Some of the nine airblast circuit-breakers type DMVF 245 nc 4, rated 245 kV, 2000 A, 16000 MVA symmetrical breaking capacity, in Gösgen substation of the Aare-Tessin Electricity Co., Switzerland
Outdoor switchgear cubicle of the 20-kV range, for a service voltage of 13.8 kV, 50 c/s, rated current 5000 A, equipped with airblast circuit-breaker, isolators and bushing-type current transformers.
INTRODUCTION

At the present time there is considerable activity in the development of high-voltage switchgear. Among the main reasons for this are

- the ever-increasing demand for electricity
- added demands of a technical and operational nature
- the call for smaller and more economical solutions requiring less and less maintenance.

As a result of this rather tense situation, which has existed for several years, new products to meet the current demands of the market appear at shorter and shorter intervals.

Brown Boveri spare no effort to keep right up at the front in this competitive race. Therefore we are once again able to publish a special issue of our Review, in which a number of new and interesting products can be introduced. In doing so we may distinguish between two distinct groups.

Firstly there are the new series of circuit-breakers which completely or partly supersede previous series. Among them are the airblast breakers type DLF for medium breaking capacities and type DMF for high capacities. Both can be supplied for rated voltages up to 765 kV. In the case of indoor airblast breakers a new, more economical conception is in the process of development, the first type of which
(DE)—for voltages up to 12 kV—is already in full production. The new low-oil-volume breakers type SB, which supersede the former types S and whose development is now completed, are already in great demand. Considerable interest, however, has been paid to the metalclad medium-voltage switchgear brought out a few years ago, for single or duplex operation.

The second group contains those products based on quite new principles, or intended for new applications, or both. Among these are the totally enclosed SF₆ switchgear units, which we are at present building for rated voltages of 245 and 123 kV. This compact design, requiring hardly any maintenance, is of fundamental importance for installations in large cities or industrial premises. A novelty of quite another kind is that the isolating chambers of our airblast breakers type DMF make excellent high-voltage load interrupting switches. This makes them an economic switching unit capable of performing all duties of the expensive circuit-breaker, except for the interruption of short circuits. This leads to some interesting applications. At present the latest novelty is 12-kV packaged switchgear with compact load switches. These units, the components of which are largely potted in synthetic resin, are ideal for distribution centres in towns and factories, on account of their compact design, their reliability and the small amount of attention they require.

(KME)  

P. Baltensperger
OUTDOOR AIRBLAST CIRCUIT-BREAKERS TYPE DMF
FOR EXTREMELY HIGH BREAKING CAPACITIES

The new DMF range of airblast breakers was introduced in an earlier article [1], in which reference was made to the design, principle, and the numerous tests to which the prototype was subjected. In the present article special stress is laid on the advantages of the building-block system, by means of which a breaker can be supplemented at some later date, its breaking capacity thereby being considerably increased, so that it will be able to cope with the short-circuit currents likely to be encountered in 15 to 20 years from now.

General

HIGH-VOLTAGE circuit-breakers with multiple interruption—having several arc extinction chambers in series—have asserted themselves in the last twenty years on account of the numerous technical and economic advantages of this system. It was in fact this principle which first permitted uniform series of breakers covering the entire range of high voltages to be developed, with the accompanying demand for large numbers of identical components which is so vital for rational production. The relatively small size of these components also allows them to be tested electrically by direct methods which are internationally accepted. For the manufacturer and user of switchgear, the building-block system greatly simplifies the problem of stocking parts and spares. But with the systems known hitherto there were only limited facilities for increasing the breaking capacity of a breaker once it had been installed. Furthermore this involved considerable expense, unless due allowance had been made at the time of delivery for subsequent extension, which of course involves additional investment.

In those areas where there is a heavily concentrated demand for power and the substations are correspondingly large, the short-circuit power grows rapidly and hitherto has meant that the switchgear has often had to be replaced by units of higher capacity after a relatively short period of service. On the other hand, it was often impossible to obtain breakers of sufficient capacity which would have satisfied all demands for a long time to come—apart from the economic drawback of having to make such investments so far ahead—because, although the industry could always satisfy momentary needs, it had not managed to gain sufficient headway.

The New Building-Block System

Exhaustive investigations into the expansion of various large power systems showed that in some 10 to 15 years short-circuit currents of the order of 60 to 70 kA may be expected. It is quite obvious that the undertakings concerned will wish to procure switchgear which even now is capable of handling such large loads, or which can subsequently be augmented without undue difficulty.

Thus the objective for development of the new high-voltage range of airblast breakers type DMF was clearly outlined. A breaker had to be developed for very high breaking capacities, the simplest version of the basic design of which should already be able to handle the largest short-circuit powers occurring in present-day networks and be suitable for augmentation to still higher capacities without unduly affecting the price of the present basic design. On the other hand it should be possible to allow for customer’s special wishes as regards increased insulation or greater creepage distances, in the cheapest possible manner.

Deliberately no attention was paid to the range of
Fig. 1. - Connection of the main contacts, resistors and resistance contacts

a. Airblast breakers type DCVF and DHVF
1 = Main contact for opening, closing and insulating
2 = Resistance contact for breaking the residual current and for insulating
r = Non-linear, high resistance

b. Airblast breakers type DMF and DMVF
3 = Impulse chamber for load interruption
4 = Isolating chamber for breaking the residual current, for closing and insulating
R = Medium or high resistance

low to medium breaking capacities, with breaking currents up to about 30 kA, because it was evident from the very start that an arc extinction system capable of interrupting currents up to about 72 kA would not be economical in the region of low breaking capacities. For this range, which is still very important and extensive, the type DLF breaker has been developed, capable of interrupting currents up to about 40 kA [3].

For a definite voltage and breaking capacity one can only manage with a minimum number of interrupting chambers when the voltage across the breaker is made to follow a uniform distribution, so that each chamber is subjected to the same stresses. This is done in practice by fitting resistors or capacitors. With the former it may be necessary, after interrupting the service current or short-circuit current, to slightly delay the interruption of the residual current by fitting simple resistance chambers. The principle employed by Brown Boveri hitherto in the breakers type DCVF and DHVF is illustrated in Fig. 1a. Parallel to each main arc extinction chamber 1 is a resistor, usually non-linear and of high
value, in series with which is the contact 2. In con-
trast, Fig. 1b shows the principle that we have used
for many years in heavy-current breakers for the
medium-voltage range. In this case the load is
actually interrupted in the impulse chamber 3, the
contacts of which are only briefly opened. They
permanently have medium or high resistances in
parallel, to ensure that the voltage distribution is
uniform across the breaker and also to damp the
transient recovery voltage. Immediately the arc is
quenched in the main chamber 3, the contacts in
the isolating chambers 4 separate, interrupting the
residual current through the resistors and creating
the necessary gap which establishes the electric
strength across the breaker. Since the impulse
chambers are always closed—except for the few
hundredths of a second during the load interrup-
tion—closure of the breaker is left entirely to the
isolating chambers. Fig. 2 shows one pole of a DMF
breaker in the open condition, the arc having been
quenched in accordance with the principle shown
in Fig. 1b.

Electrically, the two interruption systems are
equivalent. Which of these the designer is likely
to choose will depend entirely on the nature of the
duties for which the particular breaker is visualized.
If it not only has to handle very high short-circuit
currents but must also afford far-reaching, yet simple
facilities for expansion—which inevitably implies
that the residual current will vary between wide
limits—the more economical solution, as exhaustive
investigations have proved, is to divide the tasks in
the manner shown in Fig. 1b. Since the isolating
chamber is able to interrupt all residual currents
likely to be encountered and can also close on the
maximum visualized short-circuit current of 72 kA,
the isolator part of the breaker is determined solely
by the rated voltage and there is no need to change
the basic design when the breaking capacity has to
be increased. This increase can therefore be effected
in one of the following two ways.

1. On the basic model of the breaker the individual
isolating chambers are equipped with high, non-
linear resistors, which ensure that all impulse
chambers are equally stressed during interruption.
<table>
<thead>
<tr>
<th>Breaker design</th>
<th>Rated voltage [kV]</th>
<th>Surge impedance $Z_c$ [ohm]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>72.5</td>
<td>123</td>
</tr>
<tr>
<td></td>
<td>4.5–7.5</td>
<td>5.5–9.0</td>
</tr>
<tr>
<td></td>
<td>9.5–14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6.3–10.0</td>
<td>7.0–11.5</td>
</tr>
<tr>
<td></td>
<td>20–30</td>
<td>22–30</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>35</td>
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</tbody>
</table>
Now if these resistors are replaced by elements of medium resistance, this is a relatively cheap and simple method of increasing the capacity. Neither the dimensions of the breaker, nor its base, are in any way altered.

2. The alternative method of increasing the breaking capacity is based on the addition of further impulse chambers. Since these chambers can be mounted in pairs at a time on the insulator column, it is frequently possible to increase the capacity by adding another assembly, without having to change the air receiver, the controls or the ground space occupied by the breaker. In other cases it may be necessary to add a small auxiliary receiver, which is coupled to the main receiver and which carries one impulse chamber column. Whether it is more economical to increase the capacity by adding resistors or impulse chambers depends on the duties stipulated and will have to be decided from one case to the next.

The various methods of up-rating a 245-kV breaker will now be discussed with reference to Fig. 3. The basic model with four impulse chambers has a breaking capacity of 14 GVA (variant I). If the high parallel resistances are replaced by medium resistances, this simple means allows the capacity to be quickly and cheaply increased to 18 or 20 GVA (variants Ia and Ib). The capacity of the basic model, however, can also be increased to 20 GVA by adding two impulse chambers and, if this is accompanied by medium resistors, the capacity can be put up to 30 GVA (variants II and IIa). With eight impulse chambers (variant III) it is already possible to reach 30 GVA with high resistances. An overall picture of the various possible ways of expanding the DMF breakers can be gained from Table I. Fig. 4, 5 and 6 show DMF breakers for rated voltages of 245, 300 and 550 kV.

The chosen method of dividing the breaker into impulse chambers for interruption of the load, and isolating chambers to establish the electric strength, enables inexpensive variants to be made with increased insulation or greater creepage distance. The isolating chambers can be supplied with insulators of different length. The various possible arrangements for the 245 and 420-kV breakers can be seen in Table II.
Rated Current

Normally the DMF breakers are built for a rated current of 2000 A. They can, however, be augmented to carry 3000 A at some later date as it is only necessary to replace the normal copper contacts by silver-plated contacts. (According to British Standards the normal 2000-A design is acceptable for 3000 A.) The model for 4000 A merely has a somewhat reinforced current path and enlarged cooling surfaces on the ends of the impulse and isolating chambers. The contact geometry, the moving parts and thus the extinguishing properties are exactly the same for all three variants, though.

Switching Properties

Exhaustive reports have already been published regarding the numerous tests to prove the breaking capacity in the face of dead shorts across the terminals, phase opposition and short-line faults [1, 2]. As a result of our tests it proved possible to increase the breaking capacity still further. Apart from the development work carried out in the high-power testing station at Brown Boveri, Baden, extensive testing was undertaken under conditions of dead
TABLE II
Alternative designs of 245 and 420-kV breakers

<table>
<thead>
<tr>
<th>Rated voltage [kV]</th>
<th>Number and type of isolating chambers</th>
<th>Creepage distance [mm]</th>
<th>Withstand voltage [kV]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Impulse 1/2/50</td>
</tr>
<tr>
<td>245</td>
<td>2 Li</td>
<td>4 880</td>
<td>1050</td>
</tr>
<tr>
<td></td>
<td>2 Ls</td>
<td>6 800</td>
<td>1300</td>
</tr>
<tr>
<td></td>
<td>2 Lsv</td>
<td>8 540</td>
<td>1300</td>
</tr>
<tr>
<td>420</td>
<td>4 L</td>
<td>9 760</td>
<td>1550</td>
</tr>
<tr>
<td></td>
<td>4 L with reinforced control</td>
<td>9 760</td>
<td>1750</td>
</tr>
<tr>
<td></td>
<td>4 Ls</td>
<td>13 600</td>
<td>1800</td>
</tr>
<tr>
<td></td>
<td>4 Lsv</td>
<td>17 080</td>
<td>1800</td>
</tr>
</tbody>
</table>

1 L = Long isolating chamber  Ls = Extra-long isolating chamber  Lsv = Extra-long isolating chamber with enlarged creepage distance

short circuit and phase opposition at the KEMA Testing Station in Arnhem, where a single-phase capacity of about 3000 MVA can be made available for direct testing at present. The breaking capacity in the face of short-line faults was tested at the Fontenay testing establishment of Electricité de France (EdF) with the dummy line available for the purpose.

Furthermore, comprehensive tests were performed with low inductive and capacitive currents in the testing station of the Centro Elettrotecnico Sperimentale Italiano (CESI) in Milan. When disconnecting a 220-kV transformer with a no-load current of 5 A, no overvoltage whatsoever was produced. But since the phenomena during the interruption of low inductive currents depend not only on the properties of the breaker, but also on the data of the circuit, i.e. on the magnitude and distribution of existing capacitances and inductances, it was decided that additional tests should be performed with the transformer loaded by a reactor. Under these adverse conditions the overvoltage factor in most cases was between 1.2 and 1.7; even when the breaker opened at the most unfavourable instant with a current of about 20 A, the factor was 2.2 across the breaker and 2.0 to earth.

To prove the breaking capacity at low capacitive currents, lines up to 436 km long were switched at no-load with the simplest form of 220-kV breaker, i.e. having only four impulse chambers, the current being 180 A, without any restriking or reignition occurring. Thus the enormous reserves of this breaker as regards electric strength were conclusively demonstrated.

Concluding Remarks

The outstanding technical properties of the new DMF range of airblast breakers were proved under a wide range of conditions during tests and in practice. By being able to cope with breaking currents up to 72 kA symmetrical or 90 kA asymmetrical, in conjunction with the new building-block principle, they afford unprecedented scope for extension, allowing any breaker to have its breaking capacity doubled, or more, by quite simple means at some later date, although the capacity of the basic model is already in the region of the maximum figures required at present. The breakers of this type which have now been in service in the Canadian 735-kV network have proved their worth under extreme climatic conditions. Apart from the usual functional tests in the cold room and the temperature-controlled test chambers in our works, one pole of a breaker type DMF 245 nc 4 was exposed to the elements on the Jungfraujoch in Switzerland during the six winter months of 1966/67 (see colour plate inside rear cover), during which it experienced tempera-
tures down to $-30\,^\circ\mathrm{C}$ and wind velocities up to $160\,\text{km/h}$.

These tests conclusively proved that the sealing problems at very high service pressures can be satisfactorily solved over a wide temperature range. Just as important was the proof of the accuracy of mechanical operating times and the ease of movement of the moving parts at sustained low temperatures, which was undeniably established by the very positive results of all the tests performed.

