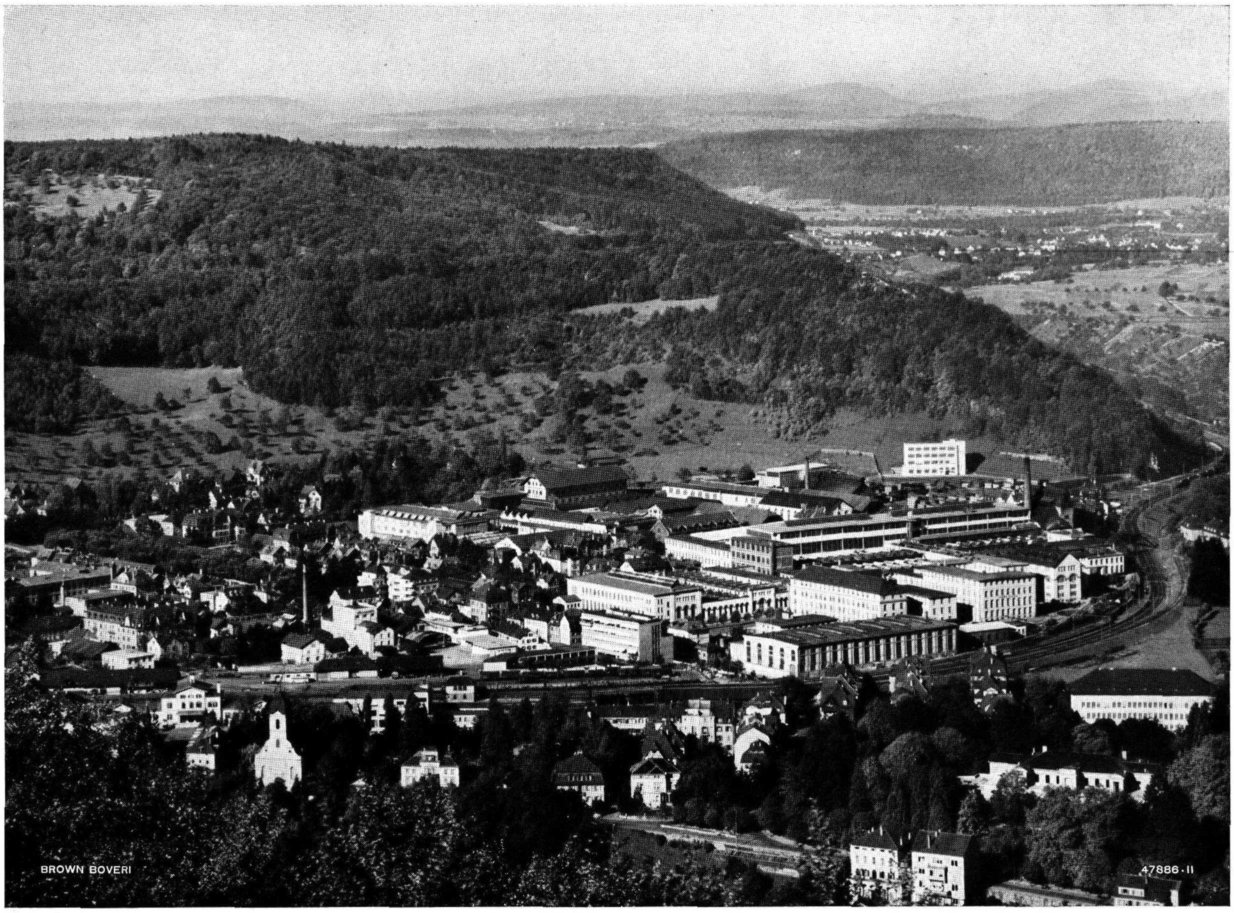
VOL. XXVI APRIL/MAY, 1939 (DOUBLE NUMBER) No. 4/5

THE BROWN BOVERI REVIEW

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



GENERAL VIEW OF THE WORKS OF MESSRS. BROWN, BOVERI & COMPANY, LIMITED, BADEN (SWITZERLAND).

BROWN BOVERI EXHIBITS AT THE SWISS NATIONAL EXHIBITION, ZURICH, 1939

Printed in Switzerland.

