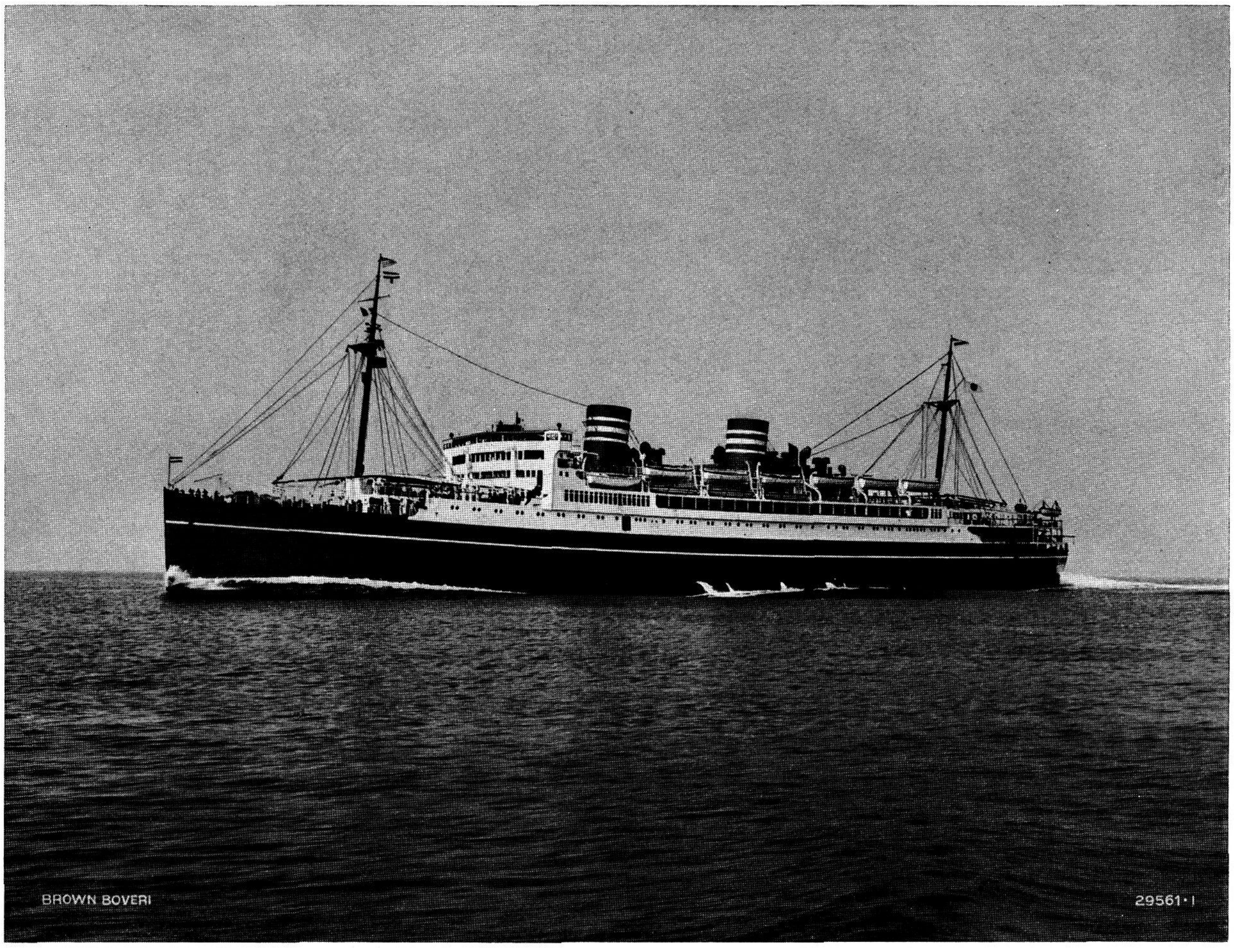
VOL. XVII JUNE, 1930 No. 6

THE BROWN BOVERI REVIEW

EDITED BY BROWN, BOVERI & COMPANY, LIMITED, BADEN (SWITZERLAND)



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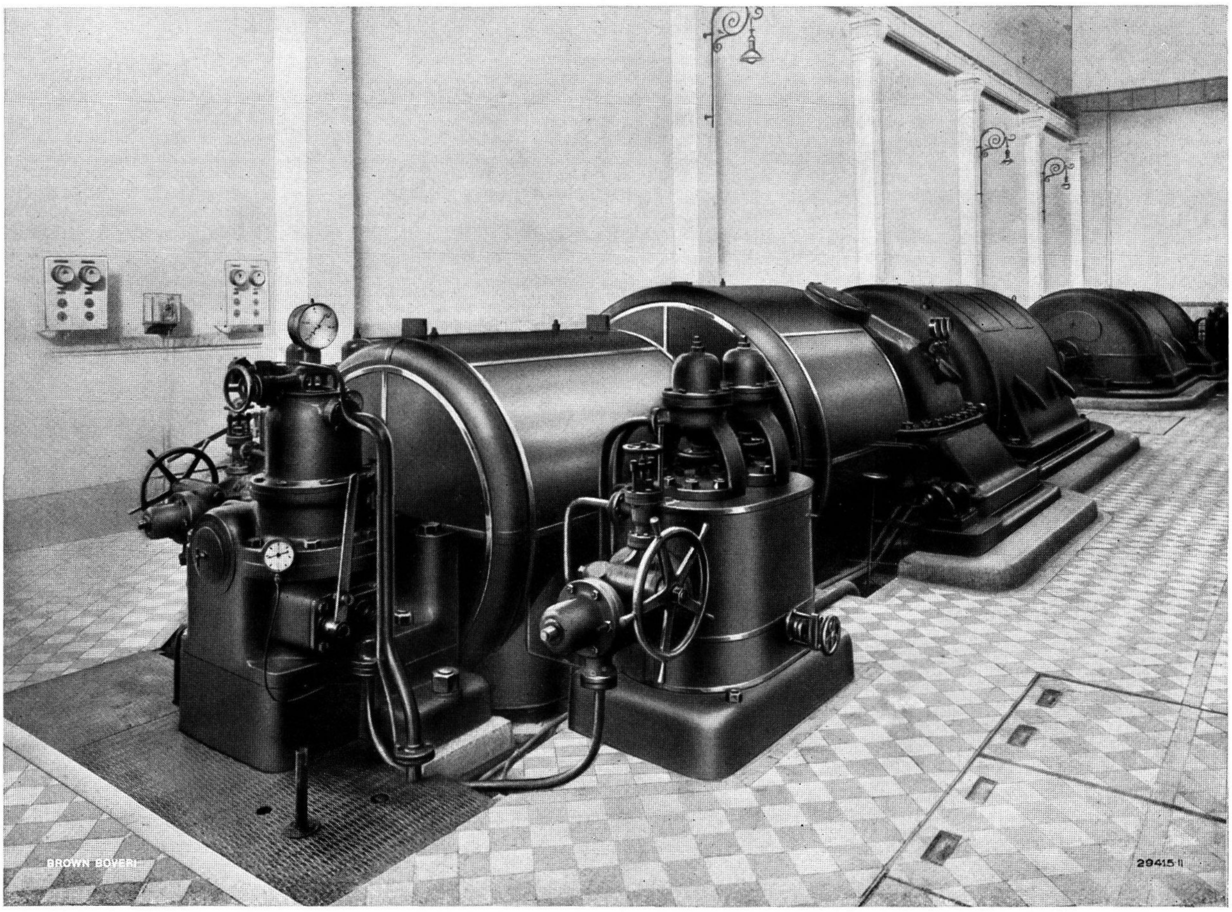
STEAM TURBINES



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TURBINES FOR STEAM AT EXTRA HIGH PRESSURES AND SUPERHEATED TO THE HIGHEST TEMPERATURES AND FOR THE HIGHEST OUTPUTS

LARGEST SET BUILT UP TO THE PRESENT: 160,000 kW

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PROJECTING THE SELECTIVE PROTECTION OF TRANSMISSION NETWORKS BY DISTANCE RELAYS.

Decimal index 621. 316. 925.

I. INTRODUCTION.

THE rapid growth within recent years in the requirements placed on network protection, is making the use of distance relays more and more imperative. Within a comparatively short time this form of selective protection has been very widely adopted, due to the numerous advantages attending its use, as follows:—

(1) Ideal automatic adjustment of the tripping time by the relay itself in direct proportion to the distance separating the relay from the fault; therefore limitation of the effect of the disturbance by isolating the affected section within the shortest possible time (on an average one second; in unfavourable cases not more than two seconds). Only the section of line affected by the short circuit is isolated (selectivity).

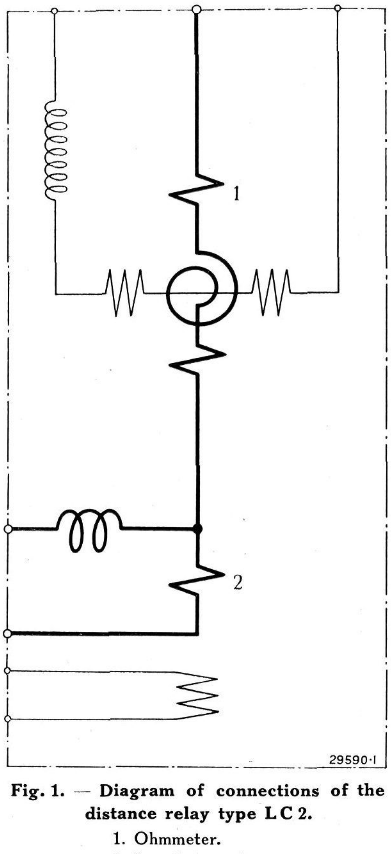

Fig. 1. — **Diagram of connections of the distance relay type L C 2.**
1. Ohmmeter.
2. Impedance release.

(2) The simple solution of the protection problem in complicated networks (double lines, ring mains, interconnected networks with variable number of feeding points) by a self-contained relay system entirely independently of the condition of the network.

(3) The independence of the tripping time adjustment of the magnitude of the voltages and currents in the network and therefore the extension of the range of protection to disturbances with short-circuit currents below the full-load current corresponding to normal operation.

(4) The full freedom given to permissible overloads within very wide limits without it being necessary to make special adjustments to the relays.

Full use cannot be made of the above advantages, however, unless the characteristic conditions of the network have been taken into consideration when designing the selective protection. The object of this article is to show in what manner the Brown Boveri distance relay protection must be adapted to the network conditions, and the means available to the designer for doing so.

II.

TYPES OF RELAYS DEVELOPED BY BROWN, BOVERI & CO.

Three types of relays have been developed for the protection of three-phase networks. Mechanically they are all exactly similar; they differ, however, as regards their windings and connections.

(1) *The approximate reactance relay type LC2*, with connections as in Fig. 1. The phase displacement in the voltage circuit

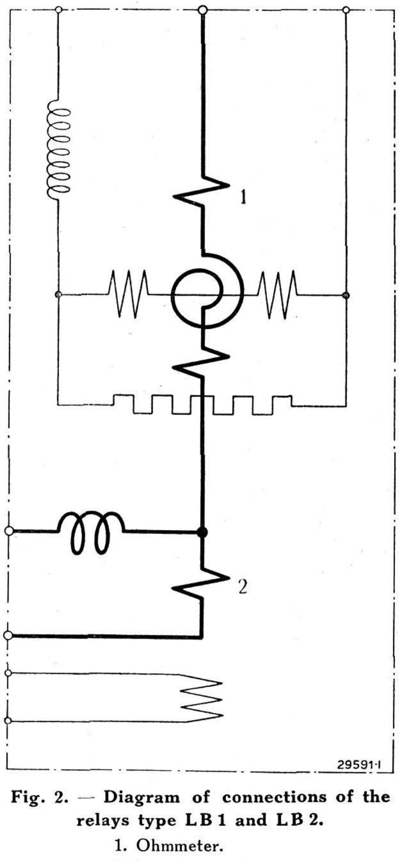

Fig. 2. — **Diagram of connections of the relays type LB 1 and LB 2.**
1. Ohmmeter.
2. Impedance release.

of the ohmmeter is 75°, so that the relay can be considered as an approximate reactance relay. At a power factor of 0·7 and with an operating time of five seconds, the measuring range, i. e., impedance of the ohmmeter, is five ohms. The smallest operating current is two-thirds the normal current or 3·3 A.

