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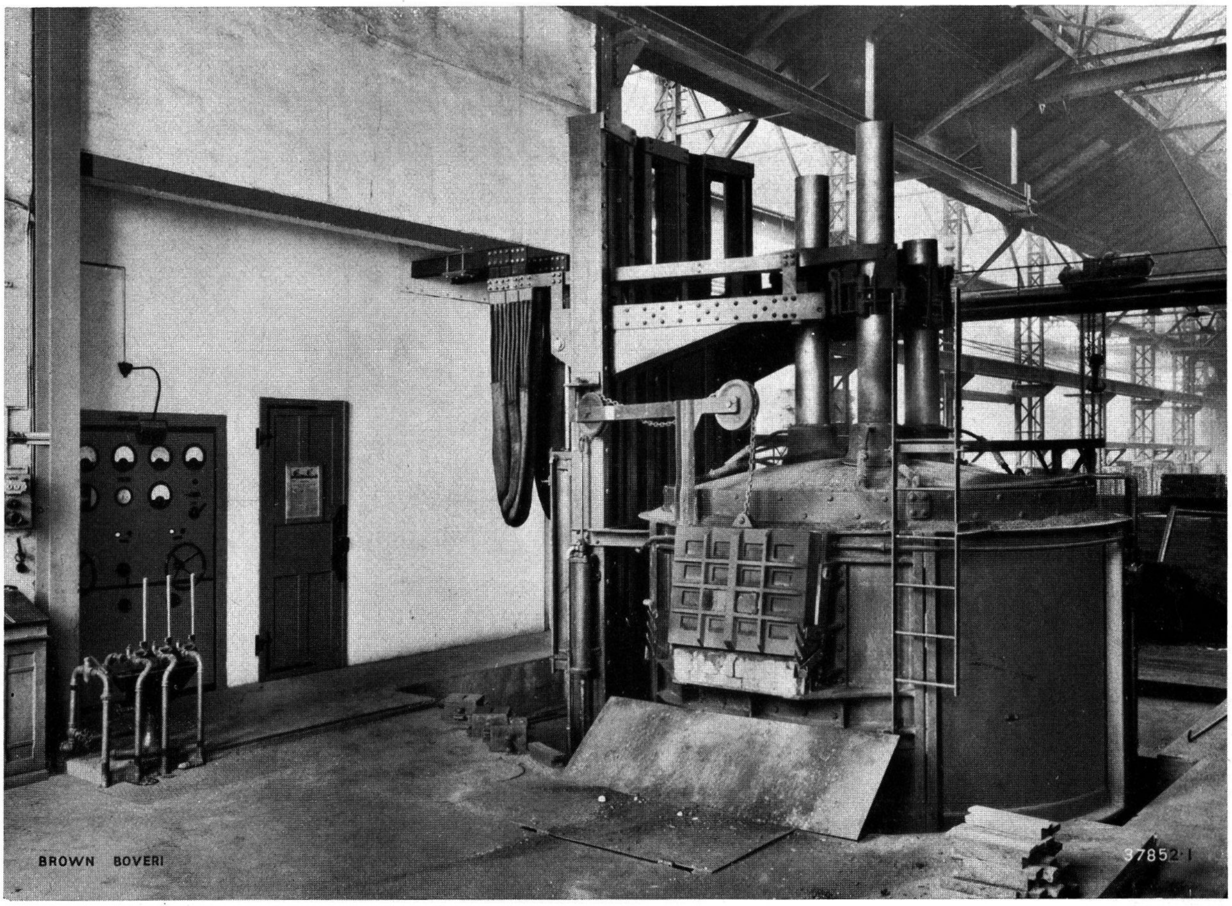
THE BROWN BOVERI REVIEW

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



A. G. ADOLF SAURER, ARBON (SWITZERLAND). ELECTRIC-ARC MELTING FURNACE FOR SPECIAL CAST IRON. CAPACITY 6–7 t.

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AUTOMATIC REGULATION OF BIG ALTERNATORS AND SYNCHRONOUS CONDENSERS.

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THE regulator of the direct-action type, that is to say one in which the measuring organ of the regulator acts directly on the regulating resistance of the system being regulated without the aid of any external source of power, has proved extremely satisfactory in practice. It was very logical, therefore, to hold to this basic principle as long as possible and only to introduce special excitation connections to reduce the duty demanded of the regulating resistance, in cases where ordinary connections meant stressing the said regulating resistance with its contacts too highly.

The following paragraphs are devoted to comments on some of these special excitation connections and to a description of a regulator with servo motor which allows the contrary solution, namely regulation with the usual connections for the regulating resistance. This leads to a discussion of the merits and disadvantages of the two solutions in question.

The Brown Boveri automatic pressure regulator with rolling sectors is the classic type of direct-action regulator. It was first put on the market 25 years ago and gave such a good account of itself, not only when fitted to Brown Boveri generators but with machines by other makers as well, that there are, to-day, 11,000 of these regulators working, all over the world. This figure refers only to regulators for stationary generators and does not include those used for train lighting, which work on the same principle; of these more than 22,000 have been delivered.

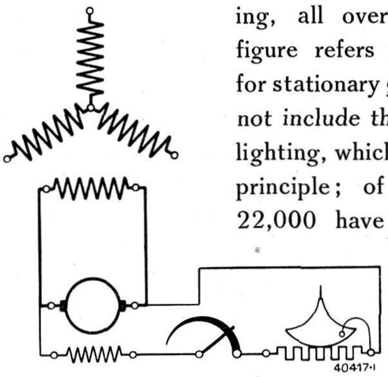

Fig. 1. — Basic diagram of regulating connections for regulation carried out in the shunt circuit of an exciter with auto-excitation.

The most standard connections of the Brown Boveri regulator are shown in Fig. 1. The regulating resistance of the regulator is inserted in series with the hand-operated rheostat and takes the place of the latter under ordinary circumstances. The exciter has auto-excitation and all regulation is carried out in its shunt circuit. Suitable design of the magnetic circuit of the exciter (regulating poles, etc.) impart to its characteristic an incurved shape (Fig. 2) and this gives stable regulation of voltage in the ratio of 1 to 5, which is sufficient to allow of regulating in the shunt circuit of the exciter solely, between no load and full alternator load, taking into account the usual voltage fluctuations and possible overloads. With this diagram of connections there is practically no limit to the use of the Brown Boveri regulator with rolling sectors. Alternators for slow speeds from 20,000 — 30,000 kVA and turbo alternators of 100,000 kVA can be regulated in this manner without difficulty.

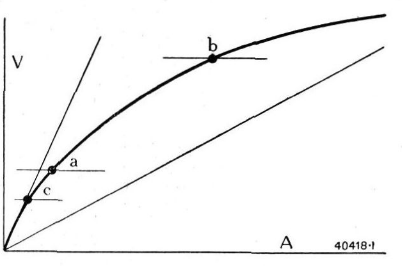

Fig. 2. — Standard characteristic of an exciter having regulating poles.

A. Shunt current of the exciter.
V. Voltage at exciter terminals.
a. Point corresponding to the no-load operation of the alternator.
b. Point corresponding to the full-load operation of the alternator.
c. Limit of stability of the exciter.

If, however, the alternator is required to operate under-excited, as happens, for example, when a long high-tension line is to be charged, regulation in the shunt circuit of the exciter no longer suffices, because the exciter becomes unstable if regulated below about one fifth of its standard voltage. Now, in certain cases, it is necessary to reduce the excitation of alternators working on capacity loads to very low values indeed even down to zero or to negative values. This happens with synchronous condensers, generally designed to work not only over-excited but under-excited, as well, in order that they may be made full use of. In these cases recourse must be had to independent excitation of the exciter which is generally attained by mounting a pilot-exciter on the shaft end. In this case, the regulating resistance of the regulator as well as the field rheostat are generally either connected in series or else in potentiometer connection when very low excitation values are required (Figs. 3a and b).

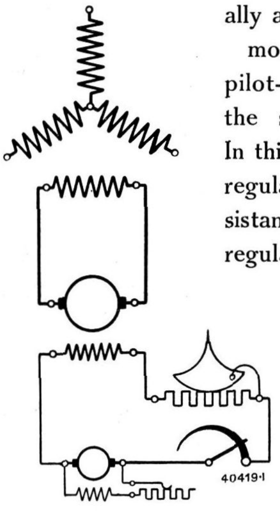

Fig. 3a. — Basic diagram of regulating connections of an exciter having separate excitation and regulating resistance connected in series.

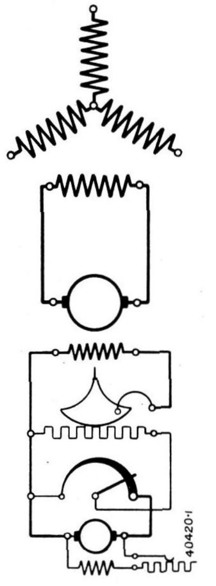

Fig. 3b. — Basic diagram of regulating connections of an exciter having separate excitation and regulating resistance in potentiometer connection.

In principle, the Brown Boveri regulator can also be used with machines having pilot exciters and this either with series (Fig. 3a) or potentiometer connection (Fig. 3b). However—and this applies chiefly to potentiometer connection—the contacts are then subjected to undesirable stressing on account of the constant excitation voltage, so that these connections can only be used in a general way with low-power and medium-power generators. It must be remembered, however, that the use of pilot exciters has chiefly become general with generators of large outputs as it is obviously machines of this type which are called on to work on long-distance power-distribution systems.

The satisfactory results obtained with regulators having rolling sectors seem to point the way to be followed, namely the adoption of some special connection which allows of using standard regulators despite the limited capacity of their contacts. The regulating work accomplished by the regulator had to be reduced without affecting the speed and stability of regulation. These conditions led to the elaboration of a diagram of connections shown in Fig. 4 and termed *regulation with compounded auxiliary exciter*. The auxiliary pilot-exciter is equipped with an ordinary shunt winding and with a series winding as well, which is very powerful as compared to the shunt winding. The latter only produces about 20 % of all the excitation required at full load, the remaining 80 % being produced by the series winding. The regulating resistance of the regulator as well as the field rheostat for hand regulation are in potentiometer connection, so that the excitation of the main exciter can be reduced to very low values and even to zero when the alternator is working on full capacity load. When the excitation current of the main exciter is zero, the compounding component of the auxiliary exciter is also zero and the excitation of the latter machine is determined by the shunt winding alone and is reduced to its lowest value. The potentiometer is subjected to a much lower voltage, at weak excitation than at maximum excitation, which results in much less stressing of the regulator contacts and allows of using the connection in question with machines of very high output. The following alternators, among many others, are equipped with automatic regulating with auxiliary exciters:—

Alternators of the Cardano power station (five sets of each 36,000 kVA at 252/300 r. p. m., 42/50 cycles and three sets of each 9000 kVA at 250 r. p. m., 16 2/3 cycles).

Alternators of the Mese power station (33,000 kVA, 420/500 r. p. m.).

Alternators of the Galleto power station (three sets of each 35,000 kVA, 337/375 r. p. m.).

Synchronous condensers of the Nagoja power station (two sets of each 30,000 kVA, 600 r. p. m.)

Synchronous condensers of the Musocco and Bovisio power stations (three sets of each 10,000 kVA, 630 r. p. m.).

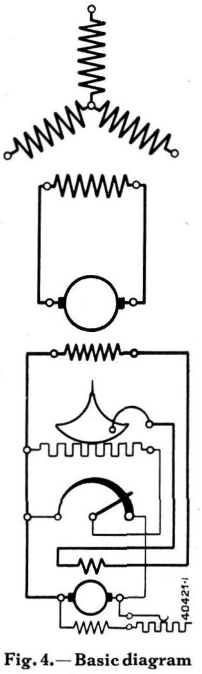

Fig. 4.— Basic diagram of regulating connections with compounded auxiliary exciter.

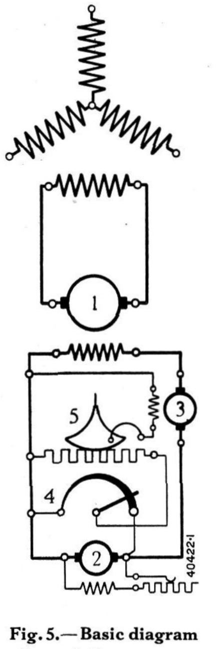

Fig. 5.— Basic diagram of regulating connections with double auxiliary exciter.

1. Main exciter.
2. Pilot exciter at constant voltage.
3. Regulating exciter.
4. Field rheostat.
5. Automatic regulator.

The solution of the question, just described, with compounded auxiliary exciter, calls for a special design of auxiliary exciter which in many cases may present some difficulties while, in other cases, the auxiliary exciter may already be built and, therefore, cannot be altered. These factors led to using a *double auxiliary exciter* the principle of which is made clear by the diagram of connections shown in Fig. 5. An auxiliary exciter 2 with ordinary characteristic, which can be replaced by a battery of accumulators, or any other source of auxiliary current at constant voltage, supplies the excitation of the main exciter 1. The regulating exciter 3 is inserted in the excitation circuit of 1. The voltage of 3 is opposed to that of 2 and the excitation of 3 is influenced by the hand rheostat 4 or by the automatic regulator 5. Owing to the potentiometer connection of the regulating resistances of the field rheostat or the automatic regulator, the voltage of the regulating exciter can be made to fluctuate from zero to a maximum value, the latter being chosen equal to or greater than the voltage of the exciter which works to constant voltage. In this way, the excitation of the main exciter can be made to vary between a maximum value and zero and even be made to become negative to counteract remanent voltage.

