RECLAMATION OF THE ZUIDER ZEE. MEDEMBLIK PUMPING STATION.
Three electrically-driven pumps equipped with Brown Boveri Scherbius sets for sub and super-synchronous speed regulation.

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OUR THREE-PHASE MOTORS WITH CENTRIFUGAL STARTERS ARE EQUALLY SUITABLE FOR LARGE OUTPUTS

FOR MANY YEARS WE HAVE BEEN SUPPLYING MOTORS FOR OUTPUTS OF

   50 to 280 H.P. with four poles
   34 " 240 H.P. " six "
   25 " 185 H.P. " eight "
   20 " 135 H.P. " ten "

PROTECTED PATTERNS • WITH DRIP-WATER PROTECTION • WITH PIPE VENTILATION WITH HORIZONTAL AND VERTICAL SHAFTS

EXCELLENT REFERENCES
ELECTRIC DRIVES IN COAL PULVERIZING PLANTS.

I. INTRODUCTION.

The introduction of pulverized coal firing for boilers raised the question of a suitable design for the motors employed. In addition to the risk of the pulverized coal exploding, due to the ignition of escaping coal dust by the fires of neighbouring boilers, or as a result of spontaneous ignition in the storage bins, there is also the danger of coal-dust clouds being ignited by electric sparks.

The liability of a mixture of pulverized coal and air to explode depends on the quantity of coal dust circulating in a given quantity of air and is greater the finer the dust and the higher the percentage of gases it contains. In general, it may be said that a cloud of coal dust which is unmixed with fire-damp or other inflammable gases is only liable to explode when it contains so much dust that it cannot be seen through. Such a mixture of coal dust and air can be formed in a coal pulverizing plant by a sudden current of air, or by some other occurrence such as a defect in a supply pipe. Then to produce the explosion, some means of ignition of sufficient intensity and duration is necessary.

II. THE COAL PULVERIZING PLANT.

Two methods of pulverizing the coal are employed in steam power stations: the storage system, in which the pulverizing plant is separate from the boilers; and the direct-fired system, in which the pulverizers are arranged close to the burners. If the quality of the coal is the same in both cases, there is no fundamental difference in the method of pulverizing the coal between the raw coal bunker and the burners. It is merely necessary to provide more or less intermediate gear for conveying the coal, such as belt or bucket conveyors, or pipe-lines.

Fig. 1 shows diagrammatically how the coal passes through the pulverizing plant. It is first supplied to the raw-coal or wet coal bunker 2. From the bunker the coal passes to the dryer 3, the rate being regulated by rotary table feeders or by scraper belts.

The coal is then carried from the dryers to the bunker 5 by a bucket conveyor 4, or, where the

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Fig. 1. — Diagrammatic arrangement of a coal pulverizing plant.

arrangement allows, directly to the mills 6. In new plants, the mills are combined with dryers so that separate dryers can be eliminated. As a rule, the coal is ground down until it will pass through a sieve of 4900 holes per square centimetre. After the mills, the dust is conveyed by the fans 7 to the cyclone separator 8 where coarse dust is separated out, to be subsequently ground again. The fine dust passes on to the bins 9 and is supplied from here by the feeders 10 to the burners.

III. THE MOTORS.

The three-phase motors supplied by Brown, Boveri & Co. for coal pulverizing plants are mostly of the type with slip rings in flame-proof enclosure (Fig. 2) or with pipe ventilation (Fig. 3)\(^1\). In addition, all the motors are provided with extra-strong insulation (tropical insulation) to counteract any reduction in the insulating properties due to deposits of coal dust. To increase their reliability still further, the motors are fitted with dust-proof bearings. Totally-enclosed fan cooled motors with cooling fins can be advantageously used for small powers.

Experience has shown that motors of the totally-enclosed type or of flame-proof design are not absolutely essential, and must be merely regarded as factors making for an increased degree of safety. A motor in which all parts subject to sparking during normal running are rendered dust-proof, and which is provided with reinforced insulation, can be considered as completely safe.

The largest motors in a coal pulverizing plant are those driving the dryers, mills, fans and feeders. A number of smaller motors are used for the intermediate conveyors. The accompanying illustrations show some drives supplied by Brown, Boveri & Co. for coal pulverizing plants. Figs. 4 and 5 show the drive for a drying drum heated by flue-gas. The slowly rotating drum is driven through a reduction gear and set of bevels by a three-phase motor of 11 kW, 500 V, 1000 r. p. m. The slip rings are in a flame-proof enclosure. The brushes of the motor

mills. Each is driven by a three-phase motor of 80 kW, 550 V, 1450 r. p. m., 50 cycles, with brushes for permanent contact, similar to those used for driving the dryers. The speed is regulated by standard starters having contact plates with dust-proof protection; one of the starters is seen on the left of the illustration. For driving fans which do not require speed regulation, motors with centrifugal starters and dust-proof protection are employed. Some drives of this type are shown in Fig. 8. The motors here are each of 15 kW at 550 V, 750 r. p. m., 50 cycles, and drive the fans of the dust separators. In Fig. 10 can be seen various small types of protected squirrel-cage motors with tropical insulation and dust-proof bearings. They are driving worm conveyors, aspirator screws and measuring wheels underneath the cyclone separators.

Another type of motor, for small outputs, which is particularly suitable for such plants is the motor with cooling fins (Figs. 9, 11, and 12). All the live parts are enclosed in a casing with external, longitudinal fins, and this in

make permanent contact so that the speed can be regulated by a resistor in the rotor circuit. The drives for some mills are illustrated in Fig. 6. The mills are of the ball type, driven through reduction gearing by three-phase motors each of 160 kW, 6000 V, 750 r. p. m., 50 cycles. The fans shown in Fig. 7 are for drawing the coal dust from the
turn by a sheet-metal cover. At the non-driving end a fan is mounted on the shaft and forces the air between the fins and the sheet-metal cover, thus cooling the casing very effectively.

IV. THE APPARATUS.

According to what was said under section I, all parts where sparking occurs must be rendered dust-proof. This is, obviously, equally true for apparatus such as starters and switchboxes. Rotor starters with oil-immersed contacts therefore enter into primary consideration.