SWITZERLAND is a small country and its only natural wealth is water power ◻ Despite this, the machinery export business is of considerable magnitude and the quality of the products can truly be said to be world renowned. The capacities and exceptional qualities of Swiss technical men and workmen are of a generally-recognized high standard ◻ The exceptional technical development of the country, however, is only due to individual initiative, to the will to keep step with progress and to be in the vanguard as regards new technical developments. This can only be attained by devoting constant effort to the field of scientific investigation.

THE BROWN BOVERI REVIEW

THE HOUSE JOURNAL OF BROWN, BOVERI & COMPANY, LIMITED, BADEN (SWITZERLAND)

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1914—1939

Decimal index 606.4 (494).

THE fifth Swiss National Exhibition was opened in May of this year, in Zurich, the biggest commercial and industrial centre of our country. Fifty-six years have elapsed since our second national exhibition, that of 1883, which was also held in Zurich.

To begin with, it may be recalled that the span of not quite six decades, from 1883 up till to-day, encompasses the entire development of *electro-technology*, a development which, rightly or wrongly, is generally assumed to have begun with the International Exhibition of Electricity of Vienna in the year 1883. However this may be, it was in this same year, namely that of our own second national exhibition, that *E. Bürgin* and *R. Thury*, pioneers in the electrical field, exhibited the first electrical machines built in Switzerland, namely, those of the firms "Bürgin & Alioth" in Basle and of "de Meuron & Cuénod" in Geneva. Then came years of an impressive upswing in our field of manufacture, so that the electrical industry of Switzerland was able to furnish material proof, when the national exhibition in Geneva took place in 1896, that its electric products enjoyed a world-wide reputation. There followed eighteen years of developments on a large scale ending in the third national exhibition, namely, that of Berne in the year 1914.

As a quarter of a century separates us from the fateful year of 1914, we think it will be of interest to make some comparisons between the state of development attained then and that reached to-day. We will attempt to show what part we, ourselves, played in electrical developments up to 1914 and what we have succeeded in doing since then. To this end, we will begin with a glance at the objects exhibited by our firm in the exhibition of 1914. The stage reached to-day and what we are able to exhibit in 1939 is summarized in, we trust, an interesting form in the articles which make up the present number of our House Journal, devoted to the objects shown at the exhibition.

One of the most interesting technical exhibits in the field of *generator design* at the exhibition of 1914 was a turbo-generator with its driving turbine for an output of 5000 kW at 3000 r. p. m., the biggest two-pole turbo-generator built up till then. Sixteen years later, this output had been increased eightfold, thanks to the progress made in metallurgical science in the intervening period. Later on, two-pole machines at 3000 r. p. m. were being built for ten and eleven times the above original maximum output. The rotors of these machines were made of one piece and very ingenious and scientific investigation of the metallurgical structure of these parts went to show that these successful forgings must rather be considered as lucky accidents in the technology of forging and it was our opinion that it was not wise to pursue further developments to bigger sizes on this risky basis. For this reason, we developed a special design of our own, as has been already mentioned in The Brown Boveri Review, namely a rotor body built up of several parts. This was the desired solution of the problem even for the biggest outputs. It was as marked a departure as had been C. E. L. Brown's introduction, at an earlier epoch, of the cylindrical rotor, with slots milled out of the solid, for the distributed excitation winding, an innovation which it will be recalled, was welcomed in technical circles on both sides of the Atlantic as being the only method leading to the desired results in turbo-rotor design.

The replacement of heavy castings for the housings and bedplates of generators by rolled sheets welded together went far to alter the external design of turbo-generators.

The period between the two exhibitions also saw the development of high-voltage turbo-generators, of which our firm were the pioneers on the Continent.

The evolution of water-turbine driven generators had followed a similar course. The generators designed and built by us for the Gösgen Power Station belong approximately to the period of the 1914 exhibition and indeed represented the biggest units of their type built so far by us. The period after the Great War saw an impressive development of the big power station with generating units the output of which was a multiple of that of the Gösgen machines. This development was made somewhat difficult in some respects by the appearance of the Kaplan type of water turbine demanding much higher overspeeds to be stood up to by the generators, and also by the demand for single-phase, $16\,^2/_3$-cycle generating units to supply the railways. To-day, we have units for 60,000 kVA with 16 and 18 poles going through our shops.