The regulating exciter 3 has only got to be designed for a relatively low output and, being separately excited, its time constant is, practically, negligeable as compared to that of the main exciter and of the alternator. The very wide range and capacity of regulation, sufficing for the requirements of all cases met with in practice, have no deleterious effect on the rapidity of regulation of the Brown Boveri regulator. This connection was used for the following alternators, among others:—

Handeck power station (four sets of each 28,000 kVA, 500 r. p. m.).

Aelvkarleby power station (five sets of each 13,300 kVA, 500 r. p. m.).

Motala power station (three sets of each 6000 kVA, 167 r. p. m.).

The two systems of connection just described (compounded auxiliary exciter according to Fig. 4 and double auxiliary exciter according to Fig. 5) have given entire satisfaction from the point of view of range of regulation, of rapidity of regulation and of stability. Comparative tests proved that the rapidity of regulation is equal and in some cases superior to that of certain regulators having servomotors and designated as being extra-rapid. The systems just described, call, however, for a special design of the pilot exciter in the shape of a compound winding or of a double machine. As said at the beginning of this article, the Brown Boveri regulator is used not only with generators built by Brown Boveri firms but extensively with generators by other makers. In fact during recent years, only 25 to 30 % of the regulators delivered were intended for use with generators built by Brown Boveri or their concessionary companies, the other 70 to 75 % were for machines built by other makers. On the one hand, the machine manufacturers did not care for the solutions just described as they meant special designs of the exciters, on the other hand the problem of automatic regulation is not always studied from the very first; in fact, very often the problem only comes up when it is too late to modify the design of the machines. Finally, the direct drive of the double auxiliary exciter is not always feasible and separate drive, which is the alternative, may be an adverse factor to service reliability of the set. It is true, nevertheless, that the speed governors of hydraulic turbines, instead of being direct-driven, are being driven more and more frequently, to-day, by electric motors supplied either from an auxiliary generator mounted on the shaft end or, even, simply from a transformer connected to the alternator terminals. The problem of the double auxiliary exciter drive is identical to that of the governor and it follows that if the drive of the speed governor can be satisfactorily solved in the way just described, the problem of the drive of the double auxiliary exciter can be considered as solved.

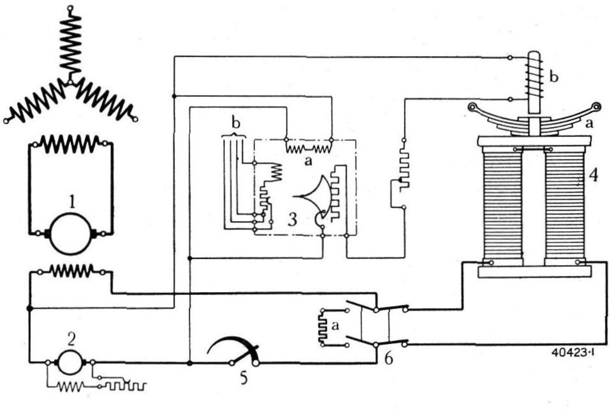

Fig. 6. — Basic diagram of connections of the carbon-pressure regulator.

1. Main exciter.
2. Pilot exciter at constant voltage.
3. Control regulator.
3a. Electro-magnetic damping.
3b. To the voltage and current transformers.
4. Piles of carbon discs.
4a. Spring.
4b. Electro-magnet.
5. Field rheostat.
6. Commutator for:— automatic regulation or hand regulation.
6a. Resistance.

The considerations just enumerated led Brown Boveri to examine the possibility of adding to the direct-action regulator a device acting as intermediary servo-motor so as to allow of regulating the most powerful machine units according to the diagram shown in Fig. 3, that is to say simply by means of a standard pilot exciter giving constant voltage. In studying this possibility, efforts were directed to the preservation of the standard regulator as control organ, so as to incorporate in the new apparatus essential organs which had proved their reliability in the course of years. The object sought after was attained by means of the arrangement shown in Fig. 6, which comprises a standard type A 4/1 regulator as control regulator and a certain number of carbon discs acting as a regulating organ.

The property of a column, or pile, of carbon discs to vary its ohmic resistance within wide limits, according to the pressure to which the pile is subjected, has been known for a long time. The numerous tests carried out with the object of utilizing this property directly to regulate voltage by altering the pression through the agency of a coil subjected to the voltage to be regulated never gave entirely satisfactory results on account of the inaccuracy of the device. It is only by combining a standard regulator as control regulator along with a certain number of carbon piles that the object sought is attained, namely to get sufficient regulating power without prejudicing the precision and speed of regulation.

Fig. 6 illustrates the operating principle of the *carbon-pressure regulator*. As shown in the preceding paragraphs, the regulating apparatus is composed of the control regulator 3 formed by a standard regulator with rolling sectors and by a certain number of carbon piles 4. These piles are inserted in series in the excitation circuit of the main exciter 1 which is, itself, excited by the pilot exciter 2 working under constant voltage. These piles are ordinarily maintained compressed by a powerful spring 4a. The pressure of this spring may be completely counteracted by the action of the electro magnet 4b, the excitation of which is determined by the regulating resistance of the control regulator 3. It is easy to understand why the precision of the system depends solely on the precision of control regulator 3. Further, as the travel of the armature of electro magnets is only one or two millimetres, the variation of the resistance follows the variation in the position of the control regulator instantaneously.

The change-over switch 6 allows of passing from automatic to hand regulation and vice versa. As the resistance of the piles of discs never falls to zero even under the greatest pressure, but only goes down to a minimum value, a fixed resistance 6a equal to this minimum value is inserted by means of the change-over switch so as to avoid perturbations when passing from hand to automatic regulation and vice versa.

In order to get sufficient damping effect, the control regulator 3 is equipped with two electro-magnets supplied from the voltage of the pilot exciter, instead of with permanent magnets as is the standard practice.

The carbon-pressure regulator has been applied with success to the biggest alternators, driven by hydraulic turbines, in service in Europe, namely to the 32,500-kVA alternators at 75 r. p. m. working in the Ryburg-Schwörstadt power station (of which there are four sets) and to those in the Albbruck-Dogern station (three sets), both on the Rhine. However, in spite of the excellent results attained in the two plants in question (high precision, very rapid regulation, certain reliability of operation, lack of parts subjected to wear), the carbon-pressure regulator has still some drawbacks in principle which oppose its general application. To begin with, it does not allow of simple shunt (potentiometer) connection, to allow of bringing the voltage down to zero, nor of bridge connection when a negative excitation voltage is required. This prevents it being used, unless the excitation can be sufficiently reduced by means of a series resistance. On the other hand, it is difficult to incorporate in it the desired number of ohms or to make it carry a sufficient load in the case of high resistances or of heavy currents. Finally, its rather high cost is an obstacle to its being used with any other than very big generators for which the price of the regulator proper is not of primary importance.

These considerations led Brown Boveri to seek some device which would allow of solving all the regulating conditions met with in practice and with whatever connections might be required for the regulating resistance, the regulator being powerful enough for the requirements of the most difficult cases of regulation met with while its price remained sufficiently low. As it seemed impossible to find a solution with an apparatus based on the rolling sector principle, oil under pressure was, once again, resorted to as a source of intermediate power to operate the contact device. It was, however, clear from the first, that it would be impossible to follow the beaten track in this field and the problem had to be approached from quite a new angle if a practical design was to be evolved.

As is well known, the principle of using oil under pressure as a source of auxiliary power, as is done in steam-turbine and water-turbine regulators is far from new, and voltage regulators based on the said principle have been on the market for

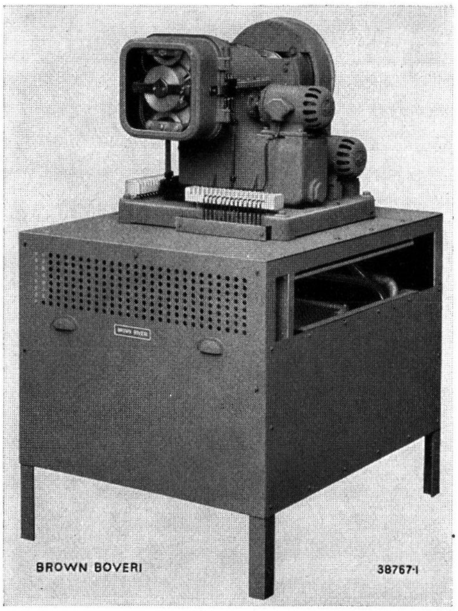

Fig. 7. — High-capacity regulator, seen from the side of the control organ.

a long time. If the use of the regulators in question has not become more general, the reason must be sought in their deficient mechanical construction. The contact device, in particular, has never been designed for continuous, sudden and rapid movements such as result from automatic regulation. In certain cases, the automatic regulator, acting through chains, simply influences the hand-operated field rheostat which is obviously not intended or designed for service of the nature required. Further, the operating devices are often so complicated that operators fight shy of them. The new apparatus, therefore, had to be exempt of these defects, had to be simple and strong and have a contact device able to stand up to continuous operation with sudden and rapid movements. The *new high-capacity Brown Boveri regulator* meets all the requirements in question. It is composed of: —

(a) The controlling organ with its damping system and recall device.

(b) The servomotor operated by oil under pressure, with the oil pump and the vibrator.

(c) The contact device under the form of a commutator having moving brushes.

(d) The regulating rheostat.

Fig. 9 gives the diagram of connections of the high-capacity regulator and Figs. 7 and 8 show the complete apparatus.

The controlling organ is chiefly composed of a motive system on the Ferraris principle identical to the motive system used in the Brown Boveri rolling-contact regulator. A laminated iron ring carries two windings, one being direct-connected to the secondary terminals of the voltage transformer, an additional resistance 1 b being inserted on the circuit of the second winding. This produces a torque, according to the Ferraris principle. A second resistance 1 a in series with the total motive system allows of adjusting the apparatus to the exact voltage desired. A mechanical torque created by main and auxiliary springs is opposed to the electric torque. The main spiral spring is wound up in the inside of the central housing (Fig. 8) while the auxiliary spring is invisible. When the voltage to be regulated attains its proper value, the two torques are in equilibrium and the motive system is at rest. If the voltage exceeds the value set, the electric torque becomes the stronger, causing a displacement of the motive system, which, in its turn, acts on a cylindrical distribution slide and sends oil under pressure on to the impulsion blade of the servomotor. The latter carries round the movable brush of the regulating rheostat thus causing the variation of excitation necessary to produce re-establishment of the voltage adjusted to.

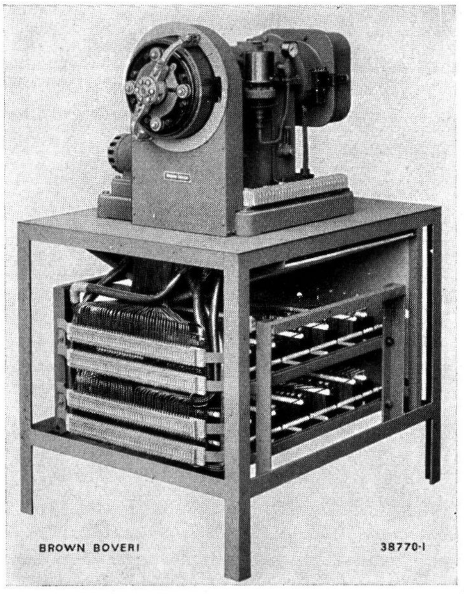

Fig. 8. — High-capacity regulator, seen from the side of the contact device.
(Housing of the regulating resistance removed)

Fig. 9 shows single-phase connections of the voltage regulator. The motive system can also be designed for three-phase connection making it impervious to whatever dissymmetries may be created when certain short circuits occur.

The auxiliary spring allows of correcting the characteristic of the main spring so that the mechanical torque may be made constant on the whole extent of the way travelled through or may be made slightly weaker at full excitation than at reduced excitation. This latter characteristic, termed static characteristic, has been made use of, for many years, in the Brown Boveri rolling-contact regulator and has shown itself very suitable for regulating high-power machines. The static characteristic would result in a higher voltage at no-load than at full-load and to avoid this variation in the voltage the secondary current of the compensating transformer 5 is made to influence the motive system through the agency of resistance 1 c, the primary winding of the said transformer being subjected to the current of the alternator. A kind of compounding results from this which compensates the voltage drop caused by the static quality of the regulator. The compensation thus attained does not depend on the absolute current value alone but also on the angle between current and voltage, that is on the p. f. of the alternator,

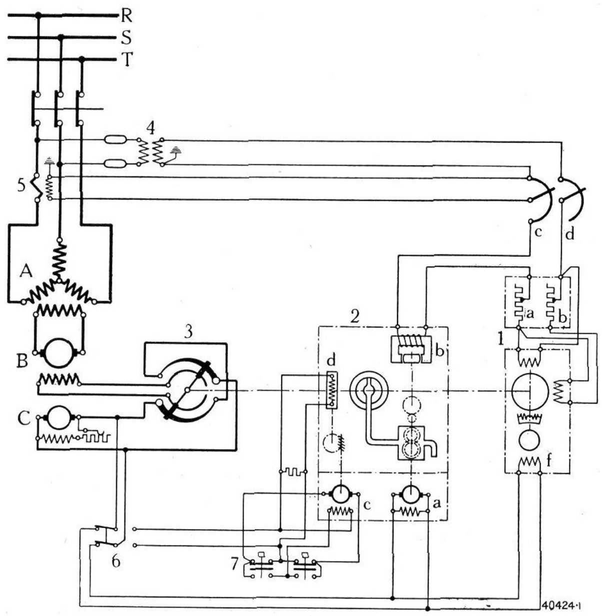

Fig. 9. — **Basic diagram of connections of the high-capacity regulator.**

1.	Control organ.	3.	Rheostat with contact device.
1a, 1b.	Additional resistance.	4.	Voltage transformer.
1c.	Compensating resistance.	5.	Current transformer for compensation.
1d.	Adjusting rheostat.	6.	Commutator for:— automatic regulation or hand regulation.
1f.	Electro-magnetic damping.	7.	Push buttons.
2.	Oil-pressure servo-motor.		
2a.	Motor of oil pump.		
2b.	Vibrator.		
2c.	Motor for regulation by hand.	A.	Alternator.
		B.	Auxiliary exciter.
2d.	Electro-magnetic coupling.	C.	Pilot exciter with constant voltage.

compensation being less for a current lagging considerably and increasing as the p. f. approaches 1. Thus by combining the static characteristic with the compensating transformer, not only constant voltage is attained but perfect parallel operation of the alternators among themselves as well as with other power stations.

