WITKOWITZ IRON AND STEEL COMPANY, WITKOWITZ (CZECHO-SLOVAKIA).

Drive for a tube rolling mill by a direct-current motor, 1100 H.P., 500 V, 90—180 r. p. m.
EQUIPMENT OF ELECTRIC SUBSTATIONS

SALT RIVER POWER STATION (SOUTH AFRICA).
Three-phase, outdoor, oil-cooled transformer, 6000 kVA, 12,000/33,000–34,650 V, 50 cycles.

TRANSFORMERS - ROTARY CONVERTERS
MOTOR GENERATORS
MERCURY-ARC RECTIFIERS - INDUCTION REGULATORS
SYNCHRONOUS CONDENSERS
SWITCHBOXES TYPE M FOR THREE-PHASE MOTORS WITH CURRENT RATINGs FROM 125-640 AMPERES.

It has been found impossible to ensure absolutely reliable protection for heavy-current three-phase motors with the switchboxes, no matter of what design, which have been available up to the present time. None has completely safeguarded the motors uniformly against the results of inadmissible overloads. The over-current relays usually employed afford protection only against the over-stepping of a definite limiting value of the current. Their normal range of operation does not enable them to prevent the motor being burnt out by continuous, small overloads, but such as are none the less dangerous; as a rule the fear of numerous unnecessary interruptions results in the tripping current being set to a fairly high value. Damping effects produced by clockwork mechanisms, pistons, springs or vanes, which have been introduced for the purpose of minimizing this objection, cannot overcome the inherent failing of the over-current relay of depending on the current strength and not on the temperature of the motor windings. Instead, they introduce further uncertain factors since their action depends on many other circumstances, but in no way on the actual condition of the motor to be protected. By their incorporation, moreover, the switchbox is made complicated, the supervision rendered difficult, and any repairs which have to be made are necessarily tedious and expensive.

Some years ago Brown, Boveri & Co. placed on the market a thermal release (protected by patents in most countries) involving the use of bi-metal strips. Releases of this kind, for currents up to 320 A, have been found completely reliable during many years’ service and it has been proved conclusively that they protect the motors from dangerous overheating caused by the current; it was therefore an obvious step to make such releases for heavier currents. On account of the connections, however, the dimensions became far too big. For heavy currents, therefore, thermal releases for small currents were used in combination with a current transformer. These operate in exactly the same way as when connected directly, except on heavy overloads in which case the secondary current in the transformer does not increase directly as the primary current but is always a certain amount smaller.

It has thus been possible to make switchboxes with thermal releases suitable for three-phase motors for currents of 125 to 640 A. The switchboxes have a rupturing capacity of about 3000 kVA. Care must be taken to arrange the plant so that the switch will not be called upon to trip a higher load.

In these switchboxes, type M, are combined all the advantages to be obtained by using thermal releases, namely:

Best protection of the motor against dangerous overloads and therefore few repairs, reduced maintenance, low running costs.

Insensitiveness to safe overloads and therefore no unnecessary shut-downs even when finely adjusted.

Fullest utilization of the motor power without risk to the motor.

After tripping, no parts to replace or re-adjust, no waiting; immediately ready for service again.

With these switchboxes the tripping current is usually set to 1·1 times the normal current. There is no reason, however, why the tripping current should not be set lower, or, in fact, as finely adjusted as the running conditions allow. In a steady drive the tripping current may very nearly coincide with the normal current. On the other hand in an

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1 The Brown Boveri Review 1926, No. 4, p. 91.
unsteady drive with many overloads of short duration it is as well to set the releases to trip at $1.1$ times the normal current. With this setting the release will not trip while the motor is starting up, except per-
haps during a few quite exceptionally heavy and long starts, and at the same time will protect the motor against dangerous overloads with absolute reliability during service. The best adjustment for the conditions arising can easily be found by trial. Fig. 1 shows the tripping time of the release as a function of the tripping current adjusted by means of the device on the scale.

The switchboxes type M are made in three sizes:
Type M 8 h for currents up to 250 A
Type M 10 i for currents up to 400 A
Type M 10 k for currents up to 640 A
all for a rated pressure of 500 V.

The switchboxes are all of similar design. The drive, with free-return clutch, to the oil circuit breaker, the thermal release which actuates the free-return clutch through a system of rods, and the scale and adjusting device are all contained in a closed cast-iron casing. The cover is hinged and can be tightly fastened up by two screw plugs. The switchbox is thus rendered drip-water proof and dust-tight.

The three-pole oil circuit breaker is built on underneath the cast-iron casing and enclosed in an oil tank screwed to the casing. A short between the phases or to the oil tank is prevented by insulating shields.

The circuit breaker is operated by means of an insulated handwheel supported by a bearing in the cover at the front of the switchbox; when the cover is opened, the wheel is brought out of engagement with the free-return clutch. The cover cannot be opened when the switch is closed, and the switch cannot be closed when the cover is open.

The leads to and from the box are arranged on both sides. The design is such that single leads or cables may be used for the connections. With single leads the terminals are covered by a protective casing, and when cables are used, trifurcating boxes are fitted which can be arranged for leading in the cables from above or below as convenient.

The parts of the switchbox which remain under tension when the switch is tripped are suitably protected against accidental contact.

In the switchboxes type M 8h the thermal releases lie directly in the motor circuit; in the two other types of switchbox they are connected to a current transformer which reduces the current strength to 5 A. The
release elements and their adjusting devices are similar to those in the switchboxes type LC.