Fig. 8. — Three-phase motors with centrifugal starters in dust-proof enclosures driving fans. Rating of each motor 15 kW, 550 V, 750 r. p. m., 50 cycles.

Fig. 9. — Totally enclosed fan cooled squirrel-cage motor with cooling fins. Sheet-metal cover open.

Fig. 10. — Squirrel-cage motors driving worm conveyors, aspirator screws and measuring wheels.

Fig. 11. — Three-phase slip-ring motor. Totally-enclosed fan cooled type with cooling fins.

Fig. 12. — Three-phase motor with centrifugal starter; totally-enclosed fan cooled type with cooling fins.
The type of switchbox with cable end boxes as manufactured by Brown, Boveri & Co. completely satisfies all the requirements imposed on the material installed in coal pulverizing plants. Fig. 13 illustrates a three-pole air-break switch with built-on ammeter and double trifurcating box as used in such plants for motors up to 45 kW at 500 V.

For larger outputs up to 460 kW at 500 V, Brown, Boveri & Co. make switchboxes with three-pole oil switches (Fig. 14). Detailed descriptions of these switchboxes have been given in earlier articles1.

If the distribution plant is installed directly in the same room as the mills, and not enclosed in special cubicles, metal-clad switchgear is employed. This results in an appreciable saving in the cables used, in much greater ease of supervision and reliability, while at the same time the amount of space occupied is a minimum. The equipment designed by Brown, Boveri & Co. for such plants is very robust so that it can withstand rough handling. By making all joints a good fit, moisture and dust are absolutely prevented from entering the apparatus. Suitable distribution plants can be built up of the individual pieces of apparatus and arranged as desired in a readily supervised manner (Fig. 15), and alterations and extensions made with the greatest ease.

(See 626) J. Senn. (E. J. B.)

1 The Brown Boveri Review, 1928, Nos. 5 and 7, pp. 158 and 211.
IMPROVING THE INSULATION OF HIGH-VOLTAGE MACHINES.

I. INTRODUCTION.

Up to the present, it has not been general practice for generator voltages to exceed about 12,000 V due to difficulties encountered with the insulation at higher voltages. It is, however, almost impossible to supply large areas economically at this relatively low voltage. The distribution plant itself is rendered very expensive, and, in addition, it becomes difficult to manufacture switchgear capable of handling the heavy currents, particularly those which flow on the occurrence of short circuits. The heavy currents necessary with these comparatively low voltages also give rise to practically insurmountable difficulties in designing the generators. For these reasons, Brown, Boveri & Co. have been convinced for a long time that the use of much higher generator voltages would be unavoidable in the future. Generators for pressures up to 17,000 V now in service, in particular single-phase machines with one pole earthed, are proving completely reliable. Nevertheless, considerable opposition is generally encountered with regard to the use of higher generator voltages, though they are now indispensable due to the continually increasing concentration of power. Some two years ago, Mr. L. Herry, chief engineer of the Langerbrugge Power Station in Flanders, approached Brown, Boveri & Co. with the request that they should build a 36,000-V generator. In view of this order and as a result of the requirements of normal progress, it was decided to submit the whole question of insulating high-voltage machines to a thorough investigation.

II. THE NEW HIGH-VOLTAGE INSULATION.

Of all insulating materials, mica is the best due to its very low dielectric losses and high resistivity to heat. The task with which the builder of electrical machinery is faced is to make insulating tubes and coverings for conductors from this material. The thin layers of mica used must form a compact layer of insulation or otherwise the insulating properties will be affected at the high field strengths by glow discharges in the thin layers of air. Micafolium has proved very satisfactory for slot insulation. Each layer of mica is carried by a thin layer of paper, itself a good insulating material when dry, and shellac is used as the binding agent.

For the generator voltages used in the past, this product has been quite satisfactory, though comprehensive research has shown that in its previous form this insulation is incapable of withstanding higher voltages.

The influence of varying proportions of mica, paper and varnish on the quality of the final product were determined by careful analytical investigations. Fig. 1 is a reproduction of a model showing the
results of these tests. The materials used — mica, paper and shellac — are marked off on the base as percentages according to a triangular system of coordinates as shown in Fig. 2. Since, with a constant field strength, the losses of a given insulating material are proportional to its volume, it is more convenient to introduce the idea of the unit loss $p$. This value corresponds to the loss of the unit volume 1 cubic decimetre ($\text{dm}^3$) reduced to a field strength of 10 kV/cm. The ordinates of the model shown in Fig. 1 represent the unit loss $p$ of the combinations of materials investigated, for a given electrical field strength and temperature, above the corresponding coordinate points of the base.

The model shows clearly that the shellac content and also the paper content have an extraordinarily large influence on the magnitude of the losses; as other tests showed, the kind of paper is also of importance with regard to the magnitude of the losses of the insulation. The less the amount of varnish, the smaller become the losses in the material, though it must always be taken into consideration that if too little varnish is used, the individual layers lose their tenacity and the losses again increase due to glow discharges in these thin layers.

Curve 1 (Fig. 3) gives the unit loss $p$ as a function of the voltage applied to an insulating material consisting of 14\% varnish. At 7 kV the ionizing voltage is reached. The layers of air begin to glow and additional losses occur which increase with increasing voltage. When the proportion of varnish is 62\%,
A further disadvantage of too small a proportion of varnish lies in the low dielectric strength when the material is in a cold condition and the voltage increases rapidly.

Even with the minimum permissible proportion of shellac, this insulation was not satisfactory at high voltages and high temperatures as regards dielectric losses. In addition, due to the fact that the shellac softens at comparatively low temperatures, the solvent vapourizes, causing the insulating material to ooze out and thus bringing about an increase in the dielectric losses, a reduction in the breakdown strength, the heat conductivity and the mechanical strength. This effect is independent of the applied voltage. It was then endeavoured to work the shellac in a dry state, merely applying heat. The dry production of insulation is, however, attended by great difficulties. Attention was therefore directed towards producing an insulating material which would be as easy to make as the insulation previously used, but which, as regards dielectric quality and resistivity at high temperatures would be superior to it.