TABLE I.

Relay type	**LC 2**	**LB1**	**LB 2**
Internal connections . . .	Fig. 1	Fig. 2	Fig. 2
Minimum operating current in amperes	3·3	3·3	1·7
Phase displacement in voltage circuit of ohmmeter . .	75°	90°	90°
Kind of relay	approximate reactance relay	pure reactance relay	pure reactance relay
Fundamental time of relay adjustable between . .	0·5 and 2 sec	0·5 and 2 sec	0·5 and 2 sec
Time equation for ohmmeter	$t = K(0{\cdot}966\,x + 0{\cdot}259\,r) + t_g$	$t = Kx + t_g$	$t = Kx + t_g$
Measuring range of ohmmeter for tripping time of 5 sec (in ohms)	5	5	10
Normal current (in amperes)	5	5	5
Permanent current permissible under normal operation (in amperes) . . .	10	10	10
Thermally admissible current for five seconds (in amp.)	300	300	170
Directional sensitivity with normal current, and power factor of 0·7, as % of the ohmmeter measuring range	1·5	1·5	1·5
Power consumption in VA in voltage circuit			
(a) Under normal service conditions at 110 V .	9	9	20
(b) When operating at 110V.	24	35	48
Power consumption in VA in current circuit			
(a) At 3·3 A	6	6	—
(b) At 1·7 A	—	—	5
(c) At 5 A	13	13	35

(2) *The reactance relay type LB2*, with connections as in Fig. 2. By tuning the series choke coil with the parallel resistor in the voltage circuit of the ohmmeter, the internal phase displacement for this type was made exactly 90°. As a result, the distance relays type LB 2 work as pure reactance relays. The measuring range of the ohmmeter, i. e., the reactance, is five ohms for an operating time of five seconds, and the minimum operating current 3·3 A, as with relay LC 2.

(3) *The reactance relay type LB 1*, with connections as in Fig. 2. This type differs from the one previously described in the larger measuring range of its ohmmeter (ten ohms instead of five) and in the widening of its operating range to include currents as low as 1·7 A.

The time equation for relay type LC 2 is:—

$$t = K\frac{e}{i}\cos(75 - \varphi) + t_g$$
$$= K(0{\cdot}966\,x + 0{\cdot}259\,r) + t_g$$

and for relays type LB 2 and LB 1:

$$t = K\frac{e}{i}\cos(90 - \varphi) + t_g$$
$$= K\,x + t_g.$$

In these equations

t = Time adjustment of the relay.
K = A constant for the ohmmeter.
e = Voltage at the terminals of the ohmmeter.
i = Current supplied to relay.
φ = Phase displacement between voltage and current at terminals of ohmmeter.
t_g = Fundamental time, adjustable between 0·5 and 2 seconds.
x = Reactance measured by ohmmeter (secondary reactance).
r = Resistance measured by ohmmeter (secondary resistance).

All Brown Boveri distance relays for transmission lines have a minimum-impedance release which is of exactly similar design for the two types of relays LC 2 and LB 2. For type LB 1 it is wound differently, so that the relay can operate on currents down to one third the normal current. For all the types the operating impedance is about nine or ten ohms, measured at the relay.

The directional sensitivity of all the types is very good. A fact of great importance is that, with the reactance relays, at the moment the direction of flow of energy is determined, the measuring position alters and therefore the resistance component of the residual voltage at the fault is measured. After the direction has been determined, the relays continue to operate as reactance relays, so that the alteration of the measuring position has no influence on the time measurement. As field tests have shown, perfectly correct directional sensitivity is attained even with arc short circuits in the immediate vicinity of the relays.

The power consumption in the voltage circuit of the relays type LC 2 and LB 2, referred to the applied voltage of 110 V, is 9 VA in normal service (ohmmeter out of circuit) and that of relay LB 1 is 20 VA. When operating with a disturbance in the network, these figures are 24, 35 and 48 VA.

It was endeavoured to keep the power consumption of the current circuit as small as possible, chiefly in view of the fact that in transmission line networks it may often be necessary to connect up the relays to bushing current transformers of very low output. In considering the figures for the power consumption in the current circuit, it must not be forgotten that the working range of the Brown Boveri distance relay covers a range within which there are short-circuit currents smaller than the normal full-load current.

For relays LC 2 and LB 2, a power consumption of 13 VA must be assumed in the current circuit, and 33 VA for the relay type LB 1. These values refer to the rated current of the relay (5 A). For the smallest operating current of the relays, the corresponding figures are six and eight volt-amperes. From the last-mentioned figures it is clearly seen that the power consumption of the current circuit has been reduced to a minimum.

The chief particulars of the various types of relays are given in the table on page 196.

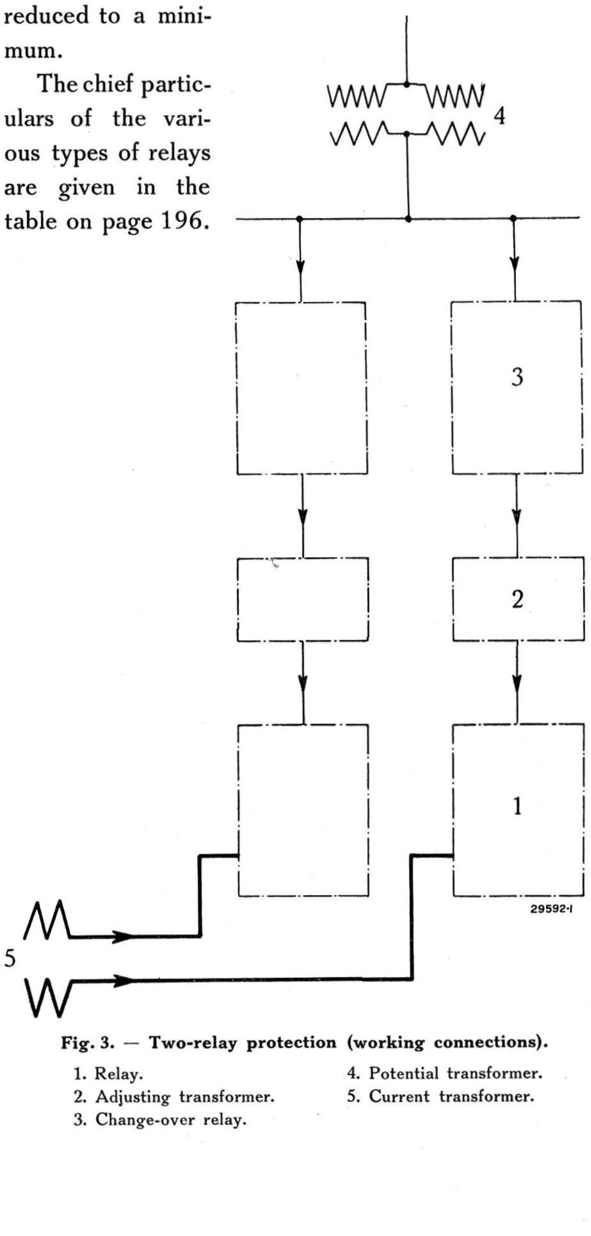

Fig. 3. — Two-relay protection (working connections).

1. Relay.
2. Adjusting transformer.
3. Change-over relay.
4. Potential transformer.
5. Current transformer.

III. THE CONNECTIONS OF THE BROWN BOVERI DISTANCE RELAY.

The following connections were developed for meeting the various kinds of faults which occur in transmission networks.

(1) *Two-relay protection.*—The protective range of this connection includes all disturbances due to short circuits, including double faults to earth, though the latter only when both faults occur within the same or adjacent sections. For connecting up the relays, current transformers in two phases and two single-phase potential transformers connected in V are necessary. Further, the complete equipment for an incoming or outgoing line includes two adjusting transformers and two change-over relays. The arrangement can be seen from Fig. 3. Obviously, the two-relay protection can only be used for networks with insulated neutral point.

(2) *Three-relay protection for networks with insulated neutral point.*—This includes all cases of short circuits, and also double earth faults, alike whether both faults lie within the same section or

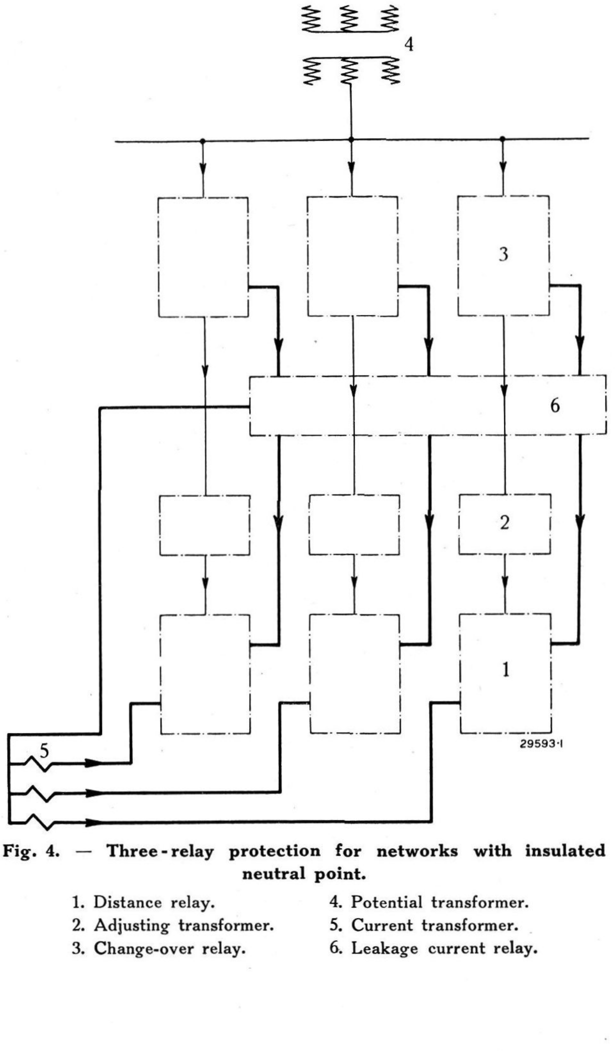

Fig. 4. — Three-relay protection for networks with insulated neutral point.

1. Distance relay.
2. Adjusting transformer.
3. Change-over relay.
4. Potential transformer.
5. Current transformer.
6. Leakage current relay.

whether a large number of sections separate the two faults. The principle of this connection is shown in Fig. 4. For each branch of line, the following are required:—

3 distance relays with their appropriate adjusting transformers;
3 change-over relays;
1 leakage current relay.

By means of the change-over relay—as with the two-relay system—the line voltages are compared in cyclic order, and, by changing over the connections, that voltage required for measuring the distance is supplied to the relay. A second additional function of the change-over relay is to interlock those distance relays which under certain circumstances are supplied with the current from the fault but not with the corresponding voltage.

(3) *Three-relay protection for networks with earthed neutral point.*—This protects from all disturbances which can arise, namely, two and three-pole short circuits (insulated or to earth), and also from faults to earth (single-pole short circuits).

