular descriptions of these types of contactors).

b) Hinged-armature contactors type C

When carrying out checks or during testing, it must be borne in mind that the coils of the CAR, CAS, CAT CE and CD contactors must not remain switched on without interruption for longer than 2 minutes. An interval of 10 minutes for cooling must follow, or during ON-OFF sequences a 20% duty-cycle duration is permissible within 10 min. This design is necessary to ensure fast operation. It should also be re-

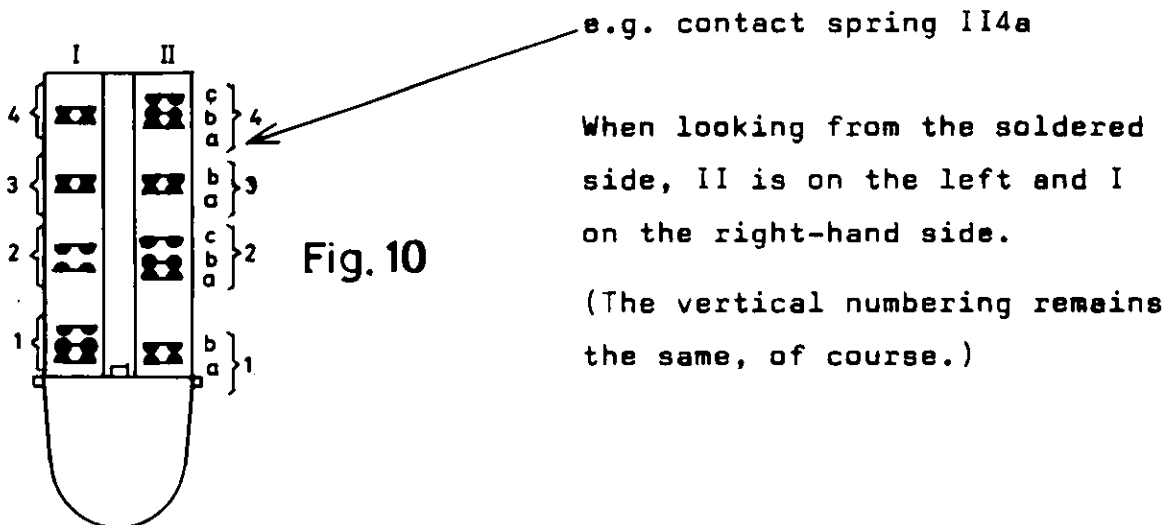
membered that in the case of a short-circuit in the network, the coils are in circuit for no longer than 5 s (max. basic time V at T), so that from a thermal aspect they are quite safe.

The setting of the contacts must not be disturbed: they are therefore protected by a transparent cover, which should never be removed.

It is nevertheless possible to test the contactors by depressing the hinged armature with the tip of the finger, for which the armature projects beyond the cover plate.

In order to locate a particular contact spring from the reference numbering shown in the drawing, the following diagram should be resorted to: (Fig. 10)

When looking from the contact side, i.e. through the transparent cover:



III.13. Connection

The distance relay is connected to the instrument transformers the d.c. supply, circuit-breaker, h.f. switchgear and signalling devices through the terminals AK. Some of these connections are led through terminals in the relay, which are grouped together and are readily accessible. These test terminals enable the connections to be very simply interrupted and are also used to plug in the relay test set type BB; the distance relay can be checked in situ with this test set without having to disturb any connections. Holes allow leads with banana plugs to be inserted.

When plugged in, the test set is automatically supplied with power from the main voltage transformers via three fuses contained in the relay (Si).

The double-pole switch G on the control panel allows all the d.c. supply to the distance relay to be switched off.

IV. GENERAL DESIGN OF THE DISTANCE RELAY

All components are mounted on a hinged frame, which can be swung out of the housing by more than 90° . The upper four supporting members of this frame are individually hinged, while the remainder of the frame stays fixed in the housing. These supporting members carry the starting relays, the hinged-armature auxiliary contactors, the time-lag auxiliary contactors and the control panel. This layout ensures maximum access to all components.

The relay frame is accommodated in a dust-tight cast housing, the door of which is provided with a large window and easily removable to allow more extensive work to be carried out inside the housing. The latch can be secured with a padlock or a lead seal.

The housing is available for flush fitting (AK 42089a) or surface mounting (AK 420891a).

The terminals are located on the rear of the housing. In the case of the raised design, connections can also be made from underneath, when the wires are introduced into the housing through a felt seal.

IV.1. Colour code for wiring

The colours of the wiring are based on the following code:

Connections between terminals or soldered junctions that are nowhere interrupted by contacts or yellow wire links employ the same colour on all sections.

The large number of connections covered by this rule makes it essential for a particular colour to be used more than once for the various sub-systems.

For example, the following two systems which are always fully isolated from one another are marked with the colours red - white - yellow:

In the voltage measuring circuit:

K8 → 17; K8 → R3a → R6a and K8 → XT3

In the auxiliary d.c. circuit:

AK 41 → Ta and AK 41 → T5 → PTaW → CE_I 7b

Beyond coils, contacts, test terminals and removable yellow wire links, the colours characterizing that system then appear, e.g. at AK 42: red-blue-green; at Tb: blue; at T4: grey-red, etc.

V. OPERATION OF THE DISTANCE RELAY AS A UNIT

RK denotes a normally closed contact (e.g. RK-CAT_{I3})

V.1. Selecting the phases for the M+PU measuring system

A distinction must be made between faults in the lines during which:

a) No summation current occurs:

These include: interphase and triple-pole symmetrical short circuits, whether the neutral is earthed or not, and inter-phase faults with earth leakage at the point where the fault occurs in systems with isolated neutral.

b) A summation current does occur, which causes the earth-fault relay CE to pick up.

These include: single and double-pole earth faults in systems with earthed neutral and double earth faults, irrespective of the neutral connection.

In normal service and in the case of line faults without summation current the voltage circuit of the impedance relay is connected by means of the terminal 13 to the phase according to which the relay is designated, whereas terminal 14 is connected to the phase which leads. This can be summarized as follows:

Voltage circuit of relay	Connected to phase		Thus voltage
	via term.13	via term.14	
ZR	R	T	U_{RT}
ZS	S	R	U_{SR}
ZT	T	S	U_{TS}

The current circuits of the impedance relays are always in the phase, according to which the relay is designated.

If a line fault occurs without summation current, e.g. inter-phase between R and S (Fig. 11), the voltage U_{RS} collapses to the lowest value, whereas the two other phase-to-phase voltages are only slightly reduced and may differ from one another.

Incidentally: the choice of the interphase fault between R and S (as opposed to ST under III.3c above) was deliberate in order to demonstrate the function of the current changeover for M.

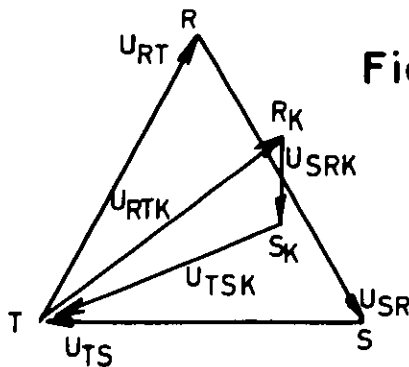


Fig.11

Shift of the voltage vectors at the point where the relay is fitted during interphase fault RS

Index K: during fault RS

Without additional index: during normal operation

As in Fig. 5, the same current I_K flows in the two affected phases (in this case R and S).

The relay ZS measures: U_{SRK}/I_K and as long as this value is smaller than the value set on the relay, it picks up.

The relay ZR measures: U_{RTK}/I_K , which because of $U_{RTK} > U_{SRK}$ produces a larger impedance than the value measured in ZS, so that ZR does not necessarily pick up.

If however the short-circuit current is sufficiently large, then U_{RTK}/I_K can also become smaller than the preset starting value, so that ZR may pick up as well.

Incidentally: ZT only receives the service current I_T , whereas the voltage U_{TSK} is hardly changed: ZT therefore does not pick up.

CAS and possibly also CAR will attract, thereby applying the following phase-to-phase currents and voltages to the M+PU measuring system:

The fault voltage U_{SRK} (see AK 112009 and 2-100546)

Phase R: (via contact CAS_{I3} through $RK-CAT_{I3}$ and CE_{I3}) to terminal 1 of the transformer HG8

Phase S: (via contact CAS_{I4} and $RK-CAT_{I4}$) to terminal 6 of the transformer HG8
.....

If CAR picks up as well, the contacts CAR_{I3} , $I4$ and $I5$ change over as well, which has no effect whatever, since only blind connections are involved.

The reference voltage U_{RTK}

Phase R: (via contact CAS_{I2} through $RK-CAT_{I2}$) to terminal 21 of Xb

Phase T: (via contacts CAS_{I1} through $RK-CAT_{I1}$) to terminal 20 of Xb
.....

If CAR picks up as well, this has no effect on the choice of phases either.

The composite fault current $I_S - I_R$ (see also Fig. 12)

Share of the current - I_R

from SH1R terminal 5 (via $RK-CAR_{II1}$) to terminal M2

or from SH1R terminal 6 (via $RK-CE_{II1}$) to CAS_{II1} and
.....
via $RK-CAT_{II1}$ to M1

Share of the current I_S

from SH1S terminal 5 (via CAS_{II1} and $RK-CAT_{II1}$) to M1

from SH1S terminal 6 (via $RK-CE_{II2}$ and CAR_{II2} and through CAS_{II2} and $RK-CAT_{II2}$) to M2

The considerably simplified diagram below shows the current connections to the replica impedance in the case of an inter-phase fault RS.

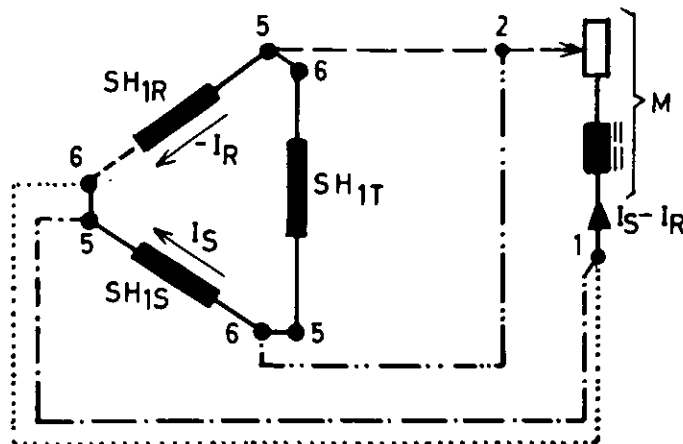


Fig.12

If CAR has picked up as well, this only affects the patch of the above current connections, without however altering the relationship between the instrument transformers and the replica impedance M. If CAS (and possibly also CAR) has picked up, SH1T is short circuited on the secondary side.

The contacts of the auxiliary contactors are arranged, so that the supply to the M+PU measuring system is always determined by that impedance relay, whose phase designation according to phase sequence is the lagging one.

In our example: if ZR and ZS pick up, ZS decides. This is known as the preferential-sequence method, briefly:

S preferred to R

T preferred to S

R preferred to T

Thus by the mere substitution of R for S, S for T and T for R, conditions in the case of short-circuits ST and TR can readily be derived.

In a system with isolated neutral, an additional earth fault at the point where the short-circuit occurs would not alter the above-mentioned circumstances.

The earth-fault is the most common occurrence in systems with earthed neutral. The resulting summation current I_g causes the earth-fault relay IE to pick up. With the aid of its auxiliary CE contactor, this relay changes over the voltage circuits from phase-to-phase to phase-to-neutral voltages, thus ensuring that the impedance in the line-earth loop is correctly measured.

In addition the CE contactor prepares the choice of measurement quantities, in this case phase values, (in contrast with the line-line values in the case of faults without summation current) for the M+PU measuring system in accordance with earth-fault conditions, by:

- a) opening the delta connection in the secondary sides of the transformers SH1 for the current circuit of the replica impedance M and instead transfers all the current-transformer terminals 6 to the star point, which is permanently connected with M2

and

- b) connecting terminal 1 of the transformer HG8 to the star point AK5 of the mains voltage transformer for the fault voltage U_F .

The reference-voltage circuit remains connected to the line voltage. CE only short-circuits a part of the resistor R_b at the phase shifter $R_b + C_b$. Thus it achieves a phase shift of 102° instead of 90° , making the angle between the reference voltage and the earth-fault current as near a right angle as possible, so that any resistance in the path to earth has a minimum influence.

If U_{SOK}/I_K sinks below the value preset at the Z relay, Z_S picks up and energizes the auxiliary contactor CAS.

In conjunction with the CE - already attracted - the CAS switches the following measurands into the M+PU measuring system:

$I_S + k_0 I_\Sigma$ as the fault current through the replica impedance: as already mentioned, k_0 -times the proportion of the summation current I_Σ is added to the phase current in the current transformers SH1.

From SH1S terminal 5 \rightarrow CAS_{II1} \rightarrow RK-CAT_{II1} \rightarrow M1 etc.

From SH1S terminal 6 \rightarrow CE_{II2} \rightarrow M2

The other transformers SH1 are short-circuited on the secondary side.

U_{S0} as the fault voltage to the transformer HG8

Phase S: AK7 \rightarrow CAS_{I4} \rightarrow RK-CAT_{I4} \rightarrow HG8 terminal 6

0 point: AK5 \rightarrow CE_{I3} \rightarrow HG8 terminal 1

U_{RT} as the reference voltage to the phase shifter

Phase R: AK6 \rightarrow CAS_{I2} \rightarrow RK-CAT_{I2} \rightarrow X_b terminal 21

Phase T: AK8 \rightarrow CAS_{I1} \rightarrow RK-CAT_{I1} \rightarrow X_b terminal 20

The considerably simplified diagram below shows the connections between the replica impedance and the instrument transformers:

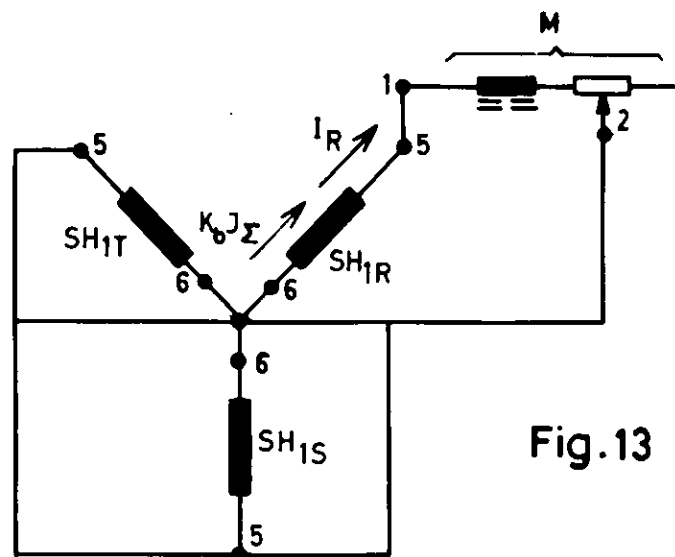


Fig.13

If two phases (e.g. R and S) develop an earth fault simultaneously at the same point or, what amounts to the same: an inter-phase fault comes into contact with earth as well (e.g. the phases R and S), a second impedance relay picks up too, in the example in question Z_R .

This does not alter in any way the above-mentioned choice of measurement quantities in the case of an earth fault from phase S, since in accordance with the preferential sequence on page 57, the relay ZS is decisive, while ZR only modifies the paths of the connections and not the relationship of the measurement quantities with the M+PU system.

In the case of a three-phase short-circuit, when all three impedance relays pick up, the same choice of phases takes place as for the interphase fault RT. (This is arbitrarily selected: connections in accordance with faults TS or SR would achieve exactly the same effect.)

Summary of V.1

Type of fault	Phase-phase without summation current	a) 1 phase-earth b) double earth fault	Phase-phase with summation ct.	triple-pole short-circuit
System neutral connection	all	a) earthed b) all	earthed	all
Pick up:	1 or 2 Z relays	*1 Z + earth relay	2 Z + earth relay	3 Z relays
Reference voltage (at X_b)	in all three cases the same phase-phase voltage (leads affected phase-phase voltage)	(leads by 90° the affected phase-0 voltage)	(leads affected phase-phase voltage)	U_{TS}
Fault voltage (at HGB transformer)	affected phase-phase voltage	in both cases same affected phase-0 voltage _____	(here the lagging of two phase-0 voltages)	U_{RT}
Current for replica impedance M	2 x current at point of short circuit	in both cases current in affected phase + k_0 times summation current (vectorial addition) _____	(here lagging of two affected phase currents)	$I_R - I_T$

* depending on location of fault, two Z relays could pick up during double earth fault: see then neighbouring column to the right.

V.2. The distance - time-step characteristic

One of the most important features required of the distance relay is selectivity, i.e. the relay must only react to faults in the section of line which it is to protect.

In the ideal case this would mean simply placing the point D in Fig. 5a-b quite close to the busbar of station B: 100% of the line, i.e. the entire section A-B would then be uniformly protected with a minimum tripping time.

In practice, however, the impedance of the section AB is unlikely to be known to a greater accuracy than $\pm 5\%$, added to which come the effect of line heating and sag, together with possible transformation errors in the power or auxiliary transformers (even if these are slight compared with the rated figures for the instrument transformers). Finally, the unavoidable scatter in the operation of the relays themselves has to be taken into account as well, such as the effect of current, no-load operation, etc., which together may well come to about $\pm 5\%$. If, due to the above-mentioned errors, the relay at A were to trip as a result of a short-circuit at the busbar B, this would already mean lack of selectivity.

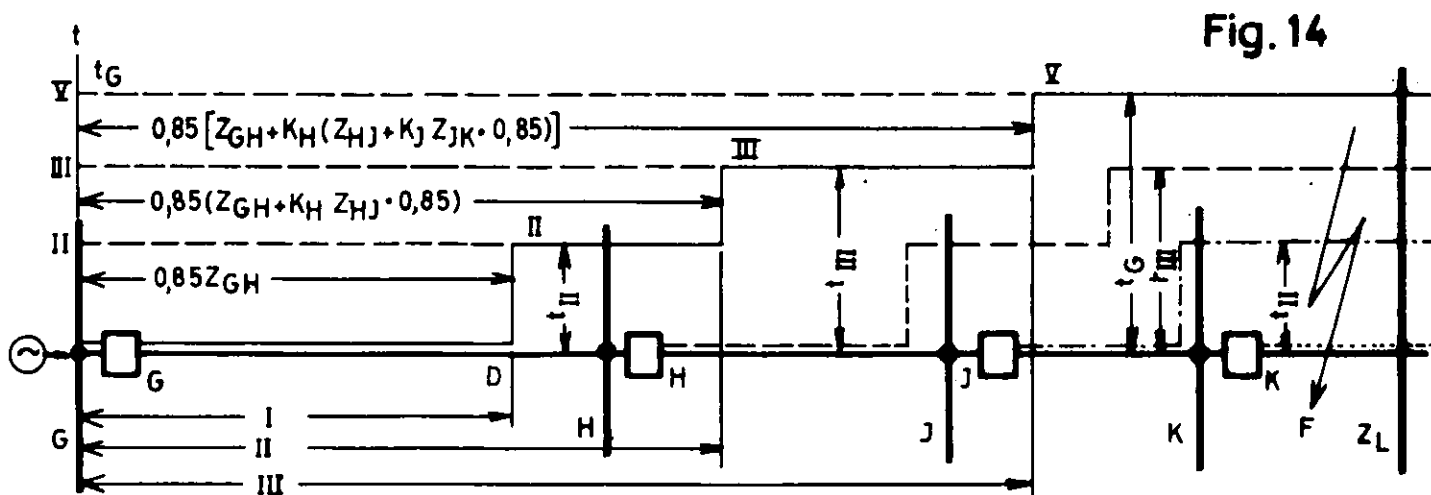
In order to safeguard selectivity, the limit D (Fig. 14) of step I of the protected section is curtailed a little, i.e. to about 85 - 90% of the impedance G-H. The relay responds to faults in this section G-D within the basic time (approx. 45 ms).

Step I is therefore determined by the basic time. In order to protect the section D-H as well, the time-step relay T is started at the same time as the starting relay Z picks up. On expiry of a preset time (usually 0.5 to 0.7 s, i.e. step II) this switches a smaller $\%u_F$ value (yellow tapping at HG8) into the M+PU difference circuit than was the case at the beginning (white tapping). This causes the point at which $u_d = 0$ to be moved further out accordingly, so that the section D-H is included as well.

The time-step relay T, which was started at the beginning of the fault, ensures that several distance relays housed successively in substations along the line can act as mutual back-up protection (Fig. 14).

For example, if a fault occurs at F and the nearest protective equipment and switchgear located at the right-hand outgoing feeder from K has not cleared the fault for some reason in basic time or within about 0.5 s, then the timers T in all the relays G to K change over the limits of protection to greater values. These values are determined, so that the relays cover 85% of the sum of their "own" section (e.g. H - J for relay H) plus k times 85% of the neighbouring section (e.g. J - K for relay H), the factor k being smaller than 1 (for the calculation see under VII.e).

Should then u_d become positive at the relay, which is next but one to the fault (e.g. J), this trips.



V : Limit time t_G effective over the entire protective range of the Z starting relays, Z_L being the limit at which the Z relays will start (regarding the use of IV: see Section V.3.b page 69, Section 5 and Section V.3.c.1, page 76).

(Incidentally: the diagram above presupposes that the lines shown (e.g. HJ) are always the shortest ones leaving the particular station. See also VII.e.).

If disconnection still does not take place at J, the timers continue running and further extend the range of the M+PU system in every relay on expiry of the time of step III, so that they now cover 85% of the sum of their "own" and the adjacent section of line plus k times the next-but-one section. These totals are shown for the relay G in the diagram above, the same calculation being applied to the relays H and J. The difference voltage u_d in relay H then becomes positive and the relay trips.

If even these measurements do not result in the fault being disconnected, the timers run on and upon expiry of time V, the so-called limit time, all the relays (especially in G) produce an unconditional tripping command for the circuit-breakers, irrespective of the position of the PU relay, i.e. also of the direction of the energy. It should be noted that the extension of the range of relays at J and M in II and III time steps only bring the PU relay in tripping direction with greater torque which however is not effective since CD has picked up. The step system dealt with above naturally encompasses all the other branches leaving the sub-station busbars as well, such branches in turn being protected by their own distance relays, if necessary.

In most cases, however, the protection must not only cover a radial line as in the above example, but the line forms part of an interconnected system, into which other incoming feeders are connected in the substations and at Z_L . Such a protective relay system with stepped characteristic must then be allocated to every energy direction along every conceivable path, all these systems having an appropriate overlap so that they can back up one another (see VII.e).

In the simplest case, the line shown above has bilateral in-feed at the two ends G and Z_L . The two sets of characteristics then complement one another as a mirror image over the entire length of the line. Each section is protected by the relays at the ends in the basic time, with the exception of the last 10 to 15% at the end remote from the relay in question. Step II of each relay then protects this 10 - 15% in front of the opposite station: e.g. the section H-J is protected by the relay H to the right of the busbar and by relay J to the left of it.

The above-mentioned applies unchanged to the other branches connected to the station busbars.

In special cases there may be a requirement for certain time steps to measure in the opposite direction ("backwards") compared with the others: this is achieved by changing over the polarity of the voltage drop in the replica impedance M with respect to the difference circuit of the M+PU measuring system. This involves connecting point 9 with 11 (instead of the normal 9 with 10) and the point 12 with 10 (instead of 12 with 11) - see AK 112009 - for the duration of the time step measuring backwards (not represented in 2-100 546).

If this reversal concerns time step II, the connection III_8 is to be changed over from III_{11} to III_{12} , so that CS II only remains attracted during the step time (normally it stays energized up to the limit time). Moreover, other connections have to be made, which insert the normally free contacts CS II_{13} and II_3 as polarity reversers between 9, 10, 11 and 12.

If the step III is to measure backwards, an additional auxiliary contactor CSX has to be incorporated, whose coil is connected in parallel to that of CS III. The two changeover contacts are then wired in the same manner as those of the above-mentioned CS II_{13} and II_3 .

V.3. D.C. control circuits

Preliminary remark to the chapters:

- V.3. D.C. control circuits
- V.3a Tripping circuit
- V.3a.1 Three-phase lock-out
- V.3b Auto-reclosure
- V.3c Joint operation of the circuit-breakers

It is not possible to make a sharp division between the material in these chapters, since causes are interlinked: the subject should therefore always be viewed as a whole.

To avoid repetitions (e.g. the principle of PTrW, PTaW and CSW in the various types of reclosure operations), the reader is referred to the basic chapter (e.g. V.3b dealing with reclosure in general).

In order to make the explanations more readily understandable, each chapter is first dealt with in brief. In every individual title reference is made to the relevant section "To", in which the operation of the contacts is dealt with in detail.

Abbreviated expressions used below:

Auxiliary contactor CA: stands for

all the auxiliary contactors CAR and/or CAS and/or CAT, one or more being understood, depending on the type of fault.

Contact designations: e.g. CA_{II3}

Are used in the same way as in the case of all the above-mentioned contacts CAR_{II3} and/or CAS_{II3} and/or CAT_{II3}

V.3a Tripping circuit - general

(for exact operation of contacts see page 82)

If a single or a multi-phase fault occurs within the limit distance, so that one or several Z relays pick up, their auxiliary contactors CA with CA_{II3} (and others) prepare the coil circuit of the quick-acting tripping contactor FD. (The contact T_I is normally closed.)

If the fault lies within the basic distance, causing the PU to pick up immediately, then the contactor FD is energized and gives the tripping command via FD 1-2.