As regards *transformers*, we exhibited a testing unit in 1914 for 500 kV as well as voltage and current transformers. These were built on the principle of the standard power transformer, therefore, with a disproportionately big amount of oil in comparison to the power output delivered. In this field, subsequent developments brought a complete departure from the old principles of design. The advantageous principle of grading the potential along the insulator shell adopted by us led to the designs without bushing insulators and with very small oil filling, namely to what we have designated as the insulator-shell design. We may say here that, to-day, the design of the power transformer itself seems to have reached a turning point, the newest designs being along similar lines to those adopted for the measurement transformers.

There have been many stages passed through in the development of *circuit breakers* in the course of the last 25 years. The oil circuit breakers exhibited in 1914 and built for voltages up to 80 kV were designed, really, on a rather insufficient basis of acquired experience. The rupturing tests carried out by *Dr. B. Bauer* for the "Kommission für Hochspannungsapparate und Brandschutz" of the S. E. V. and V. S. E., in 1914/15 in the Betznau Power Station led to the first expression and definition of the term "circuit-breaker work" and the subsequent systematic extension of these investigations in our own high-power test plant permitted us to develop single-pole oil circuit breakers up to 110—220 kV; these investigations also allowed of the developing of the medium-voltage breaker (threatened by the more strenuous duty imposed on it by the interlinking of systems) into an apparatus to meet the most modern requirements of the period. Multi-rupturing points, spherical and solenoid contacts, the oil-piston theory investigated by slow-motion films and, finally, the determination of a basis for the proper dimensioning of breakers, were all fruits of onerous scientific investigation. As a result of some foreign breaker explosions there arose among clients a demand for some new type of breaker without oil filling. We then began developing *water circuit breakers*. Here, there was no combustible medium, but a liquid one which, however, when transformed into vapour, could conceivably become an explosive mixture. Further, as compared to oil, water is not an absolute non-conductor and, therefore, cannot be used for the higher voltage range. We always considered the water circuit breaker as an intermediate stage of breaker development and were already, as early as 1922, of the opinion that compressed air promised far better results as an extinguishing medium, although at the time in question, we did not possess the necessary testing equipments to confirm this.

Nevertheless, systematic tests on the rupturing phenomena in a vapour atmosphere led to the design of an extinguishing chamber very suitable to the object sought for; this is the convector chamber which proved most valuable in the subsequent development of high-voltage breakers with small oil filling, namely the so-termed *convector circuit breakers.* This was indeed a welcome alternative to the single-pole oil-tank type of high-voltage breaker with its big oil filling, if only for reasons of oil economy.

Towards the end of the twenties, tests were begun on a big scale on the phenomena inherent to ruptures under compressed air. These confirmed our earlier assumption in this respect while providing the fundamental data for the development of air-blast breakers, a development which, it should be said, had been begun elsewhere, as well. The air-blast breaker with its incombustible and non-explosive arc-extinction medium, has such an inherent short rupturing time that it alone is able to meet the conditions requisite to the maintenance of stability when trouble occurs at some point of a closely interconnected and extensive network. Combined with a *reclosing device* which can really be relied upon to act automatically before the generators on the system fall out of step, the air-blast breaker can be counted on to maintain the further delivery of power. Circuit breaker of this type and devices of this kind are among our most important exhibits from the point of view of what may be termed the history of technical development.

Parallel to these developments, we have built and placed on the market *over-current* and *distance relays* which are exceedingly precise in the setting as regards definite time and impedance graduation. As early as 1914, we exhibited at the Berne exhibition, for the first time, definite time limit *primary* and *secondary relays.* These were most ingenious inventions of *Albert Aichele* and the apparatus was exhibited under working conditions. These relays fulfilled all practical requirements, with only insignificant modifications, for a period of twenty years. However, about four years ago, new designs of both types of relay were brought out, the tripping times of which can be adjusted to 0.05—0.10 seconds, with great exactitude.