As with the previously mentioned three-relay protection, the non-interlocked distance relays are supplied with the voltage corresponding to the distance by comparing the line voltages and by measuring the leakage current. The principle of these connections can be seen from Fig. 5.

IV. THE REQUIREMENTS PLACED ON CURRENT AND POTENTIAL TRANSFORMERS.

It would be inappropriate to stipulate a maximum permissible phase angle and error in the ratio of transformation for the current and potential transformers used for connecting the distance relays and corresponding apparatus, because, in view of the fact that the relays represent a heavy inductive load, the phase angle has practically no effect; thus only the error in the ratio of transformation must be taken into consideration. In the current transformer this is usually negative for small primary currents, zero when the current is near the rated value, and positive for higher values (Fig. 6). Within the range of the normal current, at about 10 to 15 times the rated current, a positive error of practically constant value can be expected.

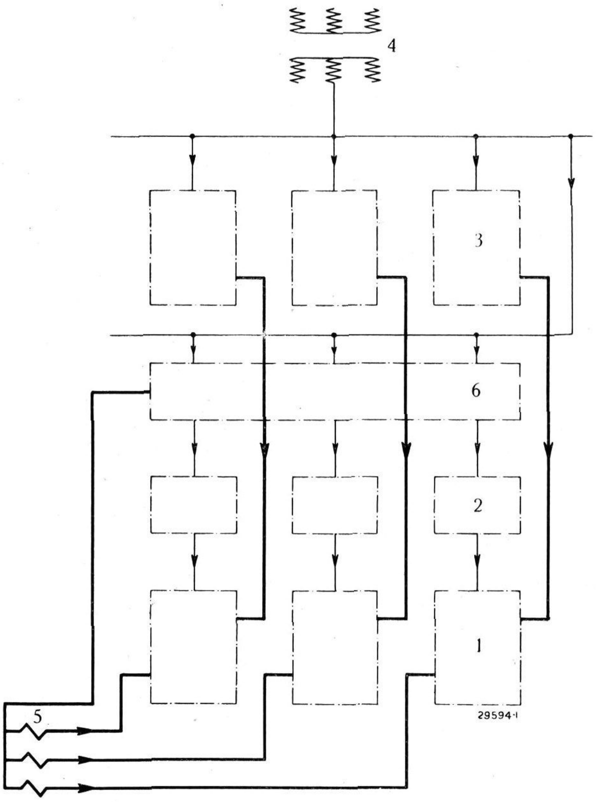

Fig. 5. — **Three-relay protection for networks with directly earthed neutral point.**

1. Distance relay.
2. Adjusting transformer.
3. Change-over relay.
4. Potential transformer.
5. Current transformer.
6. Leakage current relay.

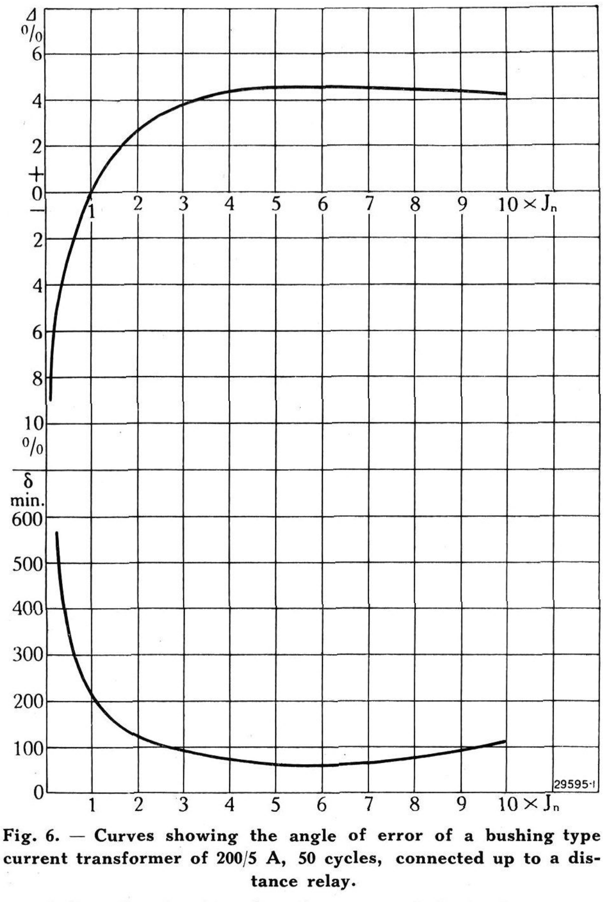

Fig. 6. — **Curves showing the angle of error of a bushing type current transformer of 200/5 A, 50 cycles, connected up to a distance relay.**

Δ. Error in ratio of transformation. δ. Angle of error.

For the distance relay protection this error can be counterbalanced by an error in the ratio of transformation of the potential transformer of proportionately equal magnitude and sense. Very frequently, however, the transformation ratio of the potential transformer is adjusted to no-load, a negative error then occurring under load. In such a case the positive error of the current transformer and the negative one of the potential transformer support each other and cause a bigger error in the measurement of the ohmmeter of the distance relay. However, even these large errors do not affect the selectivity of the protective systems if similar transformers, or transformers with about the same error curves, are used throughout the network. Finally, by equalizing the ratios of the transformers, the errors in the ratios of transformation can be considerably reduced in most cases.

The load capacity of oil-immersed current transformers, and in general of those current transformers with a primary winding having a large number of turns, is sufficient for connecting up distance relays, even when the ratio of transformation is small.

The conditions are less favourable for current transformers of the bushing or terminal type for small primary currents with only a single bar as the primary winding. The lower limit for which these transformers can be used is about 200 A. If such transformers are built into the bushings of oil circuit breakers, each of the two bushings, forming one pole of the breaker, can be equipped with a separate one. The load capacity can be doubled by connecting the two transformers in series, and the lower limit of their range thus correspondingly extended to include smaller currents.

V. CHOICE OF THE TYPE OF RELAY AND ITS CONNECTIONS.

(1) *The ratio of the current transformer not fixed.*—This case is met when new plants or extensions to existing plants are projected, or when the existing current transformers do not satisfy the requirements. The ratio of the current transformer must then be so chosen that the smallest short-circuit current to be expected on the primary side corresponds to the minimum current of the relay on the secondary side. It is quite immaterial as regards the protection whether relays type LB1 or LB2 are used.

The minimum short-circuit current must under no circumstance be assumed smaller than the value to be expected, in order that the relays may still operate within a favourable range even with the highest short-circuit currents liable to occur. This range of current for the relays includes currents from the minimum value up to about 30 times the minimum.

The heaviest current occurring in normal service should not exceed the primary current of the current transformer, to prevent the transformer being overloaded. Generally, danger of overloading the relays need not be feared, as they can withstand a continuous overload of 100 %. If the previously mentioned condition is fulfilled for both relays (type LB1 and LB2), it is advisable to use the transformer with the higher ratio of transformation and to install the relay type LB1, provided there are no reasons for using the smaller ratio, as, for example, greater degree of accuracy of the measuring instruments to be connected up.

The following example will serve as an illustration:—

The minimum short-circuit current is 80 A. For relays type LB1, transformers with ratios of $\frac{80}{0{\cdot}33 \times 5} = \frac{240}{5}$ A should be used, and for relays type LB2, transformers with ratios of $\frac{80}{0{\cdot}66 \times 5} = \frac{120}{5}$ A.

Further, the normal current is assumed to be 100 A. Thus as regards overloading the transformers in normal service, full freedom may be exercised in choosing the one or other type of relay, even though the choice of relay LB2 and the appropriate ratio of transformation $\frac{120}{5}$ A places greater requirements on the ability of the transformer to withstand short circuits.

If, however, the normal current is 180 A, then the choice of the type of relay and transformer ratio is fixed. Only type LB1 and the ratio $\frac{240}{5}$ A can be used, as a ratio of $\frac{120}{5}$ A gives a 50 % overload with a current of 180 A.

(2) *The ratio of the current transformer fixed.*—When the current transformers already exist, i.e., when the ratio is given, both types of relays—LB1 and LB2—can be readily adapted.

Reference is again made to the previous example. The existing current transformers have a ratio $\frac{100}{5}$ A. Accordingly the minimum current on the secondary side of the transformers is 4 A, and either relay type LB1 or LB2 can be used. The choice of the type now depends on the maximum short-circuit current. Assuming a maximum current of 1600 A (16 times the normal current, 20 times the minimum current) it is more advantageous to use the relay type LB2, because with type LB1 the relay current should, as far as possible, not exceed 50 A, so that the relays can operate in their most favourable range. If, on the other hand, the ratio of the current transformer were $\frac{200}{5}$ A, the minimum current on the secondary side would be $\frac{80}{200} \times 5 = 2$ A. Thus only relay type LB1 could be considered. The maximum relay current would, in that case, be 40 A, i. e., quite admissible.

The range of short-circuit current (smallest to the maximum value) must be calculated for every network by one of the well-known methods given in technical literature.

For determining the highest short-circuit current, the maximum number of generators which can be connected up must be assumed in the calculation, and for determining the lowest short-circuit current the minimum number of machines. As already mentioned, the smallest short-circuit current should not be fixed unnecessarily low by adopting a safety factor, because it may always be assumed that for operating the relay a current will be available which lies well above the minimum value. This is because the operating time of the relay is much smaller than the time required by the short-circuit current to fall to its permanent value. If the relays have operated, they continue to function even though the minimum current drops to a value below that given as the minimum operating current for the relay in question; this has been proved conclusively by numerous network tests.

In extensive extra high tension networks fed by several large power stations, widely separated from one another, and in which the generator voltage is transformed to the network voltage by transformers with a high short-circuit voltage, a maximum short-circuit current equal to about 10 times the rated current can be expected in the most unfavourable cases. In medium-tension networks of more compact arrangement with feeding points situated close together, the maximum short-circuit currents may even reach 20 times the rated current. The current range within which the types of distance relays operate was adapted to these conditions. The relay type LB1 is particularly suitable for extra high tension networks, for one reason on account of the current range ($^1/_3$ J_n to 10 J_n) and also on account of the measuring range of the ohmmeter (10 ohms). The types LB 2 and LC 2 (current range $^2/_3$ J_n to 20 J_n and measuring range 5 ohms) are more suitable for medium-tension networks.

The choice of the connections used is based on the following considerations:

Networks with earthed neutral point, including also networks in which the neutral point is earthed through a low ohmic resistance, always require three-phase protection. Thus, only the three-relay connections as shown in Fig. 5 can be considered here.

For networks with insulated neutrals, i. e., with neutral point not earthed at all or else through high ohmic resistances or extinction coils, the three-relay connections as shown in Fig. 4 should be used. For both these connections just mentioned pure reactance relays type LB 1 or LB 2 must be used.

To avoid building current or potential transformers into all three phases, for example on account of the cost or limited space available, the two-relay connections as shown in Fig. 3 can be used. If protection against double faults to earth is relinquished, experience has shown that in medium-tension networks with two-relay protection using the relay type LC 2, completely satisfactory results can be obtained.

On page 201 are tabulated various relay connections, the range of protection, and also the considerations on which the choice of connections and type of relay are based.

It is finally mentioned that the three-relay protection for networks with insulated neutral point can be easily changed over to the three-relay protection for networks with earthed neutral point. This fact is a great advantage for services where it is proposed to increase the operating voltage of the network by changing over the connections of the transformer from delta to star, while at the same time directly earthing the neutral points of the transformer on the star side (e. g., changing from 60 to 110 kV, or from 87 to 150 kV).

VI. ADAPTING THE DISTANCE RELAY PROTECTION TO GIVEN NETWORK CONDITIONS.

After the connections and type of relay have been determined for a given network, the relay must be adjusted and the tripping times thus obtained must be checked. It must then be taken into consideration that each relay equipment has a double duty to fulfil, namely:

(1) Supervising and protecting the appropriate section of the network;

(2) Acting as stand-by for the adjoining sections.