However, although the static characteristic is the one most frequently used for alternator regulation, it is also possible to impart an astatic characteristic to the regulator when it is used for an alternator working alone or for stabilisation by polygone connections. This latter system of connection is particularly interesting in the case of several synchronous condensers operating in parallel. Further the high-capacity regulator, either static or astatic, can be compounded to compensate for a voltage drop in a transmission line, just as is done in Brown Boveri rolling-sector regulators.

The damping device, 1 f, is composed of two aluminium discs connected to the axle of the regulator through gear wheels and a recall spring. These discs rotate between the poles of two electro-magnets. By using electro-magnets excited by the auxiliary exciter, a more powerful braking effect is attained than with permanent magnets. The damping device eliminates superfluous movements of the motive system as well as hunting when regulating takes place. The elastic connection between the damping device and the axle of the regulator allows displacement of the latter far beyond the new position of equilibrium, when necessary, that is to say when violent load fluctuations have to be dealt with and this property surmounts the magnetic inertia of the machines and gives rapid regulation. The motive system is brought back, in due time, by the recall spring which is stretched in such a way as to eliminate hunting and to give, practically, aperiodic regulation. This powerful excess of excitation, although transitory, combined with the elastic recall forms one of the fundamental principles of rapid regulation.

Like the main spring and the auxiliary spring, the recall spring can be adjusted easily. The compensating influence and that of the damping device can also be set according to desire. It is, thus, possible to adjust the regulator perfectly to the most varied service conditions and characteristics of the machines to be regulated. On the other hand, the electromagnetic damping device used, based on the eddy-current effect, is the only one the action of which is independent of temperature or of the quality of some liquid, as used in other apparatus; this cannot be said of either cataract-type dampers using oil or air and employed in the oil-pressure regulators known up till to-day.

By means of the adjusting rheostat 1 d, in series with the motive system, the regulated voltage adjusted to by the regulator and the dividing up of the wattless load in parallel operation can be set at will.

The *servomotor* with rotary distribution slide which is controlled by the motive system, the geared oil pump driven by motor 2 a and the oil tank are all inside a housing with removable cover and are, thus, very accessible. The distributor is formed of the rotary distribution slide, itself directly controlled by the control organ and moving (rotating) inside a cylindrical sleeve provided with a blade or fin. In the stationary position, the apertures in the sleeve are closed by the distribution slide and the oil has access to neither side of the blade. If the voltage deviates from the value set, the control organ displaces the distribution slide, the corresponding aperture is uncovered and the oil, under pressure, has access to one side of the blade, which displaces the latter and, with it, the moving brush of the contact device. In moving, the shaft of the contact device recloses the aperture which was opened by the distributor and this interrupts the regulating movement. This shows that the distributor recloses after each regulating movement. A special recall device is, therefore, quite unnecessary here.

If, for any reason, the supply of oil under pressure fails, the contact device of the rheostat remains in the position where it was before, thus causing no perturbations in the operation of the alternator. A contact-type manometer then operates an alarm device.

The coil of the vibrator 2 b is inserted on the voltage circuit of control regulator 1 (Fig. 9). The rotor or armature of the vibrator is driven by the motor which drives the oil pump, and it produces a frequency of about 7 cycles. The vibrator, therefore, acts as a self-induction coil the inductivity of which varies periodically as the armature rotates. Even if the alternator voltage remains constant the voltage at the regulator terminals fluctuates in accordance with the frequency given by the vibrator. The moving drum of the control regulator is able to follow these vibrations and, thus, oscillates continuously which gives it the highest possible degree of sensitiveness. These vibrations, however, are only imparted to the rotary distribution slide and are not perceptible on the brush of the contact device, the position of which depends on the real value of the alternator voltage only.

Fig. 8 shows the design of the contact device. A moving arm is mounted on a shaft connected to the shaft of the distributor and this arm carries the brush rockers and brushes. This arrangement of the contact device in the form of a commutator is particularly well suited for rapid and frequent movements and has already been applied successfully to field rheostats submitted to severe service conditions. It is characterized by very low friction losses which allows of using a relatively small servo-motor. When required, the commutator can easily be turned up again. Both shafts are carried on ball bearings to reduce friction to a minimum.

The *regulating resistance* is lodged in the lower part of the apparatus, in a frame which forms the support of the regulator proper. The resistance is built like an ordinary field rheostat. Eternite plates, forming a flue, allow lateral dissipation of heat developed in the rheostat. Thanks to the design of the contact device in the shape of a commutator, it is easy to give the rheostat the number of contact steps required for good hand regulation; thus, the rheostat of the regulator replaces the usual field rheostat.

To leave a free hand for mounting the regulator where most convenient, a small motor has been added allowing of operating the rheostat from a distance, when hand regulation is being carried out. Thus cumbersome chain drives, often the cause of trouble, are eliminated. The motor used for hand control is connected to the shaft of the rheostat through an electro-magnetic coupling the coil of which is put under tension only when hand regulation is to be carried out.

The transition from automatic to hand regulating or vice versa is simply made by means of a two-pole change-over switch. In the "automatic regulation" position, the motor of the oil pump is under tension, supplied by the auxiliary exciter; when going over to hand regulation, the rheostat remains in the position in which it is and can be controlled by push-buttons 7. This transition can take place at any moment without causing the slightest perturbations in service.

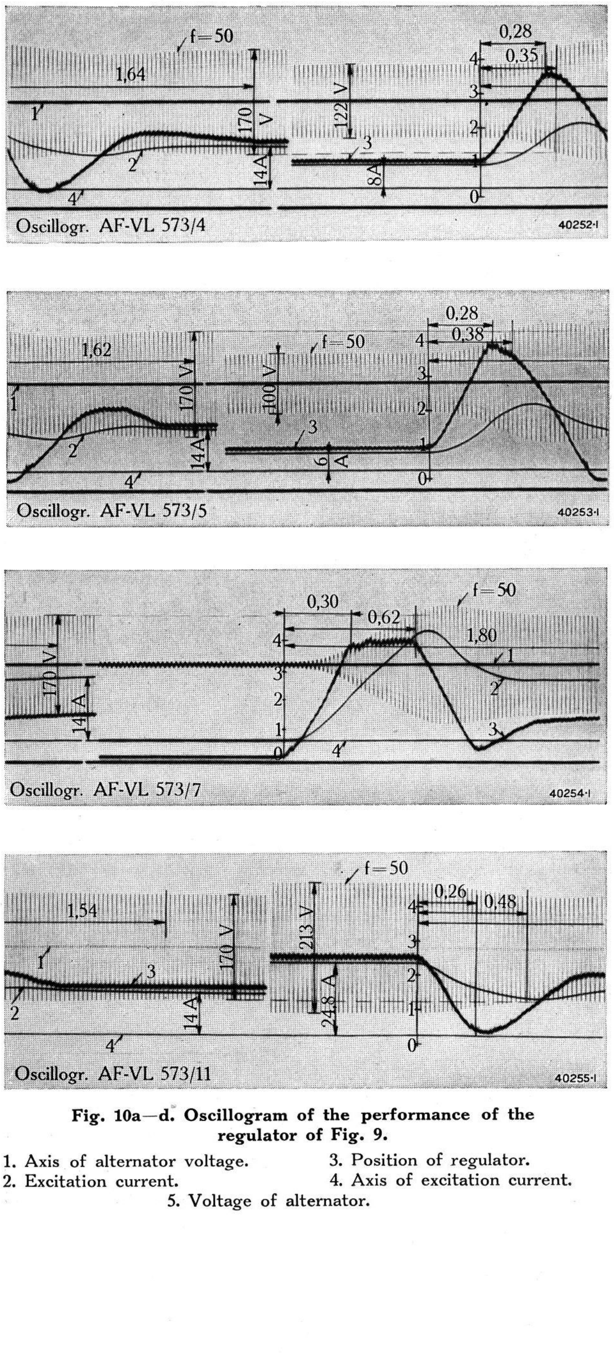

Fig. 10a—d. Oscillogram of the performance of the regulator of Fig. 9.

1. Axis of alternator voltage.
2. Excitation current.
3. Position of regulator.
4. Axis of excitation current.
5. Voltage of alternator.

According to regulating conditions called for, the resistance of the rheostat can be connected up either in series (when regulation between a maximum positive value and a minimum positive value is sufficient) or in potentiometer connection (for regulating between a positive maximum and zero) or, finally in bridge connection (for regulating between a positive maximum and a negative maximum value, after passing through a zero value).

High-capacity regulators built by Brown Boveri have already been delivered to the Rapid Blanc Plant Power Station in Canada, for the regulation of four alternators of each 36,000 kVA, 109 r. p. m. and also to the Chandoline power station of the S. A. "La Dixence" (Canton Valais, Switzerland) to be fitted to three alternators each 37,500 kVA, 500 r. p. m. It is also intended to fit these regulators to the alternators of the Klingnau power station now being built on the lower Aar (Switzerland) and which will contain three alternators each of 19,500 kVA, 75 r.p.m.

It should be of interest to mention here the results of some test-bed experiments. The oscillogram shown in Fig. 10 a represents a voltage increase of about 40 %; it shows that the regulator travelled over 70 % of its total track in 0·28 sec and that its return movement began distinctly before the voltage had reached its normal value. The oscillogram shown in Fig. 10 b shows in similar manner a voltage rise of 70 %; the regulator travelled over 80 % of its total track in 0·28 sec as well. In the oscillogram of Fig. 10 c, the machine was to be put under tension starting from zero. The regulator travelled over its total track (100 %) in 0·3 sec.

The oscillogram of Fig. 10 d shows a voltage reduction of about 20 % for which the regulator travelled over 50 % of its track in 0·26 sec.

All these oscillograms show clearly the very high regulating speed of the regulator, its stability, also, as it becomes stationary after one or two oscillations.

Advantages of the Brown Boveri high-capacity regulator.

Very high regulating speed, superior to that of similar apparatus put on the market by competitors. The total track can be travelled over in about 0·3 seconds and partial displacements are even more rapid.

Advantageous design of the contact device, specially built for sudden and repeated movements, contrarily to the designs of similar apparatus.

Rheostat with a large number of contact stops which make forced vibrations unnecessary for the brush.

Very powerful regulation allowing of regulating the machines of highest output with any connections desired.

Great adaptability of the apparatus to meet the most divergent service conditions, this because the various springs and also the damping system, the recall device and the compensating device can all be adjusted easily.

Stabilization during parallel operation, by means of the static characteristic with compensation, an arrangement which has given ample proof of its reliability during the years the Brown Boveri regulator with rolling sectors has been in use. It is, therefore, unnecessary to couple up the different regulators or to use synchronizing circuits or resistances, which is particularly advantageous in plants having several bus-bar systems, in which the machines have to operate on separate systems.

Simple and strong construction made up of parts which have given proof of their reliability by years of service in the standard Brown Boveri regulator and, therefore, giving every safeguard as regards reliable operation which it is right to expect from an automatic regulator.

Conclusions.

The preceding paragraphs show that automatic regulation of high-power machines can be carried out in two different ways:—

(a) By special connections of the excitation circuit (compounded auxiliary exciter, double auxiliary exciter) and by means of a regulator with rolling sectors of standard design.

(b) By a standard pilot exciter at constant voltage and a regulator modified so as to strengthen its regulating power (carbon-pressure regulator, high-capacity oil-pressure regulator).

The experience acquired during regulation of big machines with one or the other of these various systems shows that as far as speed of regulation and service reliability goes, all these devices give results which are very similar.

The devices mentioned in the first class have the drawback of requiring a special design of the pilot exciter, which frequently causes some difficulty. On the other hand, they allow of using the standard Brown Boveri rolling-sector regulator the advantages of which are well known. Further, although a special design of the pilot exciter increases the price of the machine slightly, the cost of the total apparatus is always relatively low.