The two thermal releases normally fitted in each switchbox are generally quite sufficient to protect the motor against dangerous overheating due to excessive currents. This was proved by the satisfactory experience with the many thousands of switchboxes type L which have been sold, and which also were provided with two release elements.

For special purposes and according to the conditions of the network to which it is connected, the switchbox can be provided with an ammeter, no-volt release and also short-circuit release. The short-circuit release is necessary in networks with earthed neutral points to protect the third phase. It can also be used in the switchboxes type M 10i and M 10k if, on the occurrence of high overloads, the switches should trip more rapidly.

Special designs embodying any or all of the following features can also be supplied: no-volt release, interlock with the starter and brush-lifting gear of the motor, remote tripping gear, and auxiliary contacts.

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for signalling purposes. Some of these designs are illustrated in the diagrams of connections, Fig. 6. The leads for signalling and interlocking purposes are introduced at the top of the box where a special leading-in connection is provided. The terminals are readily accessible on the removal of the protection cover.

The switchboxes type M may well be regarded as the first motor protective switches for heavy currents. In addition they are the only ones which afford a real protection against dangerous overheating for motors with current ratings of the order of 125 to 640 A. Their design is pleasing and of an easily supervised character and they are not expensive. It is expected that these switchboxes will find a very large and ready market.

K. Kuntze. (E. J. B.)

BROWN BOVERI ELECTRIC LOCOMOTIVES WITH SINGLE-PHASE COMMUTATOR MOTORS FOR COKE OVEN PLANTS.

In modern coke oven plants the coke is discharged from the ovens by special coke-ejecting machines. By means of a ram, the coke is pushed out at the front of the oven, where it falls into a self-emptying coke wagon. In this wagon it is conveyed to a tower where it is quenched with water, after which it is taken to a dump and tipped.

At the present day, electric locomotives are most generally employed for hauling these coke wagons, and, as will be seen from Figs. 1 and 2, they have a rather peculiar appearance.

In the following pages a description is given of such a locomotive which has been supplied for the coke oven plant built by the firm of Dr. C. Otto & Co. for the Mansfeldschen Steinkohlen-Bergwerke, Sachsen Colliery, near Hamm (Westphalia). Brown, Boveri & Co., Mannheim, supplied the electrical equipment for the locomotive; the mechanical part was built by the Lokomotivfabrik Arnold Jung, Jungenthal near Kirchen on the Sieg, to the designs of Brown, Boveri & Co.

The conditions under which such a locomotive works in a coke oven plant are rather exacting. At the commencement of the coke ejection, the coke wagon must be quickly accelerated to the required speed which calls for a very large tractive effort of the locomotive at starting. During the coke ejection, moreover, the wagon must be hauled past the ovens at a very low, constant speed which has to correspond as nearly as possible to the speed at which the coke is discharged; this is necessary in order to obtain an even distribution of the coke. If the coke cannot be evenly distributed in the wagon, but, as a result of the speed regulation not being fine enough, forms a heap, the quenching is rendered more difficult and prolonged. In travelling from the ovens to the quenching tower and dumps, on the contrary, a comparatively high speed is required, this being fixed according to the number of journeys which have to be made during a shift.

As is usually the case, only three-phase current was available at the colliery and therefore direct-current...
series motors could not be considered for driving the locomotive. The use of an ordinary three-phase induction motor was also not indicated, as the starting torque of this type of motor is not high enough, and, further, due to the method of switching out the starting resistances in steps, the motor cannot be uniformly regulated. A three-phase commutator motor, which would have met the requirements better, was not used because its connections, and therefore the requisite switching apparatus, are rather complicated, which is not desirable for the rough service encountered in coke oven plants.

The best solution appeared to be that afforded by a single-phase commutator motor of the Brown Boveri Déri type, which fulfils in the most satisfactory manner all requirements regarding speed regulation and simplicity. Exhaustive investigations showed that the unsymmetrical loading of the three-phase system caused by a single-phase motor is insignificant. As, moreover, very satisfactory results had already been obtained with single-phase motors used for driving coke ejectors, etc., in the colliery plant, this type of motor was also selected for the locomotive which it was decided to provide.

The Brown Boveri Déri single-phase commutator motor is a repulsion motor which is started and regulated by simple brush-rocking without the use of any intermediate resistances or switching apparatus whatever. It has a series characteristic and therefore a high starting torque without the unpleasant tendency to stall, common to three-phase motors.

It is thus seen that the motor is particularly well suited to the conditions under consideration; this has been proved conclusively with the locomotive in service. The great simplicity of the connections is seen from Fig. 3.

The built-in totally-enclosed single-phase commutator motor with special insulation has a one-hour rating of 46 kW at a line pressure of 500 V, 50 cycles. It drives the two pairs of wheels through worm gearing having a reduction ratio of 17:1; the one-hour tractive effort developed at the wheel tread is 2380 kg, the corresponding speed being about 6 km/h. The motor can develop a maximum tractive effort at starting several times greater than the one-hour rating. On level stretches the locomotive attains a speed of 9.9 km/h when hauling a load of 70 tons. Actually, the motor is rather more

Fig. 3. — Principal diagram of connections of a coke-oven locomotive with Brown Boveri Déri single-phase commutator motor.