By means of careful investigations on varnishes and different kinds of paper, it has been possible to produce an insulating material of appreciably better quality. The result is illustrated in Fig. 5. The conditions of the test such as temperature and electrical field strength are the same as for the shellac-mica-foilium (Fig. 1). The large variation as regards dielectric loss between the usual and improved insulation is very pronounced, as shown by the difference in the ordinates for the same percentage composition. Fig. 3, curve 3, shows the relationship between the voltage and the losses of a specimen made with the new insulating material having a shellac content of 33%. The losses vary only slightly with the voltage, and in spite of the comparatively high shellac content of 33%, their variation with the temperature was also very small (Fig. 4, curve 3). When cold, the losses are certainly somewhat greater than in the shellac specimen with 14% varnish, though in a warm condition they are smaller.

III. ELECTRICAL TESTS ON GENERATOR CONDUCTORS INSULATED WITH THE NEW INSULATING MATERIAL.

A knowledge of the dielectric losses at a given temperature as a function of the voltage is, as already mentioned, very useful for judging an insulating material with regard to the possible formation of air pockets. Fig. 6 shows the losses in a conductor reduced to a field strength of 10 kV/cm as a function of the voltage. Curve 1 is for a specimen with ordinary insulation, and curve 2 for one with improved insulation; in both cases, however, the dimensions and the percentage composition were the same.

The difference in the dielectric quality of the two insulating materials is obvious, as the improved insulation has smaller losses at a given voltage and is, in addition, practically independent of the voltage. In the case of the ordinary insulation the losses increase rapidly with the voltage. The big improvement in the insulation is seen still more clearly from Fig. 7 where the dielectric losses of the two conductors considered are plotted as a function of the temperature at constant voltage.

The relationship between the dielectric losses of the insulation used and the temperature, as shown in Fig. 7, is particularly important in the construction of electrical machinery.

The losses which, in good insulation, increase as the square of the applied voltage, produce heat in the dielectric, this heat causing a certain temperature drop according to the heat conductivity of the material. It is clear that a condition will be attained in which,
at a given voltage and a given temperature, the heat produced by the dielectric losses can just be conducted away to the surrounding medium. A condition of equilibrium will thus prevail, the heat produced being equal to the heat conducted away, and there is no reason why the equilibrium should be disturbed if the voltage and temperature are maintained constant.

If, however, the voltage is raised, the temperature remaining constant, the losses increase according to the relationship between the dielectric losses and the voltage. More heat is then produced than can be dissipated to the surrounding medium with the given heat conductivity of the material, i.e., the temperature of the material increases. The higher temperature again causes further losses at the same voltage and thus the production of heat continues to increase without the voltage being raised, until finally the insulating material is damaged due to carbonization, and a breakdown occurs. This complete process is known generally as a heat breakdown, the voltage at which the condition described is stable as the continuously maintained voltage, and that at which the process becomes unstable as the limiting voltage. The change from one condition to the other is clear from Fig. 8, which will be studied more closely later. The resistance to heat of the material is thus one of the factors determining the maximum permissible voltage during continuous operation. Another factor is the heat balance for the insulation in the machine, namely:— Heat produced in the insulation by dielectric losses — heat due to losses in the copper conductors = Heat conducted away. Thus the insulation of a machine can be loaded with a correspondingly higher voltage, the smaller the losses, the less close the dependence on the temperature, the greater the heat conductivity and the higher the permissible temperature.

Some conductors for a 36-kV generator were insulated with the new insulation and subjected to a continuous test under conditions corresponding to those in actual service. These were as follows:— The stator iron was maintained at a temperature of 70° C, and the copper conductor — of corresponding cross-section — was heated to 125° C by the current. The voltage between conductor and iron was kept constant for several hours. The results of the test are reproduced in Fig. 8. The pressure of 57 kV was carried without difficulty. The losses decreased with the time. After an hour the condition of heat equilibrium was attained. The pressure of 60 kV which, as seen from Fig. 8, can also be carried permanently, may be regarded as the critical voltage, because a slight increase in the pressure to 63 kV quickly causes the breakdown of the insulation. The losses increase rapidly and the temperature in the layer of insulation attains inadmissible values. In a star-connected machine, the critical voltage of 60 kV corresponds to a terminal pressure of about 100 kV.

In addition to the purely analytical tests, the influence of the manufacturing process, such as drying and impregnating, on the quality of the final product were also investigated. It is mentioned here that by adopting a suitable manufacturing process the losses in the material were very considerably lowered
so that an insulation can now be made, the losses of which, when warm, are about twenty times less than those of ordinary insulation.

During these investigations of the material and method of manufacture, the question of insulating the winding outside the slot and particularly just at exit from the slot, was studied. As is well known, when the voltage on a cylindrical bushing is gradually increased, discharge phenomena take place at the mounting in the following order:—corona, brush discharge, pilot sparking and, as a result of the last-named when the current is heavy enough, breakdown. As regards the stresses imposed by the voltage, the conditions at the ends of the slots in generators are the same as at the mountings of bushing insulators. The same discharge phenomena are observed in both cases. Between the iron of the generator (the mounting) and the conductor of the coil, the lines of force are approximately as in Fig. 9. The iron and the conductor thus form a two-layer condensor with dielectric constant \( \varepsilon \) and electrical conductivity \( \lambda \). According to Wagner's Theory, charges always collect on the layer separating the two insulating materials, air and insulation, when the unbalanced equation \( \varepsilon_1 \lambda_2 \neq \varepsilon_2 \lambda_1 \) exists. Due to corona on the iron, the layer of air becomes conductive. In one half-period, charges accumulate in the dividing layer, and in the next half-period fly back to the iron. Now since the strength of the charges decreases with increasing distance from the iron, a voltage is produced tangentially at the surface of the casing. This tangential voltage causes a discharge on the insulation, and, if the voltage is sufficient — i.e., if the charge builds up rapidly enough — leads to a spark discharge.