The devices of the second class allow of using a standard auxiliary exciter at constant voltage and the slightly higher cost of the regulating apparatus is fully balanced by this advantage. As, on the other hand, the utilization of the high-power regulator is not limited to certain regulating conditions, as is the case for the carbon-pressure regulator and as its cost is more advantageous, it can be expected that the high-capacity regulator will be exclusively used in the future.

(MS 840) *W. Marolf. (Mo.)*

THREE-PHASE INDUCTION MOTORS OF TOTALLY-ENCLOSED DESIGN.

Decimal index 621. 313. 333.

THE insensitiveness of the component parts of mechanical drives to ambient influences, such as dust, damp, gases or acid vapours was one of the chief factors which, formerly, made for the superiority of the mechanical drive as compared to the electric one. The earlier electric motor had a vulnerable point, with regard to the said influences, namely the windings, and the efforts of designers were, therefore, directed towards the elimination of this weakness. These efforts have been crowned with a high degree of success, due, on the one hand, to the application of special insulation impervious to damp and acids, and, on the other hand, to the development of the totally-enclosed type of motor for plants where very severe operating conditions are encountered. This design is especially suitable for plants where the working process makes it impossible in practice to keep the motor clean. Totally-enclosed motors are being used, to-day, practically to the exclusion of all others in chemical works, mines, iron works, foundries, boiler houses, textile mills, cement works, sugar and other mills, etc., that is to say wherever it is likely that the surrounding atmosphere would have a deleterious effect on the windings. These motors can be mounted out of doors without a protective roofing over them.

Brown Boveri build motors of this type in various designs, according to output. These designs are described in the following paragraphs.

(1) *Motors up to about 3 kW output.*— Motors for these small outputs can be totally-enclosed without any considerable increase in their dimensions. Those of series Me, were already described in The Brown Boveri Review No. 6, year 1933, page 172 and do not require further mention here.

(2) *Motors of 3·7 to 37 kW output.*— Totally-enclosed motors of bigger outputs can be better utilized if a separate cooling system is used. In very big machines the air passing through the motor in a closed circuit is recooled in a special cooler and then led back to the motor. The drawbacks inherent to this cooling system cause it to be practically excluded, to-day, in motors up to about 400 kW; for these units the separate cooling system is under the form of an external ventilation of the stator housing. In order to improve the transmission of heat from the rotor to the stator the air in the inside of the motor is also set moving and made to flow on the inside of those surfaces of the motor which are cooled from the outside; thus those portions of the motor which are not in direct metallic contact with the external surfaces are cooled, as well.

The design is such that good cooling conditions, small dimensions and light weight are attained, without prejudicing the strong structural qualities of the machine. Naturally, a totally-enclosed motor is heavier and more expensive than an open one of the same output. Comparison of the weights of open motors with those of totally-enclosed ones with external ventilation shows that only a small fraction of the increase in weight really goes into the active parts, that is into the laminations and winding, the major part of the increase in weight is absorbed by the construction required by the enclosed design. The increase in weight of the totally enclosed motors, in the 3·7 to 37-kW range, is about 30—50 %.

The surface of the housing of these motors is greatly increased by axially laid cooling ribs, and these surfaces are efficiently cooled by a blast of air from a fan. In squirrel-cage motors, this fan is on the non-driving side, in slip-ring and centrifugal-starter motors, it is on the driving side, outside the bearing. This arrangement has the advantage of eliminating special glands. All the tracks followed by the external cooling-air stream are smooth; there are no sudden variations in shape in the motor, so that foreign bodies carried along with the cooling air (fiber filaments, dust, shavings and the like) can hardly settle on the motor.

A special protective hood is not used, so that whatever deposits may form between the cooling ribs are visible and easy to remove. Further, water is prevented from collecting between the cooling ribs as well as condensate inside the motor.

The connecting terminals are tightly closed off both from the inside of the motor and from the outside. Usually, in motors with feet, the stator terminals are placed on the left hand side when seen from the driving side (AS). The design of the stators and bearing shields allows of their being turned, so that the contrary arrangement of the terminals is possible. Both the stator and rotor-lead connections can be turned through 90° or 180°. All stators have six terminals and an earthing terminal. The stator and rotor-leads have a cable-connecting branch or a cable-end box which can be sealed by a filling. The connecting leads are amply dimensioned so that, if required, cables can be used which are bigger than is necessary for the motor current.

The motors have roller bearings with grease lubrication and can be run when mounted at any angle.

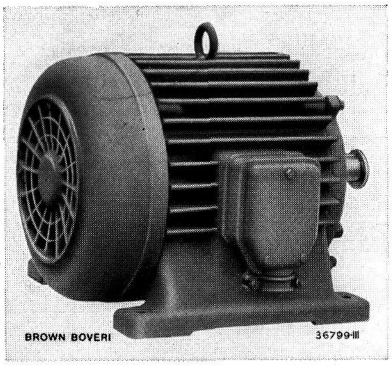

Fig. 1. — Three-phase motor, type MQUe 94, with squirrel-cage rotor, 18·5 kW, 1500 r.p.m.

The grease lubrication allows of running for long periods without any supervision. Special lubrication devices are, usually, not used, as experience has shown that too frequent lubrication is rather undesirable. However, if especially desired, Stauffer grease boxes or lubricating caps for impressed lubrication can be supplied.

The motors of series MUe of about 3·7—37 kW output are built as squirrel-cage, slip-ring and centrifugal-starter types. Figs. 1, 2 and 3 show these three designs.

The squirrel-cage motors are usually designed with multi-slot rotors, generally under the form of an upright bar winding. They can also be built as explosion-proof machines.

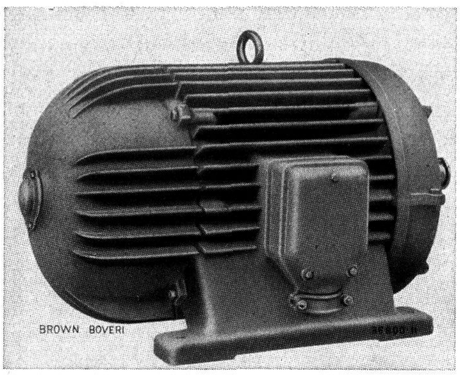

Fig. 2. — Three-phase motor, type MAUe 94a, with centrifugal starter, 22 kW, 1500 r.p.m.

The slip-ring motors can be built for continuously-applied brushes or with a brush-lifting and short-circuiting device for outputs above about 11 kW. The slip rings and brushes are easily accessible through a big door placed on one side of the bearing flange. The contacts of the short-circuiting device are visibly placed on the front of the slip rings. An auxiliary switch can be built into the short-circuiting device to interlock the motor switch when the brushes are raised.

The same grounds which lead to the choice of totally-enclosed motors for any given plant usually make it desirable that starting and stopping should be as simple as possible. For this reason, squirrel-cage motors, usually for direct-connecting up to the supply, are frequently used, control being carried out, advantageously, by push buttons close to the motor,

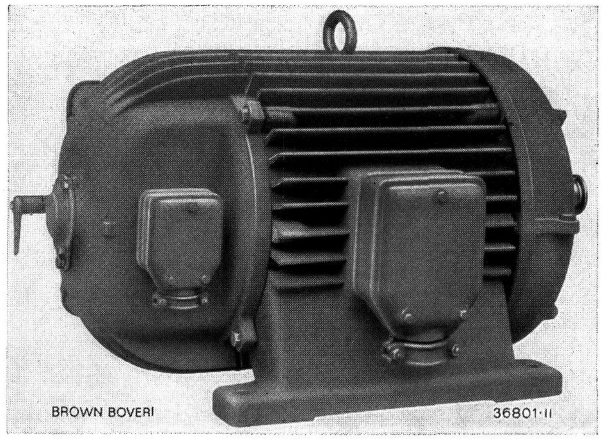

Fig. 3. — Three-phase motor, type MSUe 116a with slip-ring rotor and brush-lifting device, 37 kW, 1000 r.p.m.

the control gear proper being lodged in a closed off chamber. In all cases where the starting-current peaks, which are always considerable on account of the

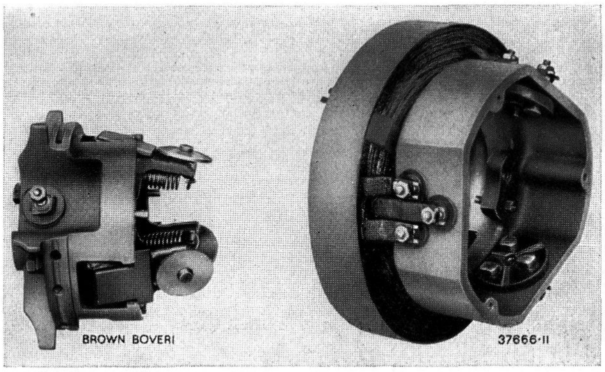

Fig. 4. — Centrifugal starter in two parts for motor shown in Fig. 2.

squirrel-cage design, should be inadmissibly high, the motor should be designed with centrifugal starter.

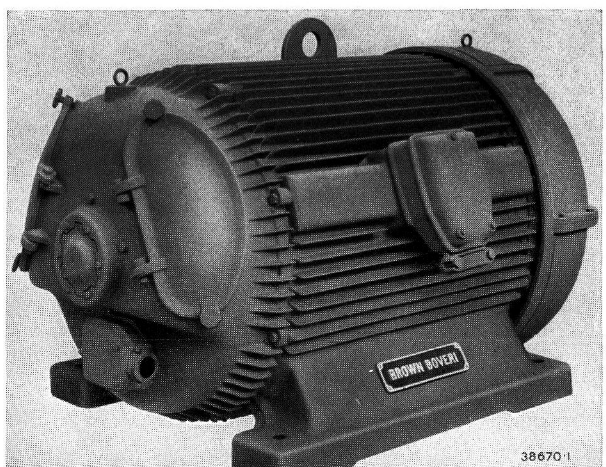

Fig. 5. — Three-phase motor, type MSUe 186 with slip-ring rotor and continuously applied brushes, 300 kW, 1000 r. p. m.

The basic and thoroughly tested out design of the starter remains the same as in former types, but the starter is built here, for the first time, in two parts, which facilitates dismantling the starter (Fig. 4). The whole starter is thus made more visible and a resistance can be changed without removing the starter hub, bearing parts, etc. from the shaft.

The motors just described are built with feet or as flange motors, to be put up horizontally, vertically or at another angle.

(3) *Motors of 37 to 370 kW output.*— If the totally-enclosed motors in this range of output were designed as those previously described, the relative surplus weight as compared to open motors would increase considerably, as the increase in outer surface no longer keeps pace with the increase of the losses to be dissipated. For this reason, ventilation has been considerably increased for the 37 to 370-kW range, to allow of leading off the heat developed inside the motor. In external appearance, the motor (Fig. 5) is very similar to the smaller ones. The motors are built with squirrel-cage rotor, with slip-ring rotor for continuously applied brushes or else with brush-lifting device and short-circuiting device and also with centrifugal starter, at least for the smaller units. Fig. 5 shows a three-phase motor with slip-ring rotor with continuously applied brushes of 300 kW, 1000 r.p.m., 500 V, 50 cycles.

(4) *Motors of above 370 kW output.*— For outputs considerably above 370 kW, the use of externally cooled motors is not considered advisable. These motors are built for semi-pipe ventilation or complete pipe ventilation, the cooling air being recooled in a special cooler if this appears desirable. A description of these motors does not, therefore, come within the scope of this article.

All the motors described in this article are designed for continuous as well as for short-term service or intermittent service. In certain cases totally-enclosed motors without external ventilation are used, but this design is being gradually given up in favour of the externally-ventilated type.

(MS 852) *E. Wiedemann. Ph. Suter. (Mo.)*

THE MÜHLEBERG CONVERTER PLANT.

(Concluded.)

Decimal index 621. 314. 26 (494).

III. DESIGN OF THE CONVERTER SET.

The Mühleberg converter set (Fig. 10) operates, in principle, according to the diagram of connections given in Fig. 11. This diagram differs from that given in Fig. 4 only in so far that two three-phase exciters are inserted between the frequency changer and the Scherbius machine, in order to keep the losses in the regulating cascade down to a minimum value. The floor space available called for as small an overall dimension of the main set as possible, and this consists, therefore, only of the main synchronous $16^2/_3$-cycle machine, the main induction 50-cycle machine and of the Scherbius machine with the frequency changer.

All exciters which are not bound to run in synchronism with any network, were grouped to form an auxiliary set composed of the following: induction motor with centrifugal starter, two three-phase exciters of the regulating cascade and the d.-c. exciter for the synchronous machine.

Fig. 10. — Converter set and auxiliaries in machine-hall of Mühleberg Power Station.

(a) *The principal data on the different machines.*

The main machines are built to the following conditions:—

(1) *Single-phase synchronous machine:—*

Rated voltage . . . . 16,000 V.

Operating voltage changeable from 15,500 to 17,000 V.

Continuous load as a generator, on the terminals and with p. f. = 0·75, overexcited, at 16,000 V and 500 r. p. m. . . . . . 8,500 kVA.