3. Mechanical brush-rocking gear.
4. Field switch.
6, 7. Automatic compressor switches.
8. Pressure regulator.
9, 10. Compressors.
11. Lighting switch with automatic cut-out.
12. To lighting-current transformer.
powerful than is necessary for the conditions encountered but as an exactly similar motor was in use on the coke-ejecting machines, for uniformity the same type was chosen for the locomotive.

Fig. 4. — Principal dimensions of the electrically-driven coke-oven locomotive.

Brush-rocking is effected through a cardan shaft by means of a handwheel with indicating device. A stator switch is coupled with this rocker gear for the purpose of disconnecting the stator from the network when the brushes are in the zero position, in order to dispense with avoidable no-load losses. As stator switch a type with oil-immersed contacts was chosen, while for more recent locomotives a simple hammer contact switch with blow-out coil has been used, similar to those that have proved so very successful for tramway car controllers. The motor is protected against inadmissibly high loads by an ironclad oil circuit breaker provided with two independent single-pole current relays with time lags and no-volt release.

Current is taken from a two-wire contact line by two specially designed trolleys. The contact line passes along the ovens and is protected from falling coke, etc., by wire netting.

The compressed-air equipment comprises two Knorr two-stage, four-cylinder compressors for a gauge pressure of 8 kg/cm², each designed for an indrawn air volume of 560 litres per minute. Each compressor is driven by a single-phase commutator motor having a one-hour rating of 3.0 kW at 1000 r. p. m. The motors are designed for constant speed and therefore have fixed brushes, and are automatically started up or stopped by an air-pressure regulator according to the demand for compressed air. Small oil circuit breakers with electro-magnetic and thermal releases protect the compressor motors against overload.

A single-phase transformer with a ratio of 500/110 V is included in the lighting installation; it is protected by a small oil circuit breaker with electro-magnetic and thermal release. Illumination is obtained from four headlamps and a lamp in the driver's cab. Three two-pole plug sockets are also provided at different points on the locomotive. The switches and fuses for the lighting circuit are all mounted together in an ironclad distribution box.

The special requirements of the service necessitated a somewhat peculiar construction for the mechanical part of the locomotive, the driver's cab being in a very elevated position and the length of the vehicle relatively short. Locomotives of this type are, however, most generally used to-day in coke oven plants. The cab is mounted high up so that the driver can command a view of the coke wagon and see that the coke is distributed correctly. The principal dimensions of the locomotive are given in Fig. 4.

The outer frame and bodywork of the locomotive are of 20-mm steel plates, firmly riveted together by means of angle iron and gusset plates. The traction motor is fixed to a simple bridge frame of strong rolled-steel sections attached directly to the housings of the two worm drives. These worm drives are flexibly coupled to the two ends of the motor shaft. The shafts run in roller bearings, the end thrusts being taken

Fig. 5. — The single-phase commutator motor in position, and the drive for the two sets of wheels.

up by ball thrusts. The whole drive is enclosed in a dust-proof and water-tight cast-iron housing and runs in oil; the running conditions are thus as favourable as possible. The arrangement of the motor and drive is shown in Fig. 5.

Space is provided above the motor and gears for the two compressors. These supply the air for the compressed-air brakes, which have four blocks, the sanding gear which is used for both directions of travel, a bell operated by compressed-air, a three-toned whistle and the pneumatically-operated flaps for emptying the coke wagon. One compressor is sufficient for normal service. Due to disturbances, however, it is sometimes necessary to attend to additional ovens out of the correct order, in which case both compressors are used.

Steps arranged on the side of the locomotive remote from the ovens lead to a platform in front of the driver's cab. From here the driver operates the water valves in the quenching tower when quenching the coke. All the control devices for the various circuits on the locomotive are assembled in the cab, the previously mentioned switch column with handwheel for regulating the brushes of the driving motor being mounted in the centre. The oil circuit breakers for the traction motor, as well as the small breakers and fuses for the compressor motors and lighting circuit, are fixed to the rear wall, opposite the door. In the driver's cab are also mounted the valves for operating the tipping mechanism of the coke wagon, the valves for the compressed-air brakes and the remaining pneumatically-operated devices as well as a throw-over lever by means of which the brake rods can be operated by hand, though this is usually done by compressed air.

Four hoses are provided for conveying the compressed air from the locomotive to the coke wagon, wire netting being used to protect the pipes from falling red-hot coke. The drawing gear and buffers of the locomotive are of the standard type used on the German State Railway. Two of the four headlamps are mounted at each end. The total weight of the locomotive is 15 tons, of which 12 tons are accounted for by the mechanical part.

The running diagrams (Fig. 6) indicate the nature of the service. The work cycle commences at the first of the two batteries of ovens, which are some distance apart, with the filling of the coke wagon. The journey to the quenching tower follows next. From the quenching tower the wagon is hauled to the dump where the quenched coke is tipped out. The other battery of ovens is situated opposite to this dump. The second cycle commences with the loading of the coke at the second battery, after which the wagon is taken again to the quenching tower and back to the dump. After being tipped it is returned again to the first battery. Between the tipping of the coke from the car and the commencement of cycle II, short load peaks caused by shunting are unavoidable. For simplicity, however, these have been omitted from the diagrams shown, which are for the most unfavourable case which is likely to occur.

The results obtained have shown that every requirement has been completely met. In particular, the
simple control arrangements and the uniform speed regulation are found to be very advantageous.