By means of the Brown Boveri corona protection sleeve and the application of a layer of varnish, the dangerous layer of air at the end of the slot is removed. With this arrangement, the insulation at the ends of the slots is such that at a test voltage of 100,000 V, scarcely visible discharges occur, whereas with conductors of earlier design, it was possible to detect discharges at 30 kV. The great breakdown strength of the new insulation is shown by tests carried out on bars for the previously mentioned 36-kV turbo-generator, during which breakdown voltages of over 200 kV were reached.

IV. MECHANICAL STRENGTH OF GENERATOR CONDUCTORS INSULATED WITH THE NEW INSULATING MATERIAL.

In designing electrical machinery, a knowledge of the mechanical properties of the insulation used is as important as a knowledge of the electrical characteristics. This applies particularly to turbo-
machines in which sudden current rushes subject the windings to high mechanical stresses.

The model-tests were conducted under conditions closely resembling those encountered in practice, the greater part of the length of the conductor being rigidly held by clamps (Fig. 10). The free end projecting greater part of the length of the conductor being clamped as in Fig. 10.

During these bending tests, with the conductors in a cold and warm condition, the breakdown strength of the insulation was tested, in order to determine the invisible effects produced, in addition to the visible formation of creases and cracks in the insulation.

The most important results from numerous tests are given in Table I. The superiority of the improved insulation over the ordinary kind is very clear from these figures. As the measurements on the 3-5 mm thick insulation show, the permissible deflection for the same breakdown strength is much higher for the improved insulation than for the usual material. The difference in the permissible deflection recorded for specimens 1 and 2 is accounted for by the different insulation was tested, in order to determine the formation of creases and cracks in the insulation.

It is seen that the insulation is appreciably weakened by the proportion of the ordinary insulation. When in a warm condition, larger deflections are permissible than when cold, the breakdown strength being the same in both cases.

Another valuable indication of the quality of the improved insulation is provided by the alteration in the dimensions due to heating to high temperatures. Fig. 11 gives the alteration in the depth and also the width on heating the conductor to 150 °C in clamps as in Fig. 10.

The ordinary insulation runs out due to the shellac softening and the solvent vapourizing. Such phenomena were not observed in the case of the improved insulation. The wave form of the curves — particularly curve 4 — in Fig. 11, is accounted for by the deflection of the casing between the clamping bolts under the influence of the high pressures.

Flowing out of the varnish at the end of the casing at high temperatures is of great practical importance because, on cooling down, air pockets form in the insulation, giving rise to corona losses and other phenomena. Table II shows the relative quantities of material which flow out with various insulations when heated to 145 °C. The quantity

<table>
<thead>
<tr>
<th>Dimension of slot mm</th>
<th>Thickness of insulation mm</th>
<th>Temperature of insulation °C</th>
<th>Max. deflection Δ mm</th>
<th>Measured length L mm</th>
<th>Breakdown voltage in kV</th>
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<tr>
<td>24×43</td>
<td>3-5</td>
<td>17</td>
<td>6-5</td>
<td>100</td>
<td>250</td>
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<td>24×75</td>
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<td>3-0</td>
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<td>17</td>
<td>8-0</td>
<td>150</td>
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<td>6-0</td>
<td>100</td>
<td>29</td>
<td>150</td>
<td>28</td>
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</table>

*) = Point at which breakdown occurred.
flowing out in the case of ordinary insulation at 145° C is taken as unity. During these measurements, the conductors were encased along their whole length as in Fig. 10.

### TABLE II.

<table>
<thead>
<tr>
<th>Thickness of insulation</th>
<th>Proportion of ordinary insulation</th>
<th>Proportion of improved insulation</th>
<th>Relative quantity of varnish flowing out at</th>
</tr>
</thead>
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<tr>
<td></td>
<td>Total mm</td>
<td>70° C</td>
<td>100° C</td>
</tr>
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<td>mm</td>
<td>mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>0.097</td>
<td>0.390</td>
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</tr>
<tr>
<td>6</td>
<td>3</td>
<td>0</td>
<td>0.240</td>
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</table>

### V. CONCLUSION.

In the foregoing article, a report has been given of an improved insulation for generators. The usual basic materials of insulation, namely, mica, paper and varnish, were used, but by careful analytical investigations the effect of varying proportions of these materials on the magnitude of the losses in the final product was investigated. These investigations also showed that the shellac used up to the present as the binding agent is not suitable for high voltages even when the constituents of the insulation are combined in the most favourable proportions. In the improved insulating material made with the new varnish, the relationship between the dielectric losses and the voltage and temperature is much more favourable.

In addition to the above-mentioned analytical investigations, the influence of the method of manufacture on the quality of the final product was investigated. As a result of the tests carried out it was possible to reduce the dielectric losses of the material to about 1/20 of those of ordinary insulation.

A further advantage of the improved insulation is the higher breakdown strength both during continuous operation in a warm condition and also on the occurrence of excess voltages of short duration.

Conductors for a 36-kV generator were arranged in a manner corresponding exactly to the service conditions and were subjected for many hours to a pressure of 60 kV without breaking down. For short periods, breakdown voltages of over 200 kV were attained.

Furthermore, the improved insulation has a much higher mechanical strength than the ordinary kind, and in addition does not flow out when heated, like shellac insulation.

At the same time as the slot insulation was improved, the insulation outside — particularly at exit from the slot — was also investigated. By utilizing the Brown Boveri arrangement of protection against corona effects, visible discharges at exit from the slot were practically eliminated, even at a test voltage of 100,000 V, whereas on conductors of previous design there were pronounced discharges at 30 kV.

The improved insulation will satisfy in every respect the high generator voltages which will be encountered in the near future.

(MS 624) F. Beldi. (E. J. B.)
THE MERCURY-ARC RECTIFIER INSTALLATIONS OF THE CONSOLIDATED MINING & SMELTING COMPANY OF CANADA, LTD., TRAIL, B. C.