TABLE II.

Neutral point of network	Kind of network	Max. and minimum short-circuit currents	Relay connections	Type of relay	Protective range	Current and potential transformers
Earthed	Optional	$\frac{1}{3}$ J_n to 10 J_n	Fig. 5	LB 1	2 and 3 pole short circuits; faults to earth	Current transformers in 3 phases, 3 single-phase potential transformers or 1 three-phase potential transformer with primary neutral point earthed
		$\frac{2}{3}$ J_n to 20 J_n	Fig. 5	LB 2		
Insulated	Optional	$\frac{1}{3}$ J_n to 10 J_n	Fig. 4	LB 1	2 and 3 pole short circuits; double faults to earth	
		$\frac{2}{3}$ J_n to 20 J_n	Fig. 4	LB 2		
Insulated	Medium-tension networks of a more compact character	$\frac{2}{3}$ J_n to 20 J_n	Fig. 3	LC 2	2 and 3 pole short circuits	Current transformers in 2 phases, 2 single-phase potential transformers connected in V

The condition that only the section containing the fault may be switched out requires that for every kind of short circuit and for every position at which the fault occurs within a section, only the distance relay of this section must trip the circuit breakers. The stand-by relays of the adjoining sections must only give this command when the command given by the first relays has not been carried out for some reason. This may happen, for example, if the battery supplying the current for tripping fails, if the tripping mechanism of the circuit breaker goes wrong or if the circuit breaker itself should be out of order. To separate the two functions of the distance relays, namely, tripping and acting as stand-by, a time interval of 1 second is generally sufficient when the breaker has a normal tripping time.

The conditions are simplest when the adjustment of the relay is based on a short circuit between two phases. Since the relays are supplied at the line voltage, the ohmmeter measures the reactance of the short-circuit loop; this corresponds to double the value of the reactance of one phase. With other kinds of short circuits (three-phase short-circuits, double faults to earth), practically the same times are measured.

The total reactance of a loop of a section depends on the length of the section and on the line reactance per kilometre of loop. The latter is again dependent on the arrangement of the conductors, on their diameter and the distance separating them. In order to determine the reactance, the diagram showing the arrangement of the masts in the section considered should contain these particulars. If these particulars are not available, the reactance may be assumed to have a mean value of 0·8 ohm per kilometre of loop.

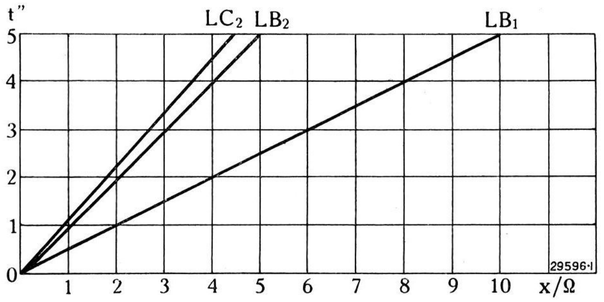

Fig. 7. — External characteristics (tripping time in seconds as a function of the measuring reactance in ohms of the ohmmeter) for the various types of distance relays.

The curve for the relay type L C 2 is valid for power factors of 0·3 to 0·7.

The reactance measured by the distance relay can be calculated from the line reactance, by considering the ratio of transformation of the network transformers. Let:

$U_e = \frac{E}{e}$ be the ratio of the potential transformers;

$U_i = \frac{J}{i}$ be the ratio of the current transformers;

X the primary reactance of the section considered;

x_s the secondary reactance of the section considered.

Then:—

$$x_s = \frac{X}{\frac{U_e}{U_i}}$$

The external characteristic (tripping time as a function of the measuring reactance of the ohmmeter) and the reactance at the terminals of the ohmmeter for a given operating time, depend on the type of distance relay chosen. Various external characteristics for the different types of relay are shown in Fig. 7. If, for example, it is required that for a short circuit at the end of a section, the tripping time of the relay at the beginning of that section should be one second, the secondary reactance x_s must be converted to the value of the measuring reactance for a tripping time of one second at the ohmmeter of the

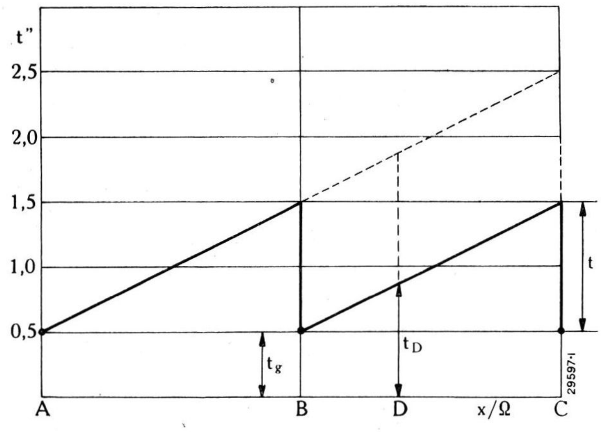

Fig. 8. — Curves showing the tripping time.
t_g. Fundamental time (0·5 sec).
t. Selective time for the section BC (1 sec).
t_D. Tripping time of the distance relay at point B for a short circuit at point D.

relay. This conversion of the secondary reactance, so-called equalizing, can be effected by means of an adjusting transformer in the current or voltage circuit of the relay or else in both circuits. In the first case, the ratio $\frac{\text{network current}}{\text{relay current}}$ is altered; in the second case the ratio $\frac{\text{network voltage}}{\text{relay voltage}}$, and in the third case both ratios. Almost without exception, the equalization affects the time-measuring mechanism of the relay and not the impedance release, which is always directly connected to the secondary side of the network transformer.

Equalizing in the current circuit by an intermediate current transformer possesses certain disadvantages, but it would lead too far to discuss them all here. It is merely mentioned that compared with potential transformers, current transformers have a much smaller load capacity and therefore by including the adjusting transformer in the current circuit, the load on the current transformer would be inadmissibly increased. For this reason, equalizing in the voltage circuit is the most advantageous solution.

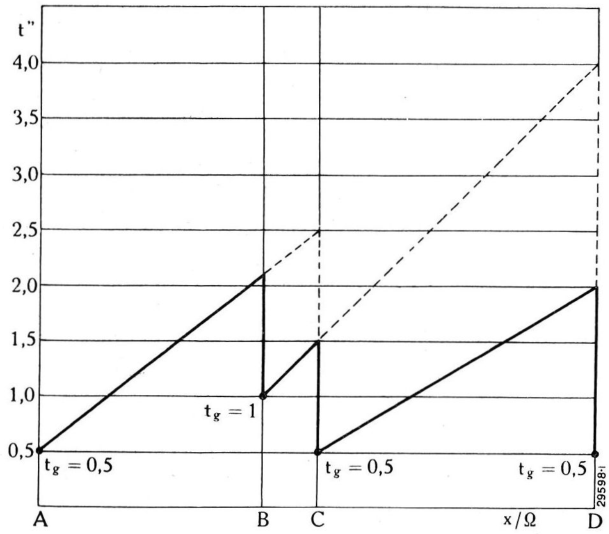

Fig. 9. — Curves showing the tripping times. Improvement of the selectivity for particularly short sections by grading the fundamental times of the relays.

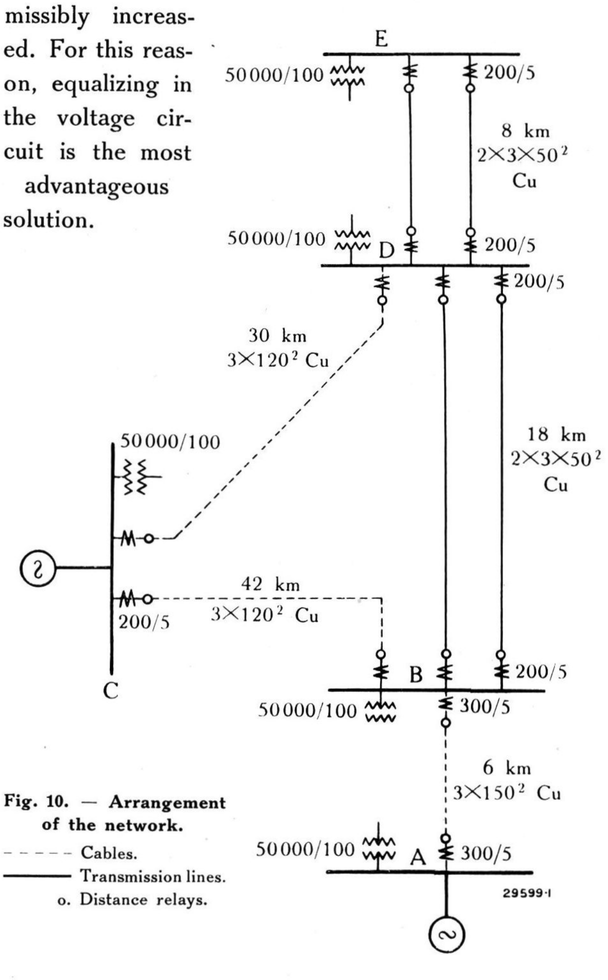

Fig. 10. — Arrangement of the network.
- - - - - Cables.
——— Transmission lines.
o. Distance relays.

The adjusting transformer is a small auto-connected potential transformer. Its primary is connected to the secondary side of the potential transformer of the network. The voltage obtainable on the secondary side is from 0 to 100 % of the primary voltage supply, variable in steps of 1 %, or from 0 to 200 %, variable in steps of 2 %. Let:—

N denote the number of the tapping on the terminal plate of the adjusting transformer;

U'_e the ratio of the network potential transformer together with the adjusting transformer;

x'_s the secondary reactance of the section considered referred to the secondary side of the adjusting transformer.

$$\text{Then } U_e' = \frac{E}{\frac{N}{100}e} = \frac{100\,E}{Ne} = \frac{100}{N}\,U_e$$

$$\text{whence } x_s' = \frac{X}{\frac{U_e'}{U_i}} = \frac{N}{100} \cdot \frac{X}{\frac{U_e}{U_i}}$$

Suppose a tripping time t is required for a section and that x denotes the measuring reactance of the ohmmeter for a tripping time of one second, then after equalization:

$$x\,t = x_s' = \frac{N}{100} \cdot \frac{X}{\frac{U_e}{U_i}}$$

$$\text{or } N = 100\,\frac{x\,t}{X} \cdot \frac{U_e}{U_i}$$

The conditions will be most clearly understood by means of a simple example. Suppose AB (Fig. 8) is a section of a line 20 km long. The ratio of the potential transformers is assumed to be 11,000/110 V and the ratio of the current transformers 200/5 A. A tripping time for the section of 1·6 second is required, and the relay type LB 2 must be used. In this case:

$$U_e = \frac{11{,}000}{110} = 100$$

$$U_i = \frac{200}{5} = 40$$

$$x = 1\ \Omega/\text{sec}$$

$$X = 20 \times 0{\cdot}8 = 16\ \Omega$$

$$t = 1{\cdot}6\ \text{sec}$$

$$\text{and therefore } N = 100\,\frac{1 \times 1{\cdot}6}{16} \cdot \frac{100}{40} = 25.$$

The tripping time for a fault at any point of a section can be read off very simply from a graph if the primary reactances are plotted as abscissae and the tripping times as ordinates. At the beginning of the section, the tripping time is t_g and at the end of the section $t + t_g$. The tripping time varies according to a straight-line law along the section. Fig. 8 shows the tripping time curves for the sections AB and BC. For a short circuit at point D, the tripping time is t_D. The curve for the section AB must be extended over the adjoining section BC in order to determine whether the time gradation of the distance relays at A and B is correct. The difference in the tripping times should not be less than about one second.