The best recommendation for the suitability of the electrical equipment with single-phase commutator motors as first designed by Brown, Boveri & Co. for such locomotives is found in the fact that, during the past year alone, four locomotives of the type described were supplied for various collieries in Germany. With the exception of very minor differences, similar electrical equipment was used in all four locomotives. The mechanical part of two of these locomotives differs from that of the others in that the motor and drive are non-rigidly mounted in the undercarriage. With this construction, the motor is arranged at one end of the locomotive and can thus be very easily lifted out by a crane. The power is transmitted through a single-worm drive, jack shaft and coupling rods to the two driving axles.

(1S 482)
H. Lutz. (E. J. B.)

SELECTIVE TRIPPING OF MERCURY-ARC RECTIFIERS ON THE OCCURRENCE OF BACK-FIRES.

I. INTRODUCTION.

Within recent years the total amount of electrical energy converted in rectifier plants has risen to very considerable proportions due to the continuous and rapid advance in the number of such plants being put into service and also due to the increasing of the mean rating of the sets. Side by side with these developments, the requirements made on the safety of these plants have also become increasingly severe. As the experience of the past years has shown, Brown, Boveri & Co. are to-day in a position to make rectifiers in which, although subjected for many months to continuous or temporary overloads, no back-fires will occur. Nevertheless, every precaution must be taken so that, even on the very rare occurrence of a back-fire, the short circuit produced may be rendered ineffective as rapidly as possible. This means that the rectifier which has back-fired — and only this one — must be disconnected from both the direct and alternating-current networks. To make the description clearer, Fig. 1 shows diagrammatically the internal current characteristic of a rectifier during a back-fire. It will be seen that the back-fire causes a six-phase short circuit rather than one in two phases only. Compared with the metallic short circuit, however, there is the essential difference that the current in the five sound phases which have not back-fired flows only in the forwards direction, i. e., from the anode, whereas in the phase which has back-fired the current flows in the reverse direction, i. e., from the arc to the anode.

When working in parallel with other sources of current, in addition to which the shunt motors supplied from the d.-c. network must be taken into consideration during a back-fire, the external short-circuit current supplied by the d.-c. network overcomes this internal short-circuit current in the primary a.-c. network. That is to say, when a back-fire occurs in a set, not only this set but also all the other sources of current with which it is operating in parallel feed on to the short circuit. According to the damping effect of the connections between these sets, either the over-current relays on the primary side or those on the direct-current side will be operated. Under certain circumstances the next result is that the other more-remotely situated sets, which, due to the damping action of the connecting leads are not directly affected, are tripped by the overload; the entire direct-current network is thus rendered currentless. This state of affairs must be avoided at all cost, which means that the set which has back-fired, and only this set, must be disconnected from both the primary and direct-current networks in the shortest possible time. The general condition which must be fulfilled in order to ensure selective tripping is that the current-limiting protective devices of the sets must not all operate under the influence of the current rush, which lasts until the affected set is cut out. In the following pages a description will be given of the means by which this selectivity in tripping is obtained and the principles underlying the methods adopted. Clearly the natural way to solve this problem is to acquire
a thorough knowledge of the current and voltage characteristics peculiar to a rectifier set that has back-fired, as compared with those corresponding to normal operation, and then to make use of these peculiarities in the protective device.

The three most important solutions will now be described in the order in which they have been developed.

II. THE REVERSE-CURRENT SELECTIVE PROTECTION.

As already mentioned, when a back-fire occurs in a rectifier working in parallel with other sources of current on the direct-current side, or supplying direct-current motors having shunt characteristics and with ratings as large as that of the rectifier, a short-circuit reverse current is produced. This current flows from the direct-current bus-bars over the direct-current switch A (Fig. 1), through the cathode K and the arc caused by the back-fire, and then through the corresponding phase of the transformer into the negative line of the network. As such a reverse current can be caused only by a back-fire it is a sure indication that the set under consideration has back-fired. Thus in this case one or two suitably polarized relays included in one of the two direct-current connections of the set can be used directly for mechanically tripping the primary oil circuit breaker and the direct-current switch; if the relays are made as contact relays they can be used for tripping these switches indirectly. When employing the latter, that is, indirect method of tripping, it has to be taken into account that the moment the back-fire occurs the voltage of the primary network drops to a small fraction of the rated value. Therefore to avoid this uncertainty in the pressure available for tripping, it is preferred to use a current relay rather than a voltage relay. For supplying this current for tripping the oil switch, a current

![Diagram](image-url)
transformer in the primary circuit of the main transformer is decidedly more suitable than a shunt on the direct-current side, as a drop in voltage in the shunt is not desirable. A simple circuit in which a reverse-current relay is used for direct mechanical tripping of the direct-current switch is shown in Fig. 2. In this case the same switch also serves as a contact relay in that, while the main contacts are opening, an auxiliary contact, which normally bridges over the leads from the current transformer to the tripping magnet of the circuit breaker, also opens. With this arrangement very short tripping times are obtained while at the same time a minimum number of relays and auxiliary contacts are required. Results obtained in practice have been very satisfactory. The only disadvantage of this reverse-current protection is that its action depends entirely on the occurrence of a reverse current when the set back-fires. Now when a set is working alone, there being then no back-electromotive force, a reverse current does not occur. When this system of protection is used, therefore, a set must never be allowed to work alone on to the network. If this condition is ignored, a back-fire occurring in the set will not be cut out by the selective protection but by the over-current relay, which is purposely set to operate more slowly. Too long a duration of the back-fire then results in damage being done to the electrodes of the rectifier. On the other hand, if the over-current relay were set to operate instantaneously, it would also trip the set when short circuits occurred in the network. Opposed to this drawback is the advantage that the system can be employed with all the different kinds of circuits used for rectifier transformers. The oscillogram in Fig. 3 gives the tripping times of a circuit breaker provided with this reverse-current tripping system. In this instance a reverse-current relay with permanent magnet was employed, the armature of the relay acting mechanically on the tripping mechanism of the switch. Two auxiliary short-circuiting contacts are provided on the switch; when the switch is closed these are short-circuited, and when it is open they also are open. On the occurrence of a back-fire they commence the tripping movement of the primary circuit breaker as shown in Fig. 2.