(KME)  

A. Eidinger

Bibliography


TYPE DLF AIRBLAST CIRCUIT-BREAKERS, A NEW RANGE OF MEDIUM-CAPACITY OUTDOOR HIGH-VOLTAGE BREAKERS

The new DLF series for medium breaking capacities makes available a circuit-breaker capable of covering the main section of the wide range of breaking capacities stipulated in practice. New, interesting arrangements for the arc extinction chambers and air receiver allow savings to be made in floor space and also in the cost of the supporting frame that is normally employed. A simple functional principle and stringent mechanical testing ensure the robustness and reliability demanded in service. In electrical tests the requirements of the standards in relation to the natural frequency of the recovery voltage were more than satisfied, thus taking account of the latest knowledge in this field.

Apart from breakers for very high breaking capacities, Brown Boveri have also designed a special type for medium capacities (breaking currents up to $42\,\text{kA}$ at voltages between $70$ and $765\,\text{kV}$) which, occupying much less floor space and having new receiver arrangements and excellent facilities for extension, satisfy customers' desires regarding economy, reliability and flexibility.

General

The heavy concentrations of energy at various key-points in power supply and transmission systems continue to grow and with them the demand for more efficient circuit-breakers. On the other hand, there are numerous points in systems where the short-circuit power is growing only slightly, if at all. This is the case at all generating stations that have reached the limit of their capacity and are connected to the rest of the system by relatively long lines. The short-circuit currents can also be limited by introducing higher distribution voltages and by largely unmeshing the subordinate network. For distribution of the energy on the one hand, not only must switchgear be developed which takes into account the growing short-circuit capacities at key-points, but also breakers which satisfy the requirements of the many stations of medium and low output at the lowest possible cost. It is quite impossible to cover this wide range economically nowadays with a single type of breaker. Though we have indeed succeeded in designing high-capacity breakers which, by virtue of the building-block principle, can be made to suit the most varied capacity requirements [1, 2] and thus exhibit maximum economy in a very wide range, it is natural that an arc extinction system designed for fault currents up to $70\,\text{kA}$ cannot be economical in installations where the fault current is not more than $20–40\,\text{kA}$. In many respects it is vastly overrated, for example in respect of dynamic short-circuit forces, and is therefore bound to be uneconomical.
Improvement of methods of arc extinction, as well as new technological and constructional knowledge—together with modern methods of production—make it necessary to examine critically the existing, well-established breakers with low and medium capacities and to search for new, still more economical solutions. Of course the manufacturer is certain to endeavour to utilize as many components as possible that have proved their worth for many years and which cannot, even today, be replaced by cheaper and simpler versions. Only by doing this can he build up on available experience and create a fully matured design.

These requirements are fulfilled by the new DLF series of breakers which, for the medium range of breaking capacities, provide new and interesting solutions combined with well-tried design principles.

Design and Principle

Fig. 1 depicts one pole of a 245-kV breaker, while Fig. 2 gives some idea of the construction and dimensions.
sions of some of the main types of DLF breakers. On first sight two main features strike the eye:

- The shed-like arrangement of the extinction chambers on the pressurized porcelain insulators serving as insulation to earth
- The vertical air receiver.

The chosen arrangement of the arc extinction chambers enables the electrical components to be accommodated in a very limited space, without adversely affecting the overall appearance and aesthetics of the breaker. In Fig. 3 the space occupied by a DLF 245 breaker is compared with former Brown Boveri types of breakers for similar capacities. The advantages of this design are obvious. A further economic and constructional advantage of this design is the small number of pressurized insulator columns providing the insulation to earth and housing part of the control device, as a result of which excellent simultaneity of contact movement can be attained.

So that staff can walk through a switchgear installation without personal risk, the present practice is to mount all components (except the power transformers) on steelwork frames. The vertical arrangement of the receiver of the DLF breaker now allows the installation planner to dispense with the framework formerly needed for the breaker. With this design the bottom of the insulator is located at a height of 2-3 m above ground, so that the safety regulations laid down for switchgear installations are thereby fulfilled. The resultant economic advantages are quite obvious. Of course, if so desired, the DLF breakers can also be supplied with the receiver horizontal.

The switching element proper, the arc extinction chamber, is actuated pneumatically. The nominal pressure in the receiver is 26 atm. The breaker can, however, fulfil its guaranteed performance at a pressure as low as 22 atm—corresponding to auto-reclosing operations. When the contacts are open, the compressed air serves as insulation, though the
chamber is also under pressure when the contacts are closed. Hence, on interruption, the available pressure causes an intense blast immediately the contacts part and ensures that the arc is extinguished. Both contacts are in the form of nozzles.

The distances between the nozzles and the exhausts have been kept as short as possible, allowing full advantage to be taken of the properties of the chambers. The moving contact performs a two-stage motion (Fig. 4). The ideal conditions for arc extinction are created during the first part of the travel; subsequently the insulation between the open contacts is positively established in the second, insulating, part of the travel. The first part is performed in the remarkably short time of 8 ms, with the result that capacitive currents and especially long, lightly loaded lines can be interrupted without restriking. The moving contact is also equipped with a follow-up system, which allows the contacts to part at an initial speed of 1·5 m/s and on closing reduces the mechanical stresses. The contacts are also blown during closure, thereby forcing an arc caused by pre-ignition into the interior of the nozzle and blowing any metallic vapour out of the chamber.

The rated current of the normal design of chamber is 2000 A, at which the temperature does not rise by more than the permitted value of 35 °C.

The small number of contact points carrying current and the clear constructional segregation of heating and sealing points allows the same chamber to be used for a current rating of 4000 A, simply by adding a silver insert to the contacts, at which the temperature rise does not exceed 65 °C.

The control system of the DLF breaker consists of pneumatic and mechanical elements. The transmission of the commands from the lower section of the breaker to the middle part containing the extinction chambers is performed as on the DMF breakers with the aid of a moving, insulated rod (Fig. 5). In this way very short switching times are achieved, with optimum simultaneity between the individual chambers. Thus the difference in time between the first and last contacts of a pole to open on a breaker with ten chambers is less than 2 ms. The same applies to the difference between contacts touching on making. With a mechanical break time of 25 ms (i.e. the time that elapses between the command pulse being given and the contacts separating) the DLF breaker is a “two-cycle” breaker (at 50 c/s). The make time of 55 ms is also remarkably short.

When the DLF breaker was being developed, scrupulous attention was paid to the reliability of the moving mechanical parts. Endurance tests were performed at elevated pressure, in order to create more strenuous conditions in the test laboratory than would ever be likely to occur in future operation. Maintenance and lubrication of this breaker had to be reduced to a minimum, so that when designing all bearing and guide parts, every effort was made to ensure that the breaker was capable of running dry for a large number of operations.

The temperature range in which the breaker is capable of functioning correctly extends between — 55 and +70 °C. In our laboratory for extreme climatic conditions the DLF breaker was subjected to numerous tests under severe temperature stresses.

For many installations, such as underground power stations or substations in densely populated areas, it is stipulated that breakers should make as little noise as possible. This requirement was taken into account when the DLF breakers were being designed, in that the mufflers provided as accessories reduce the noise of operation effectively, without reducing the breaking capacity, and fit harmoniously into the breaker as a whole.
For the distribution of the voltage across the pole, both when opening the breaker and when the contacts are open, only capacitors are used. Here too, by redesigning the capacitors, it was possible to economize considerably and, at the same time, to attain capacitance values which guarantee an evenly balanced voltage distribution, so that resistors can be dispensed with.

The principal features of the new airblast breakers for rated voltages between 72 and 765 kV, with current ratings up to 42 kA, may be summarized as follows:

- Economy, resulting from very rational construction and arranging the air receiver vertically
- Saving on space, so that for example a 245-kV pole can be accommodated in a length of 380 cm
- Extreme mechanical robustness with minimum maintenance
- Full advantage is taken of the arc extinction principle by having the chamber continuously pressurized and by providing double nozzles.

Scope of the Range

The Table lists the various models of DLF breakers which make up the standard range, together with their main technical data. These breakers comply with such standards as SEV, VDE, ASA and IEC Recommendations.

Exhaustive investigations into the shape of the transient recovery voltage carried out in a number
of European and American networks in recent years [3-7], yielded much new knowledge and proved that the natural frequencies and rates of rise of recovery voltage that may occur in practice can quite possibly exceed the values laid down in the regulations. When determining the breaking capacity of the DLF breaker due allowance was already made for the new knowledge and trends. Generally speaking, the full breaking capacity is guaranteed for an r.r.r.v. of 2000 V/μs.

Fig. 6 shows the range of application of the DLF and DMF breakers at the most important rated voltages. Between 30 and 40 kA either type of breaker may be used. The decision as to which shall be used will mainly be governed by the question of whether the breaker is going to be required for a much higher breaking capacity at some time in the future (type DMF) or whether the breaking current is not going to rise much above 40 kA (in which case the DLF breaker is preferable).

Electrical Properties and Proof of Capacity

Insulation of the gap between the open contacts of the breaker and to earth conforms to the regulations currently in force in various countries. Since an arc extinction chamber with a considerably higher dielectric strength can be supplied as a variant of the standard model, there is no great difficulty in satisfying much stricter insulation requirements, without having to increase the number of chambers. These "long" chambers possess the same mechanical parts and the same contact zone as the normal chambers, so that they also have the same extinction properties. By employing suitably extended insulator sheds, the

<table>
<thead>
<tr>
<th>Rated voltage</th>
<th>123 kV</th>
<th>170 kV</th>
<th>245 kV</th>
<th>300 kV</th>
<th>420 kV</th>
<th>550 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schematic diagram</td>
<td><img src="image" alt="Diagram" /></td>
<td><img src="image" alt="Diagram" /></td>
<td><img src="image" alt="Diagram" /></td>
<td><img src="image" alt="Diagram" /></td>
<td><img src="image" alt="Diagram" /></td>
<td><img src="image" alt="Diagram" /></td>
</tr>
<tr>
<td>Breaking capacity</td>
<td>5 GVA</td>
<td>6 GVA</td>
<td>10 GVA</td>
<td>10–13 GVA</td>
<td>17 GVA</td>
<td>10–15 GVA</td>
</tr>
<tr>
<td>Remarks</td>
<td>with long chambers</td>
<td>13 GVA with 4 distribution capacitors per pole</td>
<td>15 GVA with 4 distribution capacitors per pole</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In all cases r.r.r.v. = 2000 V/μs at 100% breaking capacity
Rated current for all types 2000 or 4000 A
Amplitude factor 1-5

Fig. 6. - Range of application of breakers types DLF and DMF
Breaking capacity $P_a$ plotted against rated voltage $U_a$
creepage distance can also be increased, as is often required for areas with polluted atmosphere, or for installation in coastal areas.

Thus, on the 245-kV breaker for instance, the specific creepage distance over the arc extinction chambers can be extended from 2·14 to 3·00 cm/kV, or over the "long" chambers from 2·91 to 4·13 cm/kV, without having to change the overall dimensions. Corresponding facilities exist for the insulation to earth.

Although the extreme stresses to which the breakers are subjected, as caused by a short circuit in the network, occur relatively seldom in normal service, it is just these faults which require most attention when developing a new type of circuit-breaker. Therefore the DLF breakers were made to perform several thousand electrical operations in our own testing station, as well as in those of KEMA (Netherlands), Electricité de France and CESI (Italy). Although the whole range of breakers consists of the same type of chambers, so that type testing can be greatly simplified, the breaking capacity of the unit had to be established over a wide range of voltages and at different natural frequencies of the recovery voltage. From this large number of tests, Fig. 7 may serve as a representative example of an interruption at full...
power and maximum short-circuit current. Fig. 8 illustrates an interruption of a short circuit at very high voltage, such as may occur under conditions of phase opposition. Exhaustive tests were also performed to determine the behaviour of the DLF extinction chambers when faced with short-line faults. A typical oscillogram of such tests can be seen in Fig. 9. The interruption of long lines at no-load, as well as the problem of overvoltages when disconnecting transformers at no-load, also received very close attention.

A. EIDINGER
G. KÖPPL

Bibliography


THE NEW RANGE OF INDOOR AIRBLAST BREAKERS
TYPE DE FOR VOLTAGES FROM 3 TO 12 KV

The airblast breakers type DE for 3–12 kV have been developed from the established DB range. They are notable for their small size, robustness, ease of maintenance and high resistance to sustained switching stresses. Proof has been obtained of their breaking capacity under all kinds of conditions likely to be experienced in service. These breakers interrupt in two cycles and can be supplied for sustained currents up to 1600 A or 2500 A, without any change of dimensions. They can also be delivered as drawout breakers in metalclad units or for installation in conventional open cells. The consistent use of the building-block principle ensures rational manufacture and restricts the number of spare parts that users need to stock.

General Description

The airblast circuit-breakers of the DE range are the outcome of the progressive development of the type DB indoor breakers that have been made for 25 years by Brown Boveri, and have become well known for their reliability and long life.

The remarkable advances made in the application of cast resin made possible a very robust and compact design (Fig. 1a–1c). Thus the DE breakers are not only suitable for the conventional type of installation in open cells, but can also be enclosed in metalclad cubicles. Efficient silencers enable them to be used when strict conditions are stipulated regarding the permissible noise level. The capacity has been proved under a wide variety of conditions by tests carried out at KEMA, Arnhem, as well as in our own High-Power Testing Station in Baden. The voltages most frequently employed for distribution in networks with short distances are between 3 and 12 kV. The steady increase in the power consumed by users results in higher inputs and therefore leads to greater short-circuit powers.

The difficulty in finding space to accommodate new installations or for the extension of existing distribution stations means that the most has to be made of the available space. This requirement is satisfied by breakers of the DE range.

These breakers require very little attention, they are easy to operate and maintain, and so they help to lower the running costs of the electricity undertakings. By virtue of their simple construction, overhauls can be carried out with ease and speed. Their robustness guarantees long life. As they can be equipped with graded damping resistors, they can cope with all kinds of switching operations with certainty. The DE breakers are equally suitable for use as feeder breakers, or for switching large machines, furnaces and capacitor banks.

Principle of the Breakers

The DE breakers (Fig. 2) can be operated at a service pressure of 26 or 16 kg/cm² g. The current is interrupted in the extinction chamber within 40 ms, the arc being quenched by a powerful blast of air.

The recovery voltage causes the auxiliary spark-gap to strike, thereby connecting a low damping resistance in parallel with the extinction chamber. Consequently the transient produced by the natural frequency of the network is aperiodically damped.

The low resistances make the breaking capacity almost independent of the natural frequency of the network. The current through the resistor ceases at the first zero. Thereupon the high, non-linear resistors in parallel with the main current path come into action. They prevent inadmissible switching surges from being produced when handling low
Fig. 1 - Views of the indoor airblast circuit-breaker type DE 12 n 1000, breaking capacity 1000 MVA
a. Side view with silencers  b. Drawout, plug-in breaker for use in metalclad cubicles  c. Side view in the open position without silencers
The state of the breaker is immediately apparent from the position of the isolator blades (arrowed).

Fig. 2 - Diagrams showing various stages in the breaking operation of an airblast breaker type DE 12 n 1000

a = Isolator blades  d = Low resistance  c = Auxiliary spark-gap cuts in a low damping resistor when the main current has been interrupted.
b = Extinction chamber  e = High resistance  d: Auxiliary spark quenched, high resistance cut in to limit overvoltages.
 c: Breaker closed. Tripping command given at $t = 0$.
g = Arc  e: Breaker open, the isolator has switched off the high resistance.

b: Main current interrupted in the extinction chamber. Time 20–40 ms after tripping command given.
inductive currents (e.g. transformers at no-load). The small residual current that flows through the high resistance is interrupted by the isolator blades in air. Since the position of these blades is clearly visible, the state of the breaker can be seen at a glance. The stages of a breaking operation are illustrated schematically in Fig. 2.