The fundamental tripping time, variable between 0·5 and 2 seconds for each relay, can be adjusted in order to improve the time gradation. For sections of approximately the same length, the fundamental time is usually given the same value of 0·5 second for all the relays. Should, however, the rupturing capacity of the circuit breakers be too small, the fundamental time of all the relays can be increased. In cases where particularly short and long sections adjoin, it is advantageous to select a high fundamental time for certain relays. This will be immediately seen from Fig. 9.

Summarized, the adaptation of distance relays to given network conditions entails:

(1) The correct choice of the tapping N on the adjusting transformer (altering the number N changes the inclination of the time curve);

(2) Correct choice of the fundamental time t_g of the relay (altering the fundamental time moves the time curve parallel to itself).

Experience has shown that these two precautions suffice to ensure correct time gradation even in very difficult cases.

VII. PRACTICAL EXAMPLE OF EQUALIZATION.

An example will show how simply the required adjustment can be calculated for a given network.

Consider a 50-kV, three-phase network with insulated neutral point (Fig. 10). Three-phase cables with paper insulation are laid, and each conductor is enclosed in an earthed lead covering. The transmission lines are arranged as double lines with the long arm of the mast below and with an earth wire. Further particulars of the different sections can be seen from the illustration. The example is very interesting because the network is very heterogeneous: single and double lines, a ring fed at two points, in addition to cables and sections of transmission lines of greatly differing lengths. Although the conditions are very unfavourable for adapting the relays correctly, it is shown later that even here the conditions for correct gradation of the times can be completely fulfilled while at the same time retaining short tripping times.

The resistance, reactance, impedance and also the phase displacement of the lines are given in the following table. The ohmic values all refer to a loop with a simple length of one kilometre (i. e., 2 kilometres, considering both conductors); each section is indicated twice if distance relays are installed in both the stations connected by the section under consideration.

TABLE III.

Station	Section	Resistance r	Reactance x	Impedance z	Cos φ $\frac{r}{z}$
		Ohms per kilometre of loop			
A	A-B	0·23	0·24	0·34	0·685
B	B-A	0·23	0·24	0·34	0·685
	B-C	0·29	0·26	0·39	0·745
	B-DI	0·70	0·80	1·07	0·660
	B-DII	0·70	0·80	1·07	0·660
C	C-B	0·29	0·26	0·39	0·745
	C-D	0·29	0·26	0·39	0·745
D	D-C	0·29	0·26	0·39	0·745
	D-BI	0·70	0·80	1·07	0·660
	D-BII	0·70	0·80	1·07	0·660
	D-EI	0·70	0·80	1·07	0·660
	D-EII	0·70	0·80	1·07	0·660
E	E-DI	0·70	0·80	1·07	0·660
	E-DII	0·70	0·80	1·07	0·660

From the table it is seen that the cable mains can be advantageously protected by relays suitable for transmission lines (reactance relays), because even though for the cables the reactance per kilometre of loop is appreciably smaller than for transmission lines, the phase displacement is of practically the same value throughout.

For grading the times of the reactance relays, only the reactance of the sections must be considered, so that for the equalization only the reactances will be calculated. The primary reactance of the various sections is first converted into the secondary reactance, the equalization by means of the adjusting transformer being temporarily left out of consideration. Table IV shows the result of this conversion:

TABLE IV.

Station	Section	Length km	Primary reactance ohms	Ratio of transformer		$\frac{U_e}{U_i}$	Secondary reactance ohms
				Voltage U_e	Current U_i		
A	A-B	6	1·44	50,000/100	300/5	8·3	0·17
B	B-A	6	1·44	„	„	„	0·17
	B-C	42	10·92	„	200/5	12·5	0·88
	B-DI	18	14·4	„	„	„	1·15
	B-DII	18	14·4	„	„	„	1·15
C	C-B	42	10·92	„	„	„	0·88
	C-B	30	7·8	„	„	„	0·62
D	D-C	30	7·8	„	„	„	0·62
	D-BI	18	14·4	„	„	„	1·15
	D-BII	18	14·4	„	„	„	1·15
	D-EI	8	6·4	„	„	„	0·51
	D-EII	8	6·4	„	„	„	0·51
E	E-DI	8	6·4	„	„	„	0·51
	E-DII	8	6·4	„	„	„	0·51

It is assumed for the case under consideration that relay type LB 2 has been chosen from a calculation of the short-circuit current. From the characteristics of this type, it follows that a reactance of 1 ohm corresponds to an operating time of one second. If the tapping 100 is chosen, the secondary reactance as given in table IV is measured unaltered by the relay, so that the tripping time of the relay in seconds is numerically equal to the secondary reactance in ohms. By choosing some other tapping N instead of 100 %, N % of the secondary voltage is supplied to the ohmmeter, and the secondary reactance and, therefore, the tripping times of the relay are altered in the ratio N : 100.

It is simplest to choose a tripping time of one second for every section and to use the graph for determining the correct time gradation. Afterwards the tripping time can be corrected by choosing other tappings or, perhaps, by increasing the fundamental time for certain sections. The curve for the tripping times is thus found very useful as seen from Fig. 11 for the ring ABDEDCBA, and from Fig. 12 for the ring ABCDEDBA. The thin full lines are for an adjustment of one second, and the thick full lines are obtained from the correction introduced later. The calculations can be followed from Table V.

TABLE V.

Station	Section	Tapping for tripping time of 1 sec	Adjustment of the relays			Operating current of leakage current relay A
			Tapping %	Selective time sec	Fundamental time sec	
A	A-B	588	200	0·34	1·2	3·3
B	B-A	588	200	0·34	0·5	3·3
	B-C	114	142	1·25	0·5	5
	B-DI	87	122	1·4	0·5	5
	B-DII	87	122	1·4	0·5	5
C	C-B	114	130	1·14	0·5	5
	C-D	162	178	1·1	0·5	5
D	D-C	162	178	1·1	0·5	5
	D-BI	87	104	1·2	0·5	5
	D-BII	87	104	1·2	0·5	5
	D-EI	196	196	1	0·5	5
	D-EII	196	196	1	0·5	5
E	E-DI	196	196	1	0·5	5
	E-DII	196	196	1	0·5	5

This table also shows the adjustment of the leakage current relays. These should operate when the current to earth in the network exceeds the value of the smallest operating current of the reactance relay. In adjusting the leakage current relay, it is

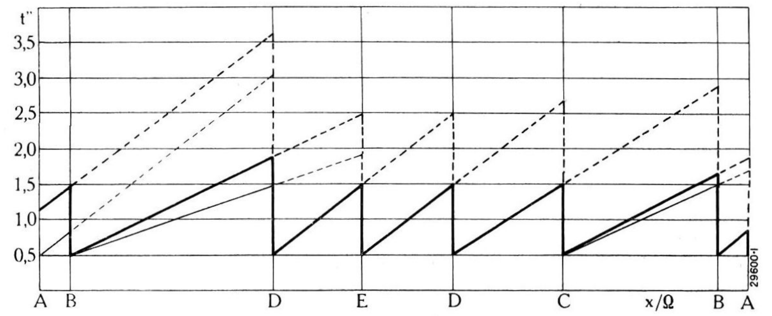

Fig. 11. — Gradation of the tripping times in the network of Fig. 10. Ring main ABDEDCBA.

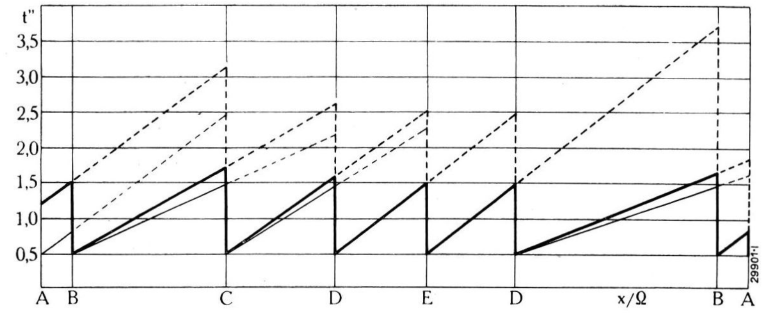

Fig. 12. — Gradation of the tripping times in the network shown in Fig. 10. Ring main ABCDEDBA.

simplest to commence with the current transformer having the highest ratio of transformation. For this, the leakage current relays connected up must be adjusted for the smallest operating current of the distance relay: when relays type LB 2 are used, for example, to 3·3 A. For current transformers with smaller ratios of transformation, the leakage current relays must be adjusted for the same current to earth in the network. In the table the adjustment of 3·3 A on the primary side of the 300/5 A transformer corresponds to a leakage current of 200 A. According to this, the ratio of transformation 200/5 A requires that the operating current must be adjusted to 5 A.

The example shows in a very convincing manner how with very simple means and by retaining clear conditions, perfectly satisfactory time gradation can be attained even in the most unfavourable cases.

(MS 602) *A. van Gastel. (E. J. B.)*

RECENT DESIGNS OF THE BROWN BOVERI INDIVIDUAL AXLE DRIVE FOR ELECTRIC LOCOMOTIVES.

Decimal index 621.335.221.

IN the BBC Mitteilungen 1922, No. 5, a description was given of the Brown Boveri individual axle drive as used on the 2 C_o 1 type express locomotives of the Swiss Federal Railways. This type of locomotive is of interest from a historical point of view as well as technically. It provided the first instance where the Brown Boveri drive was fitted, not merely for experimental purposes but as a drive specially developed for a particular locomotive which it was intended to build in large numbers. The success of this design is well known; the type of locomotive was adopted as standard by the Swiss Federal Railways and the construction of further locomotives of a type with similar axle arrangement but rod drive was stopped. It should not be omitted here to mention the valuable work carried out by the administration of the Swiss Federal Railways and the Swiss Locomotive and Machine Works, Winterthur; the latter firm built the mechanical parts of the locomotives, as for all the other locomotives of the Swiss Federal Railways.

It was later found necessary, while adhering to the well tried principles of design, to develop a type of locomotive with four instead of three driving axles, with the same driving power per axle. In view of the work which they had previously carried out in this direction, Brown, Boveri & Co. were again entrusted with the design. A description of this new locomotive, type 2 D_o 1 or A_e 4/7, was published in The Brown Boveri Review 1928, Nos. 2 and 3. Up to the present, 36 machines have been put into service and 46 are under construction.

As with all designs of individual axle drive where the motors are rigidly mounted in the frames, in the Brown Boveri drive the universal coupling between the large gear wheel and the driving axle is an element of very special importance. Particulars of the coupling will be found in the articles already referred to. Some other features of design were mentioned there and will be briefly repeated here.

(1) Arrangement of the gear drive on one side of the locomotive to reduce as much as possible the number of points where gears mesh and also the size of the transmission mechanism; arrangement of the apparatus on one side in order to equalize the weight distribution and to enable the operating gangway to be placed at the driving and commutator end of the motors, thus enabling these parts to be inspected.

(2) Arrangement of the gear drive outside the frame so that the full width of the frame is available for the traction motors.