III. THE UNSYMMETRICAL DIFFERENTIAL PROTECTION.

Since the reverse-current selective protection described employs the reversal of the current in the connections to the bus-bars for tripping the switch, this system of protection controls only the direction of the current flowing through the set. There are, however, other features peculiar to the back-firing of a rectifier set which distinguish very conclusively this state from the normal condition. Consider for a moment the six phase currents of a six-phase set to be divided into their direct and alternating-current components. It is quite clear that, neglecting the higher harmonics on the direct-current side, the direct current issuing from the cathode is equal to the sum of the six equal direct-current components of the phase currents. The six alternating-current components of the phase currents, however, continually neutralize each other. In other words, when operating normally as well as during a short circuit on the direct-current side, the cathode current is equal to six times the linear average value of the phase current. Now a back-fire in one of the six phases not only puts the anode in question out of action as regards the flow of current from anode to cathode, but also, in addition to reversing the current in that anode, as already mentioned it causes a fall or even a reversal of the current in the positive and negative connections of the set. At the same time all the other phase currents must increase as a result of the internal short circuit. If, now, the relationship between the direct-current components of the cathode current and the direct-current component of one of the phase currents is considered (in the
following pages these will be called the G cathode-
current and G phase-current), it is found that during
a back-fire all the G phase-currents increase and the
cathode current is either reduced or reversed. The
ratio \( v \) of these components, which is equal to \( +6 \),
is thus evidently completely disturbed on the occur-
rence of a back-fire, as will be shown later. The
four possible cases likely to occur will now be briefly
considered.

(1) Individual operation of a rectifier set.

(a) Ratio of the G cathode-current to the G
phase-current in the anode which has back-fired.

In accordance with the assumption, there is, in
this case, no back electromotive force, and therefore
no appreciable reverse current. In other words, during
a back-fire the cathode current can be reckoned equal
to zero. On the other hand, the G phase-current
flowing through the affected anode is equal to the
sum of the G phase-currents in all the other phases,
but has the opposite sign as compared with normal
service conditions and is also comparatively large,
such that

\[ v \approx 0 \]

(b) Ratio of the G cathode-current to the G
phase-current in the sound phases which have not
back-fired.

The conditions regarding the G cathode-current
remain unchanged, whereas the G phase-currents flowing
in the direction of the working currents are again
relatively large. Here also

\[ v \approx 0 \]

(2) Parallel operation with other direct-current
sources.

This case is distinguished from the preceding
one in that a heavy reverse current flows through the
positive and negative connections of the set during
a back-fire.

(a) Ratio of the G cathode-current to the G
phase-current in the anode which has back-fired.

Besides the remaining anodes of the same set
the other direct-current sources working in parallel
will also feed through the cathode on to the affected
anode. It is thus clear that the G phase-current of
the affected phase is at least equal to the G cathode-
current itself, i. e.,

\[ v \leq 1 \]

(b) Ratio of the G cathode-current to the G
phase-current in the sound phases which have not
back-fired.

This can be decided by the single fact that the
direction of the current in the positive and negative
connections is reversed as compared with the normal
service conditions, whereas the direction of the current
in the sound phases under consideration is not altered; thus

\[ v < 0 \]

It is thus definitely shown that the relation

\[ v = +6 \]

applies exclusively when the set is symmetrically loaded,
i. e., to service conditions including short circuits on
the direct-current side.