The breaker is closed by means of the isolator blades. The making contacts are well-tried elements of the type DB breakers.

Construction of the Breaker

Fig. 3 illustrates the design of the breaker. The lower part of the unit is composed of the air receiver mounted on rollers, on one end of which is the plate carrying the control unit and auxiliary switch. Above the main valve, located in the plane of symmetry and common to all three phases, is the distributor from which the compressed air flows into the extinction chambers of the respective poles. The chambers are of robust and simple construction, ensuring certain interruption of the arc in one quarter of a cycle throughout the entire current range.

Pneumatic damping members of ample capacity restrict the movement and prevent unduly high peak forces. The extinction chambers are incorporated without prestressing in the moulded resin lower part of the pole. The fixture between the lower part and the distributor also avoids pre-stresses. This method of construction prevents fatigue fracture at the points of connection between resin and metal.

The current-carrying parts cast in resin were designed in close collaboration with the laboratories, so as to ensure that the resin completely surrounds the metal parts, without any gaps. The shape of the inserts of the lower part of the DE breaker enables full advantage to be taken of the strength of the resin.

The auxiliary spark-gap and cooling vanes are of the classical design employed in the DB breakers. The cooling plates reduce the temperature of the ionized hot gases produced by the extinction of the arc and allow small clearances to be provided between the exhaust and the ceiling of components of the installation.

The silencers which can be attached to the exhaust pipes effectively reduce the noise, without reducing the breaking capacity. They are optional items, supplied only to order.

The low, wire-wound resistors and the high, non-linear resistors are elements which have been used for over 20 years by Brown Boveri with undiminished success. The isolator operating mechanism moves the blades in and out, the exactly adjusted damping system braking the motion in both cases. The control unit and auxiliary switch have been taken over unchanged from the DB breakers.
TABLE I

Building-block system of the DE range of airblast breakers showing the ratings of the various sizes and the recommended fields of application

<table>
<thead>
<tr>
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<th>Recommended for</th>
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<td>breakers in</td>
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<td>cable networks</td>
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<td>capacitor banks</td>
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<td>cable networks</td>
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<td>capacitive</td>
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<td></td>
<td>currents</td>
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<td>transformers</td>
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<td>at pole-boat</td>
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<td>breaker for all</td>
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<td>capacitive</td>
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<td>currents</td>
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<tr>
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<th>SVA</th>
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<tr>
<td>Rated breaking</td>
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<td></td>
<td>200</td>
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<td>Rated voltage</td>
<td>12</td>
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<td>7.2</td>
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<td>3.6</td>
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<tr>
<td>Equipped</td>
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<td>resistors</td>
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<td>spark-gap</td>
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<td>with high</td>
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<td>7.2</td>
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<td>with auxiliary spark-gap and low damping resistor</td>
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<td></td>
<td>with high resistance to limit overvoltages</td>
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<td></td>
<td>without</td>
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<td>silverclad contacts</td>
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<tr>
<td>Rated 1000 A</td>
<td>12</td>
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<td></td>
<td>7.2</td>
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<td>3.6</td>
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<td>copper</td>
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<td>contacts</td>
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</table>
The DE Range for 3–12 kV

This range is built on the unit construction principle from building blocks. The result of the consistent application of this principle is that breakers for continuous rated currents of 1600 and 2500 A have exactly the same dimensions. This greatly simplifies the planning of new installations and reduces the number of different spare parts that have to be stocked by users. Both the 1600-A and the 2500-A breakers can be supplied for two breaking capacities. The low-capacity breakers have no low resistances while those for higher capacity do have these resistors. Table I illustrates the building-block system, the facilities for extension and the special features of the individual breakers of the DE range.

The breakers can be supplied:
- As drawout units in metalclad cubicles with drawout mechanism and automatic compressed-air coupling (Fig. 4a)
- As drawout breakers for open-type cells with or without automatic compressed-air coupling (Fig. 4b)
- With screw attachments to busbars on one side only (Fig. 4c)
- With screw attachments to busbars on both sides (Fig. 4d).

Breakers delivered for 1600 A can be extended at any time so that they can handle 2500 A.

In conformity with modern knowledge of the quenching and insulating properties of compressed air, the breakers are designed to operate at an air pressure of 26 kg/cm². By slightly reducing the breaking capacity they can also be operated at 16 kg/cm², like the DB breakers, thus allowing them to be used in an existing installation, without having to replace the compressing plant and distribution system.

Rated Data

The list of rated data in Table II shows that the breakers are suitable for a wide voltage range. The tabulated values were determined at KEMA or in our own High-Power Testing Station in Baden. A notable feature of the breaking capacity is that it is not dependent on the natural frequency of the recovery voltage (Fig. 5). The full breaking capacity was still proved at a natural frequency well above the value stipulated by IEC.

<table>
<thead>
<tr>
<th>Design</th>
<th>Rated current</th>
<th>Service voltage</th>
<th>Breaking capacity</th>
<th>Symmetrical breaking current</th>
<th>Natural frequency</th>
<th>Thermal 3-sec current</th>
<th>Peak making current</th>
</tr>
</thead>
<tbody>
<tr>
<td>With low resistors</td>
<td>12¹</td>
<td>1000</td>
<td>48</td>
<td>17</td>
<td>58</td>
<td>122</td>
<td>148</td>
</tr>
<tr>
<td>n:1600</td>
<td>6</td>
<td>600</td>
<td>58</td>
<td>20</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>p:2500</td>
<td>3</td>
<td>300</td>
<td>58</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without low resistors</td>
<td>12¹</td>
<td>500</td>
<td>24</td>
<td>6-7</td>
<td>38</td>
<td>61</td>
<td>74</td>
</tr>
<tr>
<td>n:1600</td>
<td>6</td>
<td>500</td>
<td>29</td>
<td>6-7</td>
<td></td>
<td>84</td>
<td></td>
</tr>
<tr>
<td>p:2500</td>
<td>6</td>
<td>350</td>
<td>33</td>
<td>7-7</td>
<td></td>
<td>97</td>
<td></td>
</tr>
</tbody>
</table>

¹ Maximum service voltage = rated voltage
Fig. 4. – Facilities for installing type DE breakers

a: Drawout breaker in metalclad cubicle with drawout mechanism and automatic compressed-air coupling
b: Drawout, plug-in breaker in open-type cell
c: Conventional cell mounting with screwed fixing to busbars on one side
d: Breaker screwed to busbars on both sides

All the breakers in this range are able to interrupt capacitive currents up to the rated current of the breaker at the maximum service voltage, without restriking. Even in the case of phase opposition the breakers function without the least trouble.

(J. MOSELE
J. VADASZI

(KME)

Fig. 5. – Breaking current in terms of the natural frequency of the transient recovery voltage

A = Characteristic with low resistance in parallel and auxiliary spark-gap
B = Characteristic without low resistance in parallel

- = Symmetrical current
\n = 50\% asymmetry
INDOOR AIRBLAST CIRCUIT-BREAKERS TYPE DB AND SWITCHGEAR CUBICLES FOR VERY HIGH CAPACITIES

The development of the indoor airblast circuit-breaker type DB for very high capacities and currents is outlined. Metal-enclosed heavy-current cubicles for these breakers are described, together with some types of cubicle supplied to large power stations for rated currents up to 12000 A.

Development of the DB Indoor Circuit Breaker

The first examples of the DB range of indoor airblast circuit-breakers were manufactured and sold in 1944. These were high-capacity breakers for normal substations. Types for service voltages in the range 3–70 kV and current ratings between 600 and 2500 A were developed in 1950.

The DB series has since been extended step by step to meet the increasing concentration of power in substations and the production of ever larger generators. The Table summarizes the stages in the continued development of DB indoor breakers up to the highest breaking currents and capacities.

The first special-purpose types of heavy-current, high-capacity breakers were designed in the early 1950s. As a result of uninterrupted development in this field Brown Boveri lead the world in the construction of circuit-breakers for extremely high capacities and currents. Fig. 2 and 3 show two typical heavy-current breakers which were introduced very successfully by us in the early days. Their particular significance lies in their use as generator breakers in power stations.

Today, generators with outputs of more than 1000 MW are being built. These units produce rated currents of up to 24 kA, and the three-phase short-circuit capacity reaches 5000 MVA. Circuit-breaker development at Brown Boveri is keeping pace.

The Metal-Enclosed Heavy-Current Switchgear Cubicles for Anglesea Power Plant in Australia and the Peace River Project in Canada, delivered 1967

The Anglesea Power Plant has heavy-current switchgear cubicles for outdoor installation on the generator side. The insulation level for the plant and equipment has been taken as 20 kV for a service voltage of 13-8 kV. The service current is 5000 A,
Development of the Brown Boveri airblast circuit breaker type DB in the years 1944–1967

(rated currents \( I_n \) and three-phase breaking capacity \( P_n \))

<table>
<thead>
<tr>
<th>Basic form and breaker type in Fig. 1</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated current ( I_n ) [A]</td>
<td>1000</td>
<td>2500</td>
<td>5000</td>
<td>7500</td>
<td>12000</td>
</tr>
<tr>
<td>Three-phase breaking capacity ( P_n ) [MVA]</td>
<td>1000</td>
<td>2000</td>
<td>2000</td>
<td>3000</td>
<td>3000</td>
</tr>
</tbody>
</table>

Reference p. 768 [1] [2, 3] [3, 4, 5, 6] [7] [8]

while the current paths for the switchgear and main busbars are designed for 6000 A. The system frequency is 50 c/s. The current path within the cubicle is shown diagrammatically in Fig. 4, while in Fig. 5 some of the outer panels have been removed to show the general arrangement. The bottom compartment contains a triple-pole airblast circuit-breaker \( a \) type DBG for 6000 A, 2000 MVA. The partition \( d \)
between the breaker and isolator compartments is penetrated by the bushing-type current transformers $b_1$ and $b_2$, which are synthetic resin mouldings. Directly above can be seen the 4000 A heavy-current isolators $c$, two in parallel for each phase [2]. The windows allow the isolator positions to be checked from outside.

Heavy-gauge indoor cubicles for heavy-current duties at a service voltage of 13.8 kV, and fitted with switchgear of series 20, have been supplied for a plant of the Peace River Project in Canada. The service current of the installation is 10000 A at a system frequency of 60 c/s. With a view to a possible 15% overload, however, the equipment is designed for 11500 A and a somewhat higher maximum permissible temperature rise.

Fig. 6 shows the current path in the cubicle, and Fig. 7 the external appearance of the cubicle, together with the main busbar connections for the ducted supply bars. An inside view of the cubicle can be seen in Fig. 8. The main compartment $a$ contains a single-pole high-capacity airblast circuit-breaker of type DB, and a bushing-type cast-resin current transformer $b_1$ is mounted in the partition wall between the breaker and isolator compartments. The latter contains two parallel heavy-current isolators $c$. Again, the isolator positions can be checked from outside through windows. Above the outer isolator is a cast-resin single-phase voltage transformer $f$ connected through a withdrawable high-
Fig. 4. - Current path in switchgear cubicle at Anglesea Power Plant, Australia

- $a$ = Airblast circuit-breaker
- $b_1, b_2$ = Bushing-type current transformers with primary connections $K, L$ and secondary connections $k, l$
- $c$ = Isolator
- $d_1, d_2$ = Bushings in top

Fig. 5. - Outdoor switchgear cubicles, service voltage 13.8 kV, 50 Hz, rated current 5000 A

- $a$ = Airblast circuit-breaker type DGB 20 r 2000
- $b_1, b_2$ = Bushing-type current transformers
- $c$ = Isolator type ADG 20q
- $d$ = Partition

Voltage fuse $e$. A heavy-current cast-resin bushing $d$ passes through the top panel and provides the connection on the outgoing side.

Cubicle Design Details

The high magnetic field intensities of current paths carrying 12000 A a.c. make antimagnetic materials essential for the cubicle structure. The choice of materials is carefully matched to the anticipated stresses. Outdoor cubicles for 6000 A are of welded construction, all the frame components being of angled and welded sheet. Vertically, the cubicles comprise three separate sections. The roof section can also be removed for transport purposes.

The indoor cubicles for 12000 A are of welded frame construction and can be completely dismantled. The welded frames are of very strong, extruded hollow section, while the cladding is of pure aluminium. The prefabricated components make transport and erection easy, as they only have to be bolted together.

The type of heavy-current connection depends on the design features of the cubicle. With the 6000 A cubicles they are of the well-known rigid kind, whereas in cubicles for 12000 A the circuit-breakers have flexible connections to allow for the effects of
heating and constructional tolerances (Fig. 9). The isolators and bushings, on the other hand, are rigidly connected to the busbars. The heavy-current busses consist of two U-sections of pure aluminium forming a broken square. The 6000 A busses are standard extrusions, but special sections have to be made for 12000 A. Earthed metal partition walls between phases prevent inter-phase short circuits and contribute to reliability.

Fig. 7. – Indoor switchgear cubicle, service voltage 13.8 kV, 60 c/s, rated current 12000 A, seen from the back
The cubicles are equipped for remote control and remote position indication. Our well proved airblast circuit-breakers [10] and isolators [11] are protected electrically and pneumatically against faulty operation. The three single-pole breakers in each cubicle are controlled and monitored from a control cabinet.

Technical Features

**Insulation.** The insulation level of the cubicles for 6000 and 12000 A corresponds to series 20. The 1-minute withstand voltage is 55 kV and the impulse withstand voltage (1-2/50 μs) is 125 kV.

**Heating.** The high continuous currents give rise to appreciable inductive and ohmic losses in the conductors, the equipment and the cubicle structure. Through careful selection of the conductor shape, cross-section and material it has been possible to keep these losses within economically acceptable limits. The magnetic fields surrounding the current paths induce eddy currents in the flat components of the cladding, but these are restricted through suitable design such that heating of the cladding presents no problem and enables the equipment to comply with the various national specifications.

**Ventilation.** The cubicles are naturally ventilated through balanced grilles in the cladding, and the system is effective under all specified conditions. Air passing through cools the current paths, the switchgear and the enclosure, and reduces the temperature rise. Small amounts of heat are also removed by the outer surfaces of the cubicle through convection and radiation. The ventilation system is adapted in accordance with the agreed maximum permissible temperature rise under rated current conditions.

**Electrical equipment.** The electrical equipment in the cubicles is matched to the rated data of the circuit breaker in question. The busbars and ancillaries can withstand the high dynamic loading caused by the maximum peak value of the short-circuit current of 250 kA, and also the thermal load resulting from a three-second short-time current (r.m.s.) of 100 kA.

The gas outlet has been so developed, with the aid of power tests, that the full breaking capacity, as for a breaker erected outdoors, can be guaranteed and proved [9].