At the end of the nineteenth century, when electricity was first employed on a commercial scale, it was almost invariably generated in the form of direct current, which accounts for the large number of d-c. lighting and power networks still existing in the central and older parts of large cities. Since then it has been superseded in many of its previous applications by alternating current. There are, however, a number of applications for which direct current may be advantageously used, the most notable of these being electric traction and electro-chemistry, which latter, from its very nature, must use exclusively direct current. Generally speaking, both electric railways and electro-chemical works obtain their supply of direct current by the same method, i.e., high tension a-c. networks are tapped at a convenient point, the voltage is stepped down to a suitable value and then converted into d-c. at the required voltage either by motor generators, rotary converters or mercury-arc rectifiers. There are, naturally, many cases in which power stations are erected to generate direct current without going through the intermediate stage of a-c. but such cases form a minority. The question as to what type of converting machinery is to be employed is in the majority of cases of prime importance.

The advantages of mercury-arc rectifiers for traction purposes are so well known that they need not be reiterated here, more especially as rectifiers are now in extensive use on electric railways and tramways in all parts of the world. The application of rectifiers for electro-chemical purposes is, however, of so recent date that comparatively little is known on this subject. The object of this article is therefore to indicate the reasons which induced the Consolidated Mining & Smelting Company of Canada, Ltd. to order 16,500 kW of rectifier conversion machinery from Brown, Boveri & Co. in December, 1928, for the electrolytic preparation of zinc, the same company ordering in July, 1929, a further 13,000 kW of rectifier conversion machinery from Brown, Boveri & Co. for the electrolytic preparation of hydrogen.

The Consolidated Mining & Smelting Co. of Canada, Ltd., is one of the largest mining concerns and the largest producer of electrolytic zinc and lead in Canada. Hydrogen for the manufacture of fertiliser will also be produced on a very large scale by this company in the near future. The main refining and smelting works are situated near Trail, B. C. The necessary power for the supply of this plant is furnished by the West Kootenay Power & Light Company and is generated at the following three hydro-electric power stations located on the Kootenay River.

(1) Lower Bonnington (No. 1 Plant, three alternators of 17,500 kVA each).
(2) Upper Bonnington (No. 2 Plant, four alternators of 7500 kVA each).
(3) South Slocan (No. 3 Plant, three alternators of 17,500 kVA each).

Upper Bonnington generates at 2300 V, three-phase, 60 cycles, whereas Lower Bonnington and South Slocan generate at 7200 V, three-phase, 60 cycles. The alternator voltage is stepped up either to 20,000 V or 60,000 V and is transmitted over five transmission lines to the Trail Smelter, approximately thirty miles away. The power stations are paralleled on the high-tension side. At the Smelter end, the voltage is stepped down for the supply of a large number of motor generators, rotary converters and mercury-arc rectifiers feeding electrolytic cells, as well as for feeding various synchronous and induction motors in the Smelter plant. Of particular interest is the installation of ten booster type rotary converters, each rated at 2500 kW, and feeding direct current at 470–550 V to cells for the electrolytic preparation of zinc and cadmium. These sets have recently been modified so that they can be operated in pairs, forming one unit, the normal current of which is 9000 A. The transformers of the rotaries are connected directly to the 60-kV bus-bar.

Due to the acid-laden gases and fumes in the vicinity of the zinc plant, the cooling air for the rotaries is carefully cleaned by means of special washing devices. In spite of such precautions, however, zinc and acid fumes find their way into the rotary converter room and precipitate themselves on the machines. It is therefore necessary that commutators, slip rings and windings be cleaned periodically in order to maintain continuity of service.

Mercury-arc rectifiers present an all-metallic exterior, are static machines and cooled internally by water, so that acid fumes and deposits of metallic
oxide can have no deleterious effect upon them owing to the absence of commutators and slip rings. The rectifier being a stationary apparatus and not under the influence of synchronizing forces, is not affected by disturbances such as sudden voltage fluctuations and variation in frequency in the primary supply line, to which the rotary converter is sensitive. These advantages of the rectifier are of great value, particularly where it is used for electrolytic purposes. They were some of the determining factors for the engineers of the Consolidated Mining & Smelting Company of Canada, when they decided to order Brown Boveri rectifiers for the extension of their zinc plant. A further factor which influenced the engineers' decision was the question of space. It was found that by using rectifiers it would be possible to install four 10,000-A units without any appreciable modification in the design of the substation building, whereas if rotaries had been used it would only have been possible to install three units of the same output in the same space, and also radical alterations to the building would have been necessary, due to the increased head-room and crane capacity required. This is a typical example of the great advantages of mercury-arc rectifiers, viz., the small floor space required per kilowatt.

Power for the supply of the four rectifier units of the zinc plant is taken from the 60-kV bus and is subjected to a double step-down. It is led through Brown Boveri oil circuit breakers with a rupturing capacity of 1,000,000 kVA to a bank of three single-phase transformers of 8500 kVA each. Fig. 1 shows two of these step-down transformers, built by the American Brown Boveri Co., Inc., as well as the oil circuit breakers of the above capacity. The transformers are designed according to A. I. E. E. Standards and are of the oil-immersed type and cooled internally by water, at a temperature of 21°C. The secondary voltage of these transformers is 13,200 V. Since it is intended to install a fourth rectifier unit in the near future, the step-down transformer bank has been provided with sufficient capacity for the ultimate installation of four rectifier units.

The characteristics of the zinc cells require that the d-c pressure should be regulated between 460 and 560 V at a constant current of 10,000 A. In order to effect this regulation, it was necessary to equip the primary windings of the rectifier transformers with suitable taps connected to a separately mounted tapping switch for operation under load. Current is therefore taken from the 13,200-V bus over a three-phase oil circuit breaker of Brown Boveri design to the tapping switches of the rectifier transformers. Fig. 2 shows a cross-section through the substation and Fig. 3 the general layout. The relative positions of rectifiers, tapping switches and transformers are clearly indicated. The average output of the rectifier transformers is 7800 kVA, each transformer feeding two 5000-A rectifiers, forming a 10,000-A unit. These transformers are also of the oil-immersed, internally water cooled type. At the rated load of 10,000 A d.c., the temperature rise of the transformers is in accordance with A.I.E.E. Standards, but in certain emergency cases the units may be called upon to supply 12,000 A, in which case a larger temperature rise is permissible. It is worthy of note that the dimensions of the rectifier transformers were such that it was possible to locate them in a deep basement. The average kVA output of the transformers, as determined by the rectifier, amounted to 7800 kVA.
The height attained is 3.85 metres and the width 2 metres; Fig. 2 clearly shows the transformers in the basement, into which they are lowered through suitable openings in the main floor.