In close touch with the experience and requirements of practical service, supported by the evidence of investigations of cases of trouble on systems, we were able to put on the market in 1928 our *distance relay* for *selective protection* of *overhead lines.* This cross-coil ohmmeter was, at that time, the first and only apparatus available to meet the most unfavourable service conditions.

In 1937 we created a *distance relay* for the selective protection of *cables* and, finally, last year, our distance relay was combined with a directional one and brought out as a *quick-acting distance protection* equipment very suitable to the inherent short rupturing times of the air-blast high-speed circuit breaker.

Our *rolling-contact quick-acting regulator* has been recognized as a very striking example of systematic development work. Twenty-five years ago this apparatus was only used as a reliable voltage regulator to be placed on the excitation circuit of the exciters of generators and train-lighting machines. It was under these forms that it was shown in Berne in 1914. Retaining its fundamental elements, we evolved from this regulator an over-current regulator, a p. f. regulator, a frequency regulator a draw regulator for paper-making machines and, finally, a primary regulator to replace the pendulum governor of water turbines.

The first *mutators* built by us were exhibited at the Berne exhibition of 1914. These mercury vapour rectifiers, as they were then called, were of only 150-kW, output at 500 V. This apparatus, which demands so little supervision in operation, has been the object of a most astounding development since the modest beginnings of 25 years ago. The improvements introduced since then: — absorption choke coils, outputs up to 4200 kW, 8400 A in one cylinder, controlled anode grids (an evolution thus making possible the use of the mutator as a universal converter, as regards current, frequency, etc., and allowing of using it as a system-coupling organ), the development of air-cooled types, all these are innovations due to the work carried out in our laboratories and test rooms. It should not be necessary to stress, once again, the role played by the mutator in the electro-chemical industry and how important it has become in D. C. traction systems, eliminating the rotary converter, as indeed *Dr. Walter Boveri* himself predicted on the 14th December 1915 in Berne, in his talk before the Swiss Electro-Technical Association and the Swiss Association for Hydroelectric Developments, when discussing the various systems of current. The generation of high D. C. voltages (up to 50 kV and more) in mutators should be of vital importance to the problem of future power transmission over big distances and, indeed, it does not seem impossible that the transmission system at 50 kV D. C. set up by us between Wettingen Power Station (near Baden) and the National Exhibition (in Zurich) for purposes of demonstration, will be a milestone in electro-technical developments, just as was the famous Lauffener power transmission of 1891, with which the name of C. E. L. Brown is so closely associated.

The *motors of every kind* which we exhibited in Berne stressed the importance attached at that early date to series production; indeed our three-phase slip-ring and squirrel-cage motors, in their compact but very pleasing design, were thus shown to best advantage. There might have been a tendency, even then, to consider the development of motors as having reached a final stage. The post-war years, however, saw a variety of different conditions demanded of motor drives which conditions also coincided with lower buying power of clients, demanding, in its turn, rigid economy in the use of materials. This resulted in the bringing out of motors with enamelled wires, cast-aluminium squirrel-cage rotors, double and deep-slot motors and multislot motors. These innovations caused power-generating authorities to become less severe as regards the regulations governing the connection of squirrel-cage motors to secondary systems.

Other developments in motor design were the replacement of journal bearings by roller bearings and (for motors with wound rotors) the replacement of motors with automatic short-circuiting device, shown in Berne, by those with centrifugal starter. Then there were all the special designs brought out of the totally-enclosed motor with cooling shell in modern design, the flanged motor, the motor for building in to and on to the machine being driven.

The *switchboxes* exhibited in Berne as accessories to the motors were limited, at that period, to two types of starting switchboxes: with shunted fuses and with star-delta starting. To-day, a number of switchbox models of various shapes and sizes have been evolved from those original types, to meet the most varied requirements. The fuses have been replaced almost entirely by *thermal releasing devices* built of layers of bi-metallic strips, the proper dimensioning and construction of which took several years to evolve.