**Fig. 9.** - Flexible connection for 12000 A, 60 c/s

Same installation as in Fig. 6

**Stresses due to exhaust gas pressure.** To avoid harmful pressure shocks the gases are taken by ducts to a pressure-resistant dome from where they pass through broad louvres to atmosphere. This arrangement also has the advantage of avoiding dirt on the breakers and in the breaker compartment.

The Future

The unit ratings of generators continue to rise, and breaker design will have to keep pace with the more stringent requirements. Heavy-current switchgear for 12000 A, 60 c/s and service voltages of 20 kV is adequate for unit ratings of 300–350 MVA. Brown Boveri are now building machines for 700 MVA, and units of 1300 MVA have been ordered. The circuit-breakers and enclosures for these are being developed, and in the near future we shall be in a position to manufacture and offer complete switchgear installations for rated currents of up to 30 kA.

(DJS)

J. Mosele
R. Rohr
Bibliography


METALCLAD HIGH-VOLTAGE SWITCHGEAR
WITH SF₆ INSULATION

Metalclad high-voltage switchgear with SF₆ insulation has presented new possibilities in the design of installations. The enclosure prevents any contact with live parts while the use of SF₆ gas for insulation and arc quenching results in compact design and virtually maintenance-free operation. A description of the design concept follows a short discourse on the reasons leading up to this development. Various new designs are described with the aid of examples. Intrinsic advantages of this new system are indicated in a comparison of the economics.

THE large dimensions of conventional switchgear are determined by the insulating distances under normal atmospheric conditions. For a long time the development of switchgear installations was limited to combinations of existing equipment in order to arrive at optimum arrangements for operational reliability. Various designs were developed to suit available site conditions [1, 2].

The increasing demand for transmitting electrical energy of ever higher voltages into densely populated areas and industrial centres has presented considerable problems with regard to the size of the requisite installations. Even if it is possible to find a suitable location with sufficient space for a switchyard, considerable difficulty is usually encountered in complying with legal demands and requirements for the architectural layout of the installation [3]. These stipulations and the problem of pollution of the insulators are leading to the increased use of indoor high-voltage switchgear installations [4, 5]. The additional cost of the building is an incentive to keep the installation as small as possible. The reduced levels of insulation, compared to outdoor switchyards, simplified installation schemes and dispensing with individual items of equipment, are all part of the attempt to keep the overall cost of installations within reasonable limits [6, 7]. As long as the surrounding atmosphere is used for insulating purposes, there are limits to the success of such endeavours. Further development demands a change to a much better insulating medium.

Only quite recent technological developments have enabled this step to be taken. The introduction of sulphur hexafluoride gas and further improvements in synthetic resins have led to a completely new design: metalclad switchgear with SF₆ insulation [8]. Its compactness, together with sophisticated cable techniques, permits free selection of the place of erection without having to pay attention to ambient conditions.

Brown Boveri have developed this type of installation for the following ratings:

- Rated voltage up to 245 kV
- Rated current up to 2500 A
- Short-circuit currents up to 53 kA (r.m.s.)

For economic reasons the usual graduations for standard voltage ratings, as in conventional equipment, do not appear to be advisable and for technical reasons they are not necessary. Therefore two models have been developed for the range 100 to 245 kV; one for $U_N \leq 150$ kV with a short-circuit power corresponding to 26 kA, and the other for $U_N = 150$ to 245 kV and short-circuit currents up to 53 kA. Both these models are shown in Fig. 1. In this article 245-kV installations are discussed.

Main Components

All items of equipment, including busbars, isolators, breakers, etc., of the SF₆ switchgear are
assembled in a self-contained unit. The individual elements are arranged as standardized building blocks which permit the most diverse combinations to be made to suit the requirements of a given installation.

The complete metal enclosure is earthed, providing a perfectly safe and gas-tight encasement for all live parts. This metal enclosure is the common basic element for all units and carries all components contained in it. The complete installation comprises several gas-tight compartments. The gas-tight carrier is formed by uncontrolled synthetic resin bushings, which at the same time form concentric supports for the tubular conductors.

In order to maintain the electrical insulation strength, the SF₆ gas is kept at average pressure of 3.7 atm at 20 °C. The busbars can be in single or triple-pole enclosures. The triple-pole model permits a flatter and more economical arrangement for all voltages. Feeders are always separately enclosed.

The cost of an installation can be notably affected by the number of isolators required. The overall design of the installation was made as simple as possible, due consideration having been given to their importance. The operating mechanism contains a robust spring and is fitted with a rewind motor and also a hand crank for emergencies. The isolating gap between contacts for opening the main circuit in conjunction with a sliding shutter in the enclosure enables the individual units to be separated very easily and ensure good access to the contacts. Earthing switches can be fitted on both sides of the gap. A special design of rapid earthing switch is fitted to the busbars and the cable end-box. In the event of a wrong switching operation they can close on a full short circuit. The sectional drawing in Fig. 2 shows the connection of a feeder to busbars with triple-pole enclosure.

In addition to the pressure required to establish the normal insulation level, the breaker also has a high-pressure section with 13.7 atm at 20 °C for quenching the arc and operating the contacts.
Fig. 3. — Single-pole enclosed SF₆ circuit-breaker for 245 kV with a breaking capacity of 20 GVA

1 = Connection terminals
2 = Mechanism for arc-extinction chamber control and for isolator chamber
3 = Position indicator
4 = High-pressure cylinder for impulse chamber

After every operation the gas is raised to the required pressure in a closed circuit by the compressor. The breaker operates very quietly and even when interrupting full load has no external effects. As can be seen from Fig. 3, the extraordinary characteristics of SF₆ gas have resulted in a very compact design for this high-capacity breaker.

The current transformers used are of the normal ring-core type and are pushed into the enclosure. They can be fitted in the feeder or coupling units as required.

With increasing voltage the inductive voltage transformers are the largest elements, apart from the breaker. The active part, magnetic circuit and winding, cannot be appreciably reduced in size by using new types of insulation. Whereas up to about 123 kV moulded resin transformers are still small enough to be used, they are too cumbersome to permit a compact layout. Therefore over about 170 kV the most economical solution is to use cable voltage transformers.

In most cases the installation is connected to high-voltage cables. The specially designed cable end-box also provides the isolation between the SF₆ insulation and the cable insulation. Its design permits all the usual types of cable to be connected. Thus it is possible to use capacitive cable voltage transformers. An appropriate adaptor is connected to the end-box. A measuring layer about 100 m long is sufficient to provide the power needed to meet the normal burden for measuring, metering and protection up to accuracy class 0-2 [9]. Apart from the encapsulated current transformer it may also be of advantage to fit slip-over transformers on the outgoing side. As these can also be equipped with a separate core for busbar protection, it is possible to incorporate the complete SF₆ switchgear, including the cable end-box, within the range of the electronic busbar protection system [10].

**Design of Metalclad Switchgear**

The layout of this type of high-voltage switchgear must suit the overall concept of a given project. Depending on whether the installation is a substation or transformer station, the high-voltage switchgear, transformer cells, cable ducting, ancillaries, workshops and other rooms must be of such dimensions that the overall size of the building is as small as possible. Having decided upon the principal dimensions of the station, the layout of the SF₆ switchgear is then worked out.

Apart from the number of feeders and their connection, consideration must also be given at the design stage to whether bus couplers or sectionalizers are required. Each feeder has its own control unit. This contains all the necessary equipment for local control, the auxiliaries and terminals for connection to the control room, and is connected to the switchgear by the control cables, measuring cables and gas pipes.

The complete switchgear unit is mounted on a frame. The layout must be clear and easy to supervise. The drive components and position indicators for the breakers and isolators must be clearly visible from the gangways. The compactness of the design must not hamper maintenance. Correct arrangement of access gangways and transport routes is essential.

There are no ageing or contamination problems with SF₆ gas and the enclosure prevents ingress of any foreign bodies. The level of insulation may drop over a long period due to leakage. The compartmented sections of the complete installation are grouped according to the circuit diagram and the amount of gas, and therefore the insulation level is monitored by a gas density relay. Variation in the gas density is either indicated or, if a central gas supply is provided, the losses are automatically re-
plenished. If for any reason the gas density drops, the section involved is automatically cut out before the drop reaches a level which could be dangerous for electrical operation.

**Typical Examples**

Fig. 4 shows two arrangements which are examples of methods in which this equipment can be assembled. The layout for the switchgear with a single set of busbars comprises two feeders for a looped-in high-voltage line, two feeders for a transformer and a sectionalizer. The first SF₆ switchgear installation is being built in accordance with a similar circuit [11]. The circuit-breakers rated 10 GVA are equipped with two arc-extinction chambers.

Depending on local conditions, the switchgear is arranged either for a small floor area or a low overall height. If the latter is required, the equipment is arranged as shown in Fig. 4b, due consideration being given to the basic principles mentioned above. The switchgear is mounted on a frame which also carries the elevated gangway deck. The switchgear cabinets and horizontally arranged breakers are placed...
above this. The latter govern the arrangement of the transport route, which was made lateral in order to keep the building as low as possible. The type of isolators chosen in this case obviates unnecessary connecting leads.

The busbar isolators are "U"-shaped elements, the feeder isolators being "Z"-shaped, though both are suitable for connection to earthing isolators. The earthing switches are accessible from the gangway beneath the breakers.

If it is necessary for the installation to occupy minimum floor area, the switchgear can be arranged vertically as shown in Fig. 4c. The transport route is then at the front. An intermediate floor is constructed about half-way up the frame. It serves as a gangway to the busbar isolators and earthing switches.

The circuit diagram for the switchgear installation with duplicate busbars contains three line feeders and three transformer feeders as shown in Fig. 4d, the breaker with three extinction chambers having a breaking capacity of 20 GVA.

The arrangement of the construction with individually enclosed busbars is shown in Fig. 4e. The space required beneath the frame is determined by the six busbars. As the sectionalizers are arranged in "L" and "T" formations, the circuitry does not require any supplementary equipment. The transport space is above the breakers.
As can be seen in Fig. 4f, the overall height of the installation can be reduced and better use can be made of the space on either side of the breaker by using a common enclosure for the three busbars, although the layout of the equipment remains virtually unchanged. It is possible to incorporate a coupling unit in either of the above arrangements. The space required corresponds to that for one feeder.

Larger stations may demand a different ratio of length to width due to the space available. In this case the duplex arrangement [8] is used.

Economic Considerations

At this point it is useful to consider some of the economic aspects of metalclad SF₆ switchgear. As the equipment for this type of installation is more expensive to produce, the cost of the equipment is higher than for a conventional station. On the other hand, a considerable saving is made in the cost of land and the building. Depending on the arrangement of the equipment and the circuit, the space required is only a fraction of that for a conventional station. At the same time these metalclad installations are not affected by problems of pollution or external conditions, and maintenance is reduced and simplified.

The compact design of this high-voltage switchgear, completely divorced from outside influences, permits a free choice of location and also an economical layout, not only of the installation itself, but also of the distribution network.

H. P. Szente-Varga
N. Krafft

Bibliography


LOW-OIL-VOLUME CIRCUIT-BREAKERS TYPE SB
FOR MEDIUM VOLTAGES

The SB range of L.o.v. circuit-breakers designed for use in medium-voltage systems up to 36 kV and with breaking capacities up to 1000 MVA is discussed. The different models and their basic design are described, together with examples of the most important tests in a comprehensive test programme.

Introduction

Circuit-breakers of the SB range are of the low-oil-volume type and are intended for indoor installation. Built for rated voltages of 7-2-36 kV, rated currents of 630-2500 A and rated breaking capacities of 250-1000 MVA, they are available in the following forms:

a. For fixed installation in open cubicles (SBH and SBK)
b. As plug-in, drawout units for metalclad installations with no isolator (SBHJ and SBKJ)
c. As plug-in, drawout units for metal-enclosed installations with no isolator (SBHL and SBKL).

A section of an installation in service and equipped with these breakers is shown in Fig. 1.

In addition to the types described in earlier articles [1, 2], the range has been extended by breakers with the capacities and current ratings shown against A in the Table. Breakers with the data given in section B are in preparation. In both cases the principal dimensions and construction of this well-tried design are unchanged. The sole exception is the breaker for 2500 A, which, to facilitate the economical maintenance of stocks, has two 1250-A poles in parallel for each phase.

The chief aims in designing the new range were very modest dimensions and minimum supervision. The simple and clearly laid out construction allows maintenance such as replacing contacts, changing the oil and checking the current path and quenching chambers to be carried out very quickly. With the fixed type the breaker does not have to be disconnected from the busbars for maintenance purposes, and with the drawout versions there is no necessity to alter the setting of the tulip contacts. There is also no need to disturb the setting of the primary relays, if these are fitted.

Construction and Operation

The use of the same construction for all the breakers and their accessories, together with identical basic assemblies for the various types of breaker, facilitate assembly in the factory and simplify maintenance and supervision.

<table>
<thead>
<tr>
<th></th>
<th>Rated current kV</th>
<th>Breaking capacity MVA</th>
<th>Rated current A</th>
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<tr>
<td>A (already available)</td>
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<tr>
<td>7-2</td>
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<td>24</td>
<td>1000</td>
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</tr>
<tr>
<td>36</td>
<td>1000</td>
<td>1250</td>
<td>1600</td>
</tr>
<tr>
<td>B (in preparation)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>750</td>
<td>1250</td>
<td>1600</td>
</tr>
<tr>
<td>36</td>
<td>1500</td>
<td>1250</td>
<td>1600</td>
</tr>
</tbody>
</table>
SB circuit-breakers are fitted either with a spring-assisted manual operating mechanism (SBH) or spring operating mechanism (SBK). The SBH type is supplied only for capacities of 250 and 350 MVA at 12 and 24 kV, respectively, and a current rating of 630 A, while SBK breakers are available for the whole range.

The manual operating mechanism is of simple design and provides for only close-open cycles. There are separate springs for closing and opening. The breaker closes immediately the springs have been wound up. It is made to open by tripping the spring either mechanically or electrically. The springs can be tensioned only by hand.

With the spring operating mechanism, both opening and closing of the breaker are powered by the same spring. In conjunction with a reclosing relay it provides for the autoreclosure cycle open-close-open, as well as the normal close-open cycle. In contrast to the spring-assisted manual operating mechanism, the breaker is both opened and closed by mechanical or electrical tripping of the actuating spring. The spring can be wound up either manually or with a motor.

Both operating mechanisms comprise three main assemblies:

a. The actuating unit
b. The breaker frame
c. The breaker shaft.

The actuating unit contains all the components necessary to the mechanical functioning of the breaker. The unit is assembled independently of the other parts of the breakers, and is fitted as a self-contained assembly in all breakers from 7-2 to 36 kV, for both the fixed type and the plug-in, drawout versions. With breakers of the higher capacities an additional spring is fitted to assist the main spring.

The chassis is of bolted construction and carries the poles and actuating unit. The breaker is attached to this chassis when fixed in open cells. With the drawout type of breaker the truck acts as the chassis.

The breaker poles are of robust construction and comprise the housing for the operating mechanism and the moving contact, the quenching chambers, together with the connecting flanges, the contact holders and fixed contact, and the pressure-balancing chamber. The arrangement can be seen in Fig. 2.