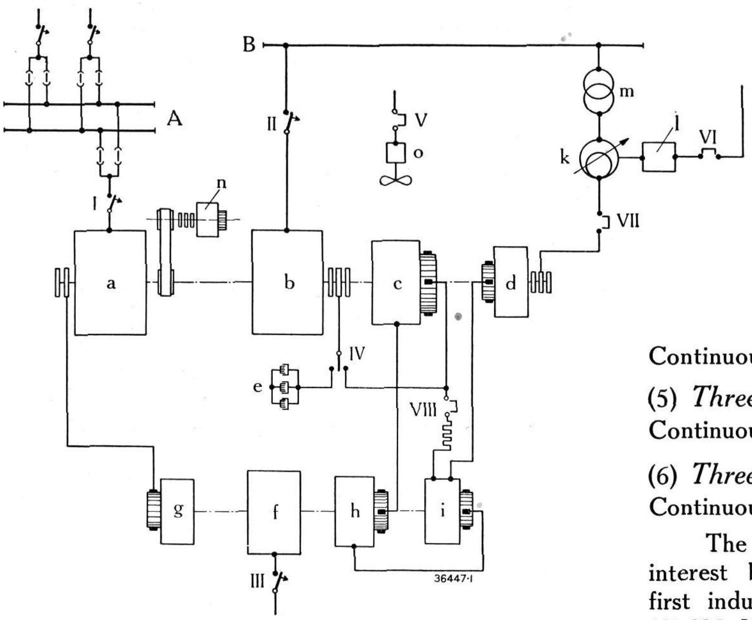

Fig. 11. — Main single-pole diagram of connections of the Mühleberg converter plant.

A. Single-phase bus-bar.
B. Three-phase bus-bar.
a. Single-phase synchronous machine.
b. Three-phase induction machine.
c. Scherbius machine.
d. Frequency changer.
e. Rotor starter.
f. Driving motor of exciter set.
g. D.-c. exciter for a.
h and i. Three-phase exciters for c.
k. Double induction regulator.
l. Servomotor.
m. Supply transformer for induction regulator.
o. Fan.
I, II, III. Oil circuit breakers.
IV. Rotor change-over switch.
V, VI, VII, VIII. Contactors.

Overload immediately following continuous load and during 90 minutes at 16,000 V, 500 r. p. m. . . 10,625 kVA.

Overload immediately following continuous load during 10 minutes, at 16,000 V, 500 r. p. m. . . 12,750 kVA.

Speed . . . . 500 ± 6 % r. p. m.

Frequency . . . . 15·67—17·67 ($16^2/_3$ ± 6 %).

Flywheel effect GD^2 . . . abt. 96,200 kgm^2.

Total weight . . . . . abt. 138,000 kg.

(2) *Three-phase induction machine:—*

Rated voltage . . . . 16,800 V.

Operating voltage . . . 16,000—17,600 V.

Continuous load as a motor, on shaft and with p. f. = 1, at 16,800 V, 470—500 r. p. m. . . . . . 6,900 kW.

Overload immediately following continuous load and during 90 min. at 16,800 V, 470—500 r. p. m. 8,630 kW.

Overload immediately following continuous load and during 10 min at 16,800 V, 470—500 r. p. m. 10,350 kW.

Continuous load at p. f. = 0, overexcited, and 16,000—17,500, 470—500 r. p. m. . . . . . 4,500 kVA.

Speed . . . . 500 ± 6 % r. p. m.

Frequency . . . . 50 ± 2 % (49—51).

Flywheel effect GD^2 abt. 69,000 kgm^2.

Total weight . abt. 64,000 kg.

(3) *Three-phase commutator machine (Scherbius machine):—*

Continuous load . . . 1,050 kVA.

Voltage . . . . . 255 V.

Current . . . . . 2,400 A.

Speed . . . . 500 ± 6 % r. p. m.

Total weight . . abt. 23,500 kg.

(4) *Frequency changer:—*

Continuous load . . . . . abt. 14 kVA.

(5) *Three-phase exciter:—*

Continuous load . . . . . abt. 19 kVA.

(6) *Three-phase exciter:—*

Continuous load . . . . . abt. 114 kVA.

The three-phase induction machine is of especial interest because, as far as is known, this is the first induction machine built for a rated voltage of 17,600 V while taking into account the following test voltages:

Length of coils to lie in slot before being built into machine . . . 40,000 V during 1 min.

Coils after being mounted and before taking over service . . . . . 32,000 V during 1 min.

Coils after being mounted and before taking over service . . . . . 24,000 V during 30 min.

These tests which apply to the synchronous machine as well, put very high stresses on the slot insulation and on the mica protection.

All the main machines (synchronous, induction and Scherbius machine) are of enclosed design. They draw cooling air from a fresh air duct and eject it into a hot air duct. A fan is provided to reinforce the cooling of the Scherbius machine. The enclosed design allows of reducing ventilation noise to a minimum.

(b) *Starting operations on the converter set.*

The starting up of the converter plant takes place in the following sequence and according to the switching operations which are easy to follow on Fig. 11.

(1) Switching in of the pump motor for the servo motor for the oil regulation of the double induction regulator, by means of contactor VI.

(2) Closing the main circuit breaker II of the induction machine and, therewith, switching on the voltage over a first-contact protective resistance, the duty of which is to keep down the switching-in current which is, mainly, wattless. During this operation the rotor change-over switch IV is connected to the water resistance.

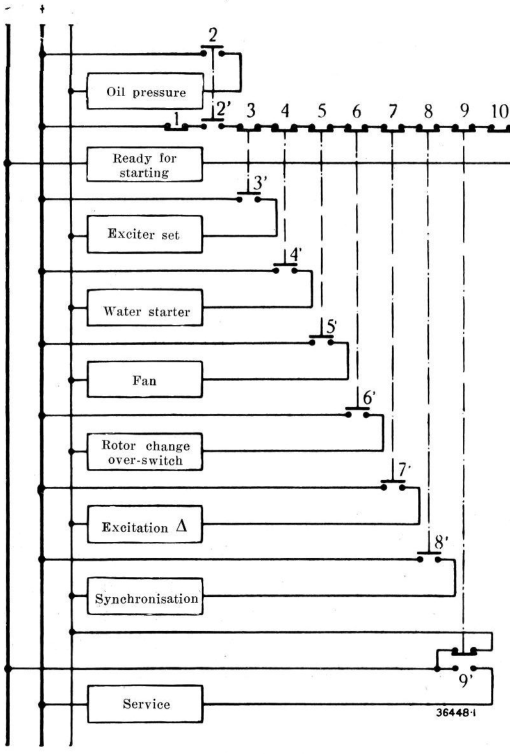

Fig. 12. — Light signals for starting operation.

1. Auxiliary contact on main circuit breaker of induction machine.
2, 2'. Auxiliary contact on contactor of pump motor.
3, 3'. Auxiliary contact on contactor of driving motor of exciter set.
4, 4'. Auxiliary contact on water starter.
5, 5'. Auxiliary contact on contactor of motor driving fan.
6, 6'. Auxiliary contact on rotor change-over switch.
7, 7'. Auxiliary contact on contactors of frequency changer and resistance excitation circuit.
8, 8'. Auxiliary contact on transition resistance.
9, 9'. Auxiliary contact on main circuit breaker of synchronous machine.
10. Auxiliary contact on hand potentiometer.
11. Auxiliary contact on double induction regulator.

(3) With the closing of the main switch, switch III of the driving motor of the exciter set is closed, by means of a retarding relay, and this set is started up.

(4) Operation of the rotor water starter e of the main machine and bringing the main set up to full speed.

(5) Starting the fan of the Scherbius machine by closing contactor V.

(6) Changing over the rotor change-over switch IV to the Scherbius machine.

(7) Simultaneous closing of contactors VII and VIII and excitation of the auxiliary exciters h and i and, therewith, of the Scherbius machine c.

(8) Synchronization of the synchronous machine and the railway network.

(9) Setting the service desired and the load wanted.

The starting operations must always be carried out in the sequence laid down and at given intervals of time, in order to avoid disturbances. In order that starting should be correct and simple, under all circumstances, the starting process was made automatic for the greater part and interlocked in such a way that switching operations can only be carried out in the proper sequence and at proper intervals of time.

A light signal (transparent) with the indication "ready for starting" shows the operator that all breakers, contactors, in short all apparatus necessary for the starting process are in the proper position and that the motor of the pump of the oil regulation is switched in. The operator should not activate the contact maker of the main switch until the above operations are accomplished. The order given can, however, only be followed if the apparatus necessary to the starting process are already in their proper positions and if none of the protective apparatus mounted have imparted a switching out order to the breaker. This interlock is arranged simply by leading the switching in current circuit of the remote motor drive of the main circuit breaker over auxiliary contacts, one of which is placed on each of the switching apparatus necessary for starting.

After hand operation of the main circuit breaker of the induction machine has been effected the whole sequence of starting operations is carried out automatically and with the necessary intervals of time between the different operations, until the single-phase machine is finally synchronized. Each switching operation carried out is signalled back on a transparent glass plate so that the operator is constantly notified as to the stadium of the starting operations. Fig. 12 shows this back signalling and the principal diagram of connections thereof. The lighting up of the transparent plate "synchronize" is to be taken as an order to the operator that he must now synchronize, by hand, the single-phase machine of the converter set with the network of the SBB. This operation could quite well be made automatic as well, by means of the automatic synchronizer, but the clients did not desire automaticity for the time being.

After synchronizing has been carried out, the transparent plate "service" lights up and all other transparent-plate indications are extinguished. When the converter set is cut out, either intentionally or owing to some disturbance, all the apparatus necessary for starting up goes back automatically to the initial positions, which is again made visible by the transparent signals, so that finally, the signal "ready for starting" lights up, which is an assurance that the whole group is ready for another starting-up operation.

(c) *Service and load regulation of the converter plant.*

The buyer required that the following service possibilities of the converter plant be fulfilled: —

(1) Operation of the converter set in regulating cascade connections.

(2) Operation of the converter set without regulating cascade connections, with excitation of the single-phase machine by the d.-c. exciter of the excitation set.

(3) Operation of the converter set without regulating cascade connections and with separate excitation of the single-phase machine.

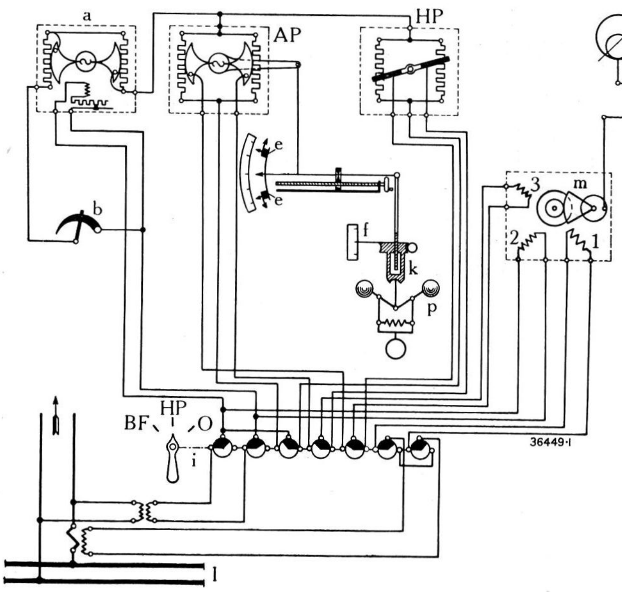
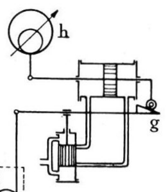

Fig. 13. — Main diagram of connections of regulation.

I. Single-phase bus-bar.
a. Voltage regulator.
b. Transition resistance.
g. Servomotor.
h. Double induction regulator.
i. Drum type switch with zero position for "cut out".
m. No-load regulator.
AP. Automatic potentiometer.
BF. Service dependent on the frequency of the railway network.
HP. Hand-operated potentiometer.
P. Pendulum.
HP. Service with hand potentiometer.

Obviously, operating condition 1 with regulating cascade connections is the only one which allows of fulfilling the requirements laid down in chapter I. The two other conditions of operation allow of limited service and have as their chief object to permit of using the main set even if the regulating cascade happens to be being repaired. Thus, operating conditions 2 allow of using the plant, within the limits imposed by the circumstances, as an ordinary synchronous-induction set, if the Scherbius machine, or the frequency changer, happens to be out of service. Finally, the plant can be used in the same way if the excitation set is also cut out, in which case the excitation of the single-phase machine must be switched over, which corresponds to operating conditions 3.

In order to simplify switching over, a drum type change-over switch with a corresponding number of positions was added. This change-over switch changes the automaticity and interlocking of the plant in such a manner that these are made suitable to the new starting and service conditions now prevailing. The operator controlling the service has no other operation to carry out as the starting automaticity is maintained and only changes so as to meet each new operating condition imposed. Service with regulating cascade connections is, of course, the only one which presents a novel interest.

As mentioned in chapter II, the converter plant is equipped with an automatic potentiometer, so that it may be able to meet the service conditions demanded of it. The hand-operated potentiometer plays the part of a stand-by. The principal of the whole regulating equipment is shown by Fig. 13. A drum-type switch i, when brought to position 0, allows of cutting out the whole regulating gear and of short-circuiting the current transformer.

When the switch is brought to position HP (hand-operated potentiometer), the hand-operated potentiometer is switched in and the automatic potentiometer switched out. Service with the switch in this position is to be considered as an emergency. With it, however, it is quite possible to transfer a given and constant power quota — which can be set at any value from 0 to full load — to the feeder cable of the SBB and, at the same time, to supply the independent railway system. Under the conditions in question, however, the regulation looses the safety factor which should come into play when given limit frequencies are exceeded.