Having established these facts, the next object
is to find a suitable apparatus that will work dependent
on this ratio and indicate all variations from the normal
value \( v = +6 \), and that can be used for selectively
tripping the set. Such an apparatus consists of a
simple magnetic circuit with two windings insulated
from each other. One of these windings is in parallel
with a shunt and is supplied with a fractional part
of the cathode current; a fractional part of the current
from any anode of the same set flows through the
second winding, but in the opposite direction. The
magnetomotive forces in the two windings are so
chosen that in service their direct-current components
exactly neutralize each other. During a back-fire,
however, the magnetomotive force in the one winding
becomes larger than that in the other according to
the prevailing conditions. The resulting magnetization
can be used directly, by means of tripping magnets,
or indirectly by means of contact relays, for selectively
tripping the affected set. With regard to the alter-
ating-current components, which also flow through
the lead traversed by the anode current, it must be
added that these have no disturbing effect if at least
one of the windings described is shunted. Shunting
the windings prevents the rise of any appreciable a.-c.
pressure and therefore no alternating current flows
through them; during normal service the occurrence of
an alternating current in the windings would tend to
disturb the equilibrium of the direct-current components
in the windings. It is thus always the direct-current
components of the two currents led through the relay
which operate it. The relay can therefore be regarded
as a "magnetic direct-current balance". Clearly, instead
of the shunt described, a short-circuit winding coupled to the magnetic circuit can be used. After what has been said it should also be obvious that it is not necessary to provide every anode of a rectifier with such a relay. On the contrary, a single relay included in any one of the anode circuits is quite sufficient to cope with all back-fires, whether these occur in the anode connected to the relay or in any other in the set. A circuit based on these principles, for selectively tripping rectifier sets, is given in Fig. 4 (German patent). This circuit affords the advantage that normal relays or tripping coils with two separate windings can be used, and the action is also completely independent of external reverse currents, i.e., from sets operating in parallel. Moreover, such a protective system, in contrast to the reverse-current protection described, also operates under the influence of certain internal disturbances in the transformer or rectifier, as, for example, interruptions in one of the primary phases, etc. Against these advantages must be set the disadvantage that the shunt through which the anode current flows must be put in between the corresponding secondary phase of the transformer and the neutral wire, or else, if it is included between the secondary phases and the anode, the inconvenience arises of having the full phase pressure of the transformer between the two windings of the relay. It is therefore found advisable to supply the second winding from a shunt in circuit with the negative lead of the set. Due to these disadvantages as compared with the systems under II and IV, this unsymmetrical differential protection is merely of theoretical value. Up to the present time it has not been adopted in practice.

IV. THE SYMMETRICAL DIFFERENTIAL PROTECTION.

In the unsymmetrical differential protection described in the previous section, the action depended on the establishment of a magnetic balance, in which both of the main currents, essentially of different kind and magnitude and acting in opposition to each other, are unequal. Now for the particular case in which a rectifier set is provided with an absorption choke coil it must be remembered that electrically this coil divides the original six-phase system into two symmetrical three-phase systems I and II, which operate in parallel with each other on to the network and normally are equally loaded. This symmetry of the two
load-carrying parts, which, apart from the negligible higher harmonics of the rectifier current, supply a steady direct current, is due to the electrical symmetry of the six-phase system; if by any chance this symmetry is disturbed, unequal distribution of the current in the two three-phase systems is bound to follow. A back-fire in a phase of one of the two three-phase systems disturbs the symmetry of this system to a very great extent. To draw a rough comparison, the back-fire has the same effect as would be produced in a system of \(2 \times 3\) similar generators working in parallel if the E.M.F. of one of the generators were suddenly to reverse. This unsymmetrical state during a back-fire thus provides a further means of selectively disconnecting a faulty set from both networks. With respect to the sound rectifier sets, the back-fire acts like a short circuit on the direct-current side, and since, in such a case, the internal symmetry remains undisturbed, these sets will not be tripped. From a constructional point of view the principle can be developed equally well either as a magnetic or electrical balance. If the two current components \(J_1\) and \(J_2\) (Fig. 5) of the set are allowed to act magnetically with equal force but in opposite directions on a relay, or better still directly on the tripping mechanism, magnetization will be produced only when a back-fire occurs. Again, if both the branch currents (Fig. 6) are led through shunts having equal resistances, and if the windings of the relays or tripping coils to be operated are connected in parallel with the terminals of the shunts, then a current, and the consequent tripping of the relays, etc., will occur only on the occurrence of a back-fire. A circuit based on this symmetrical system is given in Fig. 6. Like the one shown in Fig. 2 this arrangement has been used in many installations and has proved fully satisfactory in service (German patent). Fig. 7 shows the results of a series of trippings made by means of the arrangement described on a Brown Boveri direct-current switch type H. From what has already been said it follows that it is immediately permissible to use inductive shunt resistances with the symmetrical differential protection shown in Fig. 6 for reducing the tripping time. The use of such inductive shunts with the reverse-current protection of Fig. 2

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**Fig. 6.** — Diagram of connections for symmetrical differential protection with electrical differentiation.


**Fig. 7.** — Cutting out a back-fire by means of a switch type H and symmetrical differential protection with electrical differentiation as in Fig. 6.

introduces very narrow limits of operation in that not only an increasing reverse-current but also a decreasing current in the correct direction induces a potential at the terminals of this inductance, thus causing the reverse current relay connected in parallel to operate. This must, however, be avoided if the desired sensitivity is not to be lost. This disadvantage occurs as a direct result of the symmetry of the symmetrical differential protection, but in addition to the further advantage of being able to employ tripping forces of various strengths, this system also possesses the advantage that it can be used to operate directly on the tripping coils of any type of switch without the use of intermediate relays. It might also be mentioned that this system answers not only to back-fires but also to certain faults in the circuits and to line breakages. An instance is known to Brown Boveri where a terminal on the absorption choke coil overheated up to the melting point as a result of insufficient contact pressure, due to faulty erection. The direct-current switches, of other manufacture, had been fitted by Brown Boveri with symmetrical differential protection. At the moment the terminal completely melted away, one of the two three-phase systems connected through the absorption choke coil was rendered currentless. The resulting inequality of the currents in the two shunts (Fig. 6) caused both sides of the affected set to be tripped immediately and thus prevented the other uninterrupted three-phase system of the same set from being damaged by the hundred per cent overload.