In the simplest case when the breaker has only one tripping coil for all three poles and is not equipped for reclosure, this coil can be connected to AK 18. The contacts CA_{II5} and II6, also CSW_{II4} and the switch W are out of action (although the circuit in accordance with V.3a.1 could be adopted).

At the same time as it gives the tripping command, the FD contactor switches on the auxiliary tripping contactor CD, which closes its power contacts in parallel to FD 1-2.

As soon as the fault is cleared, the Z relay and hence also the CA contactors drop out. The contactor FD drops out as well, its contact FD 1-2 opening without load since it is covered by CD_{II5} and II6.

When the contactor FD drops out the coil of CD is deenergized, so that CD operates within its own actuating time; the contacts of CD therefore only open certainly after FD has already dropped out.

The switching sequence caters for the case, when the auxiliary contacts of the circuit-breaker in its "own" trip coil circuit - which should normally open this coil circuit immediately the breaker has opened - separate rather late. The contact FD 1-2

would be unable to interrupt the appreciable current of the trip coils, the contacts of CD being (within limits) suitable for the purpose.

(A few auxiliary contactors PTrW, etc. operate as well, but these only become significant during the reclosure cycle.)

Incidentally: Attraction of CD opens CD_{I4} , causing the time-step relay T and the relays CSII and CSIII (assuming these were attracted) to drop out.

Only applicable to type LZ32:

In the case of faults which initially only cause the back-up relay IB to pick up (e.g. earth fault with very high resistance) it is possible that even the Z relays switched over to the phase voltage by CE cannot pick up. The M+PU measuring system would then receive nothing no measurands and the fault would persist for an unlimited time. To ensure that despite this, an interruption does take place within the limit time + the actuating time of the PTaE auxiliary contactor, a connection can be made between PTaE 3 and 5: this brings the timing mechanism I into action by means of PTaE 5-6. If the small earth current continues to flow, the tripping contactor FD is finally energized at the limit time TV, whereupon the breaker opens.

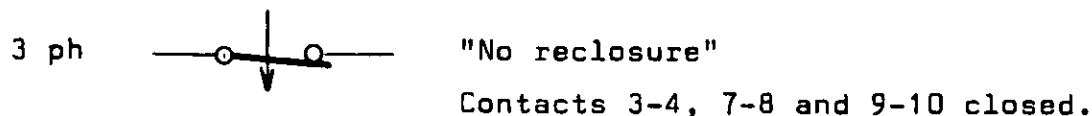
V.3a.1 Triple-pole lock-out only

In a system with a multitude of interconnections, reclosure is sometimes not adopted, since sufficient alternative paths are still available in the system when an affected line has been disconnected.

Under certain operating conditions, however, it may become necessary for an outgoing feeder equipped for reclosure to be temporarily locked out in all three phases whatever the fault.

For instance: one conductor of a double-circuit line is switched off for overhaul work, whereupon the other conductor operates close to the stability limit. So that synchronism would certainly be lost during dead time. As a result it is preferable to dispense with reclosure as it would only cause trouble.

In such cases the switch W has to be set to the position:



The contacts W7-8 and 9-10 always connect the terminals AK9, 10 and 11, so that at all times all three breaker poles are tripped, even if only one or two Z relays have picked up (together with the PU).

At this position of the switch W a circuit-breaker with only one OFF coil, which trips all three poles, can be connected to AK9 or 11: this also creates the possibility of choosing the type of operation in accordance with V.3b.2, i.e. triple-pole reclosure (page 72).

When the tripping coils of the circuit-breaker are connected directly to AK9-10-11, the breaker remains locked out until a manual closing command is given directly to the closing coil of the breaker, e.g. by means of a control switch (not shown).

If the terminals AK9, 10 and 11 are connected to the breaker coils through a separate reclosure unit (e.g. BROWN BOVERI type P12wb or CW6), the tripping command via W3-4 to terminal AK12 causes an auxiliary contactor in the reclosure unit to be held in, thus preventing a command for auto-reclosure to be given.

In the case of some circuit-breakers of other makes, only the opening coil specially fitted for triple-pole lock-out may be energized for the purpose. The three opening coils for the individual phases may not receive a signal at the same time.

In this case the connection AK18-17 has to be changed over to AK16-17: in this position the opening command is prevented from reaching AK9-10-11 by the open contact W1-2, but is still taken to AK12 via W3-4.

Only applicable to type LZ32:

The back-up earth-fault protection described in the last paragraph of V.3a applies to this type of relay as well, the breaker having to be connected to AK9, 10, 11 and 12 through a reclosure unit.

V.3b Auto-reclosure - general

(for exact operation of contacts see page 84)

The majority of line faults are associated with an arc: if the system voltage is then switched off for about 0.2 to 0.5 s - this period being known as the dead time t_p (the "first" interruption) - the ionization in the arc path decreases to the point that the arc fails to reignite upon reclosure after the time t_p (to be made less than 5 s).

Auto-reclosure ensures a supply of energy with the minimum of interruption and the optimum system stability.

The so-called blocking time (usually 3 to 5 s) is reckoned from the "first" trip. If any type of fault occurs again within this time, which causes the breaker to open, triple-pole lock-out always results, irrespective of the reclosure method selected. The auto-reclosure system is then blocked, hence the name "blocking time".

If no new fault occurs during the blocking time, the reclosure system returns to the rest position. Opening of the breaker due

to the next fault in basic time is then considered to be "first" again, followed by an auto-reclosure.

"First" faults which are not interrupted quickly, usually within about the first 0.3 s, are hardly likely to disappear during the dead time (the air at the location of the fault being too highly ionized). Such persistent faults are therefore always taken care of by a triple-pole lock-out.

For this purpose the cam T IV of the timing mechanism T is mostly set to 0.3 s: this cam switches in the CSW, thus preparing for the lock-out. In the case of auto-reclosure in step II, T IV has to be set to a higher value.

Since the circuit-breakers are not always operational (e.g. in the case of oil-circuit breakers, the spring-loaded mechanism may not yet be fully charged or with airblast breakers the air pressure in the receivers may be lower than the required minimum, etc.) functional interlocks have to be provided for the breaker and under special circumstances for the relay as well. For further details see page 99.

Two basic variants of the auto-reclosure system exist:

V.3b.1 Single-phase: Switch W in position 1 ph



(For the exact function of the contacts, see page 87)

Suitable for use in systems with a solidly earthed neutral. Only the phase affected by the earth fault is opened and re-closed. The two healthy phases still carry about 50% of the normal synchronizing torque, which considerably improves the stability of the network.

In the case of very long lines or very high voltages, the arc can be maintained by the capacitive coupling between the affected

and the healthy phases, obtaining enough current to continue burning, in spite of the fact that the breakers at both ends of the line are open. It may then become necessary to investigate whether conditions are suitable for this simple mode of auto-reclosure in one phase, or if the application of ultra rapid isolators for earth-shunting the affected phase solves the problem.

Normally a dead time ranging between 0.35 and 0.5 s is set.

The arc can still be reliably extinguished in extreme cases with a longer interval time or earth-shunting.

In accordance with page 54 , Section 2, only one impedance relay generally picks up due to interphase faults without summation current. Accordingly, only one phase is interrupted and reclosed, which is adequate since the arc can be extinguished just as effectively as with a three-phase opening.

Interphase faults with summation current (or faults not involving earth but a heavy flow of current) cause two impedance relays to pick up, resulting in a triple-pole lock-out.

Faults between three phases always provoke a triple-pole lock-out.

Two-phase: Unusual, since one healthy phase only carries 25% of the synchronizing torque and there is also a risk of an arc fed by capacitance, so that about 0.35 to 0.5 s dead time would be necessary. Three-phase auto-reclosure is preferable from the point of view of stability, since it only requires a dead time of about 0.25 s.

V.3b.2 Three-phase: Suitable for all kinds of neutral-point connection whether earthed or not (for exact function of contacts see page 89).

Every type of "first" fault is dealt with by interrupting all three phases for about 0.2 - 0.4 s; a dead time of 0.25 s (instead of 0.35 s for single-phase auto-reclosure) is generally sufficient.

V.3b.3 Single and three-phase: (for exact function of contacts see page 91).

The two most common types of auto-reclosure can be combined, so that during "first" single phase to earth faults only the affected phase is opened and reclosed. Interphase or three-phase short-circuits occurring as "first" faults are always reclosed in all the three phases.

Reckoning of the dead time and issuing the actual reclosure command must be carried out by a separate reclosure unit.

V.3c Joint operation of the circuit-breakers in the stations at the ends of the protected lines (overlap, carrier transfer)

If a fault occurs in a section of line with bilateral infeed, equipped for auto-reclosure, precautions have to be taken to ensure that the circuit-breakers at both ends of the line trip quickly and are opened together. In this manner the point at which the fault occurred remains dead during the dead time and the arc is extinguished.

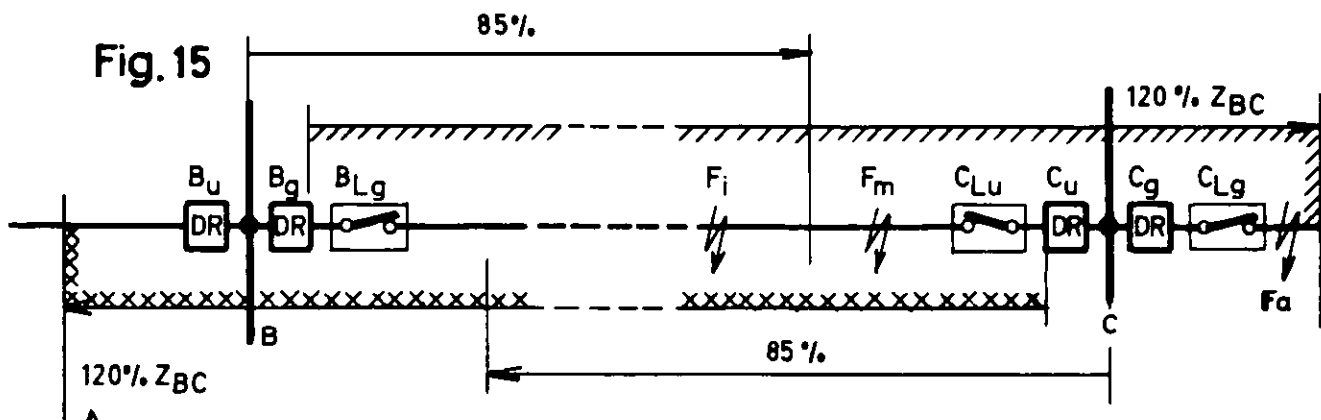
Breaker operation can be coordinated by the following methods: (These procedures are not necessary in the case of radial feeders with unilateral infeed at all times.)

V.3c.1 Overlap (for a description see page 92)

No signal connection is required between the two stations B and C at the ends of the line (Fig. 15).

For normal operating conditions, the ranges of the M+PU measuring systems in the two distance relays at B_g and C_u are adjusted to about 120% of the distance B-C: they therefore overlap into the next section beyond these two points (hence the name overlap).

Case F_i : If a fault (F_i) takes place between B and C (including the 10 to 15% in front of B or C otherwise left out), then the relays at B_g and C_u are certain to trip in the basic time.



Range of overlap circuit before "first" fault is interrupted.

The two circuit-breakers B_{Lg} and C_{Lu} are therefore opened simultaneously during the dead time, so that the conditions for extinguishing the arc are fulfilled.

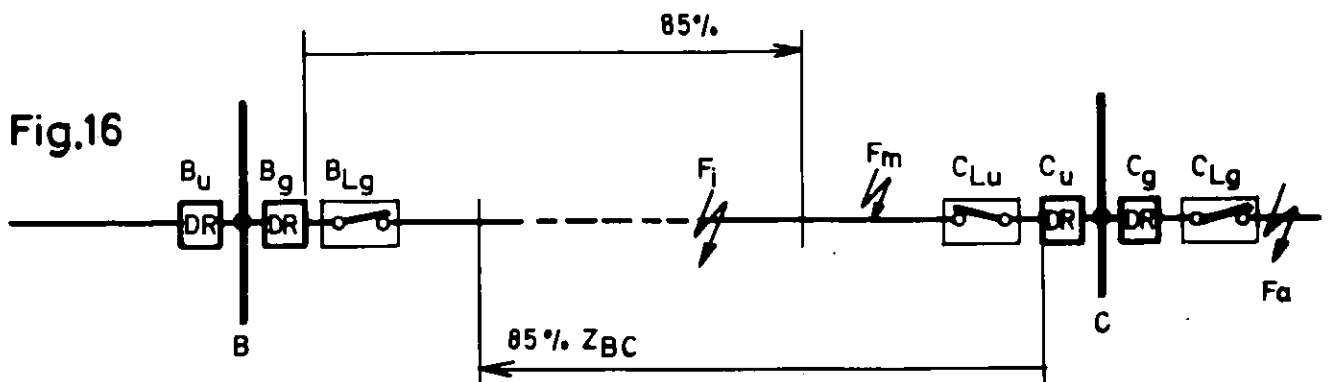
Immediately they have issued the trip commands to the breakers, the distance relays automatically carry out an internal change-over, which reduces the range to 85-90% of the impedance Z_{BC} , i.e. to the normal value of distance-time sequence (Fig. 16).

At the same time (through the auxiliary contactors CD, PTrW and PTaW) CSW is attracted, thus preparing for a triple-pole

lock-out. This is necessary in case the fault recurs upon reclosure or within the following 5 s (blocking time).

Should the fault F_i recur during the blocking time, the two relays B_g and C_u once again trip during the basic time, but now the interruption is always in all three poles and final.

Case F_m : During the "first" fault F_m , the two distance relays B_g and C_u function in the same manner as for the case F_i . If the fault returns in the blocking time, however, the relay C_u trips in the basic time and B_g in step II, both resulting in a triple-pole lock-out. B_g trips in step II since F_m is now located outside the 85% distance now applicable, as seen from B (fig. 16).



Range of the relays after the first interruption within the blocking time.

Case F_a : The overlap circuit has a minor disadvantage: if a fault F_a occurs beyond the opposite station C but still within the 120% form B_g , this initially causes the relay B_g to trip in the basic time (Fig. 15). (The relay C_g trips during the basic time as well and carries out a reclosure sequence, so that both relays are then in the blocking time).

The reclosing sequence of B_g has only a minor effect, since B_g close again after about 0.25 s.

If the fault F_a recurs (Fig. 16), it is cleared by lock-out in basic time by C_g only, whereas the Z relays in fact pick up in B_g but the PU cannot trip in the basic time, since the fault now lies beyond the effective 85% seen from B_g .

The breaker B_g therefore carries out a reclosure cycle, which is after all unnecessary. Nevertheless the flow of energy via B-C is maintained and the fault F_a was selectively locked out.

In case C_g could not interrupt the recurring fault, B_g would certainly open in step II, in exactly the same way as with the usual stepped characteristic.

If no new fault manifests itself during the blocking time, the relays automatically change over the range back to 120% and the overlap system comes into action again.

As already mentioned in V.3b, "first" faults lasting longer than about 0.3 s always cause a triple-pole lock-out. In order to prevent a fault F_a lasting longer than about 0.3 s provoking a non-selective lock-out, the coil CSA is switched off by the break contact driven by the cam T_{IV} , which reduces the range of the M+PU from the overlap distance (120%) to the normal one of about 85-90% Z_{CB} .

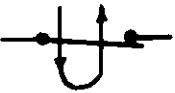
A special type of application:

If the breakers are to be reclosed using overlap only during earth faults or the breakers are to be only locked out during three-phase short-circuits, the following setting can be adopted:


This presupposes that during the earth fault the phase and summation currents are expected to be about the same.

The tapping A (green) at the HGB is set to 85% of the station distance and tapping I (white) to about 55%.

The factor k_o is deliberately set at the current transformer to a higher value than that calculated from $k_o = X_m/X$ (page 30). As general guide: for a calculated $k_o = 1$, this is raised by about 50%. If the calculated $k_o \leq 1$, the percentage should be chosen to be higher, and vice versa. For instance, at calculated $k_o = 1$, hence raised to 1.5, the range of the step is increased by some 25%.

At the switch W: set 1 ph 

During earth faults, the M+PU then measures the following due to the effect of the summation current: $85\% (U_F) \times 125\% (k_o)$ = about 106% of the inter-station distance, so that it overlaps. The relay reacts in accordance with the position of the fault, as described in V.3c.1, page 73..... and carries out an auto-reclosure. CSA is then deenergized, whereupon the tapping I becomes effective at HGB. Should an earth fault recur during the blocking time, the relay protects a certain part of the inter-station distance in basic time, in a similar manner to normal time-distance stepping and causes a lock-out.

In the case of multi-phase faults without summation current, the higher setting of k_o has no effect, so that M+PU protects the inter-station distance in the basic time as normal (without overlap). Since W is set to 1ph  such faults cause triple-pole lock-outs.

In the case of two-phase earth faults, the limits between the two above-mentioned cases can become somewhat unclear, depending on the size of the summation current.

V.3c.2 Transmission of the opening command to the station at the other end of the line by carrier transfer

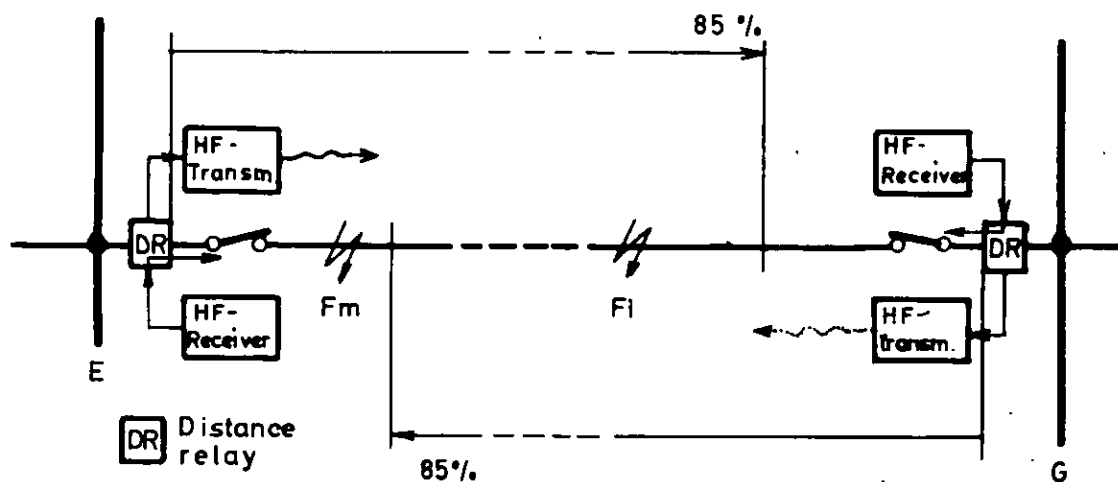
(For exact description of principle see page 94 , also timing diagram on page 119..) - also known as "carrier intertripping".

This method is the most reliable. It calls for carrier equipment, like that used for service telephone links and telemetering; either carrier along the line or microwave equipment.

The distance - time-step characteristic is set as explained in V.2 above.

When one or more Z relays pick up - depending on the type of fault - both the telephone and telemetering links are disconnected from the carrier channel in stations E and G, the receiver being connected to the terminal AK20 of the distance relay. The contact FD5-6 (AK22-23) is always coupled to the h.f. transmitter.

Fig. 17



Breaker interconnection by carrier transfer.

Case F_m: If the fault is located at F_m, the relay PU at E picks up in the basic time, trips its circuit-breaker and at the same time transmits a tripping command via the h.f. channel to G (Fig. 17).

In the case F_m G cannot trip by itself in the basic time, since the fault lies beyond the 85% basic distance. Nevertheless, the command transmitted via h.f. from E trips the breaker almost immediately (approx. 20 ms signal transitting time), without awaiting step II.

The opening command from E is a general one, i.e. without distinction between healthy and affected phases. The allocation of the opening command received in G to the breaker poles in question is undertaken by the starting relays or the CU undervoltages relays at G.

If the fault re-appears after reclosure during the blocking time, the relay at E trips again immediately and transmits the opening command to G via h.f., the breaker at G being tripped as well. Because of the blocking time, the CSW contactors at E and G are attracted, so that a three-phase lock-out results in any case.

Case F_i : When the fault F_i causes the Z relays and the PU measuring systems in the two relays at E and G to pick up in the basic time, then each automatically trips its own breaker in the basic time, without interference from the carrier transfer units. Each of the two distance relays sends also tripping commands via carrier transfer to the other. If for some reason one of these relays should trip a little later, this transmitted opening command would arrive just after that from the local relay, causing the reclosure unit to lock out, i.e. it would not be switched in again. To avoid this condition, the production of the opening command by the local relay is accompanied by blocking the acceptance of signals from the opposite end by means of the contact PTrH 3-4. After 0.2 s this blocking action is cancelled again, so that a possible second opening command (due to the recurrence of the fault after the reclosure) can be received.

If F_i is recurring during the blocking time, the two relays trip their breakers immediately and this time they remain locked out because CSW is attracted.

If the energy fed in, say from the right, is low, neither the fault F_m nor F_i may be able to start the Z relays in G because of the current being too small. To ensure that, in spite of this, the anticipated opening command from E via carrier transfer is correctly received and that it is passed on to the correct breaker pole(s), three undervoltage relays type CUH90c together with auxiliary contactors are normally added outside the distance relay in each station.

These relays CUR, CUS and CUT measure the phase voltages and are adjusted so that their contacts close at $U < 80\%$. This setting allows the CU relays to detect interphase faults too.

The contacts of the CU relays in G, for instance, act on the carrier equipment and on the phase allocation for the tripping command in the distance relay exactly as though the relevant CA contactors (e.g. in G) had picked up. The M+PU measuring system in G is not affected by the CU, so that it remains at rest without measurands.

The relay in G then operates as described for the case F_m above.

If a line is deliberately switched off (e.g. for overhaul) and the mains-voltage transformers are connected on the line side, the CU relays pick up and first initiate the disconnection of the telephone and telemetering links as described above.

To retain the use of the line for the telephone (e.g. for conversations with the overhaul team) and for telemetering purposes, an auxiliary contactor with a 5-s delayed pick-up (fitted outside the distance relay) is switched in at the same time as the CU relay picks up. After the 5 s time lag, the carrier equipment is reconnected for normal operation (telephone and telemetering), even if the CU remains in the pick-up condition.

V.3c.3 Follow-through connection (not to be confused with V.3c.2)

(Also referred to as "step-extension": for exact description of principle see page 97)

Under normal circumstances the two relays H_g and K_u are set to 85% of the distance to the station as the basic distance (Fig. 18). If, for instance, the distance relay H_g at one end of the protected section trips in the basic time because of the fault F_m , a command is transmitted to the opposite station K via carrier or pilot wire: this energizes the CSA contactor in K_u , thus extending the range of the latter to about 130% of the basic distance. This enables the K_u relay to detect a fault, even if it lies immediately in front of H_g .

The risk of unnecessary reclosure sequences, which exists with the fault F_a in the normal overlap circuit (see page 74-75), is obviated in this case. This due to the fact that the changeover to the overlap distance is only initiated when the H_g relay "sees" a fault within the basic distance in the direction K. A fault to the left of H, which cannot cause the PU relay in H_g to pick up and hence cannot originate an carrier command, is never detected by K_{II} in basic time but probably in time step II.

The follow-through connection is less affected by irregularities with the carrier signal, but because of the need for the change-over it is slightly slower..

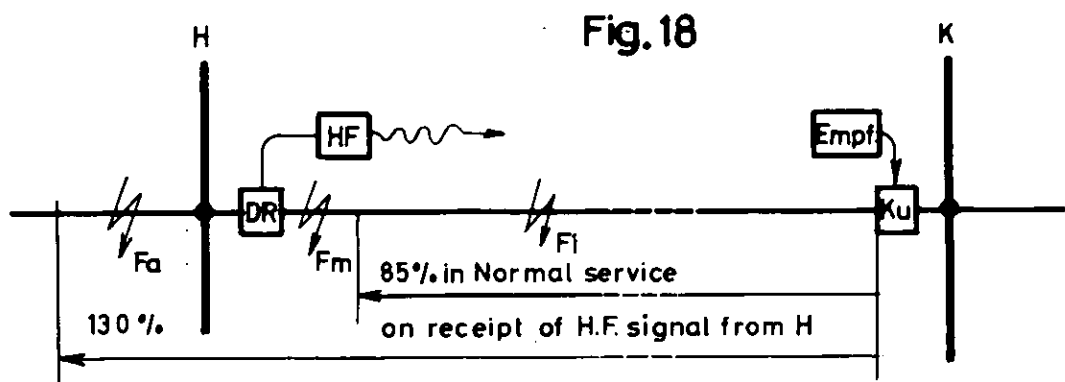


Diagram of a "follow-through" connection

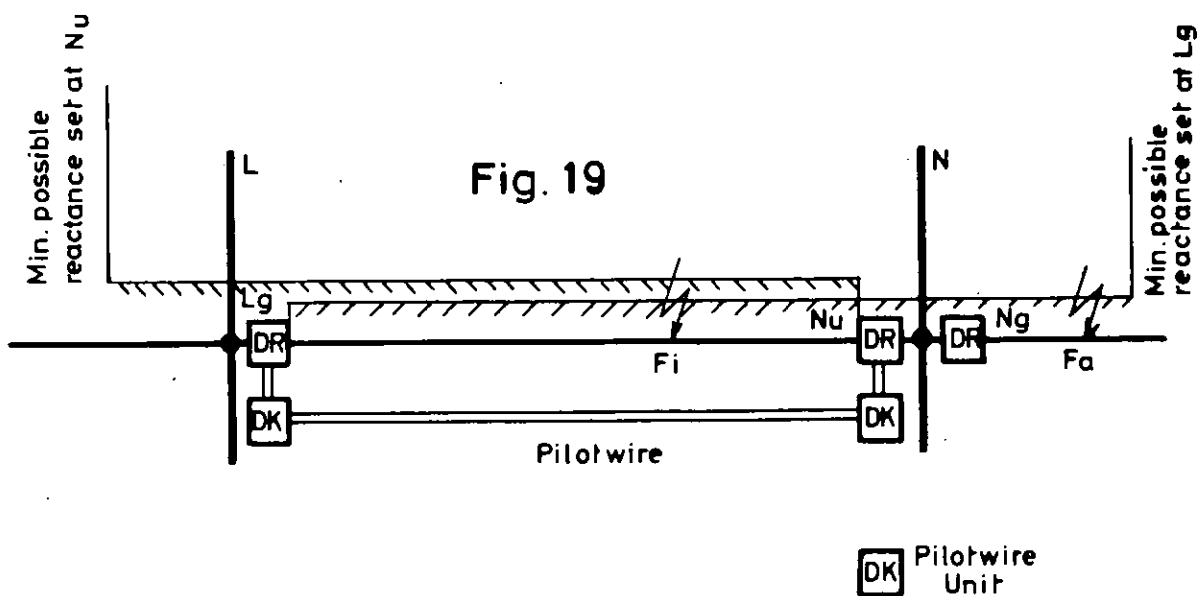
V.3c.4 Joint breaker operation using pilot wire

(Fig. 19 and also page 82 below)

This is only resorted to in special cases, when the protected line L-N is shorter than the minimum distance which can be set at the distance relays L_g and N_u . A fault F_a just on the other side of the opposite station N would then of necessity lead to the tripping of L_g in the basic time, which would be non-selective (Fig. 19).