The emergency rating of 12,000 A alluded to above is necessary, because experience has shown that on the occurrence of sudden variations in frequency and line voltage, the rotary converters frequently flash-over. The momentary voltage drop on the system which accompanies the rotary flash-over usually causes all the other synchronous machines and converters at the Smelter to trip out. The resulting loss of approximately 50,000 kVA of synchronous load causes the line voltage at the Smelter to rise. The rectifiers are naturally unaffected by frequency and voltage variations, so that they not only remain on the line during these disturbances, but take a larger load due to the increased line voltage, which load in turn tends to limit the rise of frequency and voltage, i.e., the rectifiers stabilize the whole system. A special relay with adjustable time lag is provided to reduce the rectifier d.c. voltage should the load exceed safe limits during these periods.

The actual layout of the substation was dictated by the existing building. Fig. 4 shows a view of the interior of the substation with the rotary converters in the background. Fig. 5 shows one set of two rectifiers forming a 10,000-A unit. The anode cables leading to the rectifier transformers are clearly visible. All the control switchboards are mounted in the rectifier room. All oil circuit breakers, d.c. circuit breakers and tapping switches are motor-operated so that an attendant in the rectifier room is able to control the entire substation.

The rectifiers were first put into commercial operation during the latter part of December, 1929. With the exception of a few
interruptions necessary for making adjustments and replacing some defective parts, the rectifiers have all been operated under continuous full-load up to the present time, so that it is confidently expected that their sterling qualities and marked advantages will recommend them for more extensive application to electrochemical work than has hitherto been the case.

Mention was made earlier in this article that the Consolidated Mining and Smelting Co. of Canada, Ltd., had ordered a further 13,000-kW rectifier plant from Brown, Boveri & Co. for feeding cells for the electrolytic production of hydrogen from water. This is viewed in the nature of a trial plant which, if it proves satisfactory, will undergo considerable extension within the next few years. The two rectifier sets of this hydrogen plant will be fed directly from the 60-kV bus through transformers of 9000 kVA average capacity without any intermediate step-down. Direct current is taken at 650 V to the cells, the units being again rated at 10,000 A.

This substation will be described in detail in a later article, but reference should be made here to one unique advantage of rectifiers over rotary converters when applied to the electrolytic preparation of hydrogen. Despite all modern precautions it remains possible for rotary converters and generators to reverse their polarity, causing current to flow from cathode to anode in the electrolytic cells, instead of vice versa. Hydrogen is thereupon formed at the anode and oxygen at the cathode, which gases are led away to the storage tanks where they may form an explosive mixture with the gases already in the tanks. Should the gases explode, the total destruction of the plant might be caused with an enormous subsequent loss of life and capital. With the application of mercury-arc rectifiers, the possibility of an explosion occurring is completely eliminated, since,

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NOTES.

Increasing the output of reciprocating compressors by charging with turbo-blowers.

Decimal index 621.653 + 621.512.

When a plant using compressed air is extended, it frequently happens that the compressor supplying it, although still working perfectly, has an output too small for the increased demand. In such cases, the simplest means of raising the capacity is to provide a charging blower which supplies air already compressed to the main compressor, thus increasing the weight of air handled by the latter. Even when the main compressor is of the reciprocating type—which may be more suitable than a turbo-machine because the pressure ratio compared with the delivery volume is too great—it is generally practicable to use a turbo-blower as the charging blower. Since in all practical instances of any importance the charging blower has only a small pressure ratio to overcome, turbo-blowers can already be considered for delivery volumes which are not very large. For large delivery volumes, their well known advantage—resulting from their high speed—of only occupying little space, is of particular importance where they have to be installed in existing plants.

Increasing the suction pressure of the main blower generally has an influence on the power consumption of the machine. It is usually endeavoured, however, to leave the driving machine unaltered, either because its output cannot be increased, or because a given reserve of power is to be retained for operation with raised barometric pressure and low suction temperature, or in case there should be fluctuations in the final pressure. Actually, it is not impossible for the power consumption of the main compressor to remain constant although the initial pressure is increased, because the reduction in the remaining pressure head, or in other words, in the amount by which the air must be further compressed, has a contrary effect. This is shown in the following example.

The equations for isothermal compression without loss can be used. Since only relative values enter into consideration in the calculation, the deductions hold good provided the efficiency of the main compressor remains constant. In practice, this may be assumed to be the case with a sufficient degree of accuracy. Denoting the atmospheric and intermediate pressures by the suffixes 0 and 1 respectively, and using the generally accepted abbreviations, then from the fundamental equations for constant power (N)

\[ N_0 = p_0 v_0 \log_e \left( \frac{P}{p_0} \right) \]

\[ N_1 = p_1 v_1 \log_e \left( \frac{P}{p_1} \right) \]

\[ N_0 = N_1 = \text{constant} \]

(where \( p \) is the final pressure), the further condition is obtained that the volume \( V_1 \) of the main compressor must satisfy the equation

\[ \frac{V_1}{V_0} = \frac{p_0 \log_e(p/p_0)}{p_1 \log_e(p/p_1)} \]  (1)

i.e., the power to drive the main compressor remains unaltered if the volume when compressed satisfies equation (1). This gives the variation of the charged suction volume \( V_1 \), compared with the original value \( V_0 \), as shown by Fig. 1 for various final pressures. The surprising fact is now observed that in spite of the increase in the quantity of air delivered, the suction volume of the main compressor must decrease. Therefore either the speed or the volumetric efficiency must be reduced for the charging pressures which enter into practical consideration.

The minimum volume of the main compressor is obtained by differentiating equation (1) for \( p_1 = P \) (where \( e \) is the base of the natural logarithm) this giving:

\[ \left( \frac{V_1}{V_0} \right)_{\text{min}} = \frac{p_0}{P} \log_e \left( \frac{P}{p_0} \right) \]

The corresponding numerical values, from which the actual values must therefore be chosen as remote as possible, are given in the table overleaf.