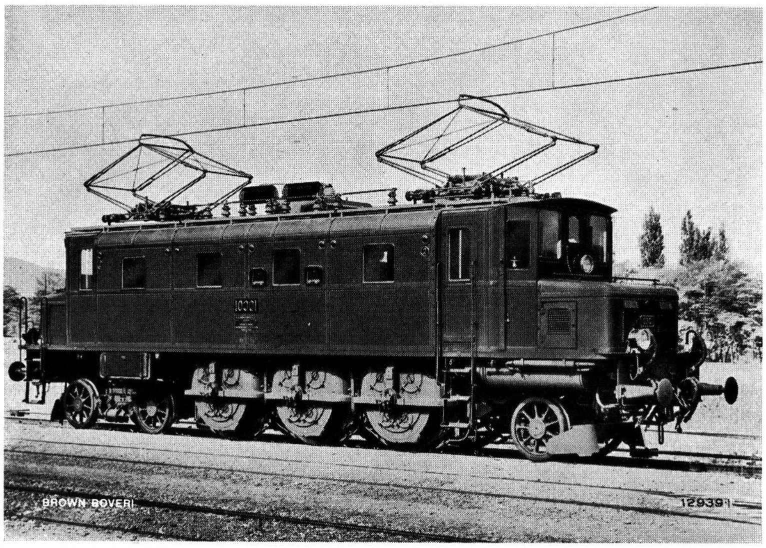

Fig. 1. — 2 C_0 1 locomotive, No. 10301, of the Swiss Federal Railways. View of the driving side showing the individual axle drives.

(3) Arranging the centre of the large gear wheel about 30 mm above the centre of the driving wheel to achieve greater freedom in the choice of the reduction ratio and more suitable dimensions for the parts of the coupling.

Fig. 1 shows a 2 C_0 1 locomotive of the Swiss Federal Railways, and in Fig. 2 the same locomotive is seen from the driving side with side panels removed. These photographs illustrate the points mentioned very clearly.

Although these principles have proved so satisfactory in practice, as will be realized from the statements made at the beginning of this article, it is interesting to note that there are many other instances where the Brown Boveri universal coupling can be used with equal success. As regards the gear drive, when the power per axle is very great the single side arrangement of drive may be departed from and the double-side drive adopted, without necessitating any appreciable alterations in design. This is done with a view to reducing the maximum stresses in the gearing and driving mechanism or on the teeth themselves. This method was adopted for example by Brown, Boveri & Co. on the express locomotives E 501 and E 502 for the Paris-Orléans Railway, described in The Brown Boveri Review 1927, Nos. 8 and 9. These locomotives, one of which is shown in Fig. 3, are also very noteworthy, not only because of their drive but due to the fact that at the time they were put into service they were the most powerful locomotives in Europe, with their one-hour rating of 3600 H. P., that is 900 H.P. per driving axle at 65 km/h, which is 50 % of the maximum permissible speed.

Another variation in design which is, under certain circumstances, very important and can be solved according to the principles already mentioned, is the use of double motors, i. e., two motors per driving shaft. Although this arrangement is generally not necessary from the point of view of the drive itself when using the Brown Boveri individual axle drive, it aids the motor designer considerably, particularly with large powers. The reasons for this are that the motor weight is reduced because certain parts, e. g., the end shields of double motors, are lighter, and especially due to the fact that the two double motors can be connected in series without increasing the danger of running away as they are mechanically coupled through the gearing. The appreciable reduction in the voltage applied to each motor simplifies their design considerably. This is equally true when the total voltage of two such motors, compared with that of a single motor of twice the power, is increased somewhat, because the currents to be controlled are then smaller, thus enabling lighter apparatus to be used.

As an example of the use of double motors in combination with the Brown Boveri individual axle drive in the manner described, the 1 D_0 1 locomotive

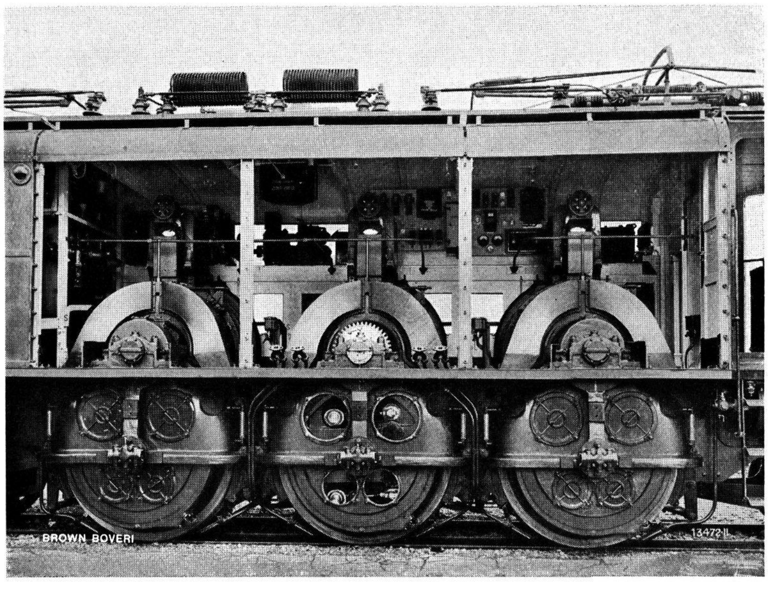

Fig. 2. — 2 C_0 1 locomotive, No. 10305, of the Swiss Federal Railways. View of the driving side, with side panels removed and inspection covers of the central individual axle drive open.

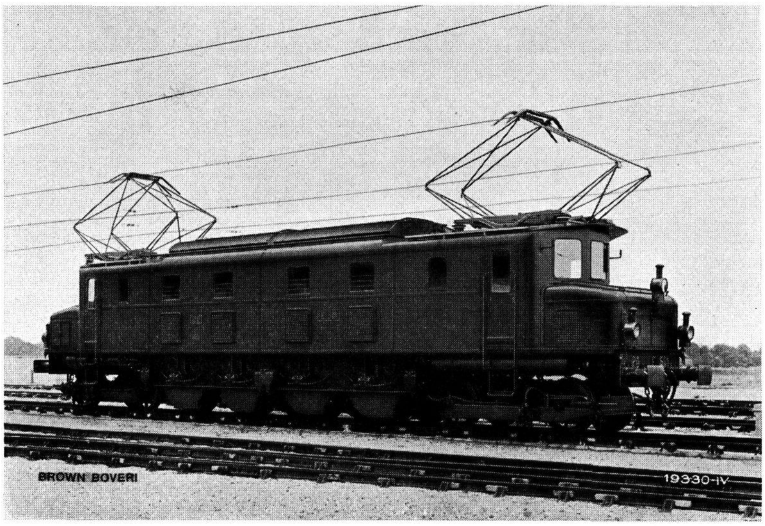

Fig. 3. — 2 D_0 2 express locomotive No. E 501 of the Paris-Orléans Railway.
Speed 130 km/h. One-hour rating at wheel tread 4000 H.P. at 72—92 km/h and 1500 V, d.c.

supplied by Brown, Boveri & Co. to the Companhia Paulista de Estradas de Ferro, São Paulo, Brazil, may be mentioned[1]. A view of the driving side of the locomotive is reproduced in Fig. 4. Fig. 5 shows part of the underframe with driving motors, and gives a clear idea of the arrangement of the motors and drive.

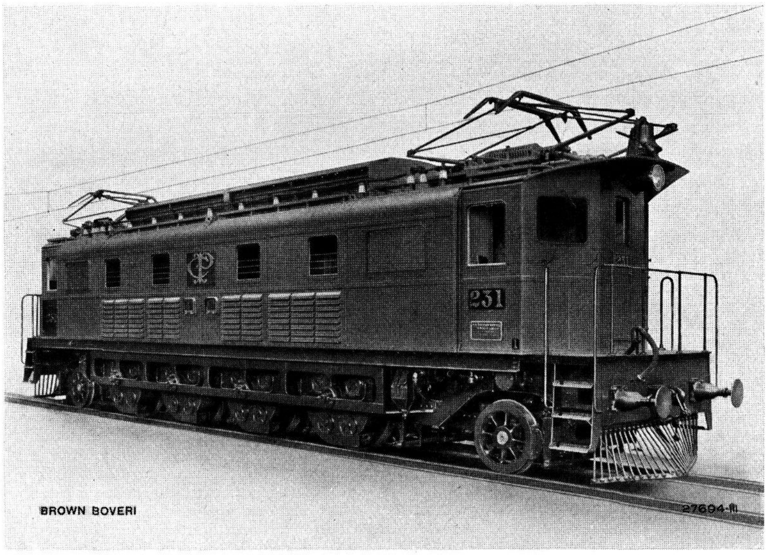

Fig. 4. — 1 D_0 1 express locomotive of the Paulista Railway, Brazil.
Gauge 1600 mm, mean d.-c. operating pressure 2700 V. View of the locomotive from the side of the individual axle drives.

On the locomotives just mentioned, the drives are arranged outside the driving wheels and the locomotive frame therefore inside the latter. As is well known, this arrangement has certain advantages over the outside-frame design, particularly as regards weight and the mechanical rigidity of the frame. With many systems of individual axle drive, however, outside frames only can be used; this applies particularly to the various designs of quill-drive. The Brown Boveri individual axle drive is free from these limitations and can be used alike for inside and outside frames.

The twelve 2 C_o - C_o 2 locomotives supplied by Brown, Boveri & Co. to the North Spanish Railway have outside frames. Fig. 6 shows one of the machines, and Fig. 7 the manner in which a driving axle is combined with its motor. Note the gear drive arranged at both sides, parts of the coupling mounted in the large gear wheel, and the hollow shaft round the driving axle; the hollow shaft does not rotate in this instance, but is rigidly attached to the frame of the driving motor. The maximum speed of the locomotive is 110 km/h; each motor develops a one-hour rating of 540 H. P. at 60 km/h, the d.-c. contact-wire pressure being 1500 V.

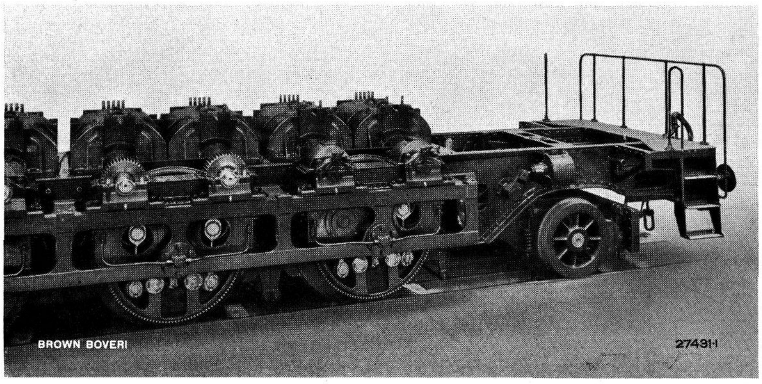

Fig. 5. — 1 D_0 1 express locomotive of the Paulista Railway, Brazil. Part of the underframe with driving motors.

Another noteworthy example of an electric locomotive with external frame is the one (type 1 D_o 1) being built at present in the workshops of the Tecnomasio Italiano Brown Boveri for

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[1] See The Brown Boveri Review, 1928, No. 9, p. 273.