The tripping of the circuit-breakers in L_g and N_u due to the faults F_i between L and N now depends on whether both distance relays L_g and N_u have tripped simultaneously or whether the Z relays in the opposite station have not picked up. This necessitates installing a twin-core pilot wire between the two stations L and N, with a wire-coupling unit in each.

In the case of a fault F_a to the right of N, for instance, the relay N_u blocks the two breakers L_g and N_u , in spite of the fact that the PU relay in L_g is ready for tripping. For the sake of selectivity, this fault must be disconnected by the relay and breaker N_g .



Joint breaker operation using pilot wire.

The connection to the pilot wire unit is made at AK51-52.

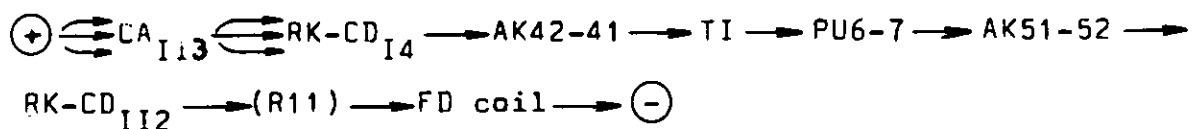
Should a fault persist until time step II, the timing auxiliary contactor CS II short-circuits AK 51-52 with its contact CS_{II2}, thus cancelling any blocking effect due to the pilot wire coupling and - provided the PU has picked up - allows the breaker to be tripped by FD.

Detailed descriptions of operations

Appendix to V.3a:

Tripping circuit in general

Once the CA have picked up, they prepare the coil circuit of FD:



(With regard to AK42-41 see page 100; AK51-52 see above; contact TI is usually set so that it is normally closed.)

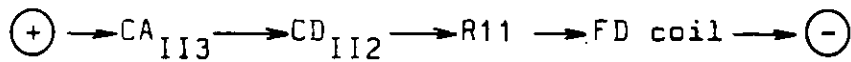
If the fault is located so that the PU picks up immediately, then PU 6-7 close and the FD attracts.

As soon as FD1-2 closes, the opening coil of the breaker is energized.

This opening-command circuit can either be fed from the same auxiliary d.c. supply as the distance relay, for which AK19 is to be connected to AK36, or another voltage source can be applied to AK19.

In parallel to the coil FD, the coil CD is simultaneously supplied with voltage via RK-CD_{II2} → RK-CD_{II3}.

As soon as CD attracts, the supply to FD is changed over without interruption via CD_{II2} and $II3$ to:



As a result FD and CD constitute a self-holding system which remains attracted, even when the PU opens, and only drops out when the CA_{II3} open.

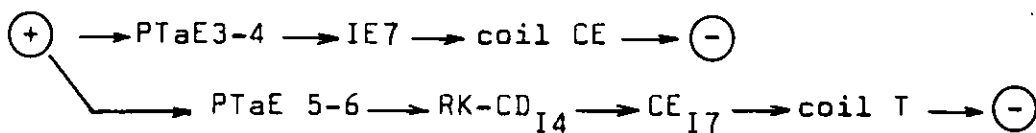
The power contacts CD_{II5} and $II6$ close in parallel to FD1-2, "covering" the latter.

The moment the fault current disappears, the Z relays and the CA contactors drop out; CA_{II3} interrupts the coil of FD, which drops out, ensuring that the contact FD1-2 in the tripping circuit definitely opens without load, while CD_{II5} and $II6$ still stay closed in parallel to it.

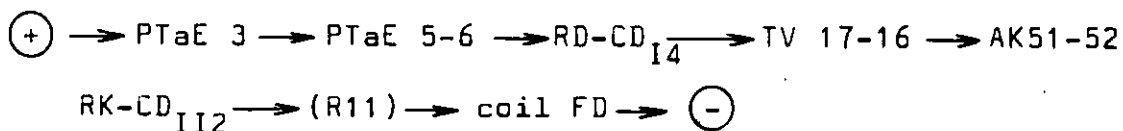
As it drops out FD7-8 switches the coil CD off, which also drops out and opens CD_{II5} and $II6$ surely after FD1-2 is already open. The reason for this precaution is explained under V.3a, page 67, section 6.

(Only in the case of LZ32)

When the connection PTaE3-5 is made to the PTaE and an earth fault occurs, which only causes IB to pick up, the PTaE completes the following circuits upon expiry of the time-lag:



If this earth fault persists until TV closes, then FD is energized through the following path:



The tripping command follows the route:

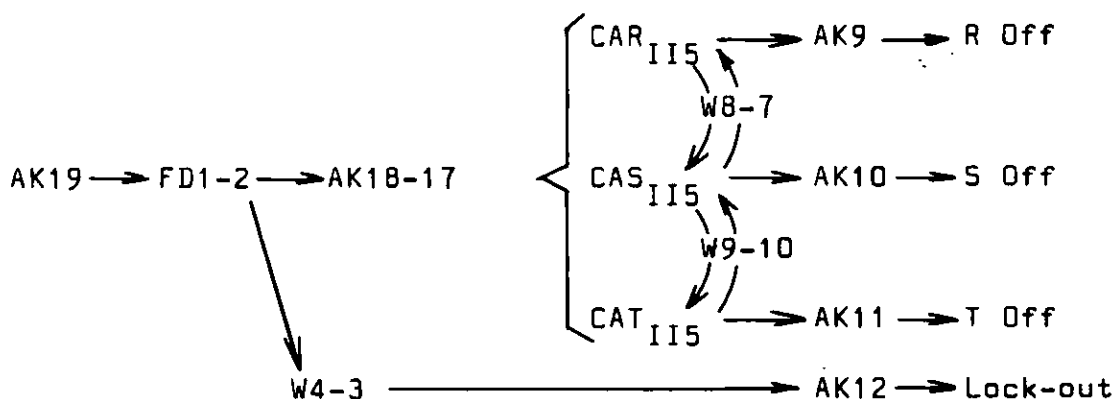
AK19 → FD1-2 → AK18 → breaker coil

Appendix to V.3a.1:

Triple-pole lock-out only

The coil circuit is completed for FD as described under "Appendix to V.3a" above.

The tripping circuit is routed as follows:



The closed contacts W8-7 and W10-9 transmit the opening command to all three phases, even if only one or two CA contactors were energized.

The function of IB and PTaE in the type LZ32 is the same as that described in the section above, with the exception that W8-7 and W10-9 are additionally connected in parallel to CSW_{I13} and CSW_{I14}.

Appendix to V.3b

Reclosure system - general

The auxiliary contactors PTrW, PTaW and CSW, together with the switch W, form the part of the reclosure system built into the LZ3, LZ31 and LZ32 relays.

The remainder have to be added as a separate reclosure unit (e.g. Brown Boveri type P12wb or CW6). Such a subdivision promotes optimum flexibility, especially when other makes of reclosure units or circuit-breakers are adopted.

During the "first" interruption the contactor with delayed drop-out PTrw is energized, either by

1. $\oplus \rightarrow CD_{I3} \rightarrow RK-CSW_{II2} \rightarrow \text{coil PTrw} \rightarrow \ominus$ or by

2. A command transmitted by carrier transfer from the opposite station (see V.3c.2)

HF receiver $\rightarrow AK21 \rightarrow RK-PTrH5-6 \rightarrow RK-CSW_{II2} \rightarrow PTrw \text{ coil} \rightarrow \ominus$

At the end of the tripping command the coil of PTrw is de-energized, and its delay-mechanism starts counting the blocking time.

The dead time is monitored by the separate reclosure unit, which also must give a possible closing command.

The PTrw maintains the connection AK68-69 during the blocking time by means of PTrw1-2, so that the carrier equipment remains reserved for opening commands (see page 94).

PTrw7-8 interrupts any supply to the CSA, thus making the overlap facility inoperative during the blocking time (see page 72).

PTrw5-6 switches in the 0.3-s delayed on pick-up auxiliary contactor PTaW:

$\oplus \rightarrow PTrw5-6 \rightarrow RK-CSW_{II1} \rightarrow PTaW \text{ coil} \rightarrow \ominus$

The time-lag ensures that the changeover to lock-out can only become operative shortly before the end of the dead time.

When PTaW has attracted, it energizes the auxiliary contactor CSW through PTaW1-2. (For the purpose of the contact 3-4: see fourth section below; for the purpose of the contact 7-8: see section V.3e, page 100 - Out of step blocking device.)

The CSW connects the terminals AK9, 10 and 11 with the contacts CSW_{II3} and II4, so that a new opening command during the blocking time always results in a triple-pole lock-out (similar to W8-7 + W10-9 in the section "with V.3a.1").

In addition, CSW_{I3} also connects the terminal 12 with the tripping circuit, so that a new tripping command during the blocking time energizes an auxiliary contactor in the reclosure unit, making the new tripping a lock-out (similar to W4-3 in the appendix to V.3a.1).

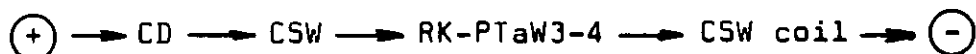
As already mentioned on page 70, the time T IV for the timing mechanism T is usually set to about 0.3 s to prevent reclosure if the fault was not interrupted quickly enough. This actuates the contact T IV 14-13, which energizes the CSW directly, this relay preparing for the triple-pole lock-out.



If an interruption then actually follows, no blocking time is called for since a lock-out took place: PTrW and PTaW must therefore be prevented from attracting. With the contactor CSW attracted its opened contact CSW_{II2} inserts the resistor R9 in series with the coil of PTrW while CSW_{II1} inserts R8 in series with the coil of PTaW.

The values of R8 and R9 are made such that PTrW and PTaW - if already attracted - remain so when these resistors are inserted or, if R8 and R9 are already inserted they prevent PTrW and PTaW from attracting.

As soon as CD energizes due to the lock-out, it interrupts the supply to T by means of CD_{I4}, so that T resets and opens T_{IV} 14-13. CSW cannot drop out yet, since it is already part of the self-holding circuit:



CSW only drops out when CD has done so and $T_{IV14-13}$ has opened. This assures the triple-pole lock-out.

When the opening command is transmitted to AK21 via the carrier the above-mentioned self-holding circuit for CSW is routed as follows:

H.F. receiver \rightarrow AK21 \rightarrow RK-PT_{tr}H5-6 \rightarrow CSW_{II2} \rightarrow and on as above.

CSW also only drops out when both $T_{IV14-13}$ is open and the carrier command has come to an end.

Appendix to V.3b.1:

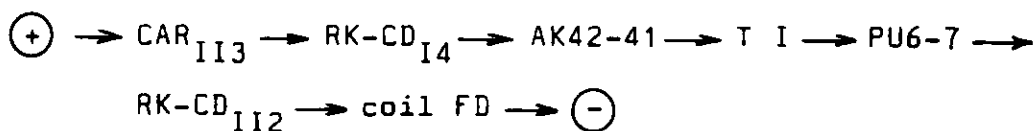
Single-phase auto-reclosure

Switch W in position
contact W 5-6 closed



If a single-phase fault occurs (e.g. RO), only one Z relay (ZR) picks up, as in the case of an interphase fault without summation current (e.g. TR), which causes little current to flow (see pages 54 and 55). These two faults are therefore dealt with in the same way by the auto-reclosure unit, which is only logical.

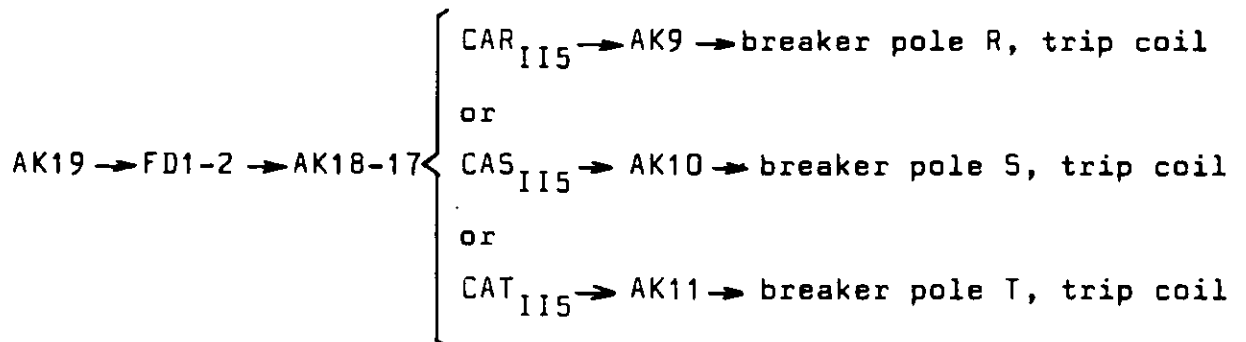
If the "first" fault (either of the above-mentioned types) is located, such that interruption takes place in the basic time, then only one phase is tripped (e.g. R). The tripping signal progresses as described in the Appendix to V.3a on page 82:
coil circuit FD:



Circuit breaker trip coil circuit:

The one auxiliary contactor CA to pick up prepares the path for

the opening command through CA_{II5} only to the coil of the pole in the affected phase (also referred to as phase selection):



Even if the auxiliary earth-fault contactor is attracted, this has no effect on the phase selection.

CD operates as under Appendix to V.3a and PTrW, PTaW and CSW, as stated on page 85, section 1-4.

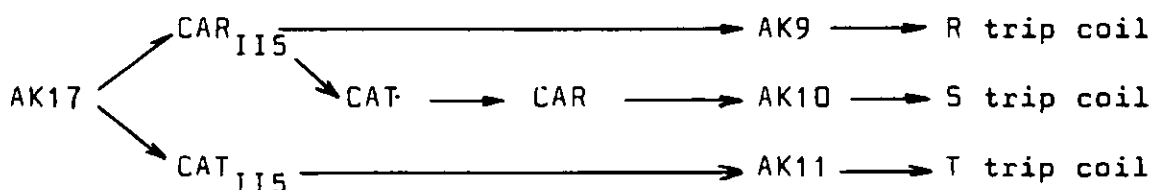
Towards the end of the dead time PTaW has attracted and CSW has closed, with the result that any new fault detected during the blocking time provokes a triple-pole lock-out, as described in the preceding section.

In the case of interphase faults (e.g. RT) with or without summation current but carrying considerable current, the two Z relays ZR and ZT in the affected phases pick up.

The coil circuit of FD is as above, except that CAT_{II3} is also in parallel to CAR_{II3} , although this has no effect.

The tripping coil circuit of the breaker now not only includes CAR_{II5} and CAT_{II5} , but also CAR_{II6} and CAT_{II6} , the last two connecting AK9 with AK10.

Accordingly the tripping command is fed as far as AK17 as above and from there onwards as follows:



If such a fault recurs during the blocking time, the above-mentioned connection AK9-10-11 is also paralleled by CSW_{II3} and CSW_{II4}.

When two CA contactors pick up (e.g. CAR and CAT), AK15 is fed with the tripping order, which is also fed to AK12 via W5-6:

AK17 → CAR_{II5} → CAT_{II6} → AK15 → W5-6 → AK12

As already mentioned, this causes the auxiliary contactor for lock-out in the separate reclosure unit to attract even during the "first" interphase fault and the "first" triple-pole short-circuit.

The other makes of breaker mentioned at the end of V.3a.1, for which the connection AK18-17 has to be changed over to AK16-17, cannot be used for single-phase reclosure alone with the distance relays type LZ3, LZ31 or LZ32, although they are suitable for 1 + 3-phase reclosure (see appropriate section).

Appendix to V.3b.2:

Three-phase auto-reclosure

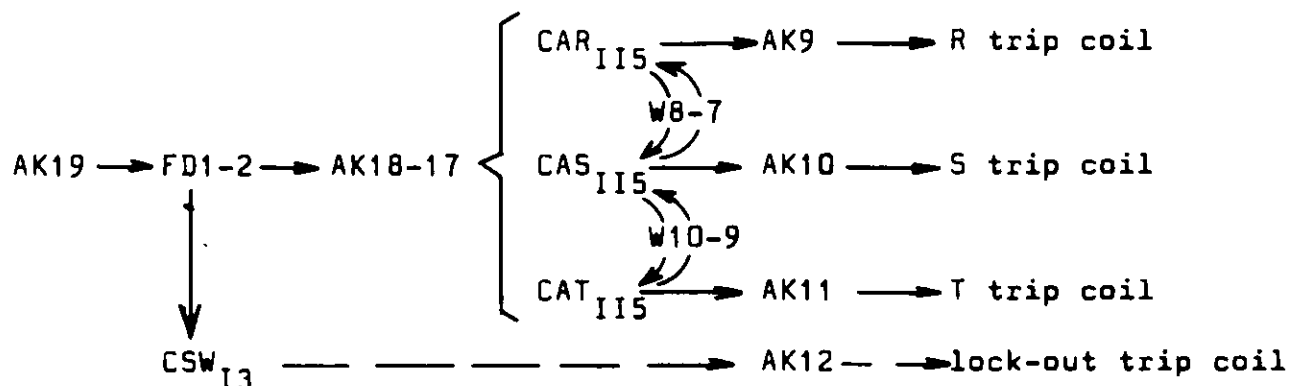
Switch W at position



contacts W 7-8 and W 9-10 closed

Whether one, two or all the three Z relays have picked up, every "first" fault is reclosed in all three phases.

As far as the coil circuit FD is concerned, tripping takes place as described in the Appendix to V.3a on page 82. . The trip coil circuit of the breaker only differs from that in Appendix to V.3a.1, in that AK12 does not receive the tripping command during the "first" fault, since CSW is not energized: no lock-out therefore takes place.



CD operates as in Appendix to V.3a and PTrW, PTaW and CSW as explained in para. 1-4 on page 85 .

At the end of the dead time PTaW attracts and switches CSW in for the duration of the blocking time, CSW_{I3} closes, thus connecting AK12 into the trip-coil circuit as well: — — — — — →

The reclosure command has to be given by a separate reclosure unit.

If any type of fault should appear during the blocking time, triple-pole interruption always follows: this is due to the fact that AK9, 10 and 11 are firmly connected through W7-8 and 9-10 and the tripping command is also transmitted to AK12 via CSW_{I3}, so that the auxiliary contactor in the reclosure unit is energized to achieve the lock-out.

In the case of the circuit-breakers of other makes mentioned in the last three paragraphs of V.3a.1, as already said, the connection AK18-17 has to be removed. For three-phase reclosure the contacts CSW_{I1} + I2 must then be connected (in series) between the terminals AK16 and AK17, for which these are to be joined to AK66 and AK67, respectively.

Any type of "first" fault causes the tripping command to be transmitted to AK9, 10 and 11 simultaneously, as explained above, so that the breaker carries out a triple-pole reclosure sequence.

At the end of the dead time CSW picks up, as described in the Appendix to V.3b: this causes CSW_{I1} and I₂ to open and CSW_{I3} to close. Accordingly, if a new fault appears during the blocking time, an opening command is only applied to AK12, initiating a triple-pole lock-out.

Appendix to V.3b.3:

Single and three-phase auto-reclosure

Switch W at position
contact W1-2 closed



1 and 3 ph

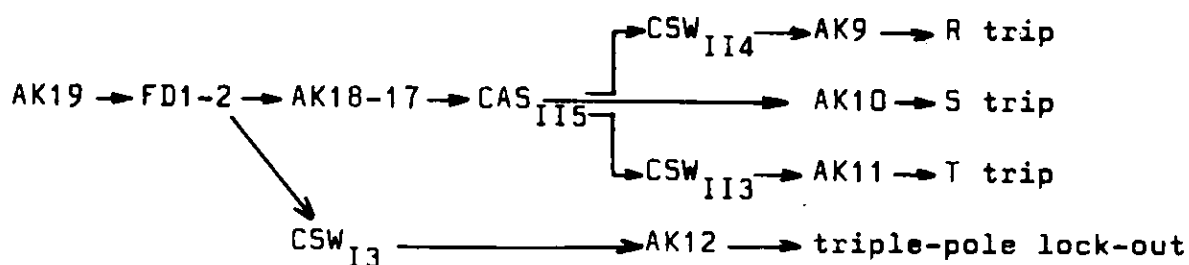
During earth and interphase "first" faults, when only one Z relay starts, the coil circuit of FD is completed as described in Appendix to V.3a on page 82 .

The tripping coil circuit of the breaker is connected as shown for single-phase reclosure (page 88).

If the "first" fault turns out to be an interphase fault with summation current or a heavy-current interphase fault without summation current, or even a three-phase short-circuit, then the tripping coil circuit operates as described above for three-phase reclosure. In these cases, however, the connection AK9, 10 and 11 is only made through the contacts CA_{II5} and II₆ of the two or three attracted CA contactors, as explained in the Appendix to V.3b.1 on page 88 .

The reclosure command is given by a separate reclosure unit.

Should the fault recur during the blocking time, then even if only one Z relay has started (e.g. CAS), the tripping command is transmitted through CSW_{II3} and II₄ to AK9, 10 and 11 and at the same time through CSW_{I3} to AK12, since CSW is attracted: this results in a triple-pole lock-out.



In the case of the circuit-breakers of other makes mentioned in the last three paragraphs of V.3a.1, 1 + 3-phase reclosure necessitates replacing the connection AK18-17 by inserting the contacts $CSW_{I1} + I2$ between AK16-17, as described in the preceding section.

During the "first" fault the tripping commands are transmitted as above, i.e. depending on the type of fault single-pole to AK9, 10 or 11 or alternatively triple-pole to AK9 and 10 and 11 simultaneously.

If the fault, any type, reappears after the reclosure the auxiliary contactor CSW - energized during the blocking time - interrupts the path for the tripping command to the terminals AK9, 10 and 11 by means of the contacts $CSW_{I1} + I2$ between AK16 and AK17, while the closed contact CSW_{I3} passes the tripping command to AK12, causing a triple-pole lock-out.

Appendix to V.3c.1:

Overlap circuit (see also diagram on page 73)

The following is to be undertaken on the two distance relays in B and C:

The "green" cables "A" at the matching transformer HGB are attached at a percentage corresponding to about 120% of the distance BC.

The switch Wa is set to the position A, so that CSA remains attracted during the rest condition of the distance relay.

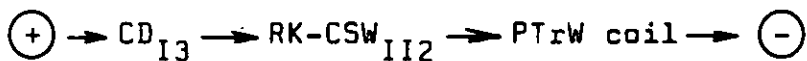


(Power consumption 1.8 W from the d.c. supply.)

With its contacts CSA_{I1} and II1 the CSA connects the tapping A, i.e. the "green" cable at the transformer HG8 to the difference circuit of the measuring system M+PU (see page 19).

When a fault occurs which causes one or more Z relays and the PU to pick up, the same operations take place as described in V.3a (paras 1 to 4), depending also on the mode of reclosure selected.

In addition CD connects the following with its contact CD_{I3} :



PTrW attracts and its contact PTrW7-8 interrupts the supply to the auxiliary contactor CSA. The delay time of PTrW is referred to as the blocking time, within which a new fault does not provoke reclosure but a lock-out.

Immediately the tripping command has been given, CSA resets and switches the "white" cables "I" at the transformer HG8 into the difference circuit (the "green" cables "A" become non-effective). As a result the range of the M+PU measuring system is reduced to 85-90% of the basic distance (depending on the percentage tapped off with the "white" cables "I" at the transformer HG8): this is important in case the PU has to measure after reclosure due to the reappearance of a fault.

The auxiliary contactors PTrW, PTaW and CSW operate as described on page 85 (Appendix to V.3b).

When the reclosure unit closes the breaker again upon expiry of the dead time and a new fault appears within blocking time (time-lag of the PTrW), then the sequence of events as described in Appendix to V.3a is repeated, though this time the

M+PU measuring system only covers 85-90% of the basic distance (whiteappings at HG8).

Case F_i : If the fault F_i occurs within 85-90% of the basic distance, the PU picks up immediately: the sequence of operations progresses as under V.3a and a tripping command is given, in this case always a triple-pole lock-out, since CSW is attracted.

Case F_m and F_a : If the fault occurs outside the 85-90%, the Cg distance relay operates as described under V.2 and also causes a triple-pole lock-out in step II or III, once again because CSW is energized.