In the SB range of breakers the arc is extinguished in a chamber having no moving parts. With heavy-current arcs the quenching system operates on the principle of a stream of quenching medium per-
Fig. 3. – Voltage, current and capacity ranges of l.o.v. circuit-breakers type SB

\[ P = \text{Breaking capacity in MVA} \]
\[ I = \text{Rated current in A} \]

The black columns show breaking capacities with a single interruption, hatched columns the breaking capacities with the second interruption in the case of auto-reclosure.

\( k, mc, n, p \) relate to current ratings in the type designation.

<table>
<thead>
<tr>
<th>Voltage Range</th>
<th>Breaking Capacity (MVA)</th>
<th>Rated Current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-7.2 kV</td>
<td>1000</td>
<td>625</td>
</tr>
<tr>
<td>10-12 kV</td>
<td>500</td>
<td>1250</td>
</tr>
<tr>
<td>15-17.5 kV</td>
<td>350</td>
<td>1600</td>
</tr>
<tr>
<td>20-24 kV</td>
<td>250</td>
<td>2000</td>
</tr>
<tr>
<td>30-36 kV</td>
<td>1250</td>
<td>2500</td>
</tr>
</tbody>
</table>

Parallel to the axis of the arc, while with small currents the quenching medium flows both transversely and longitudinally. Operation of the two quenching devices is matched to ensure rapid and reliable extinction of the arc throughout the range of currents.

**Electrical Tests**

To comply with the appropriate specifications and all the relevant IEC recommendations a circuit-breaker must be able to cope easily with the mechanical and electrical loads imposed during service, i.e. the routine and short-circuit switching operations which occur in medium-voltage networks and industrial installations.

The requirements which may possibly be included in a specification were carefully examined, and the breakers were then tested in our own test facilities and those of others, such as KEMA, CESI and SVUSE (Bechovice, Czechoslovakia), to ensure that these requirements are met. The life expectancy and reliability of the individual components and assemblies were tested in many repeated mechanical and electrical experiments under very arduous conditions such as would occur only extremely rarely, even under abnormal circumstances, e.g. with an asymmetrical breaking current and a large, extended half-wave. In all, the number of electrical short-circuit tests with all types and their variants amounted to several thousand switching operations.

The results of the tests show that the breakers function reliably over the entire range of currents and voltages, and to some extent beyond. In general they meet all national requirements, and conform to the international recommendations referred to earlier. The overall range of capacities is illustrated graphically in Fig. 3.
Fig. 4. — Oscillogram of three-phase auto-reclosure O - 0.253 s - CO with an l.o.v. circuit-breaker type SBHJ for metalclad installation, 12 kV, 500 MVA and 1250 A

\[ U_R, U_S, U_T = \text{Recovery voltages in the three phases (r.m.s.)} \]
\[ I_R, I_S, I_T = \text{Short-circuit currents in the three phases (r.m.s.)} \]
\[ i = \text{Current in the trip coil} \]
\[ S = \text{Movement of contact rod} \]
\[ 1\text{st and 2nd interruption each at 505 MVA symmetrical.} \]

Fig. 5. — Oscillogram of three-phase auto-reclosure O - 0.261 s - CO with an l.o.v. circuit-breaker type SBK for mounting in open cells, 24 kV, 1000 MVA and 1250 A

\[ U_R, U_S, U_T = \text{Recovery voltages in the three phases (r.m.s.)} \]
\[ I_R, I_S, I_T = \text{Short-circuit currents in the three phases (r.m.s.)} \]
\[ i = \text{Current in the trip coil} \]
\[ S = \text{Movement of contact rod} \]
\[ A = \text{Moment of contact separation} \]
\[ B = \text{Moment of arc extinction} \]
\[ 1\text{st interruption: 900 MVA symm.} \]
\[ 2\text{nd interruption: 950 MVA symm.} \]
\[ \text{Evidence of breaking capacities of 1000 MVA and more is contained in an earlier article} [2]. \]
The arcing times with short-circuit currents above 20 kA are always shorter than 20 ms, and virtually always less than 30 ms in the case of small inductive currents. There is no critical range of currents. Switching surges are of the usual order of magnitude for breakers of this kind.

The most important aspect of testing a circuit breaker is determining its capacity. The oscillograms illustrate auto-reclosure tests at KEMA on l.o.v. breakers type SBK for 12 and 24 kV and respective breaking capacities of 500 and 1000 MVA. The test at 12 kV was with the version for mounting in metal-clad units, and the other for installation in open cells. In the first oscillogram (Fig. 4) the recovery voltage with both tripping operations is 9-8 kV and the currents interrupted in the three phases are 30-0, 29-5 and 29-5 kA. The rated value at 10 kV is 29 kA. The longest arcing times are 17 and 16 ms. The maximum making current has a peak value of 91 kA, which is considerably higher than the rated value. The asymmetry of the breaking current at the moment of contact separation is 33 and 35%, and thus greater than prescribed by IEC for these breakers. In the second oscillogram (Fig. 5) the recovery voltage is 22-6 and 23-1 kV. Evaluation gives 23 kA in all three phases for the first interruption and 24, 23 and 23-2 kA for the second, after 0-261 s. Maximum asymmetry is 35% and the peak value of the making current is 56 kA.

Fig. 6 and 7 were obtained during the series of tests with the breaker for 12 kV and metal-clad installation. The two photographs were preceded by two O–CO cycles with a dead time of 0-26 s and...
a CO sequence at the full short-circuit capacity, which to some extent exceeded the rated values. The contact erosion shown was classified as slight to moderate in the test report. The same assessment was made for blackening of the oil and burning of the quenching chambers.

Determining the maximum capacity is an equally important part of the test programme. As an example, Fig. 8 shows the breaking capacity of type SBK circuit-breakers for 7.2 kV, 350 MVA, 1250 A and 12 kV, 500 MVA, 1250 A. It can be seen that 405 MVA can easily be handled symmetrically and repeatedly at 6 kV, as can 787 MVA at 10.2 kV. Further tests confirmed a reliable making capacity of up to 109 kA peak value, which is 28% higher than the rated value for these breakers.

The capacitive breaking capacity has been demonstrated in numerous single-phase and three-phase tests. These have shown that the breakers function over wide ranges without restriking, and are suitable for connecting and disconnecting capacitor banks. The breaking capacity is in some instances even higher than shown in Fig. 9.

**Conclusion**

These circuit-breakers constitute a new, thoroughly practical and carefully matched range capable of meeting all service requirements. They are suitable for fixed mounting in open cells and as plug-in draw-out units without isolator in either metalclad or metal-enclosed cubicles.

(DJS)

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**Bibliography**


FACTORY-ASSEMBLED SWITCHGEAR INSTALLATIONS USING LOW-OIL-VOLUME CIRCUIT-BREAKERS TYPE SB FOR 12-36 KV

Factory-assembled switchgear installations of metal-enclosed or metalclad design are being specified more and more in preference to the open-type cells erected on site, which have hitherto been the rule in Europe. Following a summary of the requirements that such installations have to satisfy, special reference is made to the wide range of prefabricated installations using the new l.o.v. breakers type SB 12-36 kV, giving examples of typical applications.

Introduction

There has been a marked change in the design of medium-voltage installations during the past few years. The constant rise in the demand for electricity resulted in a growth of the short-circuit powers. To provide proof of ability to withstand such fault conditions, it is no longer sufficient merely to develop new switchgear; all the other elements of the installation have to be included in the development process. Moreover, the requirements imposed nowadays are much more exacting, especially as regards reliability. This leads directly to factory-assembled installations, where batch production of ancillary items enables the overall price to be reduced. Installations of this type have been quite common in the USA and Britain for many years (the first metalclad installation was brought out in 1906). The first installations of this kind to be produced by Brown Boveri were made for export in 1943 (Fig. 1). At that time there was no demand for such equipment from continental Europe. It is only in recent years that the following considerations have led to a growth in interest for metalclad switchgear in this part of the world, too: shortage of qualified labour for the erection and operation of installations, enhanced reliability, prevention of false operations, protection for operating personnel, saving of space, and so on.

Fig. 1. - Enclosed truck-type switchgear with oil circuit-breakers for 11 kV (supplied to India in the early 1930s)
Present Technical Requirements for High-Voltage Installations

The technical requirements laid down for h.v. equipment by customers vary widely even today, for example different degrees of safety are stipulated for switchgear. In the course of the years three distinct categories have come to be recognized, namely "open-type plug-in", "metal-enclosed" and "metal-clad". The requirements that these have to fulfil are listed below.

1. Installations shall be factory-assembled units which can be put together on site with a minimum of erection work.

2. Isolators shall be dispensed with in order to avoid false operation, thereby leading direct to the plug-in design.

3. It must be an easy matter to exchange breakers for periodic maintenance.

4. Reliable interlocks must be provided to prevent any possibility of false operation. Among these are: the breaker may only be moved between the disconnected and service positions when it has first been opened, and between these two positions any operating command must be blocked.

5. Proof shall be provided of the electric strength, breaking capacity, mechanical and short-time short-circuit strength, and temperature rise of the switchgear when enclosed.

These five conditions are satisfied by open-type plug-in switchgear installations.

6. Enclosing the switchgear in sheet-metal, to prevent migration of possible switching arcs to other parts of the installation.

7. Insulating the live parts by means of synthetic material or partitions, so as to rule out almost all possibility of internal short circuits.

Up to item 7 the conditions are satisfied by installations of the "metal-enclosed" type.

8. Further subdivision of the individual cells by metal partitions, forming the breaker compartment, busbar compartment, current transformer and cable termination compartment, voltage transformer compartment and a space for low-voltage equipment.

9. Automatic covering of the mating contact when the breaker is withdrawn, this being done by means of an earthed metal hinged plate.

10. Each cubicle shall be able to accept the cables required for the relevant rated current, i.e. single-storey design.
11. The voltage transformer circuit shall be parallel to the outgoing feeder. Therefore, it should be possible to disconnect it for maintenance, without interrupting the main feeder.

12. It should be possible to earth the feeder and, if necessary, the busbars without any risk.

"Metalclad" switchgear, the highest of the three categories, fulfils all requirements from 1 to 12.

Open-type and metal-enclosed installations (see Fig. 2 and 3, for example) are mainly found in stations in Europe where only modest demands are imposed as regards safety and ease of maintenance. Such equipment has to be installed in rooms that can be locked and may only be operated by trained personnel. Metalclad switchgear (Fig. 4 and 5) is ideal for installation in the vicinity of concentrated loads, for power plant distribution systems and auxiliaries, or in industrial plants. Such equipment can even be installed in workshops, because it is completely safe to touch and does not need specially trained personnel for operation and maintenance.

In the USA, Britain and France, regulations have been in force for several years regarding metalclad switchgear, the main aspects of which are satisfied by Brown Boveri equipment. In other countries directives have been brought out, or the existing regulations are simply adopted for their own use. In order to standardize the existing regulations and the various additional requirements, an IEC Committee (TC 17C) is at present engaged on working out recommendations for metalclad switchgear.

**Range of Cubicles Suitable for Use with Type SB Breakers**

Parallel to the development of the new, low-oil-volume range of breakers type SB, Brown Boveri also designed a comprehensive range of factory-assembled switchgear cubicles, meeting the above specifications, the features of which will now be described.

The Table lists the various types available. The programme includes the three basic types, open-type, metal-enclosed and metalclad, the first two types being designed solely for single busbar systems. For 36 kV only metalclad units are visualized.

**Design of the Cubicles**

The design can be seen from Fig. 6 to 10. The plug-in circuit breaker is mounted on a truck and can be moved from the service position to the dis-
### Range of open-type, metal-enclosed and metalclad cubicles

<table>
<thead>
<tr>
<th>Rated voltage kV</th>
<th>Design</th>
<th>Rated feeder current A</th>
<th>Rated busbar current A</th>
<th>Breaking capacity MVA</th>
</tr>
</thead>
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<td></td>
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<td>630</td>
<td>1000</td>
<td>250/350</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1250</td>
<td>1500</td>
<td>500</td>
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<td>enclosed with single busbars</td>
<td>630</td>
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<td>630/1250/2000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Fixed = with non-drawout components, e.g. load switches, isolators, instrument transformers, etc.

Connected position inside the cubicle, or vice versa. In the disconnected position the box containing the operating mechanism of the breaker projects from the front of the cubicle, thus giving a visible indication of the state of the breaker. (An exception to this rule is the 36-kV breaker in its metalclad cubicle, for which the relatively long drawout distance necessitates the disconnected position being inside the
cubicle, see Fig. 10). Tulip contacts on the breaker establish connection with the male contacts on the fixed part of the cubicle. The movement of the breaker in and out is effected by the “Traloc” mechanism fitted to the floor of the cubicle, as can be seen in Fig. 11.

This mechanism, which can be used in all installations with drawout breakers, exhibits the following features.

- It guides the breaker when being moved from the service position to the disconnected position, or vice versa.
- It prevents the breaker from being moved at all if it is closed.
- It prevents the breaker from being unlatched, except in the disconnected position.
- It automatically ensures that contact is made with the control and indicating circuits already in the disconnected position.

At any time the “Traloc” mechanism can be augmented by fitting the following elements, enabling it to satisfy the most exacting demands with regard to remote control and remote indication.

- An auxiliary switch to indicate whether the breaker is open or closed at some remote point, allowing for the fact that in the disconnected position the auxiliary switch will signal “Off”, even though the breaker may be closed.
- Limit switches to indicate whether the breaker is in the disconnected or service position.
- Key interlocks for the breaker in the disconnected position, to prevent the breaker from being run into the service position without authorization.

These elements allow the breaker’s readiness for operation to be indicated at a remote point.

With this additional safeguard a reliable interlock is provided with other parts of the installation, depending on certain operational criteria.
- An electric motor to move the breaker between the service position and disconnected position.

By this means the installation with plug-in breakers can be completely remote-controlled.

**Open-Type Cells**

Fig. 6 depicts an open-type cell equipped with a drawout L.o.v. breaker type SB. The breaker is equipped with primary relays, the voltage transformers and cable end-boxes being in the lower part of the cell, the busbars mounted on the framework. The cell is made of ordinary commercial angle-iron sections and has doors at the front for access. The partitions between cells consist of sheets of insulating board which can simply be pushed into position. The pole spacing and the width of the cell in this case are sufficient to allow the breaker to withstand the specified test voltages without any insulating barriers having to be inserted. The fixed contacts for connection to the busbars on the one hand, and to the instrument transformers or cable end-boxes on the other, are supported by insulators.

**Metal-Enclosed Cubicles**

Fig. 7 shows the same unit in the metal-enclosed design. The busbars are inside the framework, being insulated with a shrunk-on sleeve of polyvinyl chloride (PVC) and held in position by insulation attached to the barriers between adjoining cubicles. The frame is surrounded on all sides by steel sheet. With basically the same design, but omitting the voltage transformer compartment, a small cell has been devised which, in the majority of cases though, calls for a two-storey layout, i.e. with a cable section (as in Fig. 8).