The *single-phase commutator motors in Déri connection* for the drive of ring-spinning frames were an object of great interest in 1914. A new series of these machines had just been brought out which incorporated all the improvements of the preceding years. Beside these units, we exhibited the first *three-phase series-wound commutator* motors built by us and destined in the subsequent period to oust the former type of motor, thanks to a better power factor. In their turn, the three-phase series-wound commutator units had to cede position to the *three-phase shunt commutator motors,* the field of utilization of which has extended to-day far beyond the field they were primarily intended for. They are used now for the drive of *paper-making* machines the *driving problem* of which has been most satisfactorily solved by us.

As compared to present-day conditions, the state of development of *electric traction* at the time of the 1914 exhibition was not very far advanced. There is no branch of electro-technology which was as much influenced by the World War towards expansion as that of electric traction.

In the big "Means of Transport" hall, of 1914, a two- and a four-axle motor coach of the *Basle Tramways* were exhibited. These were equipped with two and four motors respectively of our, at that period, new totally-enclosed type and with ball bearings. These motors had controllers which although of the most modern design still belonged to an early period of development. These motors and controllers are obsolete to-day. Modern traction motors to-day are all of the pipe-ventilated type with roller bearings and on tramway coaches there is a positive tendency towards replacing axle-bearing motors by very high-speed motors placed between the wheels or in the longitudinal axle of the coach, in both cases firmly secured to the frame and working on the driving axles through high-ratio gears and through couplings which can move in all directions. The directly-operated driver's cab controllers have been improved by introducing switching elements with individual blow-out.

We would recall here the 1-D_o-1 locomotive No. 302 for the Rhaetian Railways which was exhibited in Berne. This unit, although still doing duty to-day, really belongs to a pre-war period, with its repulsion type of motors carried in high bearings and three-rod drive which was itself a modification of the former slot type of drive.

It should be recalled that this privately-owned railway, the biggest of its kind in Switzerland, ordered a new type of locomotive from us on the electrification of their whole system just after the War. For the conditions imposed, this unit of C-C type, of series 401, is the most powerfull of all narrow-gauge locomotives running to-day. When passenger traffic by light motor coaches began to get popular, in recent times, the railway management rewarded the special attention we had always given to the difficult problems inherent to their narrow-gauge system, by granting us leading rank in the development of their new light motor coaches to be put into service this summer.

The newly-developed 1-D-1 locomotive No. 371 of the *Swiss Federal Railways* intended for the three-phase service of the Simplon tunnel run, was also shown in Berne 1914. The developments of electric traction in Switzerland since then have been really astounding, and is to-day the factor of primary importance to the Swiss Federal Railways. A start was made with the electrification of the Berne-Thun section (15,000 V, $16^2/_3$ cycles), which was taken over in 1919. The electrification was successively extended to over 2133 line kilometres, that is to say, to 74 % of the total full-gauge of 2868 line kilometres. Twenty types of locomotive have been developed, nine being essentially based on Brown Boveri designs, on which the individual axle drive, designed in Baden, predominates. Apart from this, we delivered a considerable amount of material for the equipment of Swiss Federal Railways power stations and sub-stations.

We would also recall the two rack locomotives for the *Bernese Oberland Railways* (D. C. 1500 V) and for the *Jungfrau Railway*. These were modern units for the period they were built, although three-phase current was hardly being considered any more, then, in the case of *new* mountain railway sections. For similar duty but of the latest design, we can mention the light motor coaches of rack type recently delivered to the *Rigi Railway* and the *Glion-Rochers-de-Naye Railway*.

Finally, we would mention our *railway-lighting system* which was already installed on a number of vehicles at the time of the Berne exhibition and which has given such a good account of itself in hundreds of equipments. The essential improvements introduced are the replacement of belt drive by a cardan-shaft drive and better regulating apparatus.