Examined more closely it is seen that the use of this symmetrical system is by no means limited to equipments with absorption choke coils. By using a short-circuit winding in the differential system, it is possible to compensate almost completely the alternating currents which would normally occur in the connections not provided with an absorption choke coil, the method being similar to that in the case of the unsymmetrical differential protection. Such a short-circuit winding, however, causes an undesirable reduction in the speed with which the system operates on the occurrence of a back-fire.

(MS 481)

E. Kern. (E. J. B.)

NOTES.

Coupling device for the control of multiple-unit electric trains.

Decimal index 621.334.7.

During rush traffic periods on tramways, interurban railways, underground railways, etc., a large number of trains must follow each other in rapid succession. The greatest difficulty which railway companies experience at such times is in meeting the demand for men to run the trains. The best solution to this problem is to increase the size of the trains and haul them by a number of locomotives or motor coaches which are controlled, not separately, but in common from one machine or driving cab. To enable this system of control to be employed, not only the motor coaches but all the trailing coaches as well must be provided with the requisite control cables and coupling arrangements. All the apparatus and machines...
in the various motor vehicles are then either electrically or electro-pneumatically controlled from the two driver’s cabs at each end of the train, false operations being prevented by means of interlocks.

The socket couplings used almost universally up to the present time do not fulfil satisfactorily the service requirements mentioned, because the split contacts lose their spring after continued use and there is then insufficient contact pressure in the sockets. Another disadvantage of this coupling is the excessive wear which takes place. If the individual contacts in all the sockets and plugs do not fit together exactly, the parts have to be forced and bent to get them into position when coupling up. Moreover, if it is desired to fit one of the plugs into another socket it is quite impossible to do so without putting in a new terminal. It is therefore not certain that good contact is made in all the connections, and it is questionable whether the control equipments of the motor vehicles will work together perfectly. For the same reasons, too much effort is also required when coupling up the coaches, which greatly hinders the work of rapidly making up trains during rush periods and can also lead to damage being done.

All these disadvantages are overcome in the new control-circuit coupling developed by Brown, Boveri & Co., Mannheim. In this coupling, instead of socket contacts, pressure contacts whose faces are firmly pressed against each other by springs are employed. As will be seen from the accompanying illustrations simple hexagonal bolts are used for these pressure contacts both in the plug and socket. They are fitted directly in the insulating material with the difference, however, that the bolts are fixed rigidly in the plug whereas the pressure contacts in the socket are provided with springs which press them against the other contacts. The individual wires of the through control cable in each coach are fitted with cable shoes at their ends inside the plug and socket casings. These shoes are secured to the contact bolts by nuts, lock-nuts and spring washers. A wooden sleeve grips the cable fast in the neck of the socket and thus prevents tension being applied to the individual wires; it also effectively makes up the hole through which the cable passes. When coupling up, the flexible cables bend inside the plug as required by the movement of the contacts.

By means of a simple cranked locking lever the plug is pushed into the socket and the contacts firmly pressed together. It is possible to design the contact faces, for which the tops of the bolt heads are used, so that perfectly concentric agreement between the faces is not necessary for the purpose of securing good contact. This is an advantage of the utmost importance as far as service and rapid manipulation are concerned. The lever locking arrangement consists of the forked lever, two catches with springs, two guide pins, two compression springs, and the cover. The catches are pivoted on the pins carrying the lever, and when the lever is brought down they engage with the pins on the plug with a snap action and draw
the plug into the socket. When the plug has been pushed right home the lever moves still further, passes the dead centre, and remains with the curved bridge-piece resting on the plug. In the meantime the cover has slipped over the lip of the foremost edge of the plug and thus prevents any possibility of the plug falling out. When uncoupling, the plug is free to be removed only when the lever has been swung back to such an extent that it has caught against the projecting pins on the cover and lifted this out of engagement with the rim on the plug.

The coupling can be operated very easily, quickly, and securely since the leverage of the cranked lever for pressing the contacts together has been made large, and because the removal of the plug from the socket is not rendered difficult by friction, but is, if anything, made still easier by the springs with which the contacts are provided. Pressing the plug so firmly into the socket ensures that the coupling will be completely dust proof and water-tight. After the coupling has been disconnected, the cranked lever is brought down, pressing the cover over the front of the socket which it thus effectively closes. When not in use the plug is hung up in a blind socket.

The coupling shown in Fig. 2 certifies pressure contacts for 20 control wires. Each contact is dimensioned for a continuous rating of 25 A. It will be seen from the illustration, however, that a still larger number of contacts could be fitted in the present design if necessary, particularly as the power carried by the control circuits is usually small. The coupling is suitable for all vehicles independently of the nature of the multiple control.

A very high degree of reliability for the whole device has been obtained by careful design which has avoided loose split pins, screws, bolts, etc. The pivots used fit tightly in the cast iron body, with which they are thus quite rigid. The various parts of the lever locking mechanism lock one another. The arrangement of the whole device is made as simple as possible in order to reduce maintenance costs to a minimum. The very high degree of reliability and the convenient way in which it can be manipulated will ensure the new coupling device receiving due consideration for electric railways where multiple train control is employed.

For a considerable time now 130 couplings of this kind have been in use on the 15 multiple-unit trains run on the Bavarian section of the German State Railway. The pressure used in the control circuits is 200 V at 16 2/3 cycles. In consideration of the excellent results experienced, a further 130 control-circuit coupling devices have been ordered for 15 new multiple-unit trains, which will be put into service during the summer of this year. Couplings of this type have also been fitted to coaches on the Isartal Railway (Lokalbahn A. G., Munich), for a service pressure of 650-V direct current. This new design has proved extraordinarily satisfactory, and is particularly in favour with the staff on account of the simple and safe manner in which the coupling can be handled. (MS 489)

F. Eckinger. (E. J. B.)

The Trieste-Opcina mountain railway.