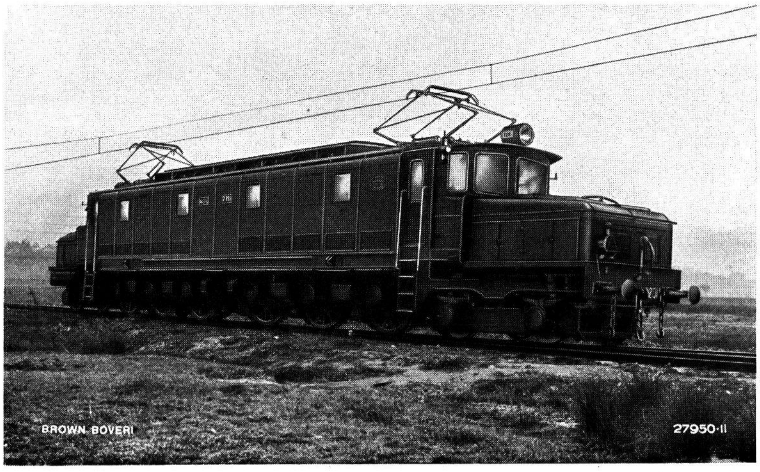

Fig. 6. — 2 C_0—C_0 2 express locomotive of the North Spanish Railway.

the Ferrovie Secondarie Meridionali, Naples; this is the first Italian locomotive to be fitted with Brown Boveri individual axle drive. A special problem was encountered in designing this locomotive due to the difficult conditions regarding the radial adjustment on curves and the running qualities on account of the exceptionally sharp curves with minimum radii of curvature of 120 metres and 70 metres on open sections and at points, respectively. The well-known Brown Boveri bogie could not be employed here on account of the outside frame, as the driving axle cannot be gripped inside due to the hollow shaft, there being thus no possibility of obtaining a fulcrum. This type of bogie was first used by Brown, Boveri & Co. on the 1 D_0 1 locomotives they supplied to the Dutch East Indies State Railways; hence the name "Java bogie", by which they are known. The requisite radial adjustment on curves was achieved in the case of the Meridionale locomotive by giving the inside driving axles side play, while the axle bearings of the two outside sets of driving wheels are connected with the adjoining pony axles by means of a special guiding mechanism so that the radial adjustment of the axles depends on the position of the pony axles.

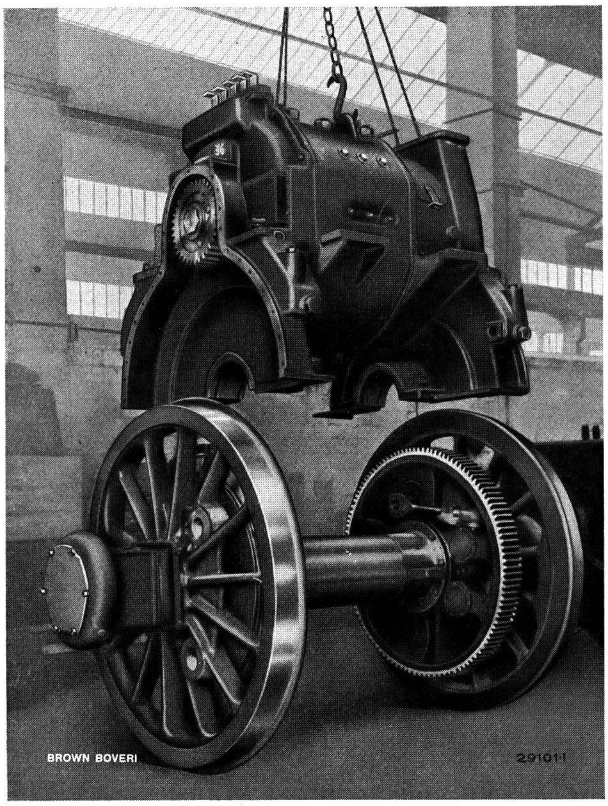

Fig. 7. — 2 C_0—C_0 2 express locomotive of the North Spanish Railway. Lowering a motor with upper part of gear casing on to the hollow shaft of a wheel set.

As regards the design of the individual axle drive of the Meridionale locomotive, it should be noted that it is an internal drive with rotating hollow shaft. Further, the torque is not transmitted, as in previous Brown Boveri drives, through two spherical-ended driving pins to the spokes of the wheel, but directly on to the driving axle by means of a forged-on two-arm lever with spherical ends. This arrangement has the advantage that the cover over the gears has only one central opening which can be made dust-proof with comparative ease.

For completeness, the principle of the above mentioned Brown Boveri bogie should be explained. A pony axle and the neighbouring driving axle are combined into a bogie and driven by a motor rigidly mounted in the frame. This requires, among other things, that the driving coupling used shall allow the relative movement between the wheel set and the gear, a condition which the Brown Boveri coupling fulfils completely. Apart from the locomotive of the Dutch East Indies State Railways already mentioned, this bogie was widely used on the 2 D_0 1 locomotives of the Swiss Federal Railways, with a modification by M. Weiss, chief engineer of these railways, according to which the pony axle itself is mounted as an Adams axle, instead of rigidly in the bogie.

It is wished to emphasize here that the Brown Boveri coupling allows free movement in every direction, and thus also greater sideways displacement of the

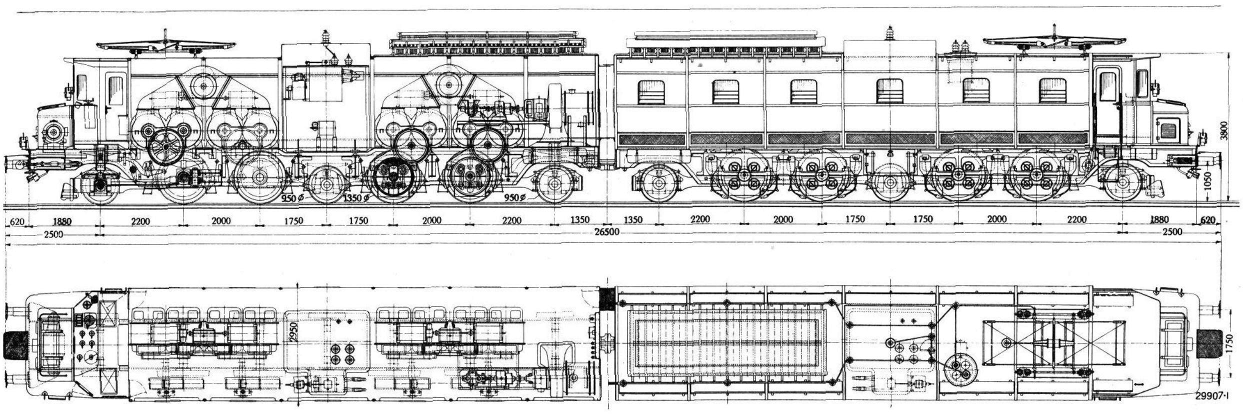

Fig. 8. — $1\,B_0\,1\,B_0\,1 + 1\,B_0\,1\,B_0\,1$ single-phase express locomotive for the Swiss Federal Railways (St. Gothard section).

wheel set and full radial adjustment, which is not the case with the quill drive, for example. Thus without any difficulty the driving axles can be given the necessary side movement for taking curves and at the same time the pony axles can be combined with the driving axles into bogies, not only on the Brown Boveri system as already described, but also for example on the Krauss-Helmholtz system in which the driving axle is only displaced sideways.

The locomotives so far considered in this article are either under construction, e. g., the Meridionale locomotives, or have been in service for some years. In conclusion, a brief description will be given of a projected design for a locomotive. The design was evolved with the co-operation of the Swiss Locomotive and Machine Works, Winterthur, and is for a heavy express goods locomotive for the Gothard section of the Swiss Federal Railways. The maximum speed is 100 km/h, and the axle arrangement $1\,B_0\,1\,B_0\,1 + 1\,B_0\,1\,B_0\,1$, the locomotive being built up of two articulated parts. The total one-hour motor rating at the shafts is 7200 H. P. at 50 km/h, the continuous rating 6760 H. P. at 53 km/h; the weight of the locomotive in running order is 224 tons. Fig. 8 shows the proposed design. As regards axle arrangement, a noteworthy feature is that the outside axles and the two inside pony axles are combined with the adjoining driving axles into Brown Boveri bogies.

In arranging the motors and apparatus, particular attention was paid to achieving maximum accessibility. The commutators of the sixteen driving motors can be inspected from the gangway on the non-driving side. In contrast to the $2\,C_0\,1$ and the $2\,D_0\,1$ locomotives of the Swiss Federal Railways, a second gangway is provided from which the motors and external bearings on the driving side and also the gears can be inspected. Otherwise the design, particularly as regards the arrangement and method of supporting the large gear wheel, follows closely on that adopted in the case of the $2\,C_0\,1$ and $2\,D_0\,1$ locomotives.

In place of the projected design just described, the Swiss Federal Railways chose a second variation proposed by Brown, Boveri & Co. This was briefly described in the Brown Boveri Review 1930, No. 1. The axle arrangement and the electrical control apparatus are essentially the same in both cases. The chief point in which the second variation differs from the first is that only one motor is provided per axle. The motor used can be built without alteration into the existing $2\,C_0\,1$ and $2\,D_0\,1$ locomotives. The drive also is essentially the same in both cases. Both these features are of great importance. The somewhat smaller motor rating could be tolerated, because the adhesion conditions are such as to prevent a higher output from being utilized. The fact that the design with double motors would have eliminated eccentric mounting of the large gear wheel was not of much importance, as the previous similar type of drive proved exceedingly satisfactory. A further point in favour of double motors with double reduction might be that it would be possible, without alterating the mechanical part, to change the transmission ratio and thus to build locomotives of almost identically similar designs for various speeds. Modern practice, however, particularly on the Swiss Federal Railways, is undoubtedly tending towards the use of one standard type of locomotive for all kinds of trains; the locomotives must therefore have a relatively high maximum speed. Freedom in the choice of the reduction ratio is thus no longer of much importance.

(MS 606) *Th. Boveri. (E. J. B.)*

NOTES.

Mutual influence of collectors in electrical discharges in rarefied gases.

Decimal index 537. 525.

If insulated bodies are present in an electrical discharge (arc discharge or glow discharge) in a rarefied gas, they acquire a negative potential with respect to their surroundings because the numerous free electrons in the path of discharge move much more quickly than the positive gas ions on account of their smaller mass; they therefore strike any body in the discharge space and are collected by it in much greater quantities than the heavier ions. The charging lasts until the field of the body repels electrons from the body to such an extent that within any given time as many electrons as ions are caught by the body. An auxiliary electrode in the discharge tube, e. g., a collector, which is connected neither to the cathode nor to the anode but is entirely independent, naturally also becomes charged in this manner and acquires a negative potential with respect to the potential in space of its surroundings and therefore also of the anode. If, however, the collector is brought to a different potential, current flows either to or from it according as to whether its potential is made lower or higher than that which it possessed when in an insulated condition. In the first case the collector takes more positive ions from the discharge, and in the second case more electrons. Thus the potential at which it becomes charged when insulated can be determined experimentally by adjusting its voltage — e. g., with respect to the anode — such that it picks up neither a positive nor a negative current. The voltage at which this occurs is the one required with respect to the anode. The phenomena occurring at such collectors have been thoroughly investigated by Langmuir and Mott-Smith, and more recently by Seeliger.

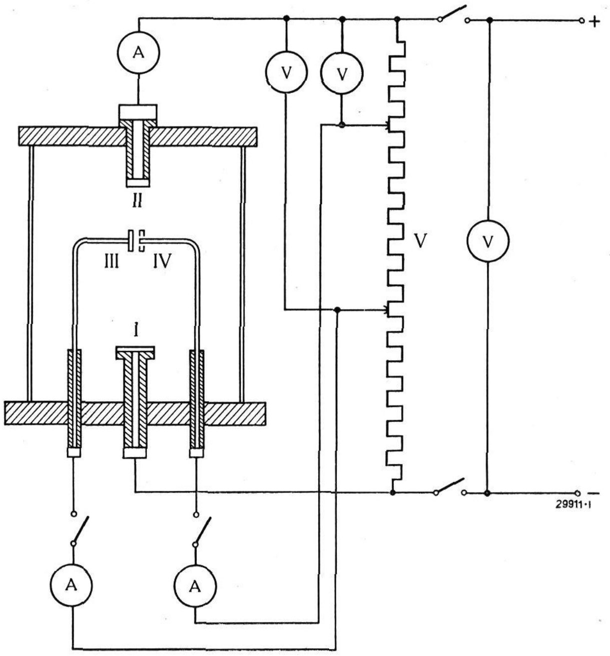

Fig. 1. — Diagrammatic arrangement of the apparatus used for determining the mutual influence of collectors in electrical discharges in rarefied gases.