If the fault does not reappear during the blocking time, PTrW runs out and resets and CSA is energized again by the closing of the contact PTrW7-8: the M+PU measuring system is now switched to the overlap distance (120% of the basic distance).

The distance relay has therefore returned completely to the condition before the "first" fault.

Appendix to V.3c.2:

Carrier transfer

The switch Wa must be set to position I, i.e. open, CSA remains dead, so that the "green" tappings "A" at HG8 are non-effective.

When at least one Z relay starts in each point, e.g. in E and G, the associated CA contactors are energized and ensure that the contacts CA_{II7} between AK68 and 69 cause the switchgear in the HF equipment to disconnect the telephone and telemetering links. In addition, the carrier receiver is connected to AK20 and 21, so that the distance relay can respond to a tripping command originating in the opposite station.

The contacts of the auxiliary contactors to the separate under-voltage relays CUR, CUS and CUT operate in parallel to CA_{II7} and can also prepare the carrier equipment for the tripping-commands.

By means of CA_{II5}, the auxiliary contactors CA prepare the tripping circuit for the PU in the two relays E and G and by means of CA_{II5} and II₆ the phase allocation for the tripping command as described in Appendix to V.3a.

Case F_m: The PU in E picks up immediately and energizes the FD (in accordance with Appendix to V.3a); this in turn trips the affected breaker pole in E by means of FD1-2 and also transmits the opening command through FD5-6 to the h.f. equipment, which passes on this command towards G.

Since F_m lies outside the 85%, the PU in G does not pick up in the basic time, but the opening command from E arrives at AK20 and - because the Z relays in the same phases start in both E and G - provoke the same single or triple-pole interruption as in E (as though FD1-2 were closed):

H.F. receiver → AK20 → RK-PT_rH3-4 → AK18-17 → and on
(as indicated in Appendix to V.3a)

At the same time the tripping command received is fed to AK21, causing P_{Tr}W to attract, which marks the beginning of the blocking time.

AK21 → RK-PT_rH5-6 → RK-CSW_{II2} → P_{Tr}W coil → ⊖

The terminals AK20 and AK21 must not be interconnected in any way, since this would result in undesired feedback. The h.f. receiver must therefore have two simultaneous acting isolated signal contacts for receiving the transmitted commands.

The auxiliary contactors PTrW, PTaW and CSW operate as described on page 85 (Appendix to V.3b).

During the dead time the fault current disappears, the Z relays in E and G, also the FD and CD in E drop out and the h.f. signal ceases.

When the dead time expires, the reclosure units in E and G initiate the reclosure.

If the fault does not recur during the blocking time, then PTrW, PTaW and CSW drop out again, so that the original condition is restored.

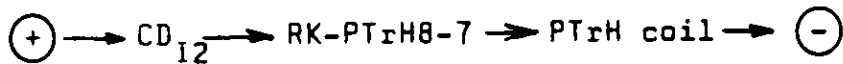
If, on the other hand, the fault reappears during the blocking time, the sequence of operations described at the outset is repeated, the distance relay in E independently causes its breaker to lock out in all three phases, while at the same time transmitting a new tripping command to G by carrier, where a triple-pole lock-out is carried out as well.

Case F_1 : If the fault lies within the basic distance of both E and G, the sequence of operations as in Appendix to V.3a takes place automatically in the two distance relays at E and G (with the exception of the two last paras), so that the breakers are tripped without awaiting a carrier signal.

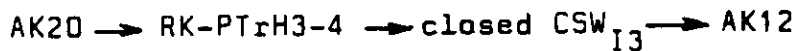
At the same time the tripping command is in any case passed to the carrier transmitter by the contacts FD5-6 of the two relays in E and G via AK22 (since the relay, say in G, could not "know" if the PU in E detects tripping conditions).

CD, PTrW, PTaW and CSW operate as in Appendix to V.3b (in this case CSA never carries current).

With CD₁₂, CD switches on contactor PTrH, which is delayed 0.2 s, on drop out, and



which with PTrH3-4 interrupts the connection from the carrier receiver, so that a tripping command from the opposite end arriving less than 0.2 s later can not reach the reclosure unit via:



which would block reclosure.

The reclosure command is given by a separate reclosure unit.

Should the fault recur during the blocking time, the sequence of operations as in Appendix to V.3a para.1-4 takes place, except that CSW is still attracted and connects AK9, 10 and 11 by means of CSW_{II3} and $II4$, so that the interruption is always triple-pole and by means of CSW_{I3} to AK12 is always a lock-out.

The entire relay then returns to the rest position 5 s later due to PTrW dropping out.

Appendix to V.3c.3:

Follow-through connection

The connections AK43-44 are to be removed in the two distance relays at H and K and the signal from the carrier receiver or the pilot wire taken to AK44. (The terminal AK20 remains unoccupied.) The switch Wa is to be set to the position "A" and percentage tapplings are to be taken from HG8 by means of the "green" cables "A" corresponding to 130% of the basic distance.

Case F_m : The fault F_m causes the relevant Z relays in H and K, together with their CA contactors, to pick up so that, as described in Sk2-6899, the M+PU measuring system receives the measurands. At the same time the CA contactors or the

CU relay (as explained in V.3b.1b, para 2) disconnects the carrier equipment from the telephone, etc., in case a tripping command has to be transmitted.

The PU in H picks up immediately and, in accordance with V.3a, trips the relevant breaker poles.

The PU in K cannot pick up at first, since F_m lies beyond the 85%.

At the same time the follow-through command is given from FD5-6 in H to the carrier transmitter or direct via the pilot wire to the CSA in the opposite station.

The command received in K is fed to AK44, so that CSA picks up and the M+PU measuring system is changed over from the "white" (I) to the "green" (A)appings at the HG8, thus extending the range beyond H.

If the PU in K detects the fault F_m , the breaker in K is tripped, as described in V.3a (except the two last paras).

In addition PTrW and PTaW, also CSW are attracted (see in Appendix to V.3b para. 3ff), although PTrW7-8 does not affect the CSA in this case since the connection AK43-44 is interrupted.

The fault current disappears the first time the breakers are opened: the Z relays, CA contactors and the PU in H and K reset, FD5-6 opens again terminating the follow-through command transmitted from the opposite station by h.f. or wire, CSA in K drops out and the "white"appings at the HG8 are in circuit once more.

If the fault F_m reappears on reclosure (or during the blocking time), the entire sequence is repeated. This time, however, the breakers are locked out, since PTrW, PTaW and CSW

are still attracted and CSW₁₃, II₃ and II₄ interconnect the terminals AK9, 10, 11 and 12.

Should the fault not return within the blocking time, then PTrW, PTaW and CSW drop out, thus restoring the original condition.

Case F_i: The two relays in H and K operate independently, as explained in V.3a, each one transmitting a follow-through command to the opposite station with the aid of FD5-6, since it cannot "know" whether the opposite station can in fact trip independently. Nevertheless, this in no way affects the correct function of these two relays.

V.3d Procedure in the case of circuit-breakers with temporarily reduced capacity

It is possible for breakers to have temporarily less capacity, e.g. if the spring of the loading mechanism in oil-immersed breakers is insufficiently charged or if the air pressure in the receivers of airblast breakers is below a certain minimum.

The execution of a complete break-make-break sequence during reclosure operation calls for considerable reserves of energy in the breaker, either in the form of spring tension or air pressure.

This is particularly important when overlapping (V.3c.1), since faults F_a on the far side of the opposite station could lead to additional tripping. If the breaker then uses up its reserve of energy to the point where the breaker control unit or pressure monitor rejects a reclosure command or prevents the reclosure unit from giving one, this would result in the breaker B_g remaining open. In the case of the fault F_a this would be unselective.

An additional precaution is therefore incorporated when operating on the overlap system in accordance with V.3c.1: if the reserves of energy - either spring tension or air - are unduly low, the M+PU measuring system is changed over to 85-90% of the line section (instead of 120% with overlap), even without line fault.

For this purpose the connection in the distance relay AK43-44 is removed and the auxiliary contact of the spring-loaded mechanism or of the pressure monitor substituted; these contacts open when values fall below the minimum spring-tension or air-pressure reserve.

As long as this annunciator contact is closed and W_a is at the position A, CSA remains attracted, so that the "green" cables (A) at the transformer HG8 (120% of line section) are effective. When the contact opens, CSA drops out, bringing the "white" cables (I) in circuit (85-90% of line section).

V.3e Out-of-step blocking service

Typical evidence of out of step condition is the fairly slow, symmetrical fall in the impedance: for this reason one separate impedance relay is combined with 2 auxiliary contactors with delayed pick-up, one of which is set to about 0.1 s.

If the impedance falls so quickly that less than 0.1 s elapses between the separate impedance relay picking up and the impedance relay in the LZ3... doing the same, then a short-circuit must be present: the out of step blocking device is then made inoperative and the LZ3... operates without it.

When actual out of step conditions occur the time for the impedance to fall is much longer: the contact of the out of step blocking device, fitted between AK42-41

opens, thus preventing FD from picking up and thus the tripping as well (T remains at rest too).

The time setting for the second time-lag relay extends to a few seconds, since if by that time the impedance relays still have not reset, this must be due to a real fault; therefore tripping is again made possible by reconnection of AK42-41.

Should an earth-fault relay pick up, so that CE picks up, this means an earth fault whose impedance could be falling slowly. The out-of-step blocking device must be made inoperative and this is done by bridging it with CE_{I7}.

During the blocking time (see page 69) the out-of-step blocking device is also short-circuited by PTaW7-8, so that the immediate clearing of a recurring interphase fault is not interfered with.

V.3f Manual changeover of the range in Step I

In systems requiring frequent changeovers accompanied by the corresponding adaptation of the range of step I (e.g. during peak loads, Sunday running, etc.), the CSA auxiliary contactor can be very useful - presupposing that the overlap connection in accordance with V.3c.1 or the follow-through system according to V.3c.3 are not planned (for which the CSA would be needed),

The connection between AK43-44 is removed, AK36 being connected to AK44 instead: closing of Wa (position A) enables the CSA to be attracted at any time.

Using the "white" (I) or the "green" (A) cables at the transformer HG8, the appropriate percentages can be tapped off in accordance with the desired two rapidly interchangeable ranges. With the switch Wa at position "A" the "green" tapplings (A) are effective, at the position I the "white" ones.

The changeover can also be made by remote control, for which Wa always remains at position A and the remote command is taken directly to AK44.

VI. ANNUNCIATOR, ALARM SYSTEM AND FAULT RECORDER

The attraction of certain auxiliary contactors is a sign that a fault has appeared in the power system.

Contacts are therefore brought out from the contactors "without potential" and intended for use with an alarm system or annunciator for operating a fault recorder or an oscilloscope, etc. These facilities enable the faults subsequently to be analysed with regard to type, events before and after the fault, etc.

VI.a Annunciator

A very suitable piece of equipment for this purpose is the BROWN BOVERI annunciator (signalling block) type B, which has up to 10 different signals, as shown in the drawings AK 112009 under item numbers 6 and 6a.

The signalling coils are normally fed from the same d.c. supply as the distance relay (when AK36-39 are to be connected), although other sources could be used (via AK39).

Upon attraction of the relevant auxiliary contactor, the pick-up coil 1-2 of the signal unit is energized and the symbol becomes visible.

Once read, all the signals are reset jointly by pushing the reset button, item 6a, which controls all the signal resetting coils 2-3 in common: the symbols then disappear.

Designation, significance and connection of the individual signals:

Signal	Aux. contactor contact	Meaning of signal	Connection to distance relay terminal
D	CD	Tripping command by distance relay to breaker	AK 25
R	CAR	Starting in phase R	AK 26
S	CAS	Starting in phase S	AK 27
T	CAT	Starting in phase T	AK 28
E	IE	Earth fault	AK 29
2	CS _{II}	Time step 2 begun	AK 31
3	CS _{III}	Time step 3 begun	AK 32
W	PTaW	Changeover to lock-out	AK 33
B	PTaE	Back-up earth-fault relay (only with LZ32); if not required, 10th signal remains available for other purpose.	AK 34
H	---	Operation of carrier transfer. In some cases this signal could be actuated by the h.f. equipment.	

If other makes of signals are used, their coil consumption should not exceed 20 W.

VI.b Alarm systems

Parallel contacts of the auxiliary contactors CE, CD and CSW and of the timer mechanism are connected in parallel and brought out in common between AK37 and 38 to which a visible or audible alarm can be connected. The maximum consumption of such an alarm may not total more than 20 W. With regard to supply, the same applies as in the paragraph above.

VI.c Fault recorder

A contact of each of the contactors CAR, CAS, CAT and CE of which one end is taken to AK46 in common, the other ends individually to AK47-50: these are available to control or transmit signals to a fault recorder.

VII. SETTING THE DISTANCE RELAY

The scope of this description only allows the basic principles of such adjustments to be dealt with, special considerations having to be taken into account in complicated power systems.

VII.a Starting elements Z

(for description see page 9)

The setting of the elements Z also determines the starting range of the distance relay; the upper limit of this range is determined by the following conditions:

After the affected section has been switched off, the Z elements in the adjacent lines must be able to reset reliably. In the case of two parallel lines, it must be borne in mind that the disconnection of one line can cause the service current in the other to rise appreciably. Furthermore, during earth faults the Z relays in the healthy phases must not pick up. The values for the upper limit of the starting range can be obtained with the aid of the following formula:

Insulated systems or those
earthed through arc-suppres-
sion coils

$$Z = \frac{E}{2 \times 1.25 \times \vec{I}_B} \quad \text{n/ph}$$

Earthed systems

$$Z = \frac{E \times 0.85}{2 \times \sqrt{3} \cdot (\vec{I}_B + \vec{I}_A)} \quad \text{n/ph}$$

E : Minimum phase-to-phase service voltage

$\frac{E \times 0.85}{\sqrt{3}}$: Minimum phase voltage in the healthy phases during earth fault

\vec{I}_B : Maximum service current possible

\vec{I}_A : Maximum possible balancing current in healthy phases during earth fault

1.25 : Correction taking effect of curve on page II into account.

.2 : EF reach is $\frac{2}{1+k_0}$; measures correctly if $k_0 = 1$.
(there is no EF compensation on starters)

On the secondary side of the instrument transformers these values are to be reduced by division by the factor N_z , which is calculated as follows:

The transformation ratio of the mains current transformer feeding the distance relay is:

$$N_i = \frac{\text{Rated primary current}}{\text{Rated secondary current}}$$

and that of the mains voltage transformer feeding the distance relay:

$$N_u = \frac{\text{Rated primary voltage}}{\text{Rated secondary voltage}}$$

From these two values the impedance transformation ratio of this combination of instrument transformers is calculated:

$$N_z = \frac{N_u}{N_i} \quad z = \frac{Z_{pri}}{N_z} \quad (\Omega/ph)$$

(possible aux. transformers with $N \neq 1:1$ must be taken into account)

If at all possible the Z relays should not be set above the following values:

$$\begin{aligned} 6 \Omega/ph & \text{ at } I_n = 5 \text{ A} \\ 30 \Omega/ph & \text{ at } I_n = 1 \text{ A} \end{aligned}$$

to prevent them from starting under an overload: the above formula take this into account.

VII.b Compounding

(only with types LZ31 and LZ32)

For a description and applications see: III.9, page 38.

Compounding the Z relays enables their starting range during short-circuits in the direction of the line to be increased

by the amount picked off the X chokes, whereas it is reduced by the same amount in the direction of the busbars. The correction factor given on page 43 , which depends on the $\cos\phi$ tapping set at the X chokes, must be borne in mind. Normally compounding is limited to about 40% of the impedance, which is to be covered by the Z starting relays.

VII.c Earth-fault relay IE

For a description see III.2, page 12

This relay should be set, so that during earth faults (earthed neutral) or double earth faults (insulated neutral or system compensated for earth faults) which occur within the basic distance, it still picks up reliably.

As a guide: set to 0.8 - 1.0 the system rated current.

On the other hand it should not be set any lower than necessary, since during heavy-current, polyphase faults, which produce no summation current themselves, a summation current can still appear on the secondary side due to unequal errors in the transformers: the IE relay must not pick up due to such a current.

VII.d Back-up earth-fault relay IB

Only with distance relay type LZ32.

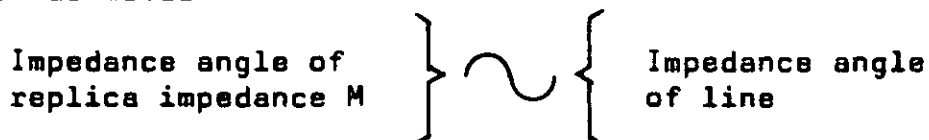
(For a description see III.2a on page 13)

This is normally set to $0.15 \times I_n$.

VII.e Step reactances

(HG8 and SH1 transformer tapplings, description page 32 and 29)

When as usual:

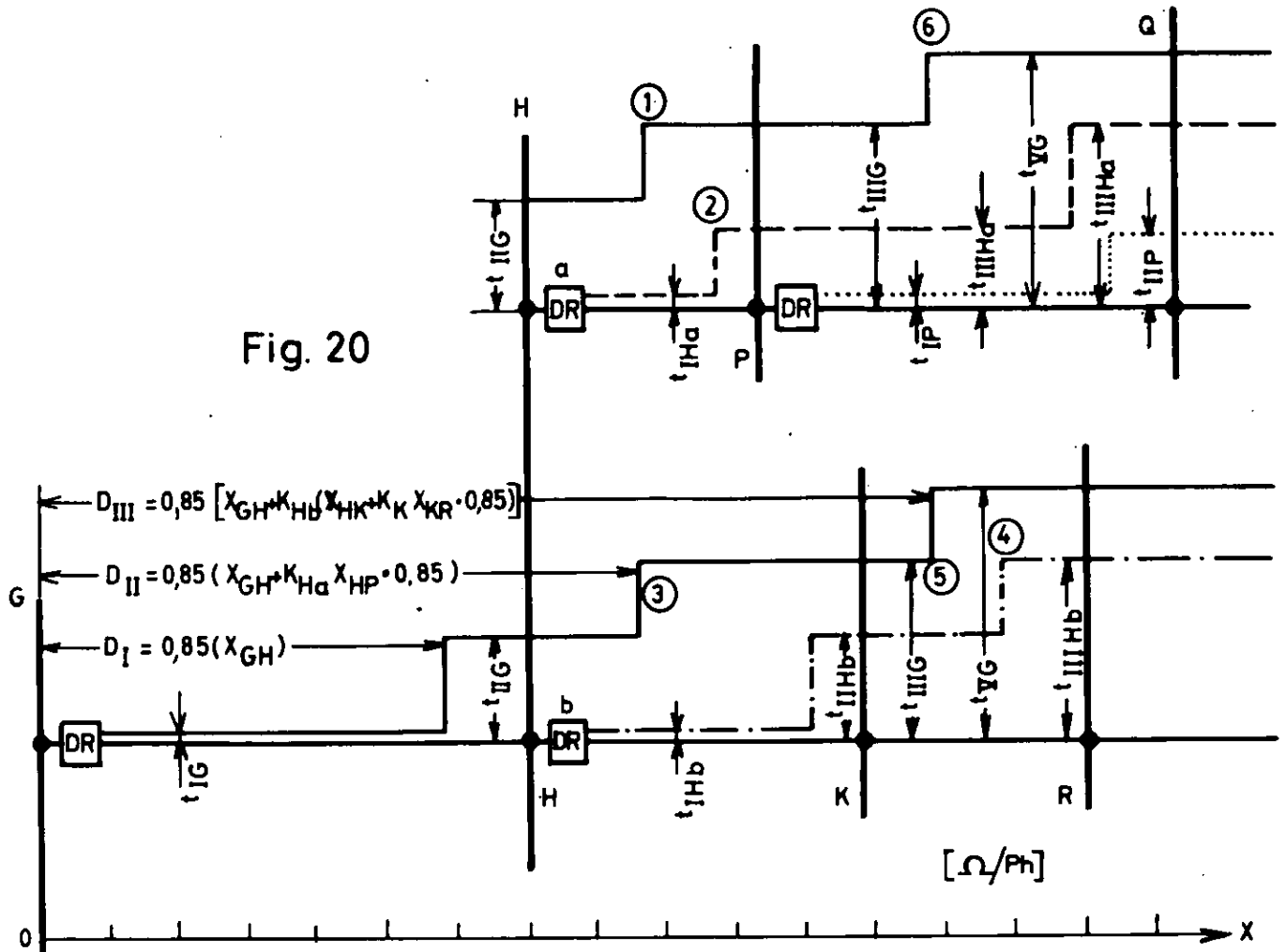


is chosen, the step range can be calculated with the line reactance X (instead of the line impedance Z).

Possibly φ_M may be deliberately made smaller than the short-circuit angle of the line: this has to be decided in accordance with conditions in the power system. Step I (also called the basic time) is normally adjusted - as described in detail in V.2 on page 61 - so that it covers 85-90% of the basic distance (G-H in Fig. 14 on page 62).

The correct calculation of step II, etc., is greatly facilitated by a system diagram to a reactance scale, the values being referred to the primary (high-voltage) side of the instrument transformers.

An example of such a diagram is shown below:



For calculating the distance step II the shortest line leaving H is decisive, since the range of step II (as far as point 1) of the relay in G must not overlap the range from where the relay in H at branch "a" (short Ha) protects in step II (from point 2 to the right), in order to retain selectivity.

Satisfaction of this requirement brings with it the incidental effect that the transition point along the line HK (point 3) between step II and III of the back-up relay to relay G does not occur at a particular place.

The setting of the distance step III must be made such that it does not overlap with the range of time-step III of the relay, whose transition from step II to III (point 4) seen from G, is the closest.

The example is intended to show that conditions in the lower line affect the sequences in the upper one (points 5 and 6).

No rigid rules can therefore be laid down, but every particular case has to be decided in accordance with the system diagram as shown above.

The factors K_H and K_K in the expressions D_{II} and D_{III} take the infeeds at H and K into account and are determined from:

$$K_H = \frac{I_G + I_{Ha}}{I_G}$$

I_G = Current flowing from G to H

I_{Ha} = Current flowing from H into branch Ha

The smallest possible value of I_{Ha} , (for instance), should be inserted.

The step reactances X calculated are referred to the primary side of the mains instrument transformers and have to be converted to the secondary side $x = X_{pri}/N_z$ (a/ph) by means of the impedance transformation ratio for the particular branch $N_z = N_e/N_i$.

The percentages to be set as tapplings at HG8 are calculated as follows:

Step I (basic distance) $N_I = \frac{\omega L \cdot 100}{x_I \cdot c} \quad (\%)$

Step II $N_{II} = \frac{\omega L \cdot 100}{x_{II} \cdot c} \quad (\%)$

Step III is calculated in a similar manner (and the overlap distance as well).

In the formula, the terms have the following meanings:

- N_I, N_{II} : The percentages to be tapped off the HGB for step I (white cable) and step II (yellow cable).
- ωL : The minimum adjustable measurement reactance (in short: the measurement reactance) of the PU relay chosen at the ωL tapplings of the current transformer SH1. (See also III.4.). It applies in the same way to all steps (for approximate values see below).
- x_I, x_{II} : The step reactances referred to the secondary sides of the instrument transformers in Ω/ph . (Not omitting any aux. transformers with $n \neq 1:1$).
- c : Tapping at HGB, either $c = 1$ or $c = 0.5$.

To enable the sensitivity of the PU to be utilized to the full, the measurement reactance ωL should be selected as large as possible and the tapping c made such that for step I we have $100\% \geq N_I \geq 50\%$. Should the step I be so short that the lowest value that can be set for L gives $N_I > 100\%$ then N_I can be set in steps of 10% between 110 and 200%, as described in Section III.6. A higher value can thus be chosen for ωL . The tables below should facilitate the choice:

For designs of relay with rated values: $I_n = 5 \text{ A}$; $U_n = 100 \text{ V}$

$x_I \text{ (}\Omega/\text{ph)}$			ωL	at which
at $N_I = 200\%..$	$..100\%..$	$..50\%$	Ω/ph	$c =$
0.075..	$..0.15..$	$..0.3$	0.15	1
0.1 ..	$..0.2 ..$	$..0.4$	0.2	1
0.2 ..	$..0.4 ..$	$..0.8$	0.4	1
---	0.8	1.6	0.4	0.5

for LI41 $\omega L = 2, 1 \text{ or } 0.5$. $C = 1 \text{ or } 0.5$

For designs of relay with rated values: $I_n = 1 \text{ A}$; $U_n = 100 \text{ V}$

x_I (a/ph)			ωL	at which
at $N_I = 200\%..$	$..100\%..$	$..50\%$	a/ph	$c =$
0.375	0.75	1.5	0.75	1
0.5	1	2	1	1
1	2	4	2	1
---	4	8	2	0.5

In the case of compounded distance relays (type LZ31 or LZ32) current transformers with larger ωL values are built in, which changes the Tables as follows:

For designs of relay with rated values: $I_n = 5 \text{ A}$; $U_n = 100 \text{ V}$

x_I (a/ph)			ωL	at which
at $N_I = 200\%..$	$..100\%..$	$..50\%$	a/ph	$c =$
0.2	0.4	0.8	0.4	1
0.4	0.8	1.6	0.8	1
---	1.6	3.2	0.8	0.5

For designs of relay with rated values: $I_n = 1 \text{ A}$; $U_n = 100 \text{ V}$

x_I (a/ph)			ωL	at which
at $N_I = 200\%..$	$..100\%..$	$..50\%$	a/ph	$c =$
1	2	4	2	1
2	4	8	4	1
-	8	16	4	0.5

values
of x_I

For relay designs with $U_n = 200 \text{ V}$, the figures in the Tables above, i.e. x_I and ωL , should be doubled; similarly these values can be obtained for relays with $I_n = 2 \text{ A}$ by halving the values of those for $I_n = 1 \text{ A}$.

for LZ32 $\omega L = 2 \text{ or } 4$ $C = 1 \text{ or } 0.5$

VII.f Share k_o of the summation current during earth faults

The share of the summation current which is to be taken into account in the distance-measurement during earth faults can be set by means of the k_o tapplings at the summation-current windings of the SH1 (see description page 25 , see also III.4).