The village of Opcina, exceptionally well situated as regards climatic conditions, is connected with the town of
Trieste by an electric railway which was opened at the beginning of the present century. Opcina lies at an altitude 344 metres higher than Trieste; the distance between the two places is 3640 metres as the crow flies. Owing to the difficult nature of the country through which the railway passes, it was necessary to make the railway line 5188 metres long and to use a track of one metre gauge laid for combined rack and adhesion service.

The railway starts at the Piazza della Caserma near the chief traffic centre of the town, and, by following the roads, reaches the hill Scorcola, at a distance of 0-4 km, by the shortest route; at this point the adhesion service finishes and the rack is used. The maximum gradient occurring on this first section is 5-6°. At the commencement of the steep section, the motor coach is taken over by a rack locomotive which pushes it up. The rack railway is laid on its own groundwork; it has a length of 800 m and an almost constant gradient of 25%, which is, however, reduced to 10% at the stopping places. The rack itself is of the Strub flat-bottomed type. At an altitude of 177 m above sea level the rack section ends and the railway continues as an adhesion track, the maximum gradient encountered being 8%. In view of the weather generally prevailing in the region round Trieste, a rack rail was provided on gradients greater than 7% to ensure greater safety in braking; the original conical wheel tyres were also turned down flat to increase the degree of adhesion.

The contact line is supplied with direct current at 540 V from a converting plant owned by the railway company. It is situated at about 200 m below the station at the end of the rack section, the building in which it is housed being combined with the engine sheds for the rack locomotives. In this converting plant, the three-phase current at 2000 V, 42 cycles, obtained from the municipal mains, is supplied to a synchronous motor. A 200-kW direct-current dynamo is coupled direct to the motor, and, connected in parallel with a storage battery of 268 elements, supplies the current for the railway. The storage battery can also be used as a reserve, and is itself capable of maintaining to a large extent the light winter service. At such times the converter set is started up merely when a train is ascending the rack section, and is shut down when the full load demands are over.

The motor coaches in use have a service weight of 13-7 tons and can carry 50 passengers. The wheelbase is 3.3 metres and the axles are built as free leading axles. The electrical equipment comprises two motors each of 30 H.P. which are permanently connected in parallel; they are regulated by a controller. Rheostatic braking is used during the downward journey. A cog-wheel brake is provided on each locomotive and is used as an emergency brake on the steep section and also on the adhesion section with gradients exceeding 7%.

The rack locomotives weigh 11 tons, half of which weight is accounted for by the electrical equipment. This consists essentially of the two shunt-wound motors each of 100-H.P. continuous rating at 700 r.p.m., rigidly mounted in the locomotive frame. During the downward journey, the shunt regulation alone enables the speed to be retained at the maximum permissible value of 2 m/sec, with the battery fully charged and a contact-line pressure of 600 V.

Up to the present time, the continual increase in the traffic has been so great that the railway administration saw that they would be justified in taking steps to enlarge the capacity of the plant. It was proposed to acquire some new motor coaches with more powerful motors, which would be capable of drawing additional trailer coach having a carrying capacity of 50 passengers. It was immediately realized, however, that the rack section presented an obstacle to the projected development which would be very difficult to surmount. After careful consideration, the solution of buying new, more powerful rack locomotives had to be abandoned as this would have necessitated an unavoidable enlarging of the existing power station. The most economical solution appeared to lie in the conversion of the rack section into a funicular railway. To this purpose, Messrs. Th. Bell & Co., Kriens, near Lucerne, drew up a detailed scheme, which was characterized by much originality in completely overcoming the numerous difficulties encountered. The electrical equipment was developed for this special case by the Tecnomaario Italiano Brown Boveri, Milan. This project met with the complete approval of the railway administration, and work in connection with the scheme was commenced in April of this year.

A detailed description of the funicular railway will appear later in The Brown Boveri Review, dealing with the carrying capacity, the nature of the service and the auxiliary equipment. It has, however, been preliminarily announced that the funicular railway will be worked by a motor of 200 H.P., i.e., the same power as one of the existing rack locomotives requires. The brake wagons, which are connected by a steel rope 42 mm in diameter and are operated by this motor, are thus capable of hauling in each direction a fully loaded motor coach and trailer at a speed of 3 m/sec in the same manner as the earlier rack locomotives. The carrying capacity has thus been increased six-fold without increasing the mechanical output of the machinery. It is further mentioned that the total weight of a fully loaded train is about 35 tons, which corresponds to a static tensile load of 8.5 tons in the cable on the 25% gradient.

Two duplicated patent quick-acting emergency brakes with hydraulic re-setting are fitted to each brake wagon; two quick-acting hand-operated rail brakes with compensated action are also provided. For this reason, and also because the vehicles pushed are fitted with flanged wheels, the usual type of automatic points used on funicular railways could not be employed. An ingenious point-operating mechanism, which is worked automatically and provides an unbroken track, has therefore been adopted.

(MS 479)  
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LOCAL AND INTERURBAN RAILWAYS
TRAMWAYS - MOUNTAIN RAILWAYS
AERIAL ROPEWAYS AND FUNICULARS