I. Cathode.
II. Anode.
III, IV. Collectors.
V. Static balancer.

Characteristic light phenomena also occur at such collectors in a gas discharge as well as at the cathode and anode. For example, a collector which is negatively charged in comparision with its surroundings is enveloped in a dark sheath which, in certain respects, is analogous to the dark space at the cathode. In this dark sheath, positive ions are accumulated which cause a positive space charge equally as in the dark cathode space. This positive space charge is so strong that it screens the field of the collector so that the discharge outside this sheath is not influenced at all by the collector. Thus a second collector near the first one, but outside its positive ion sheath, is not affected by a negative voltage on the first collector at the voltage to which it is charged when insulated. The conditions are not so clear when the minimum distance between the two collectors is smaller than the thickness of the positive ion sheath round the first collector, because in this case the screening sheath is prevented from forming undisturbed on the collector. Experiments have therefore been conducted in the physical laboratories of Brown, Boveri & Co. to determine whether and to what extent the potential of such a second collector is influenced in this case by the potential of the first one. This question is of particular interest with regard to the phenomena in mercury-arc power rectifiers.

The tests were carried out with a direct-current glow discharge in air in a vessel as shown in Fig. 1. In this diagram, I is the cathode, II the anode, and III and IV the two collectors. The collector III was brought to a definite negative voltage with respect to the anode, so that it took a positive current from the discharge, and at the collector IV the voltage was measured at which the collector charged itself with respect to the anode when insulated. This was accomplished, as already described, by determining the voltage at which the current in the collector was zero. It was possible to alter the minimum distance between the two collectors and to make it greater or less than the thickness of the dark space, i. e., the ion sheath, round the collector III. The non-insulated part of the collector III consisted of a five-millimetre diameter rod carrying on the end a disc 20 mm in diameter and three millimetres thick. Two different shapes were used for the collector IV. During the first series of tests its non-insulated part consisted of a 1-mm diameter wire with the end at right angles to the disc of collector III; during the following tests it consisted of a wire with a disc, 20 mm diameter and 1 mm thick, secured at the end and arranged parallel to the disc of the collector III, *as shown dotted in Fig.* 1.

The mean values of the chief particulars regarding the tests are as follows:—

Gas pressure	0·15 mm Hg
Potential of the cathode with respect to the anode	−1100 V
Potential of the collector III with respect to the anode	−40 to −1100 V
Cathode current	0·1 A
Thickness of dark space round collector III	5 mm

The distance between the collectors III and IV was altered between 10 and 0·5 mm. Under the given conditions, the latter distance equalled approximately the mean free path of a gas molecule in the container, i. e., the distance moved on an average by a gas molecule during the time between two successive collisions with other gas molecules.

When the distance between the two collectors was less than the thickness of the dark space round collector III, during the tests in which collector IV was without disc, its end penetrated the dark space round collector III without noticeably affecting the light phenomena there. Traces of certain products of sputtering showed, however, that opposite the end of collector IV the discharge at collector III was weaker. A circular-shaped deposit of products of sputtering formed there, whereas the remaining surface of collector III remained clean, because this, having a powerful negative potential, suffered by the discharge cathode sputtering, and therefore nothing was deposited on it. Opposite the end of collector IV, however, the discharge and therefore also the sputtering were so weak that the deposition of products of sputtering produced at other points took place. When the distance between the two collectors was 0·5 mm, the ratio between the portion of the surface of collector IV which dipped into the dark space of collector III, and the remaining surface, was 1 : 100. The measurements showed that the potential of collector III had no effect on that of collector IV even when the distance between the two collectors was a minimum, i. e., 1/10 the thickness of the dark space, and at the highest voltages between the anode and collector III. On an average, collector IV charged itself (according to the magnitude of the anode drop) up to about —40 V compared with the anode, independently of the potential difference between collector III and the anode. The anode drop (i. e., voltage drop in the discharge at the anode) altered during the tests by a few volts according to the point of the anode from which the discharge took place. If the voltage of collector IV were measured, not in comparison with the anode but with the space potential of the surroundings, an absolutely constant value would be obtained.

In order to increase the surface of collector IV facing collector III, the first collector was altered, and, as described, fitted with a disc at the end. Thus the ratio of the surface of collector IV facing collector III to the remaining surface of that collector became 1 : 5. During these tests, collector IV had a visible influence on the light phenomena occurring at collector III; the phenomena ceased near collector IV. No luminosity was visible between the two collectors. An investigation, after the tests, of the deposits of products of sputtering on the collectors showed that no discharge had taken place between the discs of the two collectors. The measurements showed that in this case also the potential of collector III had no influence on that of collector IV. The voltage to which the second was charged, in an insulated condition, with respect to the anode again had a mean value of about —40 V according to the anode drop, and was independent of the voltage between the anode and collector III.

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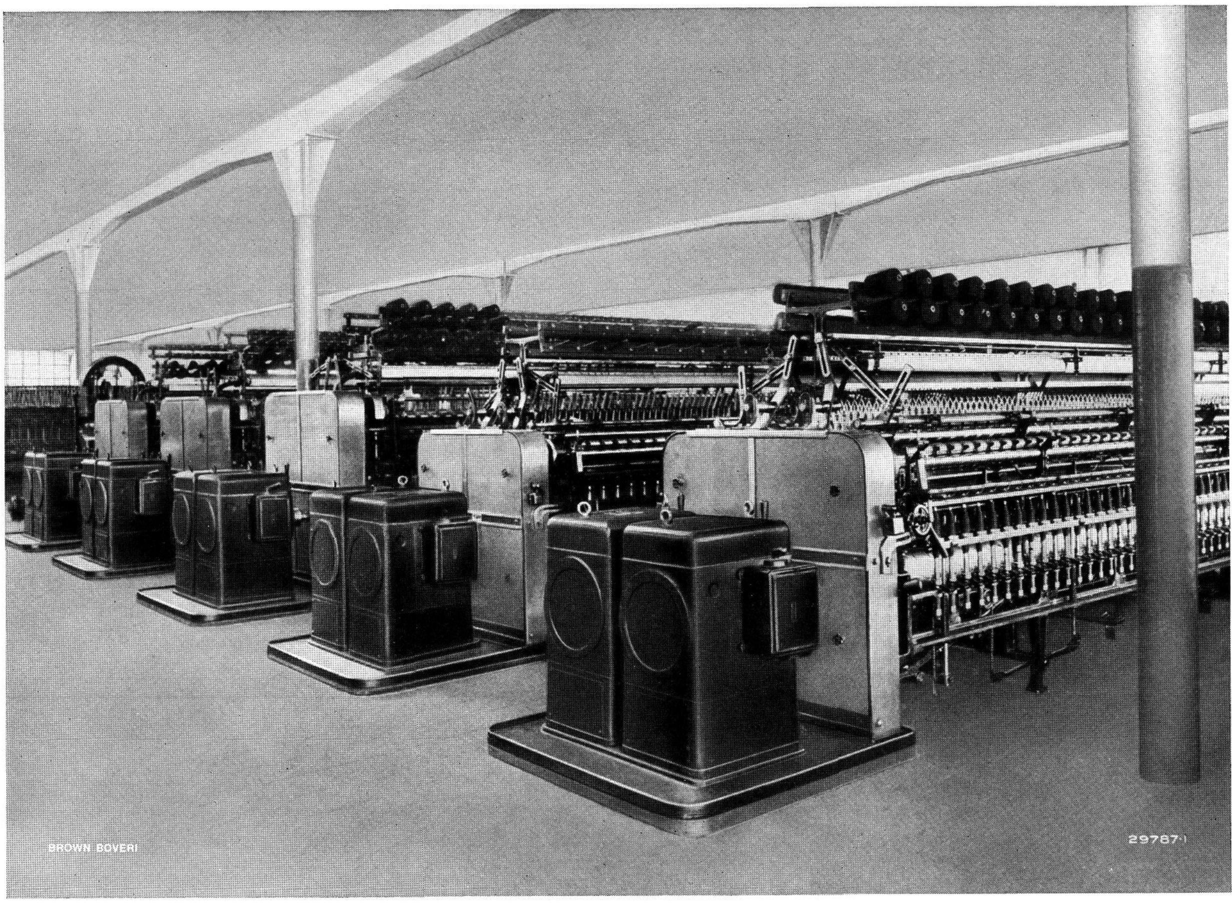

V. E. Marzotto, Lanificio, Valdagno. Variable-speed drive of double wool ring spinning frames by three-phase commutator motors with reduction gears built into the end shields.

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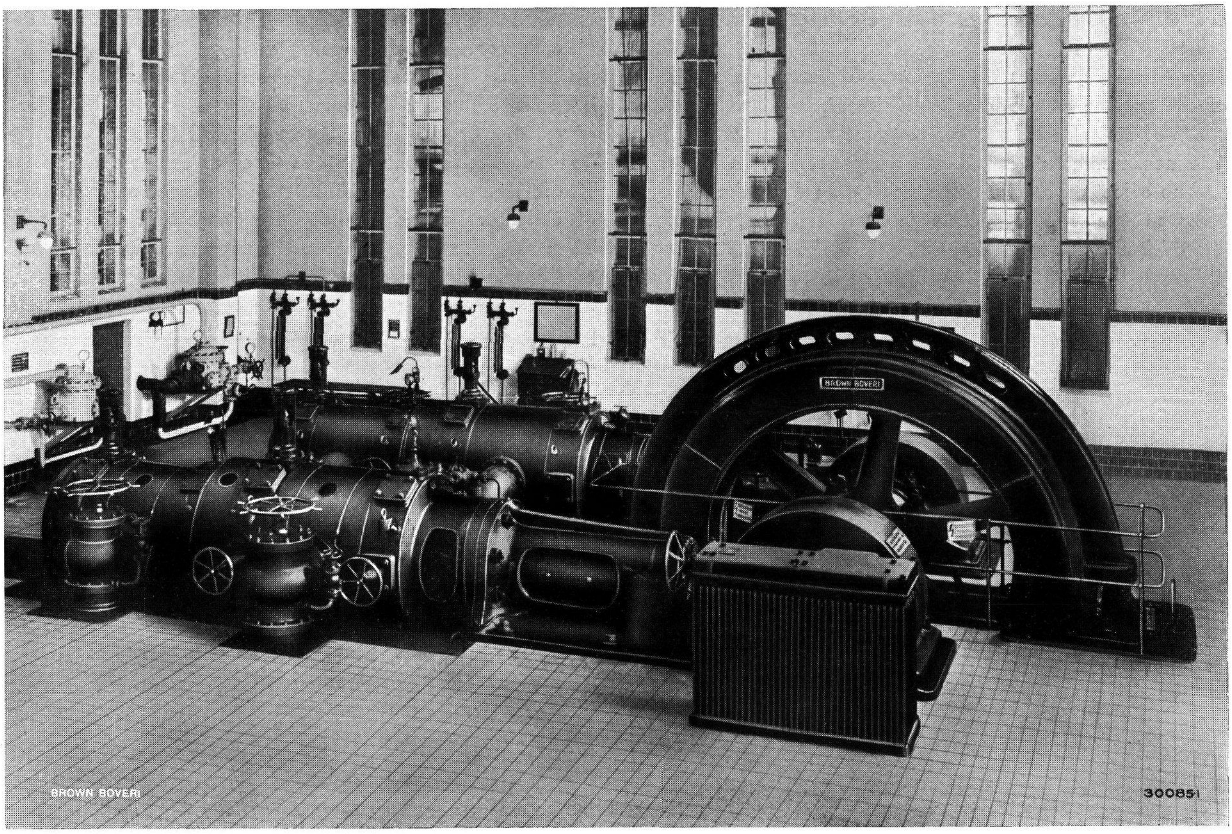
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