**Metalclad Cubicles**

The design of these units satisfies all the requirements listed in the preceding part of this article. The interior of the cubicle is divided into compartments surrounded with earthed metal partitions, as shown in Fig. 9. This subdivision and the more compact arrangement makes the whole unit more robust and, in the event of an internal short circuit, restricts any damage to a minimum.
Breaker compartment

In contrast to the types described before, the plug-in circuit-breaker is separated from the rest of the equipment by earthed metal partitions. For this reason the fixed contacts are supported by bushings instead of insulators. When the breaker is in the disconnected position or completely withdrawn from the cubicle, these contacts are covered by earthed metal covers. The plug-in breakers for 12 kV are fitted with interphase barriers, while for 24 and 36 kV the poles have an insulating hood, permitting a more compact arrangement and making internal short circuits virtually impossible.

Busbar compartment

For the busbars a tubular construction with resin-bonded paper or PVC insulation is used. The busbar sections are the same length as a cubicle is wide and are fixed to the cast resin bushings by a clamp. These
clamps are so designed that, even if there is quite an appreciable discrepancy during assembly, perfect contact is assured. The junction is insulated with plastic mouldings. Where the bars pass through the side walls of the unit, they are held by a section of insulating sheet (see Fig. 12).

Current transformer and cable termination compartment

Mounted in the partition at the back of the breaker compartment are the bushing-type current transformers. The front end of the transformer carries the male contact which mates with the tulip contact of the breaker, the back end being used for connection of the cable. For light currents the bushing type of c.t. may be replaced by insulator-type c.t. in conjunction with ordinary bushings. Space is also available for an earthing switch and for the terminations of up to four triple-core cables or six single-core cables.

Voltage transformer compartment

A separate compartment is provided for the voltage transformers. The v.t. fuses are designed as bushings and can be safely removed without interrupting the main power feeder. Moreover, this permits access to the voltage transformers without any risk of contact with live parts.

Low-voltage compartment

At the front of the cubicle, conveniently placed for operation, there is a narrow instrument box with space for two or three indicating instruments, switches or push-buttons for operation of the circuit breaker, also for operating the earthing switch with key interlock, and buttons and lamps for lighting the oil-level gauge-glasses. The box beneath the breaker compartment contains the incoming control wiring, fuses, terminals and auxiliary leads from one cubicle to another. Space is available on the door for three or four secondary relays. If additional control, measuring or monitoring elements are considered necessary, or if relays on the lower door are undesirable, these can be accommodated in an additional box mounted on top of the cubicle in a clearly visible position.
Cubicle with Two Breakers for Duplex or Twin Feeders

The small size of the breaker truck permits two breakers to be mounted one above the other in the normal height of the cubicle, as is already common practice with high-power circuit-breakers in low-voltage distribution systems. This yields a favourable layout for use with duplicate busbar systems (duplex arrangement). But also for installations with only a single busbar system, the ability to mount two breakers above one another allows a relatively large installation to be accommodated in a very small space. Fig. 13 and 14 show the corresponding layouts with two breakers for duplex and twin feeders. The breaker compartments contain the same components as in units with only one breaker. The upper breaker compartment is the normal width, the lower being 10 cm wider. As a result there are two ducts at the sides of the upper compartment, which can be used for ventilating the lower compartment, while the upper is ventilated direct. In this way the two breaker compartments can be completely separated in service. By making the cubicle 10 cm wider than that with the single breaker and by utilizing the space in the front corners to the full, a separate space 17 cm wide is obtained beside the breaker compartments in which an equipment rack can be fitted. This has a pair of hinged flaps on which the necessary control elements, such as relays and instruments are mounted. If a large number of relays
and instruments are needed for feeders, it is possible to space the cubicles slightly further apart and insert a rack 10 or 20 cm wider in the gap.

**Fixed Cubicles**

An installation containing circuit-breakers always needs a certain number of fixed cubicles for such tasks as busbar couplers, measuring equipment and small station-service transformers (see Table). These are assembled from as many parts of the standard cubicles as possible and can be combined at will with breaker cubicles. They may also contain the following kinds of equipment: on-load isolators with or without h.r.c. fuses (Fig. 15), or ordinary isolators, or instrument transformers and the associated meters.

**Earthing Feeders and Busbars**

For earthing, Brown Boveri visualize the following alternatives: earthing with an earthing switch, as incorporated in the programme of type SB cubicles with additional key interlocks to enhance the safety; secondly, a method which is gradually gaining significance and which offers complete safety in meshed networks, is the use of an earthing switch with a certain making capacity. This switch is used to earth the feeder and the busbars. It is similar in construction to a normal plug-in circuit-breaker. Its three lower tulip contacts are elongated, while the three upper connections are short-circuited with a common link and connected to the normal earth of the breaker truck. A new feature is that the busbars can be earthed with the same breaker truck in a measuring cubicle specially adapted for the purpose (see Fig. 16a and b).

(KME)

K. Munzinger
LOAD SWITCHES IN H.V. AND E.H.V. NETWORKS:
INTERESTING APPLICATIONS FOR A NEW TYPE OF UNIT

Hitherto, load switches have scarcely been used in h.v. and e.h.v. networks. The few existing designs have serious drawbacks such as long switching times, insufficient making capacity on a short circuit, smaller breaking currents than rated currents, and long arcing times. A design which avoids these disadvantages, on the other hand, opens up completely new possibilities for using load switches in h.v. and e.h.v. networks. These applications are described and the requirements made of the load switch are summarized. Taking the example of the Brown Boveri type DYLF load switch it is shown that these requirements can be met with an economical design.

Possible Applications of Load Switches in H.V. and E.H.V. Networks

The most important applications of load switches are summarized in the Table, together with the principal requirements for each case.

Load Switch as Replacement for Transformer Circuit-Breaker (see Table overleaf, case 1.1)

A load switch can be used on the high-voltage side of a transformer in place of the usual power circuit-breaker. Such an application is made possible by the fact that transformer faults in h.v. networks are extremely rare. In order to dispense with the expensive circuit-breaker, provision is therefore made for all the lines terminating at the transformer to be disconnected in the event of a fault. This is the only kind of abnormality which imposes certain operational limitations as compared with conventional switchgear practice.

With all other kinds of fault the use of load switches on the h.v. side of transformers presents no additional complications: short circuits on the lines are interrupted as before by the line circuit-breakers, and busbar short circuits are dealt with by the circuit-breakers on the low-voltage side, as well as by the line breakers.

Previous efforts in this direction have included replacing the transformer circuit-breaker with an isolator [2]. Clearly, a load switch offers greater possibilities than an isolator.

With a load switch having breaking times as short as those of a modern circuit-breaker it would even be possible to consider auto-reclosure of busbars, in which case the sequence of switching operations would be as follows.
Possible applications for load switches in h.v. and e.h.v. systems

<table>
<thead>
<tr>
<th>Case</th>
<th>1-1</th>
<th>1-2</th>
<th>1-3</th>
<th>1-4</th>
<th>1-5</th>
</tr>
</thead>
</table>
| Circuit diagram | ![Diagram](image)
| Load switch requirements | Interruption of small inductive and capacitive currents and also load currents. Ability to close on short circuits desirable. |
| Circuit breaker | Cycling ability, very short make and break times (similar to those of circuit-breaker). |
| Interruption of relatively heavy inductive currents with moderate resonant frequencies. Ability to close on short circuits desirable. |
| Ability to close on short circuits essential. Very short make and break times. |
| Interruption of light capacitive currents. Single-pole actuation necessary. |
| Interruption of light inductive and capacitive currents and also of rated currents acc. to load switch specification. |

In the event of a fault at transformer A (see 1.1 in the Table) all line breakers (1–3) and all the breakers on the low-voltage side of the transformers (4 and 5) open. The load switch (6) of the affected transformer then opens at no-load and remains open. The site of the fault is thus isolated. All the breakers, with the exception of breaker (4) on the low-voltage side of the affected transformer, can then close again immediately, and the whole busbar system is again operational.

The time for which the busbars are dead can be made very short and is governed chiefly by the operating times of the load switch and circuit breakers.

**Load Switch for System Tie (Table, case 1.2a)**

Load switches can be used to particular economic advantage instead of circuit-breakers on economic grounds wherever a system tie or transmission system consists of a two or multiple-circuit line and the corresponding transformers are allocated to these lines alone. If a short circuit occurs on one line, the circuit-breakers on the low-voltage side of the transformers open, the load switches on the affected line then open and the circuit-breakers close again. The dead time of the low-voltage circuit-breakers can be set extremely short as the affected line is also disconnected by the load switches, and there is therefore no need to make allowance for the relatively long deionization time of the free fault arc. The affected line thus remains isolated for a short time, and is not reconnected by the load switches until after the deionization time of the free fault arc, i.e. after the normal dead time. The conditions governing how much power can still be transferred stably under such circumstances have been investigated and found satisfactory.

If the same station contains two or more transformers (see Table, case 1.2b), the circuit-breakers on the high-voltage side of the transformers can also be replaced by load switches as in case 1.1.
As in conventional practice, busbar faults result in total disconnection. With a transformer fault, transformer B for example (see under 1.2b in the Table), initially all the low-voltage-side circuit-breakers (1 and 2) open. The power supply from the opposite station must, of course, also be interrupted. When this has been done, load switch 4 of the affected transformer then opens at no-load. All the low-voltage-side circuit-breakers (in this case only breaker 1) can then close again, except for breaker 2 in the faulty leg which remains open. After reclosure at the other end of the line the system is once again in operation.

Another possibility is to arrange for breaker 2 to close again together with the other low-voltage-side breakers. If the fault no longer exists, the corresponding load switch 4 can be re-closed. Should the fault still be present, however, circuit-breaker 2 opens, causing definitive disconnection.

The opposite station need not, of course, be symmetrical as shown, although under fault conditions the whole section of line must be disconnected here, too.

Load Switch Connected to the High-Voltage Side of Shunt Reactors (Table, case 1.3)

Here there are two distinct cases:

a. Reactor connected the busbars. This is basically the same as case 1.1, and similar considerations apply.

b. Reactor connected to the overhead line requiring compensation. In accordance with present-day practice the reactor is rigidly connected to the line. Adaptation to changes in transmitted power is therefore not possible. The degree of compensation can be matched more closely to the power being transmitted at any time by connecting the reactor to the line via a load switch. This system offers another advantage. In the event of a fault at the reactor the corresponding circuit-breakers trip and load switch 3 of the affected reactor opens after a certain time lag. The line can then immediately resume operation, though without compensation.

If, on the other hand, the reactor is rigidly connected to the line, the transmission line obviously goes out of service, too, under such circumstances. Very exacting demands are made of the load switch itself. The reactor current to be disconnected at a p.f. of less than 0.1 can be as much as 350 A (the highest reactor capacity at present available is 300 Mvar at 500 kV), and the corresponding resonant frequencies are of the order of 2000 c/s. Furthermore, with load switches for reactors it must be borne in mind that a jump in the system voltage will occur when the shunt reactor is disconnected, adding a further complication as regards switching conditions.

High-Speed Earthing Switch for Single-Pole Auto-reclosure in E.H.V. Networks

With e.h.v. transmission systems using a single-circuit line, single-pole auto-reclosure is desirable, for reasons of stability, when a single-phase earth fault occurs on the line. Beyond a certain length of line, however, the residual current flowing to the fault location as a result of capacitive coupling to the other lines is so high that single-pole auto-reclosure is no longer possible [3, 4]. With 500 kV the limit lies in the region of 100 km [5].

The use of single-phase earthing switches at the line ends has been suggested as a way of solving this problem [4, 5] (see Table under 1.4).

If a single-phase earth fault occurs on an overhead line, the relevant breaker poles open and interrupt the short-circuit current. The earthing switches on this phase close immediately, opening again after the deionization time of the arc on the line. The residual current is diverted via the earthing switches, and must also, of course, be interrupted again by them. These residual currents are normally between 5 and 50 A, while the recovery voltage amounts to only a fraction of the phase voltage and appears across the break at approximately the service frequency. The introduction of high-speed earthing switches thus allows single-pole auto-reclosure on long single-circuit lines, and also ensures stable operation.

With multiple-circuit lines, triple-pole as well as single-pole auto-reclosure is also practicable without
seriously endangering stability. Other problems arise, however. The overvoltages which occur when open-circuit lines are connected can reach dangerous levels, especially if the line still has a residual charge, the polarity of which is opposite to that of the voltage at the moment of closing [6]. This is exactly what may happen on three-pole auto-reclosure, but triple-pole earthing switches would ensure complete discharging of the line, and so from the outset restrict the possible occurrence of unacceptably high overvoltages. The switching sequence is the same as for single-pole earthing.

**Other Specific Applications for Load Switches**

Switching and short-circuiting of series capacitors in e.h.v. systems (Table, case 1.5a). Here the load switch has two functions. First, it must permit the transition from normal operation (transmitted power ≤ natural power) to compensated operation (transmitted power > natural power) and vice versa, i.e. it has to connect and disconnect currents in the region of the rated current. The form of the recovery voltage on disconnection is harmless as regards magnitude and resonant frequency.

The second function of the load switch is to bypass the protective spark gap of the series capacitor if the gap breaks down. This happens with a line short circuit when the voltage at the capacitor rises suddenly and the spark gap flashes over.

The shortest possible make time and the ability to close on a short circuit are essential in this case.

Connection and disconnection of braking resistors (Table, 1.5b). Braking resistors are used in certain cases to maintain stability on load rejection [7]. These act as a substitute load during the reclosure dead time, their power consumption corresponding to some 50–70% of the transmitted power. It is essential to the effectiveness of this method that the resistors can be switched in as quickly as possible when required, i.e. in the event of a short circuit on a transmission line. The resistor should be loaded as rapidly as possible after the appearance of the fault. Exacting demands are thus made of the switchgear from the point of view of short operating times. The opening process presents no particular difficulties as this is only a matter of interrupting a purely ohmic circuit. Load switches would be eminently suitable for this purpose.

In conjunction with shunt switching (Table, 1.5c). With this system, which is best suited to radial networks, a circuit-breaker is connected between the busbars and earth [8]. If a fault occurs on a feeder, this circuit-breaker closes and so transfers the fault to the busbars. The voltage here drops very quickly and the fault arc on the affected line will in most cases die of its own accord. The breaker between busbars and earth then opens and the system resumes normal operation. If the fault persists, however, the sequence is repeated, but the affected line section is then also isolated at virtually no-load in the interval of the busbar short circuit. The breakers in the feeders have only limited, protective functions. They are required principally for routine switching operations, and load switches would be an obvious choice for these purposes.

Load isolators for h.v.d.c. transmission. The use of switches operating at no-load in a meshed d.c. network to maintain operation in the event of faults is described in the literature in context with an actual project [9]. Load switches are again very well suited to this kind of application.

The question of protection when load switches are used in the applications mentioned above will be discussed in detail at a later date. Here it need only be said that, from the point of view of protection, all the possibilities described are perfectly practicable without incurring any significant increase in cost.

This brief review of the range of application of load switches and the requirements which they have to meet is now followed by an example of such a unit.