![Figure 1](image-url)
It will be realized immediately that it is impossible to reach this minimum value when high-pressure compressors are to be charged, both on account of the high final pressure which the blower would have and also on account of the reduction in the volume for the main compressor by up to 2\% at 1000 kg/cm$^2$ abs.

On the other hand, as shown by Fig. 1, the original volume of the main compressor is again reached as the intermediate pressure increases. The corresponding value of the latter is determined from the expression

$$\log e p = p_1 \log e p_i - p_0 \log e p_0$$

which is derived from equation (1) for the value $V_i/V_o = 1$. This equation, which cannot be solved for $p_i$, is represented diagrammatically in Fig. 2. The curve shows that, in general, the intermediate pressure determined by constant volume of the main compressor leaves practically no further compression work for the main compressor. This arrangement would be uneconomical, and therefore in practice an ap-

As before, let $V_i$ be the pre-compressed suction volume of the main compressor, and $V'_o$ that of the charging blower; then these two quantities are combined by the simple relationship

$$\frac{V'_o}{V_i} = \frac{p_1}{p_0} \cdot \frac{T_o}{T_i}$$

On multiplying by equation (1) the following equation is obtained:

$$\frac{V'_o}{V_o} = \log e \left(\frac{p_i}{p_0} \cdot \frac{T_o}{T_i}\right)$$

**Fig. 2.** Charging pressure $p$, with constant power consumption and suction volume of the main compressor, for varying final pressure $p$.

**Fig. 3.** Increase in the output by charging.

---

<table>
<thead>
<tr>
<th>Final pressure</th>
<th>$kg/cm^2$ abs</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>20</th>
<th>100</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charging pressure for $(V_i/V_o)_{min}$</td>
<td>kg/cm$^2$ abs</td>
<td>2.21</td>
<td>2.94</td>
<td>3.68</td>
<td>7.36</td>
<td>36.8</td>
<td>368</td>
</tr>
<tr>
<td>$(V_i/V_o)_{min}$</td>
<td>kg/cm$^2$ abs</td>
<td>0.81</td>
<td>0.707</td>
<td>0.626</td>
<td>0.407</td>
<td>0.125</td>
<td>0.019</td>
</tr>
</tbody>
</table>

---

preciable reduction in the suction volume of the main compressor must almost always be reckoned with.

The still more important question of the possible increase in the delivery quantity can now be considered.
This equation is still further simplified if an inter-cooler is provided after the charging blower—a measure giving a practicable arrangement—so that \( \frac{T_1}{T_0} \) may be assumed equal to 1 with a sufficient degree of accuracy. The full-line curves in Fig. 3 are valid for this case, while the dotted lines refer to charging without intercooling. The general expression

\[
\frac{T_1}{T_0} = 1 + \frac{1}{\eta_{ad}} \left( \frac{P_1}{P_0} \right)^{ \frac{K-1}{K} } - 1
\]

then holds, an efficiency \( \eta_{ad} = 70\% \) referred to the adiabatic being included for the charging blower.

Naturally the increase of output which can be obtained without intercooling is considerably smaller, as the higher initial temperature of the main compressor corresponds to a smaller weight compressed at a given volume. For an increase in the output by an amount not exceeding 20 to 30 \( \% \) (according to the final pressure), charging without intercooling also enters into practical consideration, as shown by the curves, without the temperature becoming inadmissibly high.

The methods of adapting the reciprocating compressor to the modified operating conditions must be examined for each case separately. As a rule it is found that the cylinder, crank shaft and driving mechanism are more heavily stressed, which is generally permissible in two-stage compressors provided the charging pressure is not very great.

As already mentioned, another factor to be considered is the temperature at which the air enters the main compressor after charging. The lubrication of the cylinder must also be adapted to the increased temperature if no intercooler is provided.

The reduction in the suction volume of the main compressor, as mentioned on reference to the curves in Fig. 1, must also be accorded particular attention. With steam engine or d.-c. motor drive this entails no difficulties because the speed can be altered as required. If, however, a three-phase driving motor is employed, the cylinder must be provided with an increased clearance volume. This can be continuously regulated by pistons and thus any delivery quantity desired obtained. This method has the great advantage of operating practically without loss, though sometimes the additional clearance volume takes up a comparatively large amount of space. Regulation by means of a by-pass valve can also be employed, some of the air from the first stage of the main compressor being allowed to flow back. This system, however, entails a corresponding loss of power so that if the original driving power of the main compressor is not to be exceeded, the charging pressure must be increased.

In conclusion it may be stated that no fundamental difficulties are encountered in using turbo-blowers for increasing the output of existing reciprocating compressors. They offer a very advantageous method of increasing the output of existing plants by double the original amount or more, while at the same time requiring very little space. In this connection, attention is also drawn to the fact that the low-pressure part of high-pressure compressors, which are generally of the reciprocating type, can be built to great advantage as turbo-machines.

(MS 619)  A. Baumann. Dr. R. Landsberg. (E. J. B.)

Acceptance tests on two turbo-generators built by Brown, Boveri & Co. for the Portobello Power Station of Edinburgh Corporation.

During last January, acceptance tests were carried out on two 31,250-kW Brown Boveri turbo-generators installed in the "Portobello" Power Station of Edinburgh Corporation.

These two turbo-generators, of which the first one has been running since February, 1929, and the second since October of the same year, were built for the following conditions:—

Three-cylinder turbine.

Steam pressure at stop valve . . . 21-4 kg/cm² abs.
Steam temperature at stop valve . . . 371° C
Average cooling water temperature . . . 13° C
Speed . . . . . . . . . . . . . . 1500 r. p. m.

Generator.

Output . . . . . . . . . . . . 36,750 kVA
Voltage . . . . . . . . . . . . 6700 V
Frequency . . . . . . . . . . . . 50 cycles
Power factor . . . . . . . . . . . . 0-85

In the accompanying table the results obtained during the official acceptance tests are given, together with an analysis of results.