When the switch is brought to position BF (automatic potentiometer dependent on the railway network frequency), all the characteristics which were set forth at the beginning of this description are attainable. The only essential condition for this is that the pendulum should be driven in synchronism with the frequency of the railway network. This result is attained by using a tachometer dynamo driven by belt from the shaft of the main set and which, therefore, must rotate in synchronism with the frequency of the single-phase system. The tachometer dynamo is a double-current generator. It delivers on its slip-rings the a.-c. current necessary for the motor of the pendulum drive. Its commutator delivers voltage proportional to the speed as its excitation is tapped from a source of power having constant voltage. This d.-c. voltage serves to indicate the speed and also to activate an over-voltage relay which acts on over speeds.

Windings 1 and 2 of the no-load regulator are supplied from the current and potential transformers of the Swiss Federal Railways feeder. The regulator would tend to control the double-induction regulator h with the help of the oil pressure regulator g, so that the output would be kept at zero in the SBB feeder independently of the slip caused by the two networks. A third winding 3, however, influences the regulator so that its rotary system is only in equilibrium when the feeder output is proportional to a voltage influencing winding 3, in other words, the output changes with a voltage supplied to winding 3. The supply voltage of winding 3 is taken from the hand-operated potentiometer with HP control or from the automatic potentiometer with BF control. A given mechanical position of the potentiometer corresponds to a given voltage, according to the

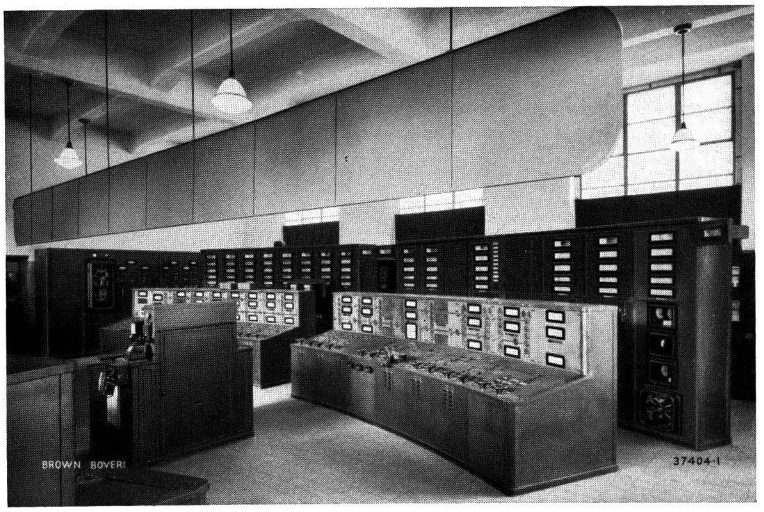

Fig. 14. — Control stand of Mühleberg Power Station.
Automatic potentiometer and transparent plates will be noticed.

potentiometer principle and, therefore, to a given SBB feeder output. With the hand operated potentiometer a fixed mechanical position is determined by a given setting by hand. The automatic potentiometer only holds a constant position under changeable frequency when the lever lies up against a travel limiter and this is always so when pointer f for the indication of no-load is somewhere beyond the region of frequencies encountered in ordinary service of the converter set, as was explained in chapter II.

In order to make the potentiometer voltage and, with it, the constancy of the load, independent of possible changes in the voltage of the network a quick-acting voltage regulator a was inserted before the potentiometer, the duty of which is to keep the supply voltage of the potentiometer at a constant value.

With the help of the shunt resistance b seen in Fig. 13, it is possible to bring down the supply voltage of the potentiometer to zero which corresponds to a lowering of the load of the converter set to the same value. This resistance is suitable to switching operations and is very useful, but apart from this it is unimportant.

The setting of the frequency indicator and of the travel limiters on the automatic potentiometer can be made by remote control from the instrument post. Two signal lamps show when the pointer g has reached travel limiters e.

In order to be able to regulate the converter set by hand, if the regulation by potentiometer is damaged, a push-button contact maker is used which allows of controlling the drum of the load regulator and in this way the double induction regulator can be regulated in any sense desired.

Control of service is extremely simple with the regulating equipment described. As was said before, the starting procedure is automatic up to the moment when the synchronous machine has to be synchronized with the SBB network. Synchronization proper is most easily carried out by using the automatic potentiometer in such a way that pointer f is brought to about the frequency of the railway network by means of a small remote-control motor and then the shunt resistance b is switched out. As, in this case, there is no load yet on the SBB feeder, the pendulum regulator regulates the set to the frequency set. If this frequency does not coincide with that of the network, nut k can be displaced by worm drive remote controlled and equality of frequencies sought for after which synchronizing can be carried out. Alteration of the point of frequency is made by push-button control from the switchboard.

To put on load, the travel limiters e are placed on the load point desired and then the frequency point for no load —that is to say pointer f—is displaced until it is beyond the region of ordinary frequencies of the converter set. The pointer g now comes up against limiter e and remains there and this gives the constant mechanical position of the automatic potentiometer and, at the same time, the load of the converter plant: *the set works to constant load.* If the load is to be changed, in service, the travel limiters must be displaced which causes the set to take over the new load automatically.

When the converter set operates in function of the railway network frequency, that is to say when the set works as a buffer, only the frequency point for no load, the travel limiters e for load limiting and staticity desired have got to be set and the *converter set works in function of the frequency of the railway network.*

Service is made certain of by means of the travel limiters e as they allow of fixing a given load which can never be exceeded and also by fixing the no-load frequency and the staticity, so that the set can never take over too heavy a load or attain too high a speed.

(d) *Protective devices for the converter plant.*

The table on the opposite page gives the protective devices with which the Mühleberg plant is equipped. This summary gives the protective appliances and also the kind of disturbances with which they are meant to deal, as well as the effects and announcing thereof.

IV. SERVICE RESULTS.

The Mühleberg converter plant took over regular service in December 1932.

For standard service conditions of the set (supplying the SBB feeder with a constant quota of power and feeding a separate railway system) the following results (given in Figs. 15a—d) were attained at the taking-over tests.

During the time from 14 to 20 o'clock the set delivered about 5000 kW constant load to the SBB, and to the BLS (separate railway system) whatever power was required to operate that system. As shown on the recording paper strips, the power required

Protective devices.

Protective device	Nature of disturbance	Parts affected	Return signal
1. Push-button contact maker to activate the remote control by motor of the main circuit breaker of the induction machine	Ordinary cutting out operation	Main circuit breakers of induction and synchronous machines and exciter switch	Desk-mounted return-signal lamps on push-button contact makers of the main circuit breakers
2. Over-current relay of the induction machine	Short circuit on the three-phase network	Main circuit breakers of induction and synchronous machines	Ditto
3. Over-voltage relay of the induction machine	Cutting out of the three-phase network	Ditto	Ditto
4. Thermostats in stator inleads of the induction machine	Overload of the induction machine	Ditto	Drop disc
5. Over-current relay in current circuit of transformer for supplying the double induction regulator	Short circuit in regulating current circuit, transformer, frequency changer, double induction regulator and exciter	Ditto	Drop disc
6. Over-current relay in current circuit of starting motor of the exciter set	Short circuit and overload of driving motor	Ditto	Drop disc
7. No-volt relay on the bus-bars supplying the driving motor of the exciter set	Failure of auxiliary voltage for the supply of the driving motor of the exciter set	Ditto	Drop disc
8. Differential current of the induction machine	Short circuit between phases in the induction machine	Main circuit breaker of the induction machine and of the synchronous machine and protection against fire	Drop disc
9. Contact maker to activate the remote control by motor of the main circuit breaker of the synchronous machine	Ordinary cutting out operations	Main circuit breaker and field switch of synchronous machine	Desk-mounted return-signal lamp on push-button contact maker of main circuit breaker
10. Thermostat in stator in-leads of the synchronous machine	Overload of the synchronous machine	Ditto	Drop disc
11. Over-current relay of the synchronous machine	Short circuit on single-phase side	Ditto	Desk-mounted return-signal lamps on push-button contact maker of main circuit breaker
12. Differential voltage relay of the synchronous machine	Short circuit between winding turns	Both main circuit breakers separately and protection against fire	Drop disc
13. Differential current relay of the synchronous machine	Short circuit between phases	Ditto	Drop disc
14. Centrifugal switch and voltage relay of tachometer dynamo	Over-speed	Main circuit breakers of induction and of synchronous machines	Drop disc
15. Air flow meter in fan of Scherbius machine	Stopping of fan	—	Drop disc
16. Over-voltage relay in rotor circuit of Scherbius machine	Auto-excitation or too big slip	Both main circuit breakers separately	Drop disc
17. Thermostat in water starter	Overheating of the electrolyte in the water starter	—	Drop disc
18. Thermostats in main bearings	Overheating of bearings	—	Drop disc
19. Contact-type manometer in servo-motor of the double induction motor	Oil pressure in servomotor too high or too low	—	Drop disc
20. Resistance element lodged in the windings of the main machines (induction machine, synchronous machine and Scherbius machine)	Control of copper temperature of the windings	Indicating instrument with indication of temperature in ^{0} C	—
21. Emergency push-button switch in machine hall	Unexpected disturbance	Both main circuit breakers	—
22. Emergency push-button in machine hall in case of fire	Unexpected disturbance	Protection against fire and main circuit breaker	—

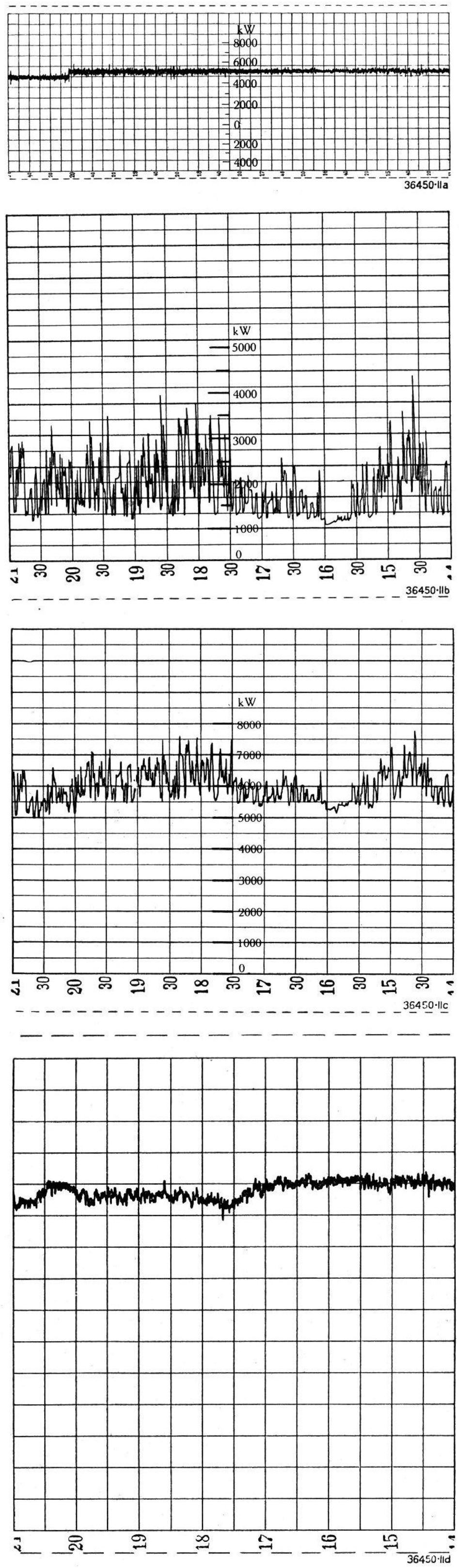

Fig. 15. — Recording paper strips.

a. Watt power in the SBB feeder cable.
b. Watt power in the separate railway supply (BLS).
c. Total watt power of the converter set measured on the three-phase side.
d. Frequency of SBB network ($16^2/_3$ cycles).

for the separate railway systems fluctuates between about 1000 and 4300 kW (Fig. 15 b). In spite of the big load surges which occur on the latter system from time to time, the load on the SBB feeder only varies very slightly. If abstraction is made of the short load peaks which are solely caused by the separate railway system, the range of load fluctuation on the SBB feeder is about ± 250 kW. As the recording paper strips show clearly, the load is absolutely independent of the slip dictated by the frequency variations of both networks. It is unfortunate that the latter was not recorded as well. It would have been found to be within the range of about ± $^1/_2$ to 1 % in the industrial network and about ± 3 % in the SBB network.

The transition — at 20 o'clock — to a load of 4500 kW is clearly shown. This is carried out, as was explained in chapter II, by a simple displacement of the travel limiter of the potentiometer regulator. The total load of the converter plant measured on the three-phase side is recorded on the recording strip C. It is the total of the load of the SBB feeder and that of the BLS. This record clearly shows what a considerable influence the rotating masses play in smoothing the service, the load peaks which appear on the BLS recording strips are sharply broken. This is a very natural result as the rotors of the machines having fairly big flywheel effects, act as a flywheel.

The Mühleberg converter set is the ninth frequency converting set which Brown Boveri have equipped for the same and for similar regulating conditions. These other plants are given herewith:—

(1) *Sociedad Duro Felguera, La Felguera (Spain).*
1 Ilgner set 2000 kW.