The required k_o is calculated as follows:

$$k_o = \frac{1}{3} \left(\frac{X_o}{X} - 1 \right) = \frac{X_m}{X}$$

in which: X_o = zero-sequence reactance of line

X = positive-sequence reactance of line

X_m = mutual reactance between two line-earth loops

(Incidentally: either primary or secondary reactances can be inserted in these formula.)

VII.g Replica impedance M

(For description see page 31)

The phase angle of M can be matched to that of the line within the range $\cos\phi = 0.1$ to 0.8 by means of the sliding resistance.

VII.h Time-step relay T

(For description see page 35)

The cam TI is normally set so that its set of contacts are always changed over.

The time TII is usually calculated as the sum of: relay, breaker and arcing times plus a tolerance, which produces about 0.4 to 0.5 s (slightly longer in the case of two parallel lines).

The time TIII could be set to about $2 \times$ TII.

The time TIV is usually set to about 0.3 s (for reason see page 70, Para 2).

The time TV (Limit time) is normally set to $3 - 4 \times TII$ or slightly longer.

In special cases the values actually set can deviate considerably from those suggested above.

VII.i Auxiliary earth-fault contactor PTaE
(Only with distance relay type LZ32)

Setting range : 0 - 2 s
Normal : 2 s

VII.k Time-lag contactor for blocking the carrier trip reception PTrH

Setting range : 0.05 - 0.5 s
Normal : 0.2 s

VII.l Time-lag contactor for blocking time PTrW

Setting range : 2 - 5 s
Normal : 3 - 5 s

VII.m Time-lag contactor for lock-out PTaW

Setting range : 0.1 - 0.5 s
Normal : 0.3 s

The setting of the time-lag contactors with delayed drop-out PTr... is locked with a screw accessible from above, which should be loosened before any adjustments are carried out.

VIII. TESTING THE DISTANCE RELAY

Two basic methods can be used for testing the distance relay:

- a) With the aid of the BROWN BOVERI test set BB, which enables the pick-up values to be checked for quantitative agreement with the scheduled values: this requires trained personnel. The test covers the complete distance relay, from the starting relay through the M+PU measuring system to the tripping contactor, including the timer and the various auxiliary contactors.

After opening the front cover this test proceeds in the following sequence:

1. Turn the isolating elements at the test terminals 12, 13, 14 and 17 (breaker tripping and carrier circuits) to the interrupted position (horizontal). If the announcing or fault-recording equipment is not to operate as well, 15, 16 and 18 are to be interrupted too, also 19 - depending on external connections.
2. Fit the shorting link across the test terminals 1, 2, 3 and 4 (i.e. short-circuit mains current transformers).
3. Turn isolating elements of test terminals 1 - 8 into the horizontal position (interrupted).
4. Connect the multiple plug of BB test set onto test terminals 1 - 15. No mistake can be made providing pin 1 of the plug is lined up with test terminal 1.

Settings are then chosen on the test set simulating the fault according to type and distance; the distance relay under test being fed with the current and voltage values by actuating a push-button on the test set. The operating time of the relay can be measured with a separate chronometer.

Since the BB test set is portable, a number of distance relays can be checked one after the other. Various types of current, voltage and impedance relays can be tested with it too.

On completion of the tests, the relay is returned to the operational condition in the reverse order to points 1 to 4 above.

- b) Alternatively, testing can be undertaken with a quick-test circuit, consisting in the main of one manual test switch per distance relay and an auxiliary transformer, which supplies the test circuits for all the relays.

This simple test can be carried out by semi-skilled personnel.

Usually the test switches are in the "Operation" position, the connected distance relay then being normally operational.

On turning the test switch to "Test", the breaker tripping circuit and the auxiliary d.c. supply are disconnected from the distance relay first.

At the position "Test" the connection to the above-mentioned auxiliary transformer is established, this adding a sufficiently large current in the measuring circuit of the distance relay to the one already being supplied by the main instrument transformers, that the starting relays in the distance relay are sure to pick up. If then a push-button next to the test switch is depressed too, the auxiliary voltage is restored to the distance relay, enabling the various auxiliary contactors and the PU to react accordingly.

The push-button is intended to avoid excessively long operation of the auxiliary contactors, to prevent overheating their coils.

When the test switch is traversed through the two different test positions, currents and voltages are connected to the distance relay, which cause the individual elements to pick up.

A signal can be transmitted to the control room to indicate when the test-switch is out of the "operation" position.

This test is only qualitative ("go" - "no go") and also serves to operate the various elements from time to time to ensure their readiness to function.

IX. REQUIREMENTS WITH REGARD TO SYSTEM CURRENT AND VOLTAGE TRANSFORMERS, D.C. SUPPLY AND CIRCUIT-BREAKERS

IX.1 Current transformers

The measurements carried out by the distance relay should be especially accurate in the case of short-circuits at the end of distance step I: from which the accuracy requirements for the current transformer are derived.

The maximum overcurrent I_{KI} is calculated for a short-circuit at the end of distance step I. The current transformers must satisfy the following standard with regard to this short-circuit overcurrent I_K :

IEC 5P (i.e. max. $\pm 5\%$ vectorial error)

at max. consumption by the distance-relay circuit, referred to the rated current:

Distance relay type LZ3: 4.2 VA/phase

Distance relay type LZ31 and 32: 16 VA/phase
(with compounding choke X set to max. α/ph)

IX.2 Voltage transformers

- a) Magnetic voltage transformers should at least comply with Class 3, whilst the errors of the voltage transformer in the different phases may not differ by more than 0,5 %.
- b) Capacitive voltage transformers must meet the following requirements:
1. When the primary side, connected to the rated voltage, is short-circuited, the voltage on the secondary side must collapse immediately from the rated value to zero. Any transient phenomenon should have a decay frequency of less than $0,3 \times f_n$, or behave aperiodically (superimposed oscillations of more than $6 \times f_n$ are also permissible). In the event of a transient at any instant of a phase (including voltage zero) the residual voltage must fall below the value (expressed in V_{SW}) given in the following table within the time specified, and may not subsequently exceed this value.

	Decay frequency $(0.3 - 0) \times f_n$ or aperiodically.	
	Relay for: $U_n = 100/110 \text{ V}$	Relay for: $U_n = 200/220 \text{ V}$
permissible residual voltage after 25 ms	$3 \cdot V_{SW} \times \frac{1}{N}$	$6 \cdot V_{SW} \times \frac{1}{N}$

(V_{SW} : voltage peak value)

where N is the transformation ratio of the balancing transformer HG 8 in the distance relay; for a setting of 35% and $c = 1$, for example $N = 0.35$.

The transient must therefore always be weaker with increasing N, i.e. with decreasing length of the protected line.

In the case of decay frequencies which are closer to the rated frequency only smaller residual voltages are acceptable. At rated frequency an error of measurement of 10 % arises if after 40 ms the residual voltage attains the following value (in V_{eff}):

Relay for $U_n = 100/110$ V	Relay for $U_n = 200/220$ V
$U_R (V_{eff}) = \frac{X \times I_K}{U_n} \times 10$	$U_R (V_{eff}) = \frac{X \times I_K}{U_n} \times 20$

U_R = Residual voltage on secondary side
of transformer in V_{eff}

X = Primary line reactance in ohm/phase

I_K = Primary short-circuit current in A

U_n = Primary rated voltage (phase-to-phase) in V

2. The short-circuit impedance measured from the secondary side should not be greater than 0.25 ohm when $U_n = 110(100) : \sqrt{3}$ V, and not greater than 1 ohm when $U_n = 220(200) : \sqrt{3}$ V.
3. With uniform loading and down to 50 % of the rated voltage, the difference between the transformation errors of the dividers of two phases must be less than 0.1 % of the rated voltage at any given time. An additional error of at most 0.2 % is acceptable if the loading of two phases differs by 50 VA. A difference of 50 VA is to be expected when two or three distance relays are connected, since, in the case of certain short-circuits, the power consumption is not symmetrical.

4. The capacitive divider must not produce any sub-harmonics (even including switching processes in the installation on the primary and secondary sides of the dividers), steady state mains-frequency overvoltages or violent oscillations after energizing.
5. Should the dividers of the three phases have an open delta secondary winding to monitor the neutral voltage, any spurious voltage of the third harmonic which may be present in the system must not appear at the terminals in question, or to be amplified.
6. In the event of a short circuit on the secondary side, the current must be sufficient to cause the overcurrent protective devices (fuses, circuit-breakers, etc.) to act sufficiently quickly. If necessary, the pick-up current of these devices must be adapted to suit the voltage transformer. If a single LZ 3 distance relay is connected (an L6 panel may also be connected) the pick-up current can be reduced to 8 A in the case of relays with U_n 100/110 V, or 4 A with U_n 200/220 V; the current in the event of short-circuit between phase and neutral should then be at least 20 A.

IX.3 Circuit-breakers

(including breaker control unit and reclosure device)

If voltage is supplied to one or more of the terminals AK9, AK10 or AK11, the associated breaker pole (R, S or T) must open and reclose immediately afterwards. The reclosure pulse and the determination of the dead time are the responsibility of the breaker control unit or a reclosure device.

Voltage at the terminals AK12 and AK9 and/or AK10 and/or AK11 must provoke triple-pole lock-out of the breaker. Simultaneous energizing of the terminals AK9 and/or AK10 and/or AK11 together with AK12 has the advantage that triple-pole lock-out follows still quicker than mentioned above.

Certain types of breaker of other makes do not allow AK9, 10, 11 with AK12 to be simultaneously energized for lock-out, only AK12 may be energized. By changing over certain connections in the distance relay and adding auxiliary contactors externally, the distance relay can be adapted to these types of breakers; single-phase reclosure cannot be executed (see also V.3a.1 to V.3b.1, last para. in each case).

The trip coil circuits must be interrupted by auxiliary contactors on the breaker itself at the latest simultaneously with the main contacts.

Maximum permissible make current for the breaker tripping coils:
7 A per phase, i.e. 20 A for all three together.

If the changeover to lock-out is carried out by the breaker control unit too, this should not take place within 0.1 s of the first interruption to give the distance relay sufficient time to reset after interruption of the fault current.

X. APPENDIX

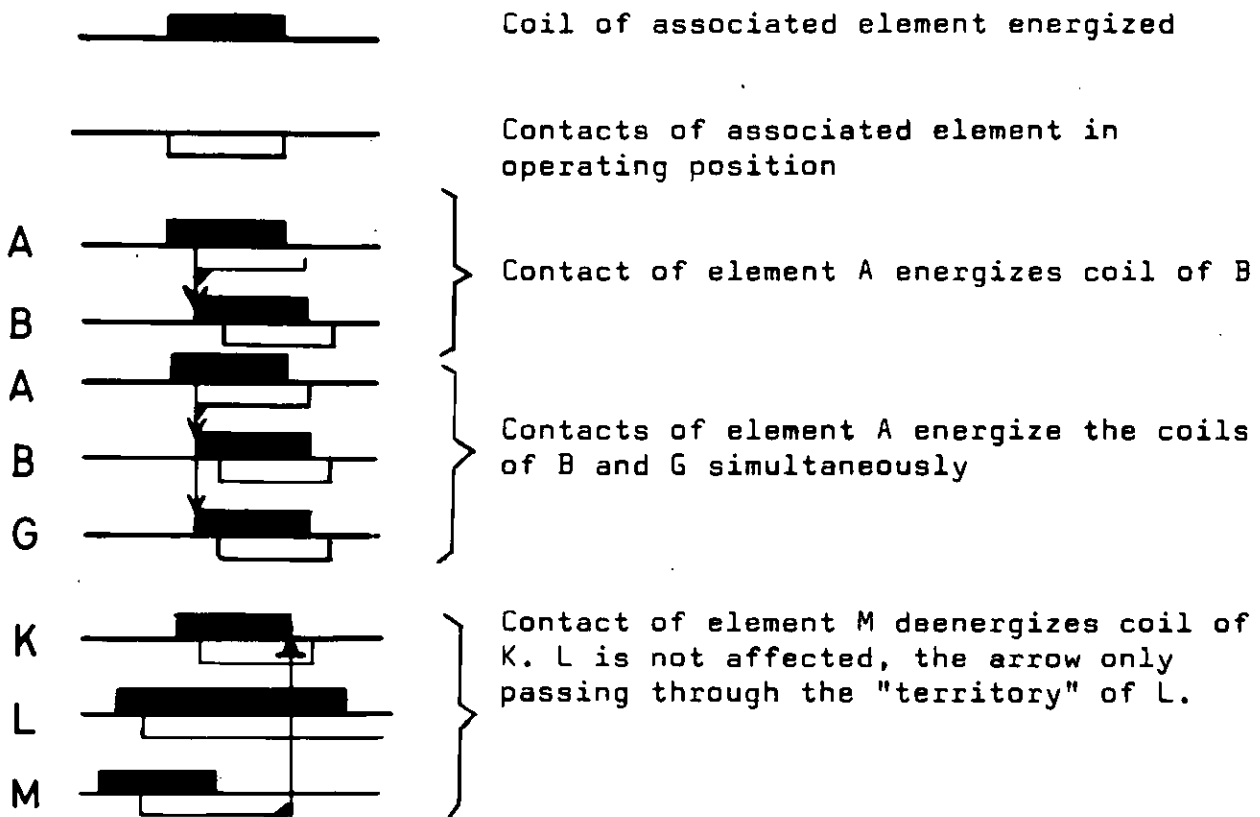
X.1. Timing diagram showing sequence of operation of various units in distance relay with carrier transfer

In order to present a more straightforward picture of the interaction of the various elements described with words in V.3c.2, the diagram (page 127) shows the sequence of operations and timing of the individual units in the case of a fault F_i , the two stations C and D being connected by carrier transfer.

A complete reclosure sequence is represented. It is also assumed that the fault recurs during reclosure, so that finally the two relays order a triple-pole lock-out.

LEGEND to sequence of operations of individual elements

Explanation of symbols



(NOTE: Station E in V.3c.2 corresponds here to station C, similarly G and D.)

At t = 0: Start of "first" fault, whereupon:

in C	}	<u>start</u>	one or several	}	<u>Z</u> relays	}	after about 10ms operating time contacts close
and D					<u>CU</u> relays (separately) when earth fault also <u>IE</u> relay		

so that at t = 10 ms:

in C	}	energizing of relevant aux. contactors	}	<u>CA</u> (R, S, T)	}	contacts (operating time approx. 15 ms)
and D				<u>PCU</u> (R, S, T) separately <u>CE</u>		

results at t = 25 ms:

in C	}	<u>Application</u> to <u>M+PU</u> systems of currents and voltages depending on type of fault, also preparation of path for tripping command to affected breaker phases (last not represented).
and D		

at the same time:

in C	}	disconnection of <u>carrier link</u> from telephone and tele- metering by CA and/or PCU and/or CE and <u>set to stand-by</u> for tripping signals.
and D		

At t = 38 ms

only	}	because of location of fault PU picks up and <u>energizes</u> FD (operating time about 2 ms), whose contacts
in C		

at t = 40 ms

only in C: transmit the tripping command to the relevant coils of the circuit-breaker in C

(Up to this instant 40 ms counts as the minimum operating time of the distance relay; since all the subsequent actions in the relay have no influence on the interruption of the "first" fault by the breaker in station C.)

At the same time:

only in C: Tripping command passed to carrier link for transmission to D
(transmission time about 20 ms)

At t = 60 ms:

only in D: Tripping command received via carrier link passes through AK19 via the path prepared by CA to the relevant breaker tripping coils.

At the same time:

only in D: Tripping command received via carrier link energizes coil of PT_{rw} through AK21

At t = 40 ms:

only in C: Other contact of FD energizes CD, whose contacts in turn cause:

at t = 55 ms:

only in C: Back-up for FD contact in tripping coil circuit of breaker, also

at the same time:

only in C: Energizing of coil PTrH, so that carrier receipt of tripping signals, which may arrive from D, is blocked.

Also at the same time:

only in C: Interruption of difference circuit of the M+PU, so that PU resets.

Also at the same time:

only in C: Energizing of PTrW with delayed drop-out.

At $t = 75 \text{ ms}$:

in C and D: One contact of each of the PTrW energizes the PTaW with about 0.25 s delay on pick-up.

At $t = 125 \text{ ms}$:

By now the breakers in C and D have progressed so far with their mechanical operation, that their auxiliary contacts interrupt the tripping coil circuits, their main contacts are now open and the breaker arc extinguished. The fault current has ceased to flow and the fault arc (if any) eliminated. Now - in D always at a time d later than in C -

at $t = 125 \text{ ms}$:

in C and D: Z and IE } reset (the ones which had been attracted)
relays }

so that at $t = 135 \text{ ms}$:

in C and D: CA and CE } drop out
contactors }

Causing:

in C and D: the M+PU systems to be disconnected for the measurands again.

Also: at t = 145 ms:

only in C: the CA contactors switch off the FD coil, whose contacts

at t = 147 ms:

only in C: switch off the coils CD

at t = 157 ms:

only in C: CD, by means of its contacts:

at the same time:

only in C: switches the coil PTrH off, its time-lag expires, so that after about 0.25 s the blocking action on the carrier link is removed;

at the same time:

one CD contact switches off the PTrW coil, starting a 5 s delay in drop-out, i.e. the blocking time.

at the same time:

only in C: two CD contacts in series interrupt the tripping coil circuit of the breaker (if not already carried out by the auxiliary contacts of the breaker control system),

at the same time:

in C and D: End of the tripping command transferred by carrier.

whereupon, at t = 175 ms:

in D: The carrier unit interrupts the tripping coil circuit of the breaker (remark as for last but one para.)

in D: and switches off the PTrW coil, starting the 5 s delay in drop-out, i.e. the blocking time.

NOTE: The interruption of that part of the fault current passing through D is delayed by the transmission time. The dead time of 0.25 s represents the effective interval, during which the arc path at the fault location is able to deionize.

At t = 325 ms:

in C and D: After the 0.25 s delay in pick-up has expired, the PTaW contacts close, so that:

in C and D: the coils CSW are energized, whose contacts

at t = 335 ms:

in C and D: prepare the triple-pole lock-out, should the fault recur within 5 s.

at t = 305 ms:

in C and D: the various reclosure units give the closing commands to the relevant coils of the breakers, which close their main contacts within about 80 ms.

at t = 395 ms:

Assuming that the fault recurs immediately, the same sequence of operations as at t = 0 for the "first" fault is repeated, with the following differences:

in C and D: The carrier link is still at the ready from the first fault through a contact of the PTrW with delayed drop-out.

at t = 435 ms:

in C: Tripping command to the breaker in C, which is always for a triple-pole lock-out since the CSW has been preparing for this since t = 325 ms.

at t = 455 ms:

in D: The tripping command received via carrier transfer trips the breaker in D, always as triple-pole lock-out prepared by CSW since t = 340 ms.

When at t = 520 ms the breaker in C and
at t = 535 ms the breaker in D have
interrupted their shares of the fault current,
then the various elements reset, as described
from t = 125 ms to t = 175 ms above.

at t = about 5550 ms (5,5 s)

in C: the delay in drop-out for PTrW runs out, so that

at the same time:

in C: the carrier link is once again cleared for telephone and telemetering,

and at the same time:

in C: the coil PTaW is switched off.

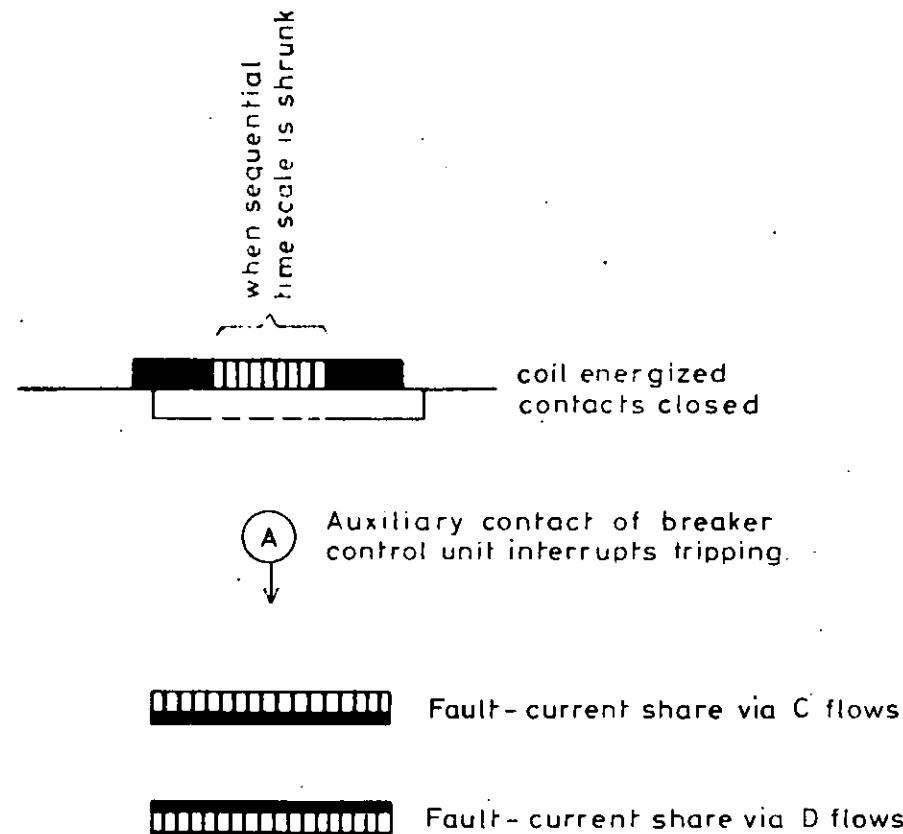
at t = about 5565 ms:

in C: the contacts of PTaW switch the coil of CSW off,
so that

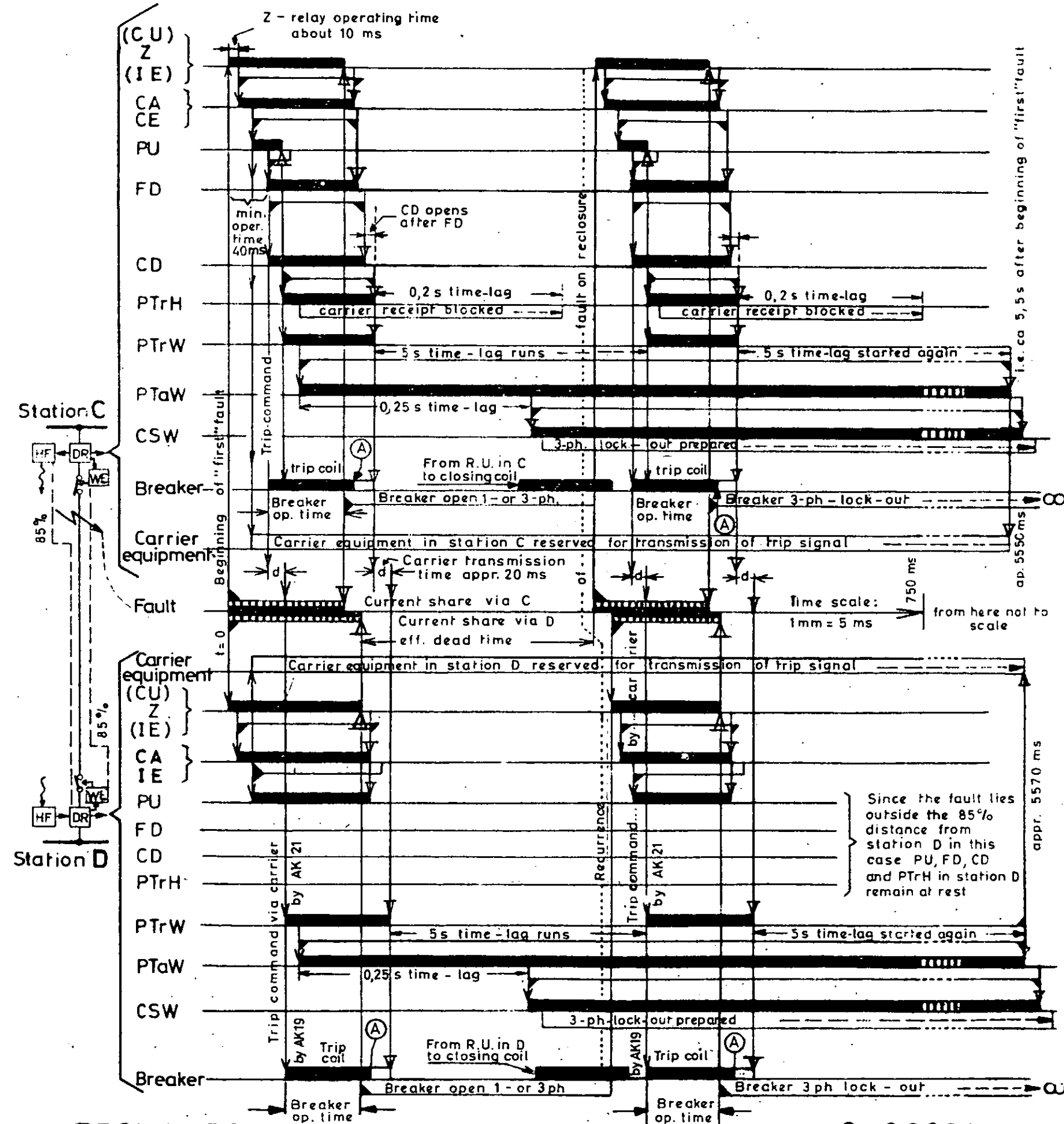
at t = about 5580 ms:

in C: the preparation for the triple-pole lock-out is
cancelled and, after the breaker is closed (by
means of the separate manually operated control
switch), any possible new fault is treated as
a "first" again. The distance relay therefore
does not "remember" what happened previously.

in D: As from t = about 5570 ms the same sequence of
operations takes place in D as that in C from
t = about 5550 ms.