**The DYLF Load Switch for Voltages from 72-5 to 765 kV**

Fig. 1 shows one pole of a type DYLF load switch for 245 kV. The insulating and control column is
mounted on an air receiver holding about 150 l. Compressed air at 26 kgf/cm² is used as the insulating, quenching and actuating medium. The composition of the basic types in the range from 123–420 kV is shown in Fig. 2. A particularly convenient solution was found to the problem of the break chambers: these could be taken over unchanged from the DMF circuit-breaker, in which they are employed as isolating chambers. The construction of these chambers is described elsewhere [10, 11]. The control system is also largely composed of elements used in the DMF breaker. It has thus been possible to provide the load switch with triple-pole and single-pole control without the need for any changes in design. Single-pole operation is required when the switch is used for earthing, as in Section 1.4.

The enclosures for the individual columns deserve special mention. If pressure is lost in the compressor system, the entire unit retains its insulating capacity and operating ability for a limited number of operations. Leakage resulting from a major defect in one column does not affect the other columns.

Fig. 1. – Pole of a pneumatic load switch type DYLF rated 245 kV, 2000 A

Fig. 2. – The principal types in the DYLF range of pneumatic load switches for 123 to 420 kV
a: 123 kV  b: 245 kV  c: 420 kV
It goes without saying that the Brown Boveri pneumatic load switch conforms to the relevant national and IEC requirements. It can interrupt a service current of 2000 A at $\cos \varphi = 0.7$, and this is also its current rating. The same value is attained for the closed-loop breaking capacity. Its breaking capacity with inductive and capacitive currents has also been verified experimentally. A line system of 436 km, for example, has been disconnected by one chamber at 173 kV without restriking.

The DYLF load switch has various features, over and above the specification, which enable it to be used generally, as described in Sections 1.1 to 1.5. It is able to close on short circuits, and making currents up to 170 kA are effectively dealt with. Its break time (from the “open” command to separation of the contacts) is 25 ms, and is thus shorter than that of most power circuit-breakers. The make time of 55 ms is also very short. Furthermore, these load switches can perform the same switching cycles as circuit-breakers.

The deciding factor in electing to use load switches is their price. The simple construction, small number of chambers for the voltage, and economical manufacture through using the same components as for the DMF range of circuit-breakers means that the DYLF type of load switch can be produced for approximately a third of the cost of a power circuit-breaker. They are thus a sound economic proposition. In addition, the capabilities of the equipment regarding making capacity, operating times and cycling ability far exceed the requirements of the specification, and it is because of this that these load switches have such a wide range of potential applications.

In short, load switches are well suited to a variety of functions in h.v. and e.h.v. networks. Fully adequate in respect of speed, reliability and switching performance they are able to contribute to secure and economical system operation.

(DJS)

G. Köppl

Bibliography

VERTICAL-REACH ISOLATORS TYPE TF
FOR VERY HIGH VOLTAGES AND CURRENTS

Referring to a large order for 550-kV vertical-reach isolators for the Tennessee Valley Authority (TVA), the authors deal with the special requirements that had to be fulfilled in respect of the electric strength. Problems associated with the passage of current, as well as those raised by operation in wind and ice, are briefly mentioned.

In the past they have been variously referred to as single-column isolators, pantograph isolators and sometimes scissors isolators. As none of these terms is strictly true in every case, the more applicable adjective “vertical-reach” has now been adopted. Considering an order for 78 isolators type TF 550 that has been executed, we will now show how all requirements, even the most exacting, with respect

Fig. 1. – Part of a switchyard of the Tennessee Valley Authority, USA, with five vertical-reach isolators type TF 550 visible in the foreground
Stipulated and measured values for 550-kV isolators as supplied to the TVA

<table>
<thead>
<tr>
<th></th>
<th>Stipulated</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage</td>
<td>kV</td>
<td>550</td>
</tr>
<tr>
<td>Rated current (Δt &lt; 35 deg C for the whole current path)</td>
<td>A</td>
<td>2000/2500</td>
</tr>
<tr>
<td>Withstand voltages¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60 c/s, 1 min, dry, to earth</td>
<td>kV</td>
<td>870</td>
</tr>
<tr>
<td>60 c/s, 10 s, wet, to earth</td>
<td>kV</td>
<td>780</td>
</tr>
<tr>
<td>60 c/s, 1 min, dry, between open contacts, 10% &gt; breakdown voltage to earth</td>
<td>kV</td>
<td>1110</td>
</tr>
<tr>
<td>Impulse 1-5/40, to earth</td>
<td>kV</td>
<td>1800</td>
</tr>
<tr>
<td>Impulse 1-5/40 between open contacts, 10% &gt; breakdown voltage to earth</td>
<td>kV</td>
<td>2380</td>
</tr>
<tr>
<td>Impulse 300/3000 (tolerance ±100/±1000) dry and wet, to earth</td>
<td>kV</td>
<td>1170</td>
</tr>
<tr>
<td>Impulse 300/3000 (tolerance ±100/±1000) dry and wet across open contacts with a peak applied 60-c/s voltage of 490 kV at the second terminal</td>
<td>kV</td>
<td>1170 + 490</td>
</tr>
<tr>
<td>Corona inception voltage (r.m.s. value)</td>
<td>kV</td>
<td>&gt; 350</td>
</tr>
<tr>
<td>Limiting short-circuit current (peak value)</td>
<td>kA</td>
<td>70 (120 kA)</td>
</tr>
<tr>
<td>Short-time current (4 s to ASA)</td>
<td>kA</td>
<td>45</td>
</tr>
<tr>
<td>Wind velocity without isolator operation</td>
<td>km/h</td>
<td>209</td>
</tr>
<tr>
<td>Wind velocity with isolator operation</td>
<td>km/h</td>
<td>64</td>
</tr>
<tr>
<td>Line tension</td>
<td>kg</td>
<td>700</td>
</tr>
<tr>
<td>Thickness of ice coating on surface of blades at which the isolator still functions properly</td>
<td>mm</td>
<td>13</td>
</tr>
</tbody>
</table>

¹ At 60 c/s, r.m.s. values; on impulse, peak values.

Stipulated and measured values for 550-kV isolators as supplied to the TVA:

Special Requirements as Regards Electric Strength

The Table shows the strict coordination requirements that were specified and which led to a design with dimensions considerably in excess of those of a normal 550-kV isolator. It was stipulated that in the face of the power-frequency test voltage at 60 c/s, impulse voltages of the form 1-5/40 and switching surges, the electric strength of the contact gap should be 10% higher than the breakdown voltage of the insulation to earth. The tests performed all proved that the isolators complied with the specification.

Special Constructional Problems

The abnormally heavy additional loads resulting from a coating of ice 13 mm thick at the maximum meant that the operating mechanism had to be given
Fig. 2. — Contact part. With four transfer points the line contact adapts itself to suit the position of the blades.

Fig. 3. — Icing test. Blades and line contact of the isolator type TF 550 before opening.

special attention. At an operating pressure of 170–230 psig, it was found that the isolator would already operate under normal conditions as low as 56 psig. There is therefore a reserve of 3 to 4 times this figure, which ensures that the isolators will indeed function reliably, even under extreme icing conditions.

A further problem arose out of the stipulation that at a rated current of 2000 or 2500 A, the temperature of current-carrying parts must not rise by more than 35 deg C. While retaining the pantograph system as used hitherto, it was necessary to adopt a design of line contact permitting current transfer at four points. All the other features of the well-tried design, such as simple, rolling pressure contacts, with a very high pressure at the points of contact, reliable operation when dirty, or in ice and snow, regardless of the degree of maintenance, have been retained (Fig. 2).

Special Acceptance Tests

Apart from the ordinary tests to prove the stipulated electric strength, as well as the guaranteed dynamic and thermal short-circuit strength, to which may be added the shear stresses imposed on the tripod insulator support, which were described in the previous articles, reference will now be made to the special tests which had to be performed to prove the ability of the type TF isolators to stand up to extremely severe climatic conditions at very high voltages and very heavy currents.

Mechanical Endurance Tests

Under normal conditions a complete isolator was made to perform 4000 switching cycles, which it did
without the least trouble, thereby proving the mechanical dependability of this design.

Behaviour when Exposed to Wind

In order to test the behaviour of the isolator in its open and closed positions at maximum wind velocities up to 209 km/h, weights were attached to represent the forces that would be imposed by such conditions. Likewise, the assembly was loaded to represent 64 km/h and made to perform a large number of switching operations, which it did without difficulty.

Proof of Reliability when Exposed to Icing

The proof that the vertical-reach isolator was still able to open and close properly when coated all over with ice 13 mm thick, was obtained by operating the isolator with corresponding weights attached to the pantograph.

During the second test the pantograph and line contact were coated with ice in the open and closed positions, the actual thickness of the ice being nearly 20 mm and thus far more than the specified value. In both cases the isolator was able to open and close without trouble, the ice at the points of contact being shattered and perfect contact being made in the closed position (Fig. 3).

The above tests thus proved that the design of the type TF vertical-reach isolators was quite capable of meeting all the requirements at extremely high voltages and currents, as well as under extreme technical and climatic conditions. The design of current-carrying and contact parts greatly facilitates maintenance and requires far less attention than other makes, a feature which is greatly appreciated by the users.

The 550-kV vertical-reach isolators supplied by Brown Boveri were the first of this type to be installed in North America and bear witness to the high esteem in which our design is held.

(KME)

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Bibliography

PACKAGED SWITCHGEAR INSTALLATIONS USING COMPACT ON-LOAD ISOLATORS

In the present article a new type of Brown Boveri switchgear installation for 12 kV is introduced, and a packaged station employing compact on-load isolators. By using solid insulation the dimensions can be considerably reduced, even at the voltages normally used for distribution. This kind of equipment should prove very sought-after in situations where space is cramped, e.g. in towns, or in industrial and residential areas.

Principle of Packaged Switchgear Stations

The persistent rise in the demand for electricity in all spheres has forced the power undertakings to augment their medium-voltage distribution networks, at the same time increasing the load density of their lines and stations. In built-up areas the question of finding space for new substations is becoming increasingly difficult. In order to keep the investment involved within tolerable limits, the costs of ground and equipment can be reduced by employing what are known as packaged switchgear installations. These employ solid insulation instead of air, which enables the design to be made very compact indeed. Apart from certain notable exceptions, these stations employ the on-load isolators that have been so successful in the past. At the same time new, compact transformers are used. The packaged station does not have to be installed as an integral unit outdoors, but can just as easily be placed in a building, be it an office block, a residential unit or an industrial building of some kind. The economic advantages of such installations are obvious at a glance. In view of the difficulties already experienced with the accommodation of distribution installations in built-up areas, it stands to reason that there should be excellent prospects for such packaged installations. The safety regulations so far drawn up by national and international bodies (VDE, UTE, IEC, etc.) in relation to distribution switchgear installations, can be applied to and satisfied by the packaged switchgear. The use of solid insulation ensures the same degree of safety in operation as attained with the equipment used hitherto.

Choice of Switchgear for Packaged Installations

Most 12-kV distribution networks are arranged as illustrated in Fig. 1. The energy is obtained from a network with a high voltage, e.g. 110 kV. The transformer stations concerned, in this case I and II, feed the power into the cables of the network through transformers and switches a, b, c, d, linking the series distribution stations III, IV, etc., with one another. This creates ring networks which in normal service are mostly opened up and operated as radial networks.

The distribution stations III, IV, V, etc., comprise:
- Two sectionalizers of the cable loop AB
- The busbars S
- One or more feeder switches C
- The transformers D
- The low-voltage distribution gear E.

Whereas the breakers a, b, c, d of the substations are primarily responsible for the supply to, and protection against short circuits of, the whole 12-kV network, the switchgear in the distribution stations A, B, C, etc., are only concerned with the normal, operational distribution of power.

The fuses of the feeder switches C have to protect the feeder against short circuits. These fuses must
be selective with respect to the breakers of the transformer station, though the time-lag of the latter must be no longer than the dynamic and thermal short-circuit strength of the m.v. network permits.

The question now arises of whether circuit-breakers, on-load isolators or some other form of switchgear ought to be employed in such stations. The answer depends largely on the operational requirements at the particular place, as well as on economical questions.

On-load isolators are very suitable as sectionals. From economic considerations circuit-breakers cannot be used, though there is a risk of personnel being exposed to danger if isolators are accidentally operated on-load. Accordingly, in the draft IEC recommendations for load switches [17A(Central Office)54] special clauses were included, covering the testing with ring loads. It is important for the ring switches, depending on the load on the ring, as well as on the location of the switch, to be able to switch frequently load currents of similar nature to those handled by the feeder breakers (e.g. active load or transformers at no-load). They must also be capable, however, of disconnecting unloaded cables or, in mixed networks, unloaded lines.

Though the frequency of operation of the on-load isolators in the ring may not be unduly severe, it must still be proved with the aid of a comprehensive test programme that they can satisfy the enhanced requirements (i.e. service and fault currents) compared with the feeder breakers, in addition to being able to close on a short circuit and interrupt all possible load currents as laid down in the relevant regulations.

The operational requirements for the feeder switch can also be satisfied by the on-load isolator, which is simpler and cheaper than the circuit-breaker, provided the task of short-circuit protection is entrusted to fuses. The fact that short circuits at transformers are so rare lends weight to this argument. The use of fuses also offers a number of advantages. For instance, at heavy fault currents their current-limiting effect ensures that the thermal and dynamic stresses imposed on the cables and the network generally are not severe, which with long cables carrying sustained currents of less than, say, 200 A may result in appreciable savings. The service current in the feeder is considerably lower than in the ring. Therefore the ratings required for these load switches are relatively small.

The load switch and the fuses must work properly
together in the face of all short circuits or overcurrents resulting in one or more fuses blowing. The interruption of the supply of current when a fuse blows in one of the three phases ought to result automatically in the load switch tripping in its three phases. This is stipulated by most power companies. The reason for this is that a failure in one phase on the h.v. side of the transformer, depending on how its windings are connected, may lead to the voltage on the load side dropping well below the specified value. This can cause contactors to drop out, control gear to become uncontrollable, electronic equipment to be damaged, and the like. Furthermore, if one phase fails, motors running at rated load may be thermally overloaded. Admittedly they are usually protected against such eventualities, but it would be too much to expect them to trip every time a h.v. fuse blows. Finally, triple-pole interruption affords added safety and makes operation of the switch easier. In order to trip a switch automatically when a fuse blows, the latter have a mechanical release which causes the switch to trip in all three phases when one fuse blows. This combined operation can only be performed properly if the load switch has sufficient breaking capacity to cope with the load or overcurrents of the other phases, in which the fuses are still intact. The situation is somewhat similar when, at quite a low fault current, a high-rating fuse takes a relatively long time to blow. Then the load switch, though tripped instantaneously, must be capable of interrupting a current equal to as much as ten times the rating of the fuse. If the load switch does possess a large enough breaking capacity, it may be combined with fuses to replace a circuit-breaker. Comparing the prices, it is quite evident that a load switch plus fuses is cheaper than a circuit-breaker, so long as short circuits are rare and the cost of replacing fuse cartridges does not become significant. The same applies to compact load switches, which can be made to fit into a remarkably small space (Fig. 2). The space gained in 12-kV installations resulting from using these compact switches is considerable, as it is possible to accommodate up to three switches in the width of a normal open-type unit. The isolator required for operation of the distribution gear can be provided in the form of a plug and socket, which takes up very little room (Fig. 3).

Design and Principle of the Compact On-Load Isolator Type RG 12i

The load switch consists of various sub-assemblies. From the very start the aim of the design was to obtain a narrow space-saving switch.