(2) *Stà. Generale Elettrica Tridentina for Mezzocorona Power Station (Italy).*
1 frequency converting set for flexible coupling of a three-phase network 10,200 V, 42 cycles, with a three-phase network 3650/4200 V, $16^2/_3$ cycles. Output of synchronous machine as a generator 9200 kVA, p. f. = 0·8, r. p. m. 500.

(3) *Sté Métallurgique des Terres Rouges, Esch s/Alzette (Luxemburg).*
1 frequency converter set for flexible coupling of a three-phase network 5000 V, 50 cycles to a three-phase network 5000 V, 42·5 cycles. Output of synchronous machine as a generator 4000 kVA, p. f. = 1, r. p. m. 510.

(4) *Prager Eisenindustrie, Kladno Works (Czecho-Slovakia).*
1 frequency converter set for flexible coupling of a three-phase network 5500 V, 50 cycles to a three-phase network 5500 V, 25 cycles. Output of synchronous machine as a generator 3600 kVA, p. f. = 0·875, r. p. m. 500.

(5) *Acciaierie e Ferrierie Lombarde, Milan. Pontremoli Power Station (Italy).*
3 frequency converter sets for flexible coupling of a three-phase network 6 kV, 50/42 cycles and a three-phase network 3·6 kV, 16 cycles. Output of synchronous machine as a generator 7500 kVA, p. f. = 0·67, r. p. m. 500.

(6) *Swiss Federal Railways. Seebach Substation (Switzerland).*
1 frequency converting set for flexible coupling of a three-phase network (NOK) 8 kV, 50 cycles and a single-phase network (SBB) 10 kV, $16^2/_3$ cycles. Output of synchronous machine as a generator 8600 kVA, p. f. = 0·7, r.p.m. 500.

(7) *Ferrovie dello Stato Roma, Collegno Substation (Italy).*
1 frequency converter set for flexible coupling of a three-phase system 6400 V, 50 cycles and a three-phase system 3700 V, 16·5 cycles. Output of synchronous machine as a generator 9500 kVA, p. f. = 0·75, r. p. m. of set 500.

(MS 1344) *F. Grieb. (Mo.)*

NOTES.

Portable compressor plants for use in workshops, depots and substations.

Decimal index 621. 512. 2—219.

PORTABLE compressor plants are often used in workshops, depots and substations to drive compressed-air tools or to clean machined parts and machinery of all kinds.

Brown Boveri has delivered numerous compressor plants of this kind in various sizes and designs. As an example, a small set may be mentioned which was delivered, recently, to the Madrid workshops of the Spanish Northern Railway and which is shown in Fig. 1.

The motor-compressor set, pressure regulator, switchboxes and all accessories are mounted on a portable air receiver of 85 litres capacity. The two-cylinder reciprocating compressor delivers an air volume of about 110 l/min against a counter gauge pressure of 5 kg/cm². The compressor is driven by a standard-type enclosed three-phase squirrel-cage motor of 1·5 kW continuous output at 940 r.p.m., 500 V and 50 cycles, through a semi-flexible coupling. The pressure regulator switches the driving motor in and out, automatically, between the limits adjusted to of 4 and 6 kg/cm² gauge pressure. A switchbox with fuses controls the whole plant. The other accessories, such as check valve, safety valve, manometer, closing-off cock, with the branch connection for the rubber pipe and plug switch for the supply cable are laid out so as to be easy to supervise.

The whole set which has an overall length of 1330 mm, a width of 390 mm and a maximum height of 740 mm, only weighs 145 kg and is, therefore, very portable.

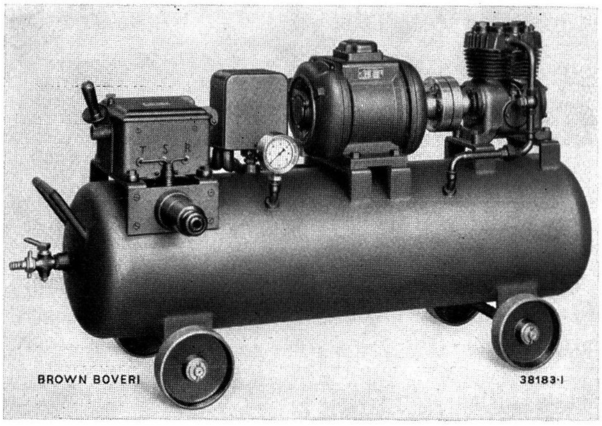

Fig. 1. — View of a portable Brown Boveri compressor.

Portable compressor plants of this kind are much appreciated in workshops, depots and substations because they can always be brought to the exact spot where compressed air is required, if an electric connection is available. They are simple to operate and are ready for service instantaneously.

Brown Boveri is always in a position to give quick delivery of sets of this type or similar ones of bigger output and of other designs, for any type of current or voltage.

(MS 834) *O. Gysin. (Mo.)*

Sectional drive of a combined cardboard-making machine.

Decimal index 621. 34 : 676. 6. 05.

SECTIONAL drive of paper-making machines has, practically, come into universal use, in recent years, owing to its superiority over other drives. To-day, it is generally used for big fast-running newsprint machines and also, increasingly frequently, for small fine-paper and cardboard-making machines of special designs. Lately, Brown Boveri delivered a drive of this kind to the A. S. De Forenede Papirfabrikker, Copenhagen, and this drive is summarily described in the following paragraphs.

The cardboard-making machine in question has a wire width of 3325 mm and was built by the Maschinenfabrik Banning & Seybold, A.-G. in Düren, Rheinland. It is equipped with two wire parts:— a plan wire and a cylindrical wire and it allows of making either ordinary paper, or stronger packing paper, as well as ordinary and duplex cardboard up to 800 g/m². Paper is made with the plan wire alone, at working speeds up to 120 m/min, while in making duplex cardboard, the thick cardboard coming off the cylindrical wire and the covering sheet coming off the plan wire are combined in the couch rollers. The cardboard from the cylindrical wire, which chiefly serves as a filling mass to attain the desired thickness, can be composed of cheap fibrous material, while the covering sheet coming from the plan wire must be made of higher-grade material, so that it possesses the necessary resistance to external stressing or, for example, can carry the requisite stamp, when the cardboard is required for making railway tickets.

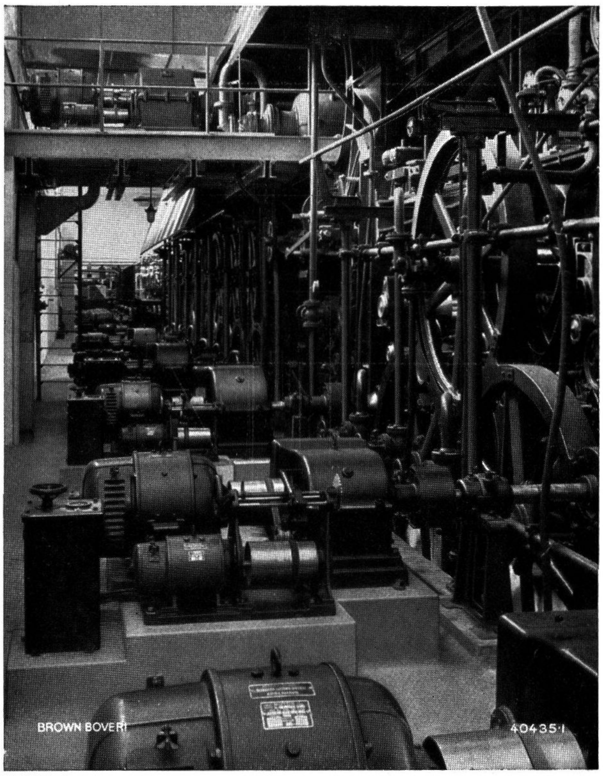

Fig. 1. — Sectional drive of a combined cardboard-making machine.

Fig. 1 shows the sectional drive seen from the end of the dry part, looking towards the wire. The simple, compact easily-supervised layout which characterizes the Brown Boveri drive is clearly apparent. The basic principles and working method of the Brown Boveri sectional drive were described in The Brown Boveri Review, so that they can be taken as generally known.[1]

Each driving set is composed of a spray-water proof d.-c. motor and a completely enclosed reduction gear with gear wheels cut with great precision which revolve in oil. The motor and the reduction gear are mounted on a common bed-plate and connected together by a flexible coupling, in the form of a conical pulley. The sectional frequency generator, also completely enclosed, is driven from this conical pulley and generates a three-phase voltage of variable frequency, proportional to the speed of the sectional motor. This frequency is compared, in the draw regulator to the master frequency, common to all the sets, through the agency of an electrical differential, and the speed of the sectional motor is immediately corrected if there is any deviation from the value set. The setting of the paper draw between the different sections of the machine is carried out, by displacing the driving belt on the conical pulley of the sectional frequency generator. This displacement is made with the help of a special adjustment device on the above generator, which carries a millimetric scale and allows of a very close adjustment. The various sections are started up by means of an oil-immersed drum-type starter with over-current no-load release and built-in ammeter, placed near the motor. The sections of the machine can be stopped from the operating side as well by operating various "stop" push-button switches mounted there. The draw regulator with the regulating resistances and the electric differential are lodged in the switchboard in a special room, so that the drive side of the cardboard-making machine is also kept free and is very accessible.

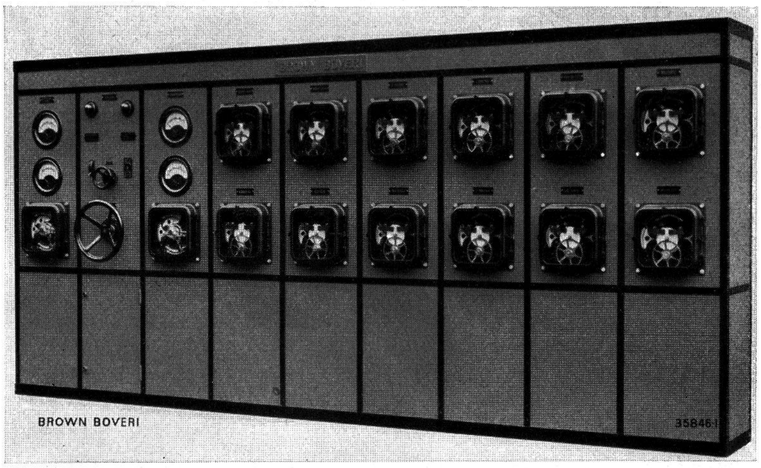

Fig. 2. — Switchboard for sectional drive.

The drive of the store cylinder is mounted on a pedestal (Fig. 1), which is the most convenient layout for driving the shaft of this big cylinder, the axis of which is at a considerable height. There are no difficulties here for laying the electric lines required for the maintenance of proper speed. In contrast to the system with master shaft and mechanical differentials, only cables of small diameter are required here.

A common fan provides the cooling air for the motors with forced ventilation, the cooling air being led in from below through suitable apertures in the foundations. The hot air is ejected directly into the machine hall through the openings provided with slats on the bearing flange on the commutator side. Further, the plant is equipped with a modern heat-recuperating and ventilating plant. The hot vapours which are produced during drying are drawn in through a funnel placed above the dry part and visible in Fig. 1 and these vapours are utilized in a counter-flow apparatus to warm up the cold air which is supplied to the machine from below.

The control set is composed of a Ward Leonard dynamo, a common exciter, an auxiliary exciter for rapid regulation and the three-phase driving motor. The latter also drives the fan to cool the d.-c. motors through a second shaft end. The control set, the master set and the switchboard are placed in a separate closed room on one side of the paper-making machine hall.

Fig. 2 shows the switchboard with the draw regulators and the apparatus and instruments for the control set. Two quick-acting automatic regulators for the Ward-Leonard machine and the exciter allow of maintaining the speed of the paper exactly constant, independently of the frequency and load fluctuations.

The control of the whole drive is from an enclosed main-control box which is placed on a column near the first dry part, on the operating side. This panel contains an ammeter and a voltmeter for the current circuit of the Ward-Leonard dynamo as well as the necessary push-buttons and the close-adjustment resistance for remote control of the drive. The working speed can be read off a scale calibrated in m/min.

The drive has given an excellent account of itself during more than a year of continuous and severe service; it has proved that sectional drive has very definite technical advantages, not only for big units, but for small machines, as well.

(MS 849) *E. Oschwald. (Mo.)*

[1] See booklet 1329 E:— "Brown Boveri Sectional Drive of Paper-making Machines."

Helux lighting equipments for small vessels.

Decimal index 628.948 : 629.12.

EVERYONE is familiar with bicycle lamps which are supplied with current from a tiny dynamo driven by one of the wheels of the bicycle, against the rim of which the dynamo pulley presses. Since about ten years, these lighting equipments have practically replaced the old fashioned oil lamp or acetylene lamp.

It could, therefore, only be a matter of time before the same principle for lighting small vessels, from a dynamo driven by the propeller shaft, was given practical application. This type of drive gave rise to the name "Helux", combined of helix (screw) and lux (light). There were, however, two difficulties to be surmounted:—

(1) The voltage of the dynamos has to be maintained at a constant value for speeds fluctuating between 50 and 100 % of standard speed. In bicycle dynamos this constancy of voltage is attained by a process which can hardly be applied to bigger machines.

(2) From 0 to 50 % of standard speed, lighting must be taken care of by an accumulator battery, which must be charged again automatically by the dynamo. The change-over of the lighting system to the dynamo or to the battery has also got to be automatic.