The turbine is designed with one tapping branch only for feed water heating; during the tests, however, only the steam passing to the condenser was measured, the tapping branch being closed by a blank flange. All instruments were calibrated before and after the tests by the National Physical Laboratory in London.

1 Particulars kindly supplied by Messrs. Maschinenfabrik Burckhardt A.G., Basle, and Messrs. Sulzer Brothers Ltd., Winterthur.
Official acceptance tests on Brown Boveri Turbo-Generator No. 7 at the Portobello Power Station of the Edinburgh Corporation on the 10th January, 1930.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>9—10</td>
<td>10.30—11.30</td>
<td>12—1</td>
<td>3—4</td>
</tr>
<tr>
<td>Load</td>
<td>1/1</td>
<td>3/4</td>
<td>2/4</td>
<td>5/4</td>
</tr>
<tr>
<td>Steam pressure at stop valve</td>
<td>kg/cm² abs</td>
<td>21.37</td>
<td>21.13</td>
<td>21.6</td>
</tr>
<tr>
<td>Steam temperature at stop valve</td>
<td>°C</td>
<td>362.0</td>
<td>368.7</td>
<td>371.5</td>
</tr>
<tr>
<td>Vacuum at turbine exhaust</td>
<td>kg/cm² abs</td>
<td>0.0315</td>
<td>0.0269</td>
<td>0.0226</td>
</tr>
<tr>
<td>Output at generator terminals</td>
<td>kW</td>
<td>25.068</td>
<td>18.739</td>
<td>12.714</td>
</tr>
<tr>
<td>Steam consumption measured</td>
<td>kg/h</td>
<td>102,850</td>
<td>77,085</td>
<td>54,385</td>
</tr>
</tbody>
</table>

**Corrections.**

<table>
<thead>
<tr>
<th>Load</th>
<th>%</th>
<th>%</th>
<th>%</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam pressure</td>
<td>-0.0</td>
<td>-0.13</td>
<td>0.0</td>
<td>-0.30</td>
</tr>
<tr>
<td>Steam temperature</td>
<td>-1.30</td>
<td>-0.30</td>
<td>+0.06</td>
<td>-2.80</td>
</tr>
<tr>
<td>Vacuum</td>
<td>+0.45</td>
<td>+0.60</td>
<td>+0.64</td>
<td>-0.10</td>
</tr>
<tr>
<td>Total correction</td>
<td>-0.85</td>
<td>+0.17</td>
<td>+0.70</td>
<td>-3.20</td>
</tr>
<tr>
<td>Steam consumption corrected</td>
<td>kg/h</td>
<td>101,976</td>
<td>77,206</td>
<td>54,765</td>
</tr>
<tr>
<td>Steam consumption corrected</td>
<td>kg/kWh</td>
<td>4.068</td>
<td>4.12</td>
<td>4.307</td>
</tr>
<tr>
<td>Steam consumption guaranteed</td>
<td>kg/kWh</td>
<td>4.073</td>
<td>4.193</td>
<td>4.44</td>
</tr>
<tr>
<td>Difference from guarantee</td>
<td>%</td>
<td>-0.12</td>
<td>-1.73</td>
<td>-2.98</td>
</tr>
<tr>
<td>Average steam consumption guaranteed</td>
<td>kg/kWh</td>
<td>4.19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average steam consumption measured</td>
<td>kg/kWh</td>
<td>4.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difference between measured and guaranteed steam consumption</td>
<td>%</td>
<td>-1.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Test No.

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guarnated vacuum</td>
<td>kg/cm² abs</td>
<td>0.0345</td>
<td>0.03105</td>
<td>0.029</td>
</tr>
<tr>
<td>Adiabatic heat drop referred to guarantee conditions and before stop valve</td>
<td>kcal/kg</td>
<td>260.6</td>
<td>263.4</td>
<td>265.2</td>
</tr>
<tr>
<td>Measured steam consumption referred to guarantee conditions</td>
<td>kg/kWh</td>
<td>4.069</td>
<td>4.12</td>
<td>4.309</td>
</tr>
<tr>
<td>Efficiency referred to output at terminals</td>
<td>%</td>
<td>81.15</td>
<td>79.2</td>
<td>75.3</td>
</tr>
<tr>
<td>Efficiency of generator</td>
<td>%</td>
<td>95.7</td>
<td>94.7</td>
<td>93.0</td>
</tr>
<tr>
<td>Efficiency at coupling for turbine alone referred to conditions before stop valve</td>
<td>%</td>
<td>84.7</td>
<td>83.6</td>
<td>80.9</td>
</tr>
</tbody>
</table>

1. The alternator fan is integral with the alternator rotor and the exciter is direct coupled to the main generator. No other auxiliary power has, however, been included in the above test results.
2. The large number of figures after the decimal point results from the conversion from English to metric units.
3. The average steam consumption was calculated as follows:
   Steam consumption at 5/4 load multiplied by 1
   4/4 × × × 4
   3/4 × × × 3
   2/4 × × × 2
4. The above heat drops and efficiencies were worked out from Stodola's Entropy Diagram, 6th edition.

The tests carried out show, above all, that the results obtained are very satisfactory, the measured average steam consumption being 1-4% better than the guaranteed steam consumption. For the other turbo-generator the results were also very satisfactory, the measured average steam consumption being 0-72% better than guaranteed. The efficiencies must be regarded as particularly good when consideration is taken of the very high vacua obtaining during the tests.
Three Brown Boveri turbo-generators, each with an output of 10,000/12,500 kW, were installed in the same power station at the end of 1922 and since then have been in continuous service and have always given complete satisfaction with regard to efficiency and operation.

(MS 625)

R. Vodoz.
BROWN, BOVERI & COMPANY LIMITED
BADEN (SWITZERLAND)
WORKS: BADEN AND MUNCHENSTEIN (SWITZERLAND)

MARCONI'S WIRELESS TELEGRAPH CO., LONDON.
Chelmsford rectifier plant, 400 kW, 15,000-V direct-current pressure.

MERCURY-ARC POWER RECTIFIERS FOR
WIRELESS TRANSMISSION STATIONS