Remarks: For sake of clarity the breaker operating time has been chosen relatively long



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2-300888

X.2 Explanation of symbols in 2 - 100546



Resistor



Variable resistor, potentiometer



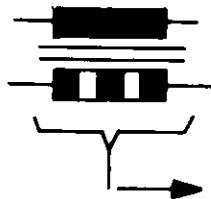
Winding on iron core
(without air-gap)



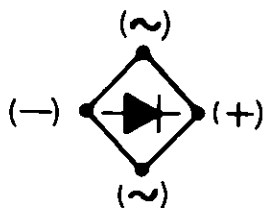
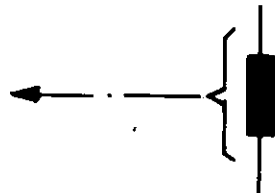
ditto with air-gap



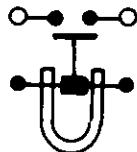
Instrument transformer



ditto, but secondary winding acts
at other point, follow arrow



Rectifier bridge,
point of diode towards positive pole



Moving-coil relay



Auxiliary contactor coil



Delayed pick-up (aux. contactors)



Delayed drop-out (aux. contactors)



Normally open contact



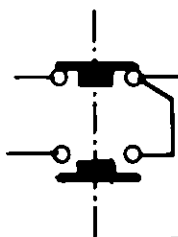
Leading normally open contact



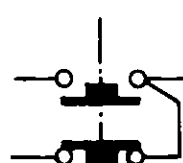
Opening contact



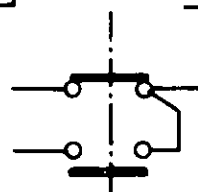
Lagging normally closed contact



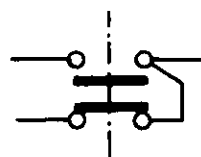
or



changeover make before
break contact



or



changeover break before
make contact



Terminals of distance relay



Components outside distance
relay shaded grey



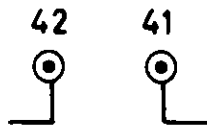
Only fitted in LZ31 and LZ32



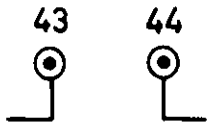
Only fitted in type LZ32

For clarity's
sake all contacts
are shown as
double-break type
(in fact so for
PTRH), even when
only-single-break
(actually: CA)

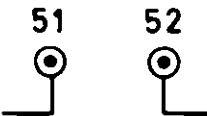
Special connections to external ancillaries
(short-circuited when not required)



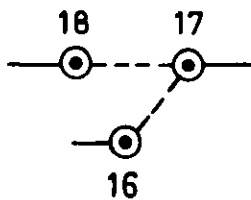
Out-of-step blocking (NC) contact



Minimum-pressure (NC) contact
for blocking overlap



Closing contact for pilot wire unit



For Brown Boveri breakers: short-circuit
AK18-17 for breakers acc. to V.3a.1
last para. short circuit AK16-17

PTaE3-PTaE5 Connection for back-up tripping with IB alone

Remarks:

Omitted in this diagram because they are not essential for understanding:

- a) Aux. resistors in elements
- b) Spark-suppression, contact-pressure increasing circuits and test circuits for moving-coil relays
- e) Aux. tripping circuit for PU relay
- f) Unit-percentage tapings at HG8 with associated time-step contacts
- g) Protective resistors, fuses or magnetic tripped switch in voltage-transformer circuit
- i) Tappings:
 - 1.) at resistor of replica impedance M
 - 2.) at primary and secondary side of X chokes
 - 3.) L and k_0 at current transformers SH1
- k) Additional tripping contacts AK61-67
- l) Coils of contactors CSII and CSIII
- m) Possibility for choosing phase angle of replica impedance for earth fault different to that of interphase fault

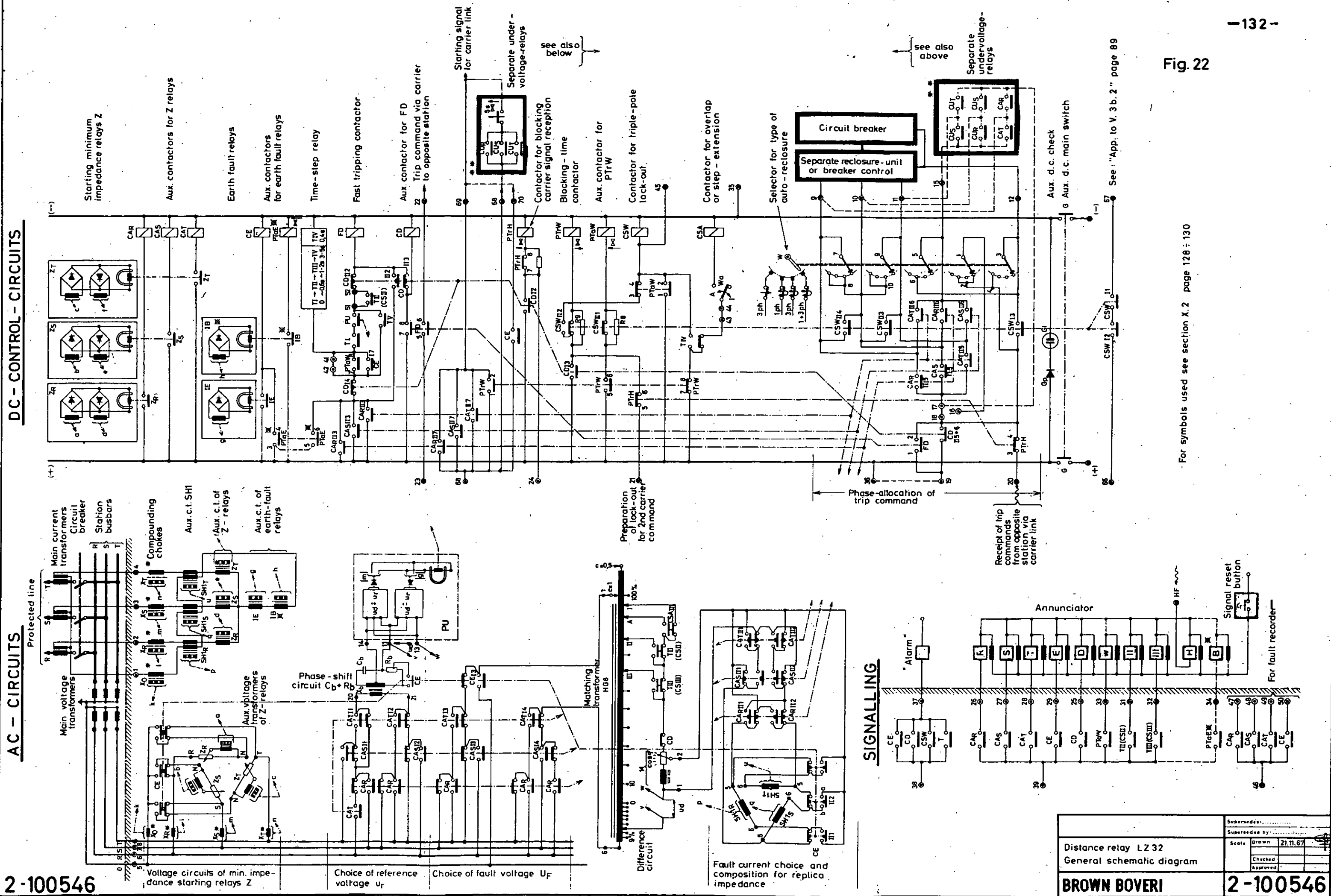
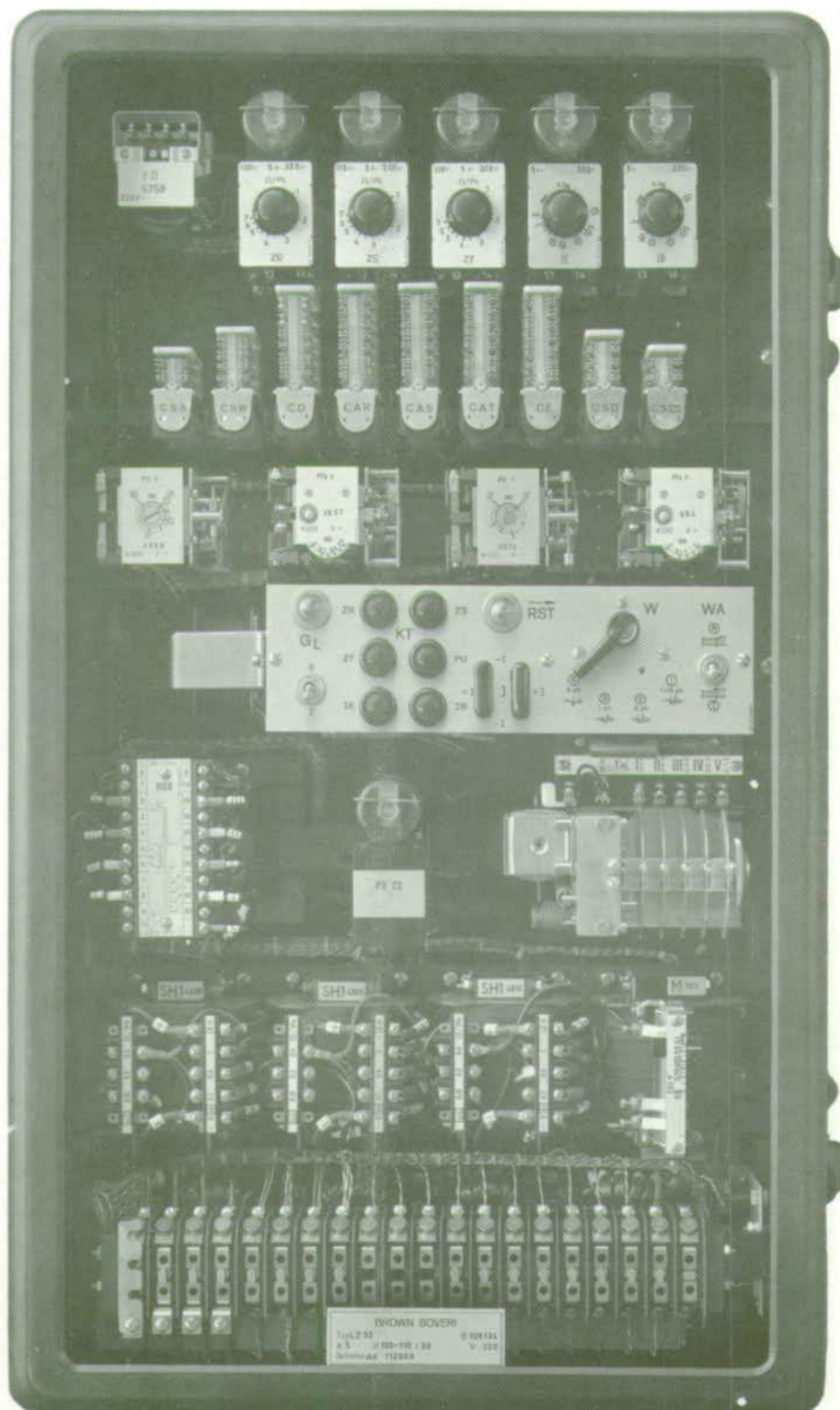


Fig. 22

For symbols used see section X.2 page 128 ÷ 130

LZ 3



BROWN BOVERI

135469

X.3 Legend to diagram AK 112009

This diagram shows the circuitry of the type LZ32; the type LZ31 does not contain the components marked ~~✕~~.

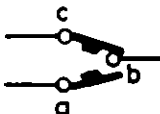
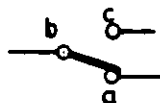
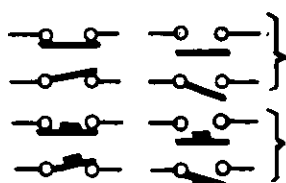
The type LZ3 differs from the LZ31 in that the components marked *) are not fitted either.

AK	Terminals (AK1 - 80), "Reserve" representing free AK available for special purposes
CA	Aux. contactors CAR, CAS, CAT for starting relays ZR, ZS and ZT with resistors for easy self-holding
C _b	Capacitor of reference voltage shifting circuit
CD	Auxiliary contactor for FD
CE	Auxiliary contactor for earth-fault relay with protective resistors
CS II	} { Aux. contactors for distance-step changeover IIInd and IIIrd steps
CS III	
CSA	Aux. contactor for overlapping
CSW	Aux. contactor for preparing lock-out
FD	Fast tripping contactor
G _H	Main d.c. switch
G _L	Pilot lamp for d.c. supply
G _p	Diode for polarity check of d.c. supply
HGB	Matching voltage transformer
J	Changeover plug for reversing measuring direction of PU
IB	Back-up earth-fault relay
IE	Earth-fault relay

K	Test terminals (K 1 - 20) o = upper and u = lower contact piece
KT	Test buttons (KTZR, KTZS, KTZT, KTIE, KTIB, KTPU) for relays ZR, ZS, ZT, IE, IB, PU.
M	Replica impedance
PTaE	Time-lag contactor for back-up earth-fault relay IB
PTaW	Time-lag contactor for preparing lock-out
PTrH	Time-lag contactor for blocking h.f. trip
PTrW	Time-lag contactor for blocking time
PU	Phase-comparison relay
R 1-6	Protective resistors for contacts of CA against possible switching short-circuits
R 7-11	Field-weakening and series resistors
RKT	Protective series resistors for ZR, ZS and ZT check circuits
RST	Rotating-field pilot lamp lit when all three phases correct
SH1	Current transformers (SH1R, SH1S, SH1T)
Si	Fuses for test-set connections
T	Time-step relay (I = basic time, II = 2nd step, III = 3rd step, IV = changeover to lock-out, V = limit time)
W	Selector switch for type of reclosure
Wa	Overlap switch (setting 1 for operation without overlap)
X	Compounding chokes (XR, XS, XT, XD)
X _b	Auxiliary transformer of the phase-shift circuit for the reference voltage
Z	Minimum-impedance starting relay (ZR, ZS, ZT)

Elements outside distance relay or connections for them

- 2) Main voltage transformer
- 3) Main current transformer
- 4) Coils for tripping the circuit-breaker
AW: with reclosure
AD: for lock-out (see also diagram of reclosure unit or of breaker)
- 5) Signal unit for alarm
- 6, 6a) Annunciator, reset button
- 7) Incoming "trip" signals from carrier receiver
- 7a) Outgoing "trip" signals (AK22) and start for carrier transmitter (AK69-70)
- 8) To undervoltage relay CU for additional phase allocation of the received tripping order (required with carrier transfer)
- 9) Additional tripping circuits (can be combined with the others)
- 10) To fault recorder



Contacts
Contacts with normal opening

Contacts with smaller opening

Changeover contact break before make, centre contact spring moves

Changeover contact make before break, outer two contact springs move


For numbering of contact springs of contactor C...
see page 49

The following connections are made with yellow wire or wire with yellow sleeves and can be altered if required:

1. For follow-through connection remove AK43-44 and take incoming signals to AK44 (see also V.3c.3, page 80)

Instead of connection AK43-44, pressure-switch contact can be inserted (see also V.3d, page 99)

2. If it is desired to make the execution of a received carrier trip-command (App. to V.3c.2, page 94) dependent on whether at least one starting Z-relay and/or one undervoltage relay CU have picked up, and when switch W is in position 3ph

 , the connection W4-W2 is to be changed over to W4-W8.

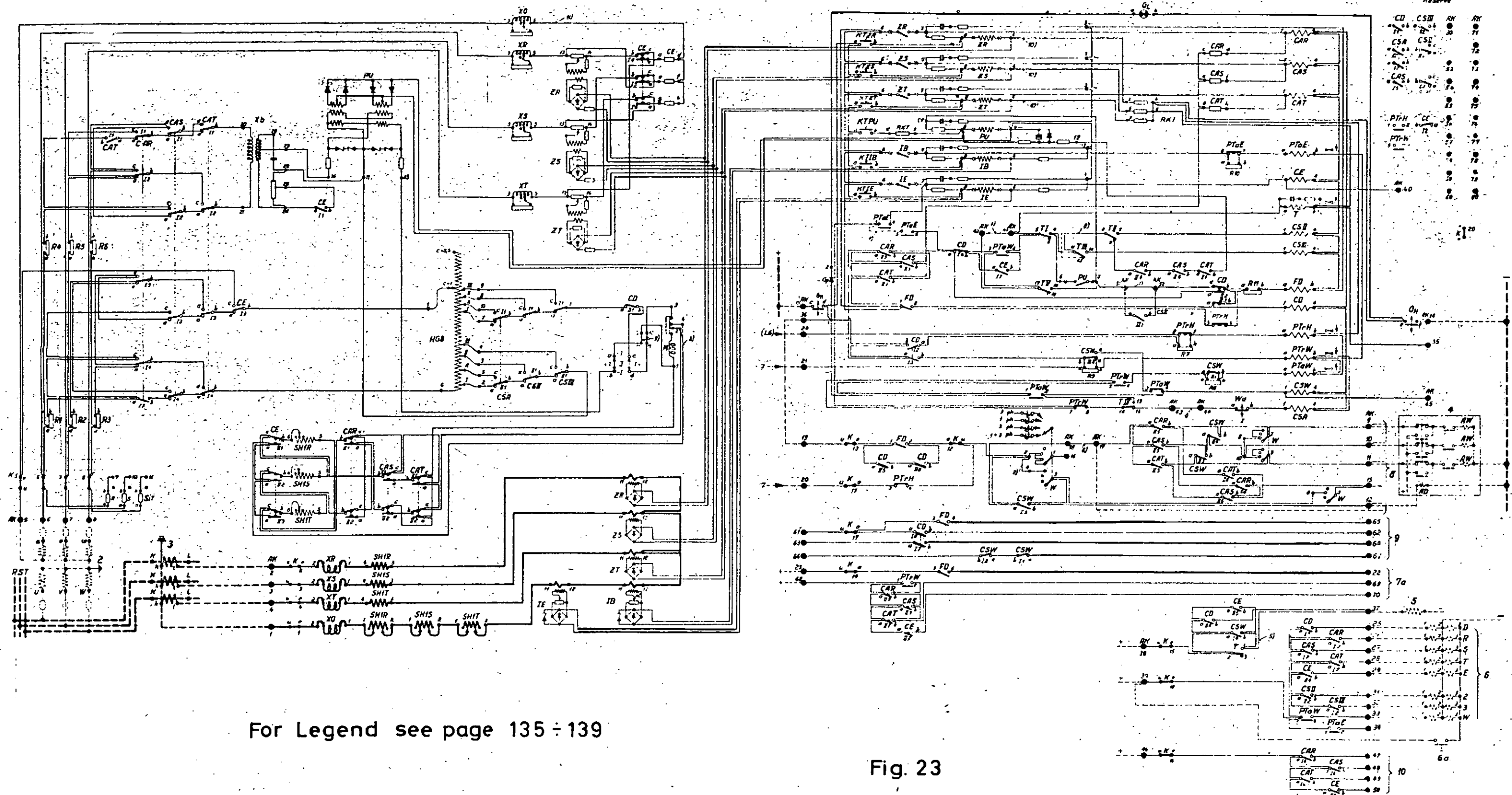
3. If the replica impedance phase angle for earth faults is required to be different from the angles for interphase short-circuits, the connection CEII 1a-M2 is to be transferred to CEII 1a-M4 (see also III.5, page 31).

4. For back-up starting or limit-time tripping by back-up earth-fault relay IB, connect PTaE3 and PTaE5 (see also page 67).

5. If the starting of the timer is not to give an alarm at AK37, disconnect AK37-T1 at T1 (and insulate the end of wire).

6. For breakers whose AW coils may not be energized for lock-out, change AK17-18 to AK17-16 (see also page 69).

7. For the out-of step blocking device, remove connection AK41-42 and connect contact of device here (see also V.3e, page 100).



For Legend see page 135 ÷ 139

[illegible]

8. For reversing measuring direction of PU in distance step II only, apply 9. (below) and change connection TII8 - TIII11 to TII8 - TIII12 (see also V.2, page 61).
9. If the measuring direction of the PU for given distance steps (see 8. above) is to be reversed, insert one changeover contact each of the CSII contactor or of a separate CSX in place of the wires connecting 9-10 and 11-12.
10. Changeover facility for special purposes.
11. To take the impedance line-earth into account, which can be smaller than the impedance line-line, the connection CE_d-XO₅ is to be changed to XO₄ (see also page 43).

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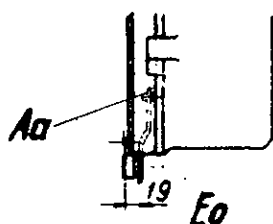
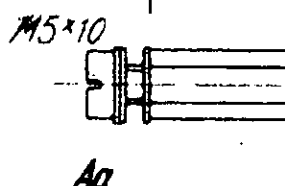
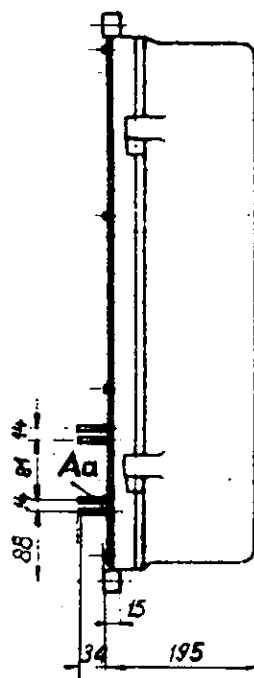
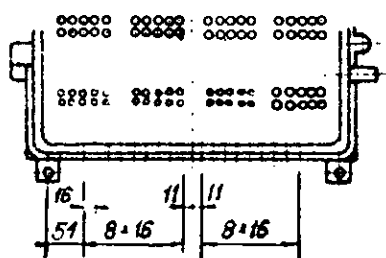
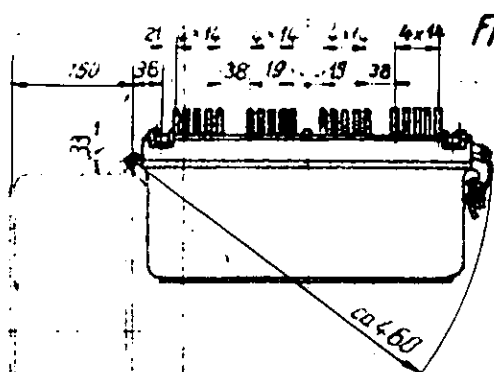
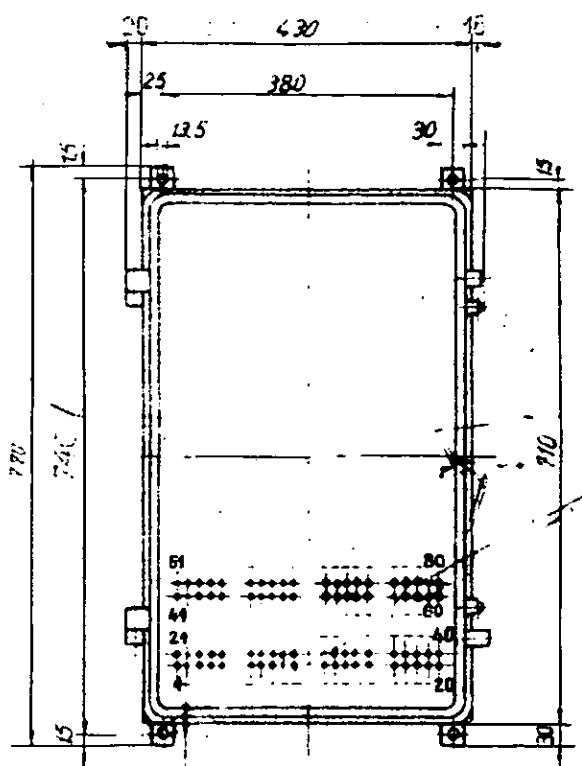


Fig. 1

Fig. 2

Fig.1 Für rückseitigen Anschluss
Fig.2 Für vorderseitigen Anschluss

Aa Anschlüsse M5

Eröffnung für vorder-
seitigen Anschluss

fig.1 For rear connection
fig.2 For front connection

Aa Terminalis M5

Ed Apertures for front connection

fig.1 Pour raccordement arrière
fig.2 Pour raccordement devant

Aa Bornes M.5

En Ouverture pour raccorde-
ment devant

Fig. 24

**Distanzreials Typ
Aufbau-Montage**

Distance relay type
surface mounting

Relais de distance type
pour montage en saillie

LZ 3
LZ 31
LZ 32

P7-W87

A 16h

287.60

⑨ 26. 11.
1962
W.