These difficulties are perfectly solved by means of the lighting regulator which is the distinctive feature of the Helux equipments. The latter are being more and more extensively used and the day can be foreseen when any other system of lighting for small vessels will seem as old fashioned as an oil lamp on a bicycle.

The illustration shows an oil tanker equipped with a Helux lighting equipment, by the Cie. Electro Navale et Industrielle of Antwerp. The satisfaction of the customers was such that they subsequently equipped 36 barges with Helux lighting equipments.

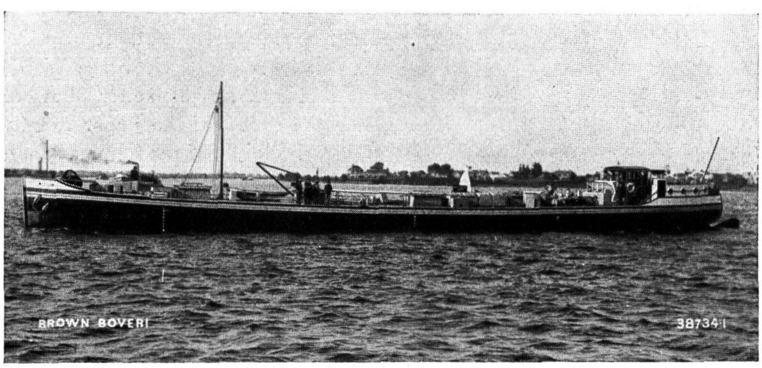

Fig. 1. — River tanker of the Plouvier Shipping Co., Antwerp, equipped with a Brown Boveri-Helux lighting plant.

These equipments are now made for all voltages met with in practice and for outputs of from some hundreds of watts up to 10 kW.

(MS 850) *E. Kersting. (Mo.)*

Life of electric vehicles.

Decimal index 621. 335. 4.

EXPERIENCE shows that electric vehicles practically never wear out. Many have been 30 years and more in service without it having been necessary to replace a single essential part. What replacement work has been carried out has usually been done with the object of improving the vehicle by introducing some inovation in partial design.

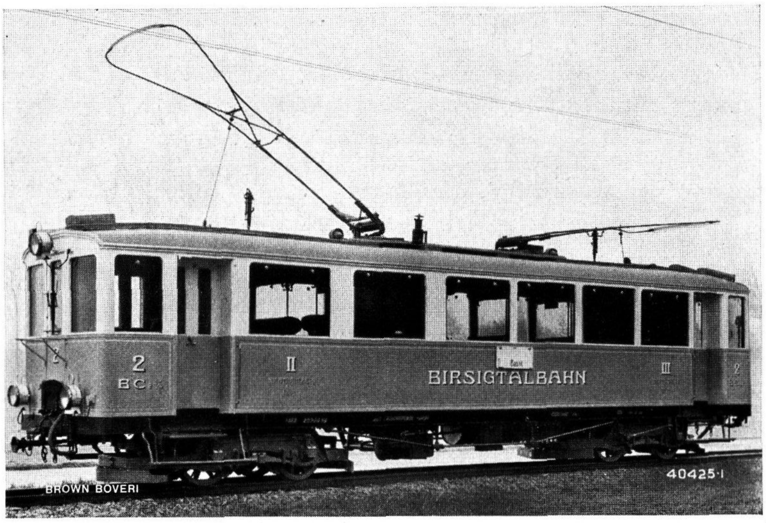

Fig. 1. — Motor coach of the Birsig Valley Railway (Basle, Switzerland).

Many electric locomotives and electric motor coaches have travelled over a million kilometres since they were put into service, without showing any sign of age.

The Railway Company operating the railway in the Birsig valley (near Basle, Switzerland) draws our attention to one of their motor coaches which was put into service on June 2nd, 1905 and had travelled 1,542,000 kilometres by the end of December 1933, that being a distance equal to 38 times the circumference of the earth. This coach is equipped with 4 motors of 50 H.P. one-hour rating, 26·5 km/h coach speed and 750 V. Despite the distance travelled over, the coach is in first-class condition which the company ascribes not only to careful upkeep but to the high-grade workmanship and design of the coach.

We thought it worth while to publish the service data relative to this electric coach, as the results attained not only exceed all records of non-electrical motor vehicles but prove our assertion of the long length of life which characterizes electric vehicles.

(MS 841) *M. Hiertzeler. (Mo.)*

Water circuit breakers Type U for Belgium.

Decimal index 621. 315. 54. 064. 25.

THE photographs shown in Figs. 1 and 2 are of a Brown Boveri water circuit breaker type U 11 i 250. The operating principle and the design of breakers of this type were described, in some detail, in the January number of this Review.

The following are the characteristics of the breaker shown here:—

Rated voltage	11 kV
Test voltage	42 kV
Rated current	400 A
Rated rupturing capacity	250 MVA
Maximum closing current	42,000 A (peak value).

The design is in accordance with VDE rules for circuit breakers series 10.

Fig. 2 shows a breaker belonging to a series of apparatus built for Belgium and now in service. A number of these breakers are working in the Remy plant in Wygmael

Fig. 1. — Water circuit breaker Type U11i250, 11 kV, 400 A, 250 MVA, with built-on compressed-air drive.

for connecting the said plant up to the big distribution system belonging to the Société Intercommunale Belge d'Electricité. The other breakers are in the Vive—Saint-Bavon substation (Gent) belonging to the Sté. d'Electricité de l'Ouest de la Belgique, in Courtrai. All the breakers of this series are equipped with built-on compressed-air drive. The breaker and its drive thus form a unit mounted on rollers, which can be easily removed from its cell, when desired. The remarkable simplicity of the compressed-air drive and its transmission organs is seen from the illustrations. Fig. 1 shows one of the plants with the water circuit breakers erected.

It is interesting to summarize, here, the special advantages presented by the water circuit breaker for many plants and it should be mentioned that a wide field of application would seem to be open to this type of breaker, in Belgium. The parallel operation of power stations has been greatly extended, in Belgium, during recent years. On the one hand, small industrial plants have combined to form local groups, examples of which are the "Union des Centrales du Hainaut" and the "Union des Centrales du Pays de Liége", while, on the other hand, certain industrial centres have linked up their own power stations to a big distribution system, as was the case with the "Sté. Intercommunale Belge d'Electricité", mentioned before. A considerable number of the smaller and older industrial power plants in Belgium, belonging to both the above classes and having switchgear plants only designed for the output of the station proper, are, now, interested in parallel operation. The short-circuit outputs reached in parallel operation may, however, attain very high figures. The result is that most of these switchgear plants are not able to cope or stand up to the short-circuit outputs which are to be expected after linking-up. As, usually, it is not possible—although it would be necessary in many cases—to complete the whole switchgear plant or simply to reinforce it so that it could stand up to the demands put on it by the total short-circuit output, the only means available is to protect the switchgear by inserting heavy-duty circuit breakers in the connecting leads and to adjust the different breakers available in the power station so that a too weak breaker has never got to cut out the short-circuit current before the power station has been cut off from the connecting line. The connecting-line breakers must, however, frequently be lodged in the power station itself. In old plants, the space available is usually inadequate for putting in oil circuit breakers and the conditions such that heavy-duty oil circuit breakers could not be mounted with the requisite degree of safety. The problem is simply to get the biggest rupturing capacity possible into the restricted space available while eliminating all danger of fire. If it is impossible to mount heavy-duty oil circuit breakers in the so-called countersunk manner, the only other solution which meets all the conditions called for is to use circuit breakers without any oil. When this solution is adopted it may be possible under favourable

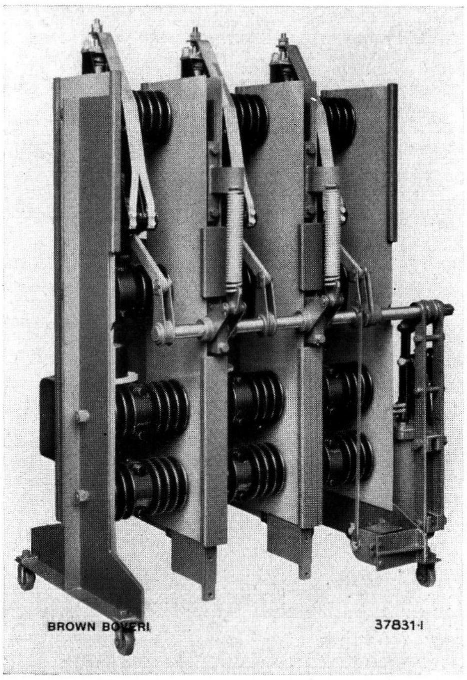

Fig. 2. — Water circuit breaker Type U11i250. Back view.

circumstances to increase considerably the rupturing capacity of the power station being linked up at small additional outlay. There are cases, for example, where the adaption of water circuit breakers multiplies the rupturing capacity tenfold without altering the available cells to hold the breakers. An increase in the rupturing capacity of a plant using oil circuit breakers may call for complete transformation of the switchgear plant and of the building with less advantageous results.

(MS 837) *J. Defreyn. (Mo.)*

The automatic hydro-electric power stations of the Samaden Municipality (Switzerland).

Decimal index 621. 311. 22—519 (494).

THE Samaden Municipality inaugurated a drinking-water system combined with a power-generating plant, at the end of last year. A pipe line, nine kilometres long, carries spring water from the Rosegtal to Samaden. About one fifth of the volume of water is led through a reducing valve into the water-distribution system while the remaining four fifths are utilized to drive a hydro-electric generating set of 180 kVA output. The new power station containing this set is situated at about 500 m from an old electricity works, not in use now, in which a new hydro-electric generating set of 60 kVA output has now been placed. This unit is supplied with water from the Val Champagna from which the former drinking water supply was tapped. Apart from the old electricity works, there is also a transformer station containing three three-phase transformers, 160 kVA, which allows of connecting the local electricity distributing system to that of the Bündner Kraftwerke.

In the old power station, which contains the business offices of the electricity works, a new central control point for all the electrical plants has now been lodged. Both the new hydraulic sets—apart from starting up and closing down—are completely automatic in operation and close down of themselves in case of trouble.

Under ordinary conditions, both plants are in continuous service. As the turbine of the 60-kVA set has no speed regulator, it is adjusted to give constant load while the load of the 180-kVA set varies so as to conform to the power requirements of the system. If the load of the 180-kVA generator reaches its full-load value, an alarm signal is given in the old power station so as to allow of power for the local system being tapped from the Bündner Kraftwerke system, through the transformer station. Synchronizing is carried out from the old power station, as the speed of the 180-kVA generator can be remote-controlled from there. Remote control of the high-voltage circuit breakers in the substation was also put in, to allow of synchronization, as this is, of course, necessary.

Thanks to the little supervision required by the electric equipment, which is limited to synchronizing operations with the Bündner Kraftwerke and, possibly, to intervention in case of trouble, it has been found possible to pay all interest and redemption charges on the entire new electric plant including the drinking water plant out of the receipts from the sale of electricity and this despite low metering charges. The new plants have, therefore, had a very benificial effect on the finances of the municipality.

(MS 829) *W. Kissling. (Mo.)*

Extension of single-phase a.-c. motor-coach traffic on the Norwegian State Railways.

Decimal index 621. 335. 4 (481).

THE Brown Boveri Review of November 1931 contained a short description of the two first single-phase motor coaches delivered to the Norwegian State Railways[1]. These coaches were acquired with the object of improving the suburban traffic on the Oslo-Drammen-Kongsberg line sections. The inovation proved so successful that, as early as the beginning of 1932, the State Railways ordered two other similar motor coaches from the A/S Norsk Elektrisk & Brown Boveri, Oslo. These are now in service on the Oslo-Drammen line, as well.

In 1933, the Norwegian State Railways decided to build the Voss-Eide line section, laid out for electrification from the beginning, and they again gave the A/S Norsk Elektrisk & Brown Boveri the order for the three four-axle passenger motor coaches required for this line.

This is a full-gauge branch line of the well-known Bergen Railway. It begins at the Voss station of the said line (about 110 km from Bergen) and links up the main line to the locality of Eide, on the southern part of the Fjord, after passing over a mountain ridge. The mountainous nature of the line, which is 27·5 km long, required long gradients, the stiffest of which is 45 ‰ and called for a different design of motor coach than that used on the flat Oslo-Drammen line. At the same time, it was desired to incorporate in the new coaches as many as possible of those separate features of the electrical equipment which had proved so reliable in the first coaches and the light construction used in the latter.

The type of current is the same as that on the Oslo-Drammen and other electrified sections of the State Railways (single-phase current 15,000 V, $16^2/_3$ cycles). Traffic with trains of a total weight of about 106 t on the Voss-Eide line section calls for the total available adhesive weight of all four axles and, therefore, the incorporation of four driving motors (wheras there are only two on the Oslo-Drammen line). Each axle is driven by an axle-type motor of 116 kW one-hour rating and 95 kW continuous rating (two sets of each two motors continuously connected in series); the travelling speed with the one-hour rating (corresponding approximately to a total weight of 106 t on a 45 ‰ grade) at 15,000 V contact-wire voltage, is 30 km/h. The highest travelling speed is set at 50 km/h. The electro-magnetic contactor control used with the earlier motor coaches is retained. Further an electric resistance brake is built in, which is sufficient to brake down the motor-coach weight on the grades encountered.

The three motor coaches being built should be put into service in the autumn of the present year.

[1] The Brown Boveri Review, November 1931, page 339.

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