The lower part of the switch houses the operating mechanism 1 with the various tripping elements: the mechanism with the mechanical tripping gear (the
Fig. 3. - Design and principle of the switching and extinction system

Left: Switchgear open with one switch withdrawn from its service position

Right: Principle of the switching and extinction system

a: Open, springs relieved
b: Springs charged
c: Closing
d: Switch closed
e: Opening

1 = Operating mechanism
2 = Arc chutes
3 = Cable end-box
4 = Isolating plug
5 = Busbars
6 = Charging handle
7 = Closing spring
8 = Opening spring
9 = Operating rods
10 = Blast pistons
11 = Contact tube (fixed)
12 = Tulip contact (moving)
13 = Arc
14 = Exhaust cooler
15 = Nozzle
16 = Indicator
17 = Air inlet slits

By moving the charging handle 6 five times the spring operator is charged. It is released for closing or opening by the tripping handle. The arc is extinguished by a combination of air blast (piston 10) and "hard" gas effect (nozzle 15).

handle for manual tripping can be seen in Fig. 2 on one side of the charging handle), the fuse trip and remote trip with no-volt release. In the middle part of the switch are the three arc chutes 2. The current from the cable end-box 3 passes through the isolating plug 4 (which may be fused, as in Fig. 2). The connection between the switch and the busbars 5 is made at the top of the switch.

The opening and closing of the load switch is always a three-phase operation. Fig. 3 illustrates the switching sequence. The switch is assumed to start in the open state (a), the springs of the operating mechanism both being relieved. By moving the charging handle 6 five times the closing spring 7 and opening spring 8 are charged (b). The command to close is given manually by means of the handle (with knob as in Fig. 2). On closing, the operating rods 9 with pistons 10 move upwards until the contact tube 11 enters tulip contacts 12 (c). At the end of
the closing movement the closing spring is relieved, but the opening spring continues to remain charged (d).

The switch can be tripped and opened by one of the above tripping devices. If, for instance, the manual trip, this being simultaneously the opening or closing trip, is actuated a second time, the operating mechanism will release the actuating rods for the opening movement (e). The air compressed behind the pistons 10 flows through the contact tube 11, at the same time creating a down-blast on the arc 13, and is exhausted to atmosphere through the cooler 14. The heat generated by the arc produces a gas from the nozzle material 15, which facilitates the interruption of quite heavy currents.

Thus the principle of arc quenching is a combination of an air blast, independent of current, with a “hard” gas effect, varying with the current.

At the end of the opening movement, fresh air flows into the contact zone through slits 17 (e) and the switch is at once ready for the next switching cycle.

At the front of the operating mechanism there is an indicator to show what position the switch is in at any given instant and to show whether the springs of the mechanism are charged or relieved.

Isolation is performed by withdrawing the plug of ring switches or the fused plug of feeder switches. Effective interlocks are provided to prevent the plug from being inserted or withdrawn if the switch is closed.

Having first checked that the cable concerned is dead, with the aid of a voltage detector, an earthing plug connected with the station earth by copper flexible can be inserted in place of the isolating plug.

The state of the fuses can be inspected through a window (Fig. 2). To replace a blown fuse, the fused isolating plug has to be withdrawn, whereupon the defective cartridge can be changed without risk. The fused isolating plug contains normal pin-type fuse cartridges to DIN 43625, which may be used up to a rated current of 100 A. As stated already, the load switch is made to open all three phases by the pin and tripping linkage. If this is not desired, fuse cartridges without the pin may be used.

All maintenance or installation work, such as connecting a cable when the switch has been withdrawn, is on principle performed from the front, thereby simplifying these tasks in cramped conditions.

Construction of the Brown Boveri Packaged 12-kV Switchgear

Using the on-load isolators type RG 12i, various arrangements of distribution station can be obtained. Here an extremely compact “package” will be described.

The high-voltage section is an integral unit forming part of the complete station. The individual switches, busbars and cable end-boxes of the packaged installation are always supplied as a complete entity. Access to the load switches type RG 12i is obtained through the metal door, which can be locked. Two load switches form part of the closed loop, the third with the fused isolating plug being provided for the transformer. In the same part of the enclosure is a further switch cell on the left, which can be equipped with a fourth load switch for a teed line. This cell can, however, alternatively be used for a bus coupler, linking the unit with an adjacent packaged unit if the station has to be extended to cater for more feeders. In the middle section of the packaged unit is a newly developed compact transformer with a unit rating between 160 and 630 kVA. This transformer, filled with oil or askarel, has a flat conservator and a corrugated metal tank with built-on radiator pockets. The core complies with normal DIN specifications. Of course, these transformers can be equipped with all the usual accessories, such as Buchholz relays, thermometer, and the like.

The space on the right in Fig. 5 is reserved for the l.v. gear, which can be selected to suit the specific requirements of a particular installation.

Rating and Performance Data

The technical data of the installation and of the switchgear in particular had to be suitably matched to allow for their intended employment in 12-kV distribution networks.

As a result of statistically evaluated enquiries and market research, the following electrical data were
Fig. 4. Brown Boveri packaged transformer station for 12 kV

On the left is the 12-kV switchgear, on the right the l.v. distribution gear. In the space in the middle a transformer with a rating of up to 630 kVA can be accommodated.

Fig. 5. Brown Boveri packaged switchgear unit with type RG 12i load switches

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage</td>
<td>12 kV (VDE series 10N)</td>
</tr>
<tr>
<td>Rated current</td>
<td>400 A</td>
</tr>
<tr>
<td>Rated surge current</td>
<td>40 kA</td>
</tr>
<tr>
<td>Short-time rating, 1 s</td>
<td>16 kA (r.m.s.)</td>
</tr>
<tr>
<td>Dimensions:</td>
<td></td>
</tr>
<tr>
<td>Width</td>
<td>1100 mm</td>
</tr>
<tr>
<td>Depth</td>
<td>2300 mm</td>
</tr>
<tr>
<td>Height</td>
<td>1750 mm</td>
</tr>
</tbody>
</table>

The “packaged unit” can be delivered as factory-assembled transformer station equipped with transformers rated from 160 to 630 kVA, for installation indoors or outdoors, as desired.
decided upon, as they should be quite adequate for the majority of 12-kV distribution systems in Europe for many years to come.

### Switching sequence for active load and closing on a short circuit

<table>
<thead>
<tr>
<th>Number of operations</th>
<th>Making or breaking current A</th>
<th>( \cos \varphi )</th>
<th>Voltage kV</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make and break</td>
<td>5</td>
<td>400</td>
<td>0.7</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>20</td>
<td>0.7</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>400</td>
<td>0.7</td>
<td>12</td>
</tr>
<tr>
<td>Closing on short circuit</td>
<td>2</td>
<td>800</td>
<td>0.7</td>
<td>12</td>
</tr>
<tr>
<td>Make and break</td>
<td>2</td>
<td>400</td>
<td>0.7</td>
<td>12</td>
</tr>
</tbody>
</table>

The above sequence was performed without overhauling the switch or replacing the contact tips.

### Switching sequence with ring load

<table>
<thead>
<tr>
<th>Number of operations</th>
<th>Breaking current A</th>
<th>( \cos \varphi )</th>
<th>Voltage kV</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>400</td>
<td>0.3</td>
<td>25/30% of 12</td>
<td>IEC/VDE</td>
</tr>
<tr>
<td>3</td>
<td>1200</td>
<td>0.3</td>
<td>12</td>
<td>max. breaking capacity</td>
</tr>
</tbody>
</table>

The high value of 1200 A for the breaking capacity compared with the rated current of 400 A, assures the feeder switch the necessary safety margin if it is made to operate by the fuse trip in the event of a short circuit. It is in fact possible, if the fault current is relatively small, for the fuse to take such a long time to blow that the simultaneously tripped switch is forced to interrupt a current up to ten times the rating of the fuses.

The disconnection of unloaded transformers was tested with adequate reserve, without inadmissible overvoltages being produced at currents up to 30 A. Cable charging currents up to 10 A were interrupted three-phase without restriking.

### Testing the Insulating Level

Solid insulating materials have a much higher dielectric strength than air. Thus, if air is replaced.
by solid insulation in order to reduce the overall dimensions of the equipment, the reliability is also enhanced as the risk of accidental contact with live parts and of arcing is likewise reduced.

The need for safety in operating electrical installations makes comprehensive testing to ensure that the set goal has been achieved an essential part of modern development programmes.

Apart from the normal insulation tests with power-frequency and impulse voltages (e.g. as specified for the VDE series 10N) and tests at rated voltage under adverse climatic conditions, special tests were also performed to establish the quality of the parts insulated with moulded resin. Here a low-temperature test, combined with measurement of the corona inception voltage was found to be very convenient. The parts were cooled down to a temperature of $-40\, ^\circ C$. If the parts are satisfactory, the corona inception voltages, measured before and after the low-temperature test, ought to be the same.

It is a well-known fact that insulation of a conductor carrying high voltage is not sufficient protection against inadvertent contact. Therefore the operating side of the switch was covered with an earthed metal plate, separating it from the switch and busbar compartment. Also the protection against accidental contact by foreign bodies when the switch is in operation or when the isolating plug is withdrawn is assured in strict conformity with the regulations. Complete protection against dangerous voltages on the surface of insulating parts or isolated metal parts is provided by a further very effective measure. This consists in separating all such parts from the live parts by an earthed barrier. As a result creepage or fault currents on, for example, cracked insulators cannot reach the zone where contact might be possible, as they have already been led away to earth.

The Brown Boveri 12-kV packaged switchgear using compact on-load isolators meets the requirements nowadays imposed for medium-voltage distribution systems. This space-saving, factory-assembled equipment will find plenty of applications in places where space is at a premium, such as urban electricity supply stations or industrial plants. The compact design incorporating solid insulating media and metal enclosure guarantees safe operation free from trouble.
In the course of the last 40 years our tap changers have been developed for use at voltages up to 150 kV. Excellent results have been obtained during the many years' service of the countless transformers in which they are fitted. For use in 220-kV networks Brown Boveri brought out quite a new conception, in the form of the newly developed single-phase built-in tap changer type LB 245 [1], suitable for a maximum service voltage of 245 kV. The first transformer banks to be equipped with them have been in service at Sils im Domleschg substation of the Kraftwerke Hinterhein AG., Thusis, Switzerland, since 1961 [2]. It is the duty of this substation to transform the energy fed in at 220 kV from the upper stations of this scheme, as well as the output of the generators in Sils power station, and feed it into the outgoing 220 and 400-kV lines to Northern Switzerland. The largest regulating transformers at present in operation in Switzerland—they transform the energy coming in on the 400-kV lines to the distribution voltage of 220 kV and are located in the Breite substation of Nordostschweizerische Kraftwerke near Winterthur—are also equipped with these tap changers (see illustration). The transformers and tap changers of these two installations are designed for the following technical data.

<table>
<thead>
<tr>
<th></th>
<th>Sils</th>
<th>Breite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transformer rating (single-phase)</td>
<td>MVA 400/3</td>
<td>600/3</td>
</tr>
<tr>
<td>Voltage ratio</td>
<td>kV 420/220/10-5</td>
<td>420/220</td>
</tr>
<tr>
<td>Max. service voltage of tap changer</td>
<td>kV 245/√3</td>
<td>245/√3</td>
</tr>
<tr>
<td>Tapping voltage</td>
<td>V 3287/√3</td>
<td>2395/√3</td>
</tr>
<tr>
<td>Tapping rating</td>
<td>kVA 1400</td>
<td>2000</td>
</tr>
<tr>
<td>Regulating range</td>
<td>± 17 steps</td>
<td>± 8 steps</td>
</tr>
<tr>
<td>Service current</td>
<td>A 530–730</td>
<td>1414</td>
</tr>
<tr>
<td>In service since</td>
<td>1961</td>
<td>1964</td>
</tr>
</tbody>
</table>

In both installations the performance of the tap changers has been excellent. Even when such equipment is able to operate without disturbance it is valuable for the manufacturer to be able to keep track of the performance of such newly developed devices, and to compare the results with figures obtained during tests. For this reason two tap changers were removed from the tanks in each station last summer and tested, especially with respect to the long-term behaviour of the highly stressed insulation, contamination, contact erosion and mechanical wear.

In both cases the tap changers are mounted at the 220-kV input to the regulating transformers. This means that their main insulation is constantly stressed by the full phase voltage, as well as by surges occurring in the network. The new, glass-fibre-reinforced insulating material was subjected to exhaustive tests, even under very dirty conditions, and was not adopted until it had been proved...
beyond all doubt that it could be expected to satisfy the reliability requirements. Despite the continuous stresses to which all four tap changers had been subjected, it was apparent from visual inspection that neither the main insulation nor the diverter switches showed any signs of trouble or contamination. This excellent result may be attributed to the good design and construction, which prevents deposits of dirt or oil sludge collecting at critical points. The insulating oil had not become visibly cloudy and the electric strength was well above the level specified for the insulation of diverter switches. The extraordinarily clean state of the oil was due to the built-in filtration system.

It is inevitable that every on-load changing operation will give rise to some soot, depending on the load handled, due to the action of the arc on the oil, and that material will be carried away from the main contacts and blown out through the arcing chambers. Since the latter are located in the lower part of the tap changer, the few, coarse particles soon sink to the floor of the oil tank, where they can remain without causing any harm. The good resistance to erosion of the main contacts, proved during numerous tests was also confirmed in service. If the stresses remain as they have been during the first few years, it may be expected that the main contacts of the tap changers in Breite will last for another 20 years, while those in Sils should be good for 40 more years. These high figures allow for the fact that the number of tap-changing operations in Breite (about 2000 per year) is less than anticipated. Also the mechanical behaviour of the diverter switches, the gearing and the motor operating mechanism came up to expectations and they are as good as new.

Summarizing, it may be stated that the new tap changers have proved themselves in every respect in service and that the phenomena observed and predetermined stresses were all correctly estimated in advance. This excellent performance is all the more meritable, in that it has been obtained with a completely new concept of tap changer.

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Excellent Performance of Airblast Breakers on Locomotives of the French National Railways

Most of the electric locomotives and motor-coaches of the French National Railways (SNCF) for single-phase a.c. supply are equipped with Brown Boveri airblast circuit-breakers1 produced in the Le Havre factory of the Compagnie Electro-Mécanique. By up to about the middle of 1967 more than 1100 breakers of this type had been delivered, some of them to countries outside France.

The excellent performance of these locomotive circuit-breakers is borne out by statistics prepared by SNCF for the Eastern Region of their network; for 5 million kilometres travelled between 1960 and 1965 only 1 operational breakdown could be attributed to the breakers. Even so it may be underlined that efforts are constantly being made to improve the breakers, and so make them still safer and more reliable.

The increasing use of silicon power diodes in recent years on such locomotives has largely been rendered feasible by the ability of the airblast breakers to interrupt short-circuit currents extremely quickly, before they can overload the rectifier cells.

In conclusion it may be mentioned that CEM also supplied 75 locomotives overseas, all equipped with these breakers. Special measures had to be adopted with these units as they have to be able to withstand temperatures down to —50 °C.

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