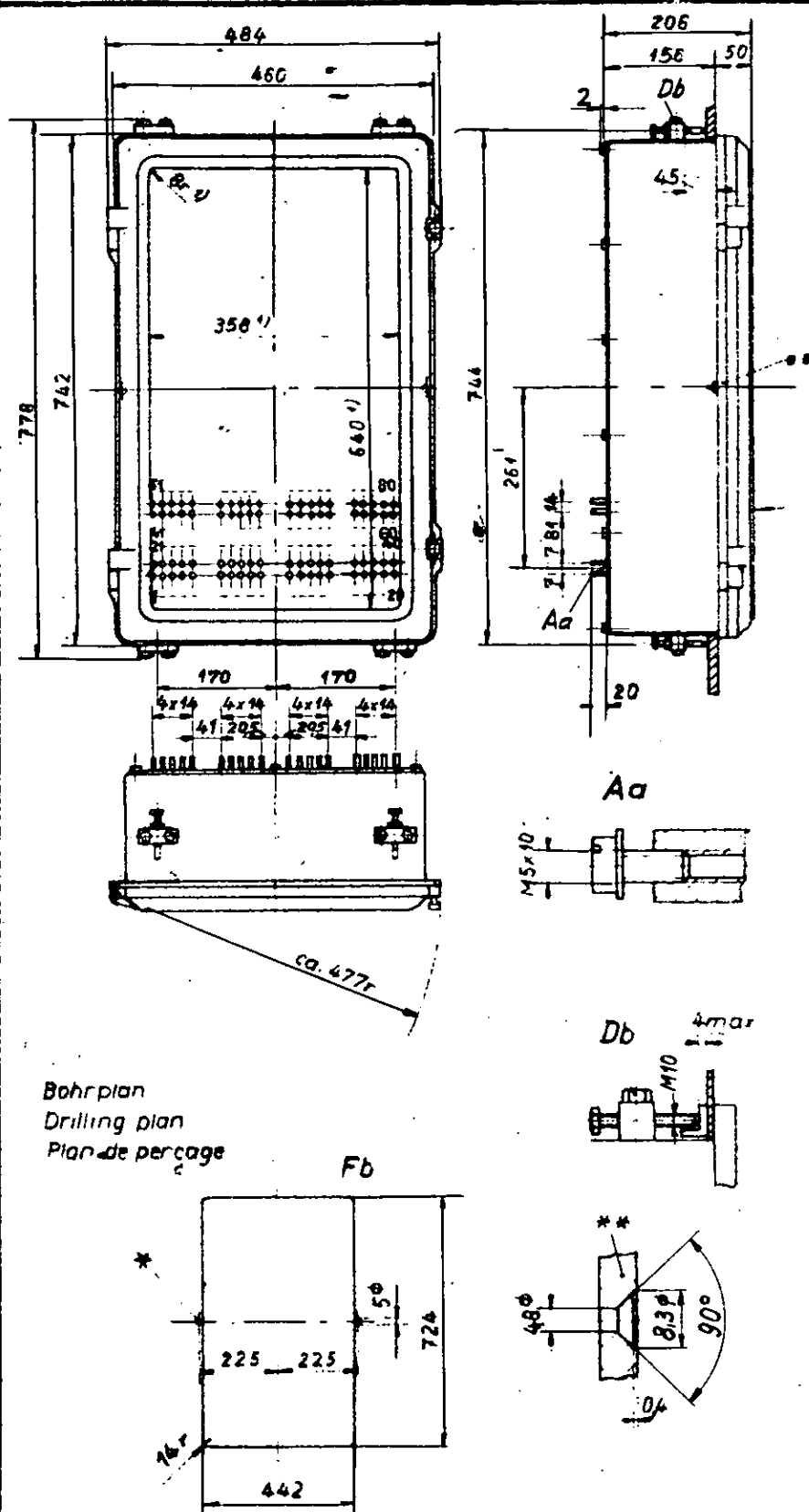
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- 140 a -

1) Öffnung des blasfensters
1) Pane-of-glass dimensions
1) Dimensions de la vitre

Erklärung

- Aa Anschlüsse M5
- Db Festklemmvorrichtung
abnehmbar;
- Fb Schalttafel-ausschnitt
- * Löcher im Kastenfl. als Bohr-
lehre benutzen

References

- Aa Terminals M5
- Db Fixing device (detachable)
- Fb Cutting out on switchboard
- * Use the holes in the case
as drilling gauge

Légende

- Aa Bornes M5
- Db Dispositif de fixation du boîtier
(démontable);
- Fb Ouverture de montage
- * Utiliser les trous dans le boîtier
comme jauge de perçage

Fig. 25

Distanzrelais Typ
Einbau-Montage

Distance relay type
Flush type

Relais de distance type
Pour montage encastré

LZ 3
LZ 31
LZ 32

PZ-WBZ

A16 h

28. 7. 60

frad

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BROWN BOVERI

AK 420892

X.4 Remarks on Sk2-6899 with regard to double earth-fault

A double earth-fault is defined as: an earth fault at two phases, at least one substation coming between the two earth-fault locations.

Since a double earth-fault is affected by several factors (location of faults to one another and to relay, interconnection of power system, etc.), the explanation below can only deal with the basic principles.

Only such double earth faults are considered (system with isolated neutral) as cause a summation current at location of relay in question, so that IE picks up and hence CE attracts, whereupon the starting relays Z and the measuring system M+PU are changed over to the phase values (see also pages 12 and 57).

It is also assumed that the Z relays belonging to the affected phases pick up.

The LZ3 reacts to double earth faults without or with little summation current as to corresponding interphase faults (see lines 1 - 3 of Sk2- 6899).

In the case of unilateral infeed, the position of the more remote earth fault is decisive. Additional infeeds cause further currents to flow via the double earth fault, whose voltage drops increase the voltage at the relay in question. This gives it the impression of a higher impedance than that actually possible for the more remote earth-fault location. As a result this location is "seen" as being further away still, so that the M+PU may only pick up in step II or III, in the extreme case tripping only taking place in the limit time.

A summation current only appears at the relay location:

- a) On simple tie lines when one of the faults is in the direction of measurement but the other "behind" of the distance relay, (i.e. the relay lies between the two earth faults (Fig. 28, 30 and 31).
- b) In meshed systems, in principle wherever the faults occurs on the line (Fig. 29, 29a and 32). The size of the summation current depends on the location of the faults to one another and with respect to the relay. If for instance the two faults are close together and in the measuring direction of the relay, the summation current is small.

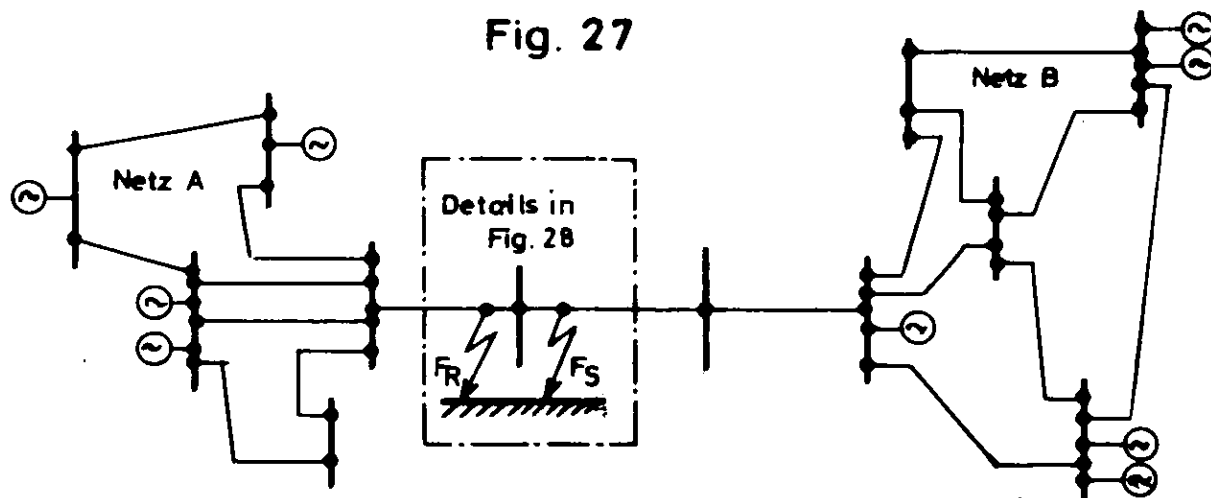
By way of simplification in Fig. 28-32, it is assumed that all the impedances Z_U , Z_g and Z_L , etc. have the same short-circuit angles.

Case 1: Earth fault S close

R close as well

(Lines 8 and 10 in Sk2-6899)

Close in this case means within distance step I. The fact that the two faults are close to one another is of particular importance. The diagram below shows the location along a simple tie line - given in detail in Fig. 28 or 30 - connecting two systems, for instance.



Legend to Fig. 28 (page 152)

D	=	Distance relay
E	=	Earth potential
F	=	Location of fault
I	=	Currents
K, L	=	Terminals of main current transformer
St	=	Station busbar
U	=	Voltages
Z	=	Impedances of various line sections
u_d	=	Difference voltage (see page 16)
u_M	=	Voltage at replica impedance M
u_r	=	Reference voltage of M+PU system (see page 18 + 22)
R, S, T	=	Phase potentials at location in question

Subscripts:

g	=	To the right of station busbar St
u	=	To the left of station busbar St
E	=	Earth
F	=	During double earth fault
R, S, T	=	Phases
	=	Summation current

(For vector indications see page 20)

"In the earth" each part of the current on transition from u to g changes its name and sign, since according to the vector system it is first considered from one side and - after flowing through earth - from the other: e.g. I_{Su} becomes $-I_{Ru}$.

For the sake of simplicity, any voltage drop across the earth locations F_R and F_S , also the earth impedance between the two faults (since they are close) is taken as being negligible in Fig. 28. Hence U_{REF} , U_{SEF} and U_{SRF} at the location of the relay will be negligible as well. The "lightning" in the vector diagram is only a fault symbol and is not intended to show voltage size.

If the impedance in the fault loop (even though the fault lies in the impedance step I) is not negligible compared with the supply impedance, U_{REF} , U_{SEF} and U_{SRF} can be sizeable at the relay location. Yet if Z_S and/or Z_R in D_U and D_g still pick up, the fault is regarded as "close".

(The voltage star U_{RE} , U_{SE} and U_{TE} before the fault begins is given at the extreme left.)

In the two distance relays the following currents flow:

In Phase R: I_{Rg} from the right and

In phase S: I_{Su} from the left.

It is assumed that I_{Su} is large enough, so that together with the collapse of U_{SE} at least the impedance relays Z_S in D_U and D_g are made to pick up. The voltage U_{SE} is then chosen as fault voltage U_F (in acc. with line 5 of Sk2-6899).

To present as general a picture as possible, it is assumed in Fig. 28a-e that the supply impedances from the left (Z_U) and from the right (Z_g) differ, i.e. $Z_U < Z_g$. It follows from that: $I_{Ru} > I_{Rg}$ and $I_{Su} > I_{Sg}$, which is also the reason why the currents I_{Rg} and I_{Su} in the two phases R and S of the distance relays D_U and D_g are of different size: $I_{Su} > I_{Rg}$. The explanation below applies regardless of whether $Z_U = Z_g$ or $Z_U > Z_g$. (If at least Z_S is made to pick up.)

When two impedance relays start, the lagging fault current of the two determines the behaviour of the M+PU system, in accordance with the preferential sequence (page 57):

The relay D_g will therefore trip, since it "sees" the fault F_S in its measurement direction.

The conditions for D_g are given in line 8 of Sk2-6899 .(As already said, $U_F \sim U_{SE}$ is assumed, so that the replica voltage produced by I_S in D_g acts with virtually no reduction as u_d , which is thus certain to have a component opposite to u_r (see also Fig. 5c, page 27). The M+PU system in D_g therefore trips.

In contrast, the relay D_U will not trip, since the fault " F_S " is "behind" it.

The conditions for D_U are given in line 10 of Sk2-6899 . Since the current transformers of the two relays D_U and D_g are connected to the busbar through terminal K, the current in the transformers to D_U in the direction L - K is therefore opposite to that in the transformer to D_g , where it flows from K to L. For this reason the current I_{SU} in the diagram Fig. 28c appears with the opposite sign (negative) to that in Fig. 28b, d and e. The same applies to the current I_{Rg} in Fig. 28d and 28b, c and e.

Accordingly the current through the replica impedance in D_U is opposite to that in D_g , so that u_d and D_g has an inphase component to u_r . This is why the PU in D_g does not trip.

At the start of the fault the voltage U_{RT} at its location changes to U_{RTF} , becoming slightly smaller but at least 0.86 of the normal value. The reference voltage u_r derived from it is thus more than adequate to ensure the operation of the PU, as in the case of the interphase fault on page 25 .

If in Fig. 28 for instance Z_U is so much larger than Z_g and accordingly I_U so much smaller than I_g , that in the extreme case only the ZR in D_U and D_g pick up, then U_{RE} is chosen as the fault voltage and I_R as the fault current, with U_{TSF} as the reference voltage. In the case in question $U_{TSF} = -U_{RTF}$, so that now the relay D_U sees the fault F_R in its measurement direction and trips, ending the double earth fault. Nevertheless D_g does not trip. (See also below for the behaviour with unilateral infeed.)

A moderate additional infeed at St does not materially affect the operation of the relay, only the phase current S in D_g and R in D_U is increased.

If however the double earth fault is mainly supplied from St (not shown in Fig. 28), then D_U virtually draws current only in phase R, so that only Z_R starts. The M+PU system receives measurands as for a single -pole earth fault RE in the measurement direction with earthed neutral (reference voltage U_{TSF}) and interrupts the fault F_R . Since the relay D_g only obtains

current in phase S, Z_S starts there, U_{RTF} being chosen as the reference voltage. As in the case of a single-pole earth fault SE, the relay D_g measures in the measurement direction and also trip. (Incidentally: $U_{TSF} = -U_{RTF}$.)

If the line belongs to a system (Fig. 29, page 152), then the currents in the interconnected meshed lines hardly affect the currents in the relays - provided they do not provoke a marked change in the supply via St: the distance relay therefore behaves as described above.

The diagram below, like that in Fig. 29 and 29a, only in less detail, shows how the location in question could lie in a meshed system.

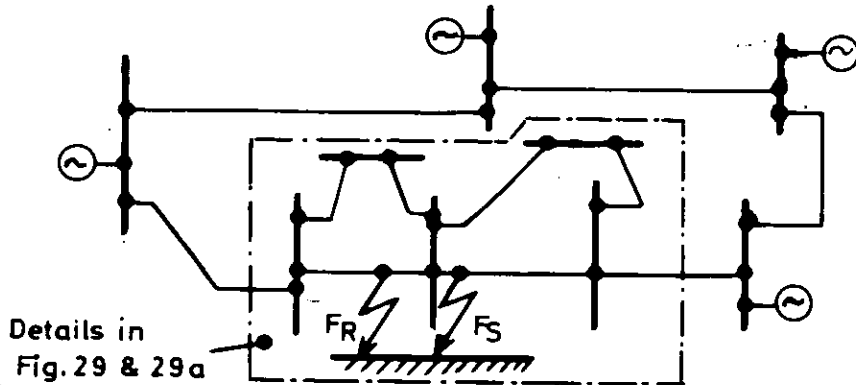


Fig. 27a

Fig. 29a on page 153 represents the conditions for the two distance relays D_{uu} and D_{gg} , which lie beyond the double earth fault. It can clearly be seen that the currents through the meshed lines produce the summation current which causes CE to pick up (assumption for this chapter).

With Fig. 30a - e (page 153): unmeshed line with fault resistance ρ_E at fault location.

The voltage drop at the resistance ρ_E against earth, e.g. with fault F_S appears as U_{SEF} . It is produced by the sum $(I_{Su} + I_{Sg})$ of the two currents and is almost parallel to $(I_{Su} + I_{Sg})$ and thus perpendicular to u_r , so that it does not or only slightly affect the operation of the PU.

The diagrams in Fig. 30c and 30d (in distance relay) differ from one another for the same reasons as those in Fig. 28c and 28d, except that in Fig. 30c and 30d $-U_{SEF}$ has to be added, producing u_d .

If the earth fault resistance ρ_E occurs in F_R (instead of F_S) or in both fault locations, this brings no significant change: in this case the voltage drop merely takes place across ρ_E due to $(I_{Ru} + I_{Rg})$, so that it is referred to as U_{REF} , whose direction in the vector diagram is opposite to U_{SEF} .

If the line being considered only has unilateral infeed (e.g. from the left), then all the currents and voltages with the subscript g (from the right) should be delected in Fig. 28. Only phase S in the distance relay will then obtain current, appearing at the same time as summation current. The relays ZS and IE therefore pick up and the distance relay therefore reacts as to a single-pole earth fault SE in a system with earthed neutral.

The relay Dg "sees" the fault F_S in the measurement direction and trips, whereas the relay D_u remains blocked.

If the fault F_R lies to the right and F_S to the left of the relays in question, then only the relay in phase R will pick up: D_g trips and D_u is blocked.

Case 2:

Earth faults S near by earth fault R distant (with respect to relay D_g) or

Earth fault R near earth fault S distant (with respect to relay D_u) (Lines 9 and 11 in Sk2-6899).

In unmeshed line

As already mentioned, the question is vitally affected by the location of the fault: whether it is regared as "near by" or "distant", i.e. so that the phase-earth voltage of the "near by" fault collapses to the extent that, together with the associated phase current, the impedance relay in question is made to pick up.

A double earth fault on an unmeshed line is shown in Fig. 31a-d, the sections of line between the two faults F_R and F_S having impedances of Z_L and Z_E (see page 154).

It is evident that for D_u the voltage $U_{REuF} \sim 0$, whereas $U_{SEuF} = I_{Su} \cdot Z_L + (I_{Su} + I_{Sg}) Z_E$: Z_R in D_u will therefore certainly start.

It is also assumed that the voltage U_{SEuF} becomes so large that I_{Su} fails to pick up Z_S . As a result D_u has to make a choice of measurands as in the case of the single-pole earth fault RE in accordance with line 5 in Sk2- 6899. D_u selects U_{TSF} as reference voltage.

In a similar way, $U_{SEgF} \sim 0$ for D_g and $U_{REgF} = I_{Rg} \cdot Z_L + (I_{Rg} + I_{Ru}) Z_E$. Z_S in D_g will therefore pick up.

Whether Z_R in D_g also picks up is really of no consequence (page 56). D_g makes its choice of measurand as for the single-pole earth fault SE in accordance with line 6 of Sk2- 6899.

The voltage U_{RT} acts as the referecne voltage for D_g .

The two relays D_U and D_g thus choose different reference voltages, although this is still insignificant in the case in question, since the angle β (Fig. 31c and d) between the reference and fault voltages in the two relays is about the same, though opposite. The two relays will trip in the basic time (even though u_d and u_r are not exactly opposed).

The vector diagram in Fig. 31a (page 154) shows the conditions at the location F_R , derived from the voltages to the left of Z_U . For this reason the voltage drop across Z_E should be regarded as due to $(I_{Su} + I_{Sg})$.

The same applies in Fig. 31d for F_S , so that the voltage drop across Z_E should be regarded as due to $(I_{Rg} + I_{Ru})$. This is why both the vectors for $(I_{Rg} + I_{Ru})$ and $(I_{Su} + I_{Sg})$ are drawn in along Z_E . The two current circuits from the left and right are coupled to one another by the voltage drop across Z_E .

It is also possible for the voltages U_{SEuF} and U_{REgF} between earth and the two phases to collapse to the point where they cause both ZR and ZS to pick up.

In this case D_U and D_g both choose the same measurands, in fact as for the earth fault SE, in accordance with case 1 dealt with above.

The same as above applies to a meshed line, with the generalization that the two faults can be considered as being in the same direction from the distance relay, since the currents via the meshed lines provide the summation current required to make IE pick up, as already indicated in Fig. 29a.

An infeed I_{Stu} from St_U and/or St_g superposes itself in the relay D_U on the current I_{Rg} .

The reasons why ZR in D_g should pick up become even stronger, whereas ZS remains unaffected.

The additional infeed of current in D_g also supports the picking up of ZS, leaving ZR unchanged.

The two relays D_U and D_g will therefore react as explained above, even if only the additional infeeds from St were available. (Additional index in Fig. 30: Z = intermediate infeed).

When the earth-faults at F_R and/or F_S have a significant fault resistance ρ_{ER} and/or ρ_{ES} (Fig. 32 page 154), then the current $(I_{Ru} + I_{Rg})$ or $-(I_{Su} + I_{Sg})$ produce a voltage drop almost parallel to the current (for explanations of this analogy see above).

The relay D_U chooses U_{TS} as the reference voltage, while D_g chooses U_{RT} : it follows that in relay D_g the drop across ρ_{ES} is almost parallel to the reference voltage U_{RTF} , hence can hardly affect the operation of M+PU: it therefore trips in the basic time. This is summarized in line 9 of Sk2- 6899

In D_U on the other hand, which chooses U_{TS} as reference voltage, the drop across ρ_{ER} exhibits an appreciable angle α with respect to the reference voltage: it thus influences the operation of M+PU, in fact in the blocking sense ($-I_C$ has a large component in the same directions as u_{Tu}). As a result D_U does not trip in the basic time but - should the double earth fault for some reason not be interrupted at F_S - will only trip in a later time step.

With intermediate infeed from the station busbars St_U and/or St_g , the current via Z_L in phase S and/or the phase R, also via Z_E increases. This does not, however, materially influence the measurement, especially since the angle of the fault voltage U_{SEuF} of the relay D_g remains unchanged: the current through phase S of the relay D_g is more likely to rise, so that tripping will occur as before.

If "case 2" with earth-fault resistance occurs along a meshed line, the above continues to apply: another case is added, when both faults lie in the measurement direction of the relays in

question. The currents due to infeeds between the two earth faults have no effect on the relay and have consequently no influence.

Currents flowing through the relay one way but by-passing it by returning via the meshed lines, could be added to the currents through the relay, which does not alter the reaction of the relay.

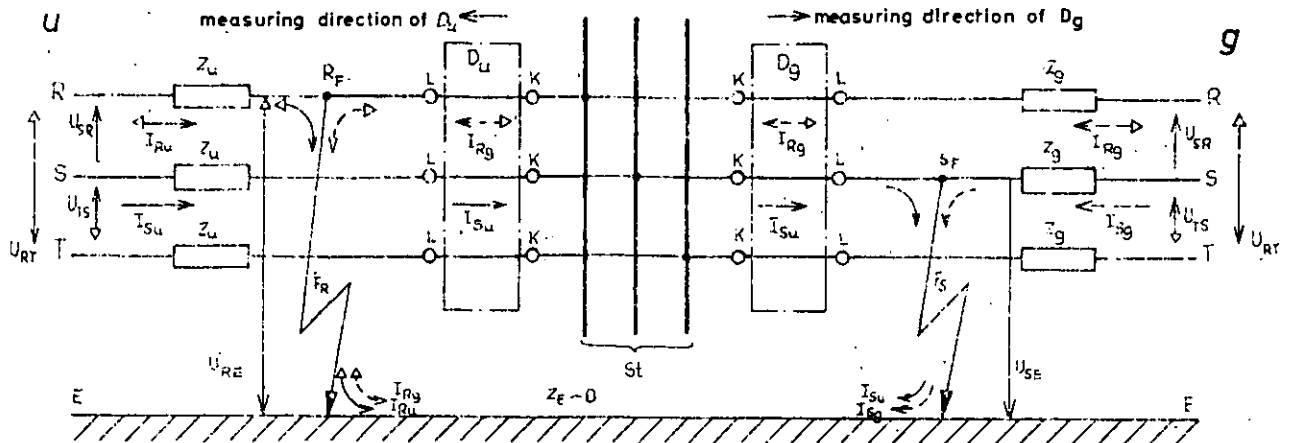
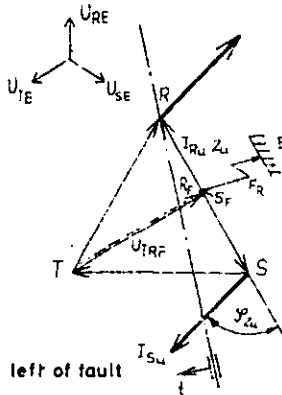


Fig. 28

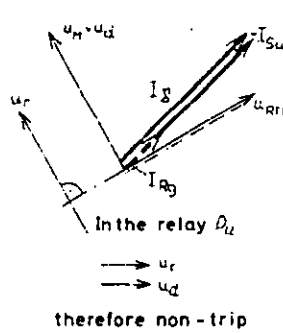
before beginning of fault

Fig. 28b



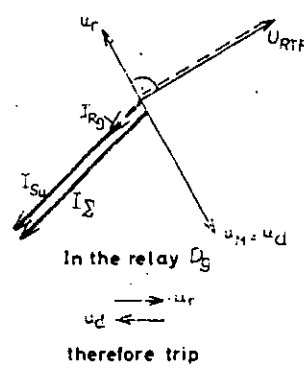
to the left of fault

Fig. 28c



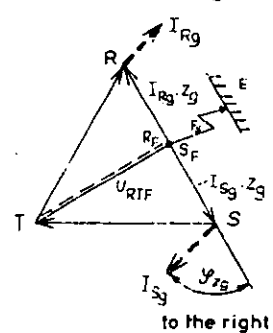
therefore non-trip

Fig. 28d



therefore trip

Fig. 28e



to the right of fault

Double earth fault on simple tie-line, fed from both ends
Earth fault on S close on the one side of the busbars
Earth fault on R also close on the other side of the busbar

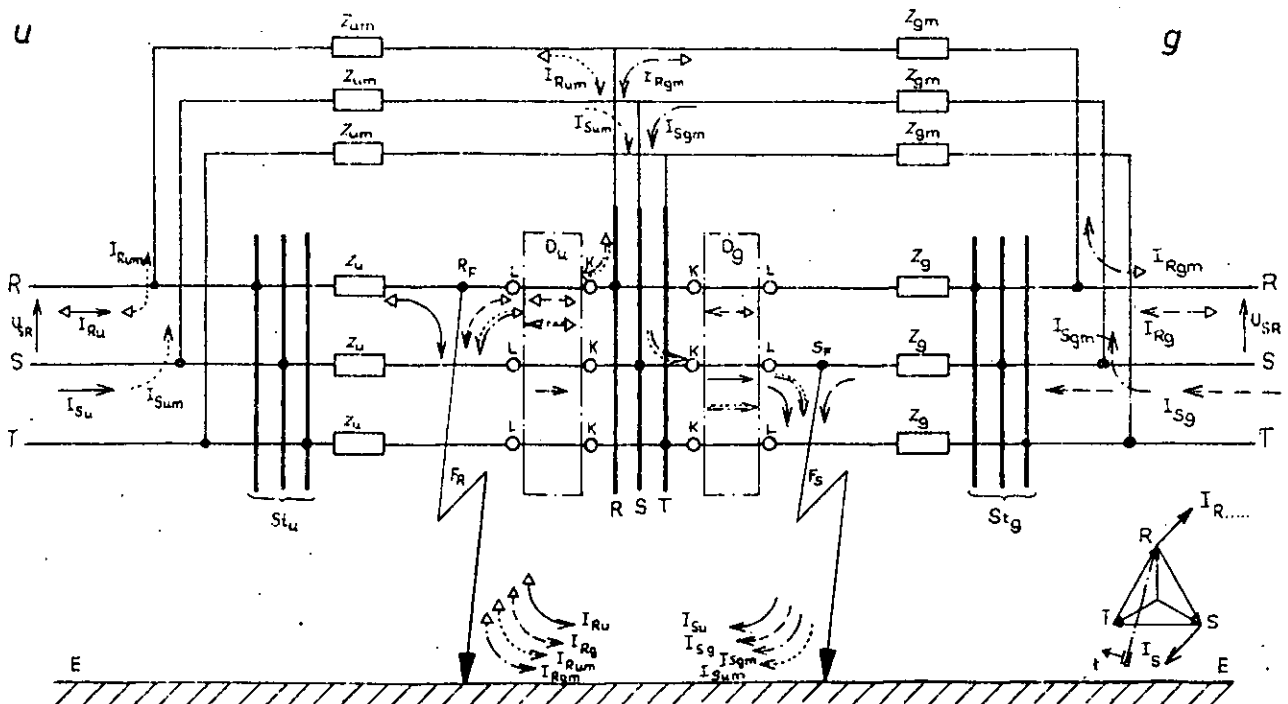


Fig. 29

Circumstances like in Fig. 28 but for line in meshed system

Sk2 - 6896

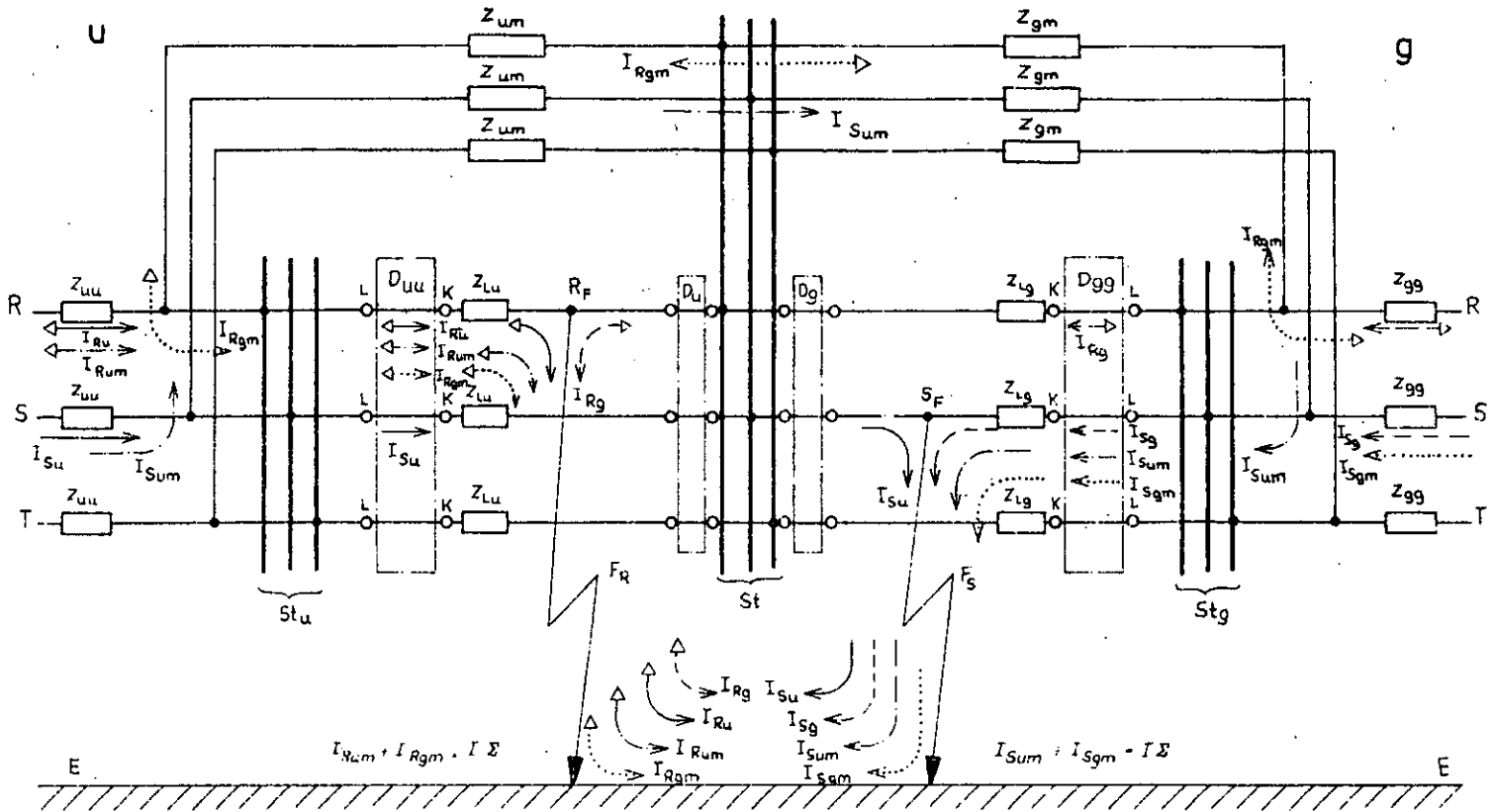


Fig. 29a Double earth-fault on a line fed from both ends in meshed system, both earth-faults clear and in measuring direction.

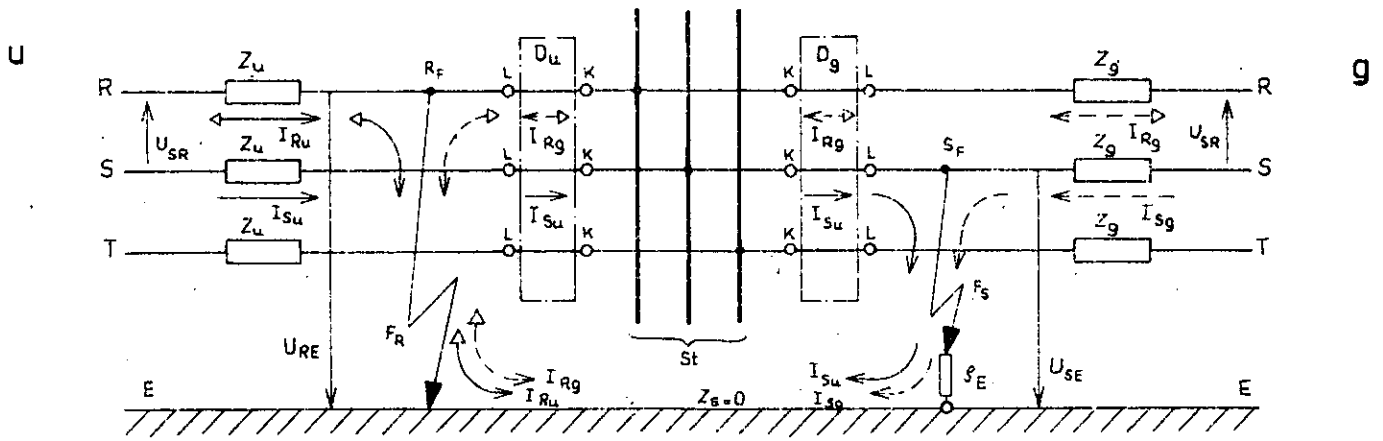
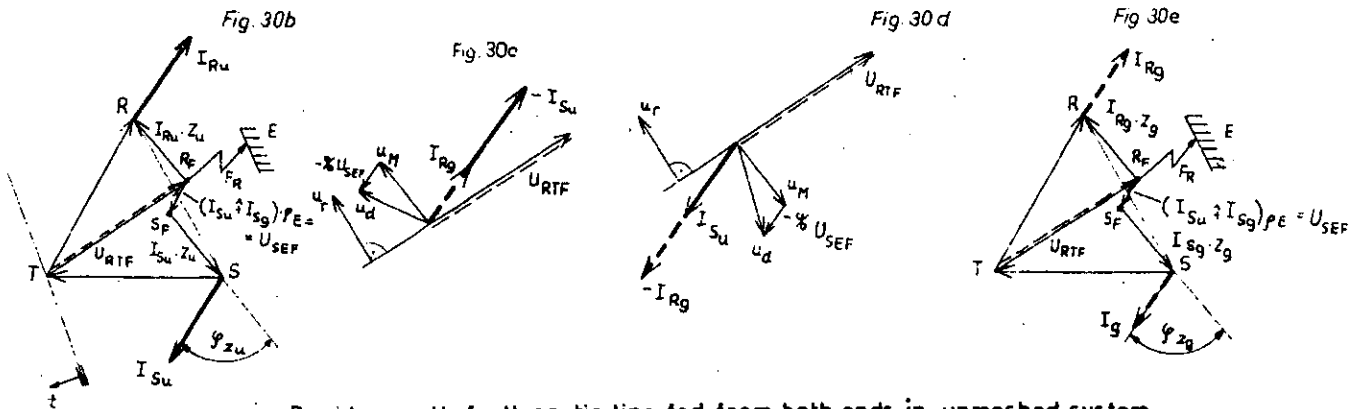
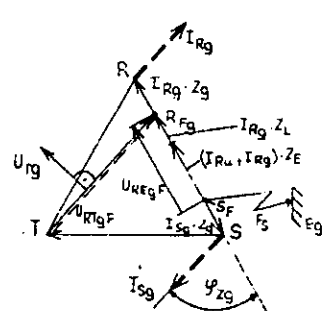
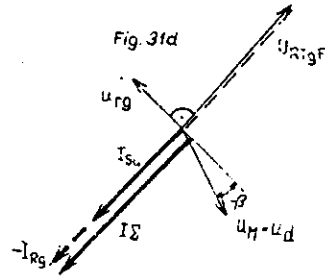
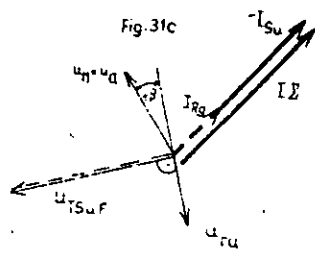
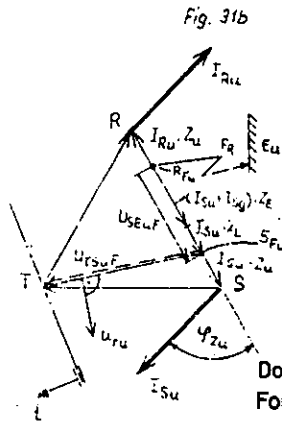
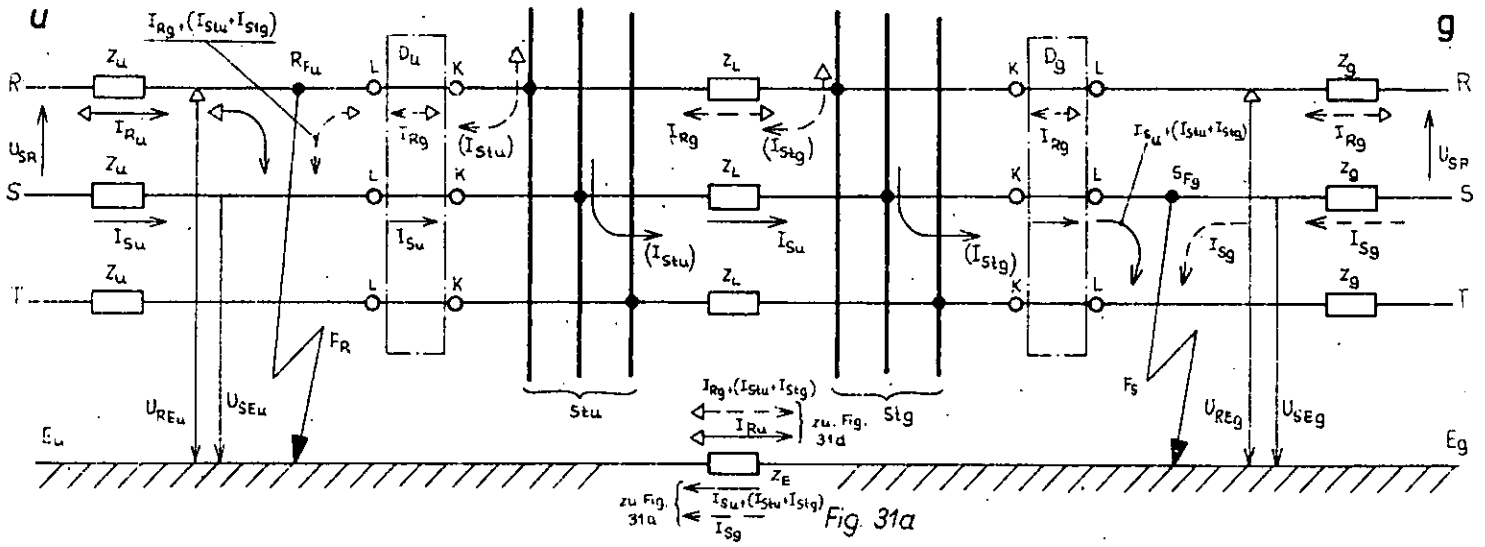


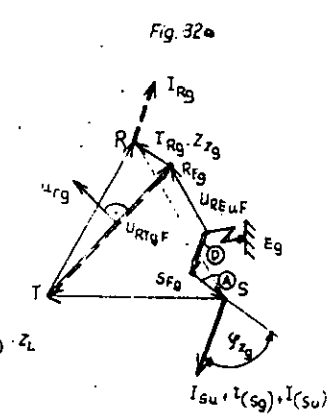
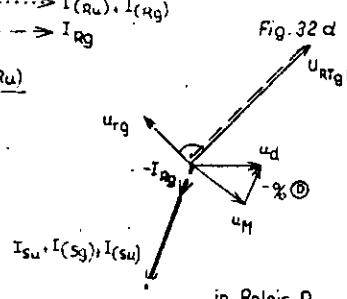
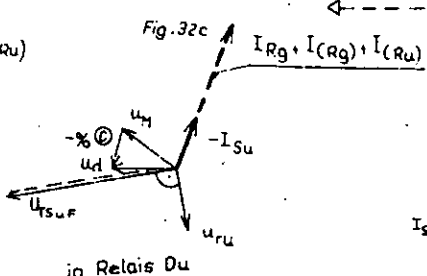
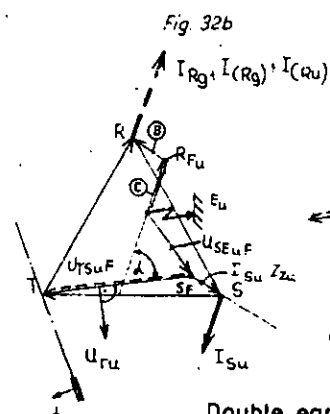
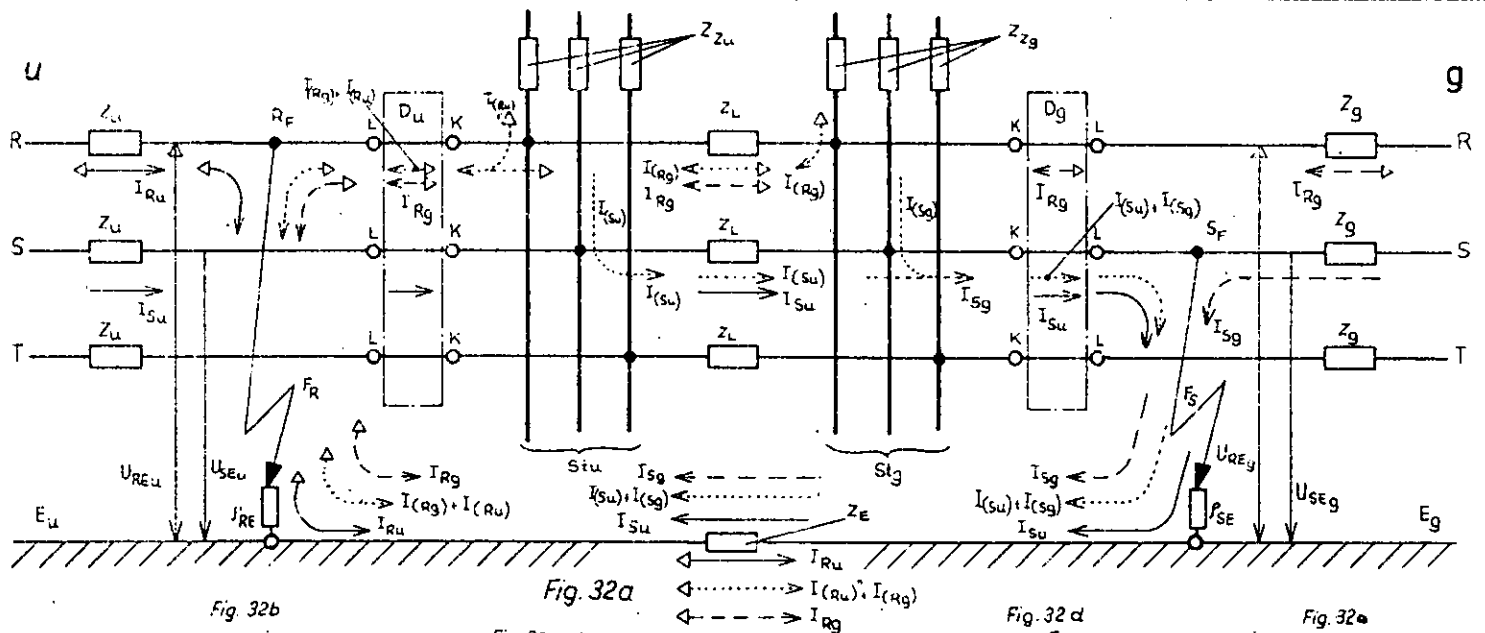
Fig. 30a



Double earth-fault on tie-line fed from both ends in unmeshed system
Earth-fault R close on the one side of the busbar
Earth-fault S close, with fault resistance R_F on the other side of the busbar.



Double earth - fault on tie - line fed from both ends in unmeshed system.
For Dg the earth fault S is close in measuring direction and earth-fault R distant
in the rear (corresp. line 9 of Sk2-6899) for Du the contrary (i.e. corr. line 11 of Sk2-6899)



Double earth - fault like in Fig. 31 but on tie - line in meshed system
with earth-fault resistances in both fault locations.

Fault			row no	IE + CE operate	ZA									CA			M fed with ct.	M+PU fed at terminals 1-6, 11-14 of HG8 voltage with: (X)	PU operates	CD operates	
Kind	Location	concerns			R			S			T			R operates	S	T					
					fed with ct.	operates with voltage	operates	fed with ct.	operates with voltage	operates	fed with ct.	operates with voltage	operates								
2-pole short-circuit (not involving earth)	—	SR	1	0	R	RT	(+)	S	SR	+	T \approx 0	TS	0	(+)	+	0	S-R	SR	RT	+	+
	—	TS	2	0	R \approx 0	RT	0	S	SR	(+)	T	TS	+	0	(+)	+	T-S	TS	SR	+	+
	—	RT	3	0	R	RT	+	S \approx 0	SR	0	T	TS	(+)	+	0	(+)	R-T	RT	TS	+	+

① On very close 3-pole fault, when reference voltage < 0,1 V PU is made to pick up by tripping-aid circuit, which is only operative during time - step I

3-pole short-circuit	—	RST	4	0	R	RT	+	S	SR	+	T	TS	+	+	+	+	R-T	RT	TS	+	+
----------------------	---	-----	---	---	---	----	---	---	----	---	---	----	---	---	---	---	-----	----	----	---	---

1-pole short-circuit to earth (neutral earthed)	—	RE	5	+	R	RE	+	S \approx 0	SE	0	T \approx 0	TE	0	+	0	0	R+ Σ	RE	TS	+	+
	—	SE	6	+	R \approx 0	RE	0	S	SE	+	T \approx 0	TE	0	0	+	0	S+ Σ	SE	RT	+	+
	—	TE	7	+	R \approx 0	RE	0	S \approx 0	SE	0	T	TE	+	0	0	+	T+ Σ	TE	SR	+	+

Double earth-faults (neutral not earthed)	earth-fault in S close ^x	earth-fault in R close too	SR	8	+	R	RE	+	S	SE	+	T \cong 0	TE	0	+	+	0	S+ Σ	SE	RT	+	+
	earth-fault in R distant			9	+	R \cong 0	RE	0	S	SE	+	T \cong 0	TE	0	0	+	0	S+ Σ	SE	RT	+	+
	earth-fault in S close too			10	+	R	RE	+	S	SE	+	T \cong 0	TE	0	+	+	0	S+ Σ	SE	RT	0	0
	earth-fault in S distant			11	+	R	RE	+	S \cong 0	SE	0	T \cong 0	TE	0	+	0	0	R+ Σ	RE	TS	(+) ②	(+) ②
	—	TS RT or	12	May be derived from above by cyclic sequencing RST																		

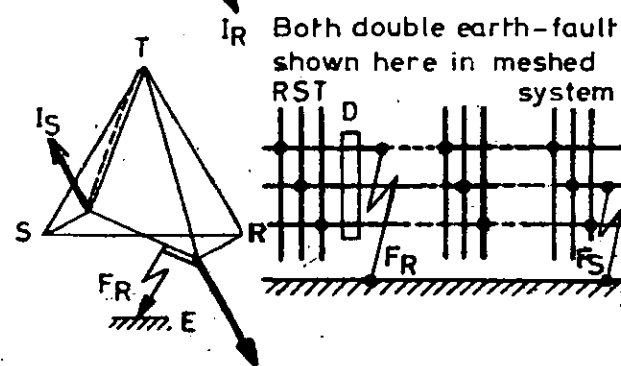
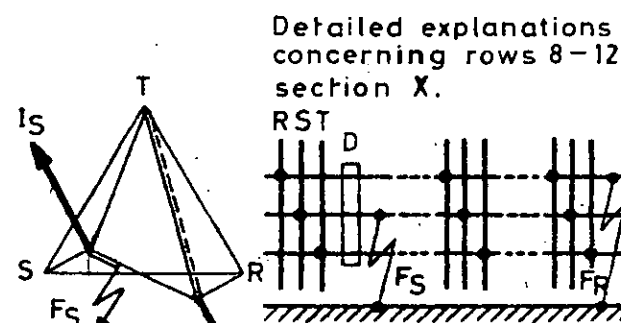
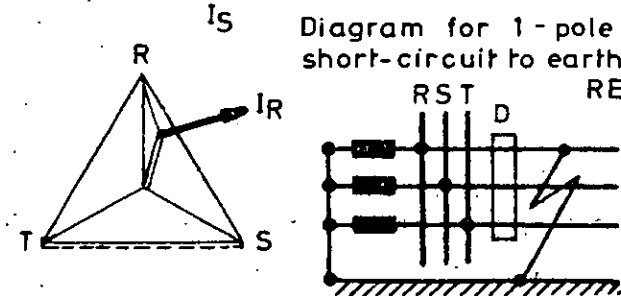
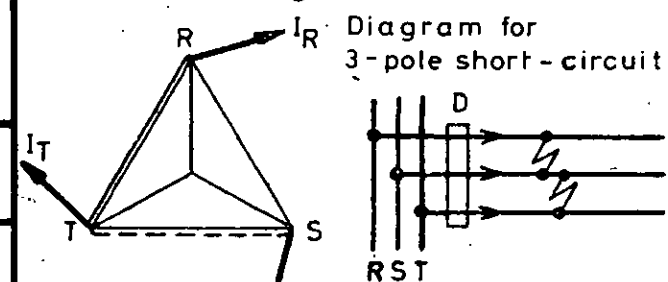
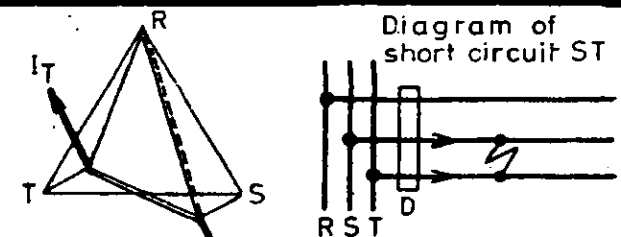
Legend:

- + operates
- (+) possible operates
- 0 does not operate

(X) The indicated voltages are fed into the terminals 11-14 after having been shifted 90° leading by $C_b + R_b$

- x in measuring direction
- ∇ in the rear (only important in meshed system)
- ② detailed explanation see section X. 4

Vectorial diagram and System schematics



Legend:

- D Distance relay
- Fault voltage
- reference voltage

Operation of the distance relays type LZ3, LZ31 and LZ32 on different faults.

Date 24.11.67
Drawn: [Signature]
Checked: [Signature]

Sk2-6899