As regards *thermal machines*, apart from the driving turbine of the 5000-kV turbo-generator already mentioned here, we also showed, in Berne, a turbo-blower driven by a steam turbine, a motor-driven blower, condensing pump sets and a surface condenser in two parts. These exhibits define very well the stage of technical developments reached at that period. It would be a difficult matter to-day to give, in the scope of an exhibition hall, even an approximate idea of the stage reached. The increase in the output of generating units led to the evolution of multi-cylinder steam turbines and then, we may say, under our leadership, to the practical application of very high steam pressures up to 120 kg/cm^2 and also to the considerable improvement in thermal economy, thanks to using high-pressure superheated steam up to 500° C. Then efforts were bent on bringing out a technically and economically satisfactory gas turbine, which we were convinced had to be one of the constant-pressure type. The work done in this field was the primary cause of the development of a subsidiary product which became of great importance; this was nothing less than an entirely new kind of steam generator which we named the *Velox steam generator*. This generator has already been built in units generating 75,000 kg of steam per hour, for the maximum steam pressure of 55 kg/cm^2 and maximum steam temperatures of 500° C. Units for as much as 150,000 kg of steam per hour at 100 kg/cm^2 and 500° C are under consideration at the time of writing. The development of the constant-pressure gas turbine considered as an integral part of the Velox steam generator has been brought to the point, that, in the form of a multi-stage reaction turbine, it can be used quite alone and as a generating unit and thus find a field of utilization in stand-by plants, for covering peaks and also for constant power delivery. Here the heating up of the combustion air by the exhaust gases from the gas turbine allows of a welcome increase in the thermal efficiency.

As regards its exhibits at any exhibition, a big firm has the choice between objects which will hold the attention of visitors by their imposing dimensions and those which justify their position through the evidence given of study and development work carried out. These two alternatives are rather in opposition one to the other, because only those developments which are close to their final stage, that is to say, having years of patient work behind them, can lead to the production of practical objects of impressive dimensions; new designs are, nearly always, modest in their beginnings and size. Pioneer work which it is desired to make evident under the form of exhibits is rather apt to be overlooked, on account of the unobtrusiveness of the exhibits. Despite this, we have favoured the second alternative, striving to demonstrate our creative power at the National Exhibition through the agency of a few definite exhibits of modest overall dimensions, which, however, should appeal far more strongly to the technical man. We trust the said exhibits will give sufficient proof that we are still in the van of technical developments in our own field and leading in various lines of technical investigation, as we were 25 years ago. Thorough, independent research work and a proper use made of the results attained are the only methods of attaining practical results.

We hope that the Swiss National Exhibition will know a goodly measure of success and that this nation-wide effort will carry conviction of the present advanced stage of Swiss culture, far beyond the limits of our own narrowly-defined field of activity, namely, that it will testify to efficiency, to hard work, — and what to-day is more imperative than ever before:— to an undaunted spirit of independence.

Brown, Boveri & Company, Limited
Baden (Switzerland).

THE FIRST 50,000 VOLT DIRECT-CURRENT POWER TRANSMISSION BY MEANS OF MUTATORS.

Decimal index 621. 315. 051. 024.

This article goes into the problem of D. C. power transmission and stresses its very economical character for the transmission of big amounts of power over long distances. The trial plant with mutators shown at the National Exhibition is, itself, the proof that apparatus is available to-day for D. C. high-voltage transmission at constant voltage.

INDUCTIVE and capacitive phenomena are inherent to the transmission of big quantities of power at high operating voltages. The latter are necessary in order to meet constantly increasing power requirements and, also, longer distances between the centres of power generation and those of power consumption. The said phenomena lead to serious inconveniences despite all the skill and artifices expended on the various three-phase transmission-line designs. High-voltage D. C., on the contrary, allows of utilizing a whole series of technical and economic advantages and it thus facilitates power transmission over big distances. In the first place, the use of D. C. allows of eliminating inductive voltage drops, which, at high operating voltages, attain a figure which is a multiple of the ohmic voltage drop; then, the transmission line has not to carry any reactive (wattless) load. In the interests of stability on three-phase transmission systems over long distances, wattless-current generators have to be put in on determined sections of the system. This is not necessary with D. C. transmission so that the latter is more economical.

The construction of the line itself is an important factor in power transmission. Of the many kinds of line arrangements available for D. C., that with two conductors and earthed neutral point or with earth as middle conductor has proved the best. The transmission voltage is, here, limited by the voltage of the outside conductors against earth. If the same insulation stressing is allowed for the conductor under A. C. and D. C., an operating voltage $\sqrt{2}$ the times operating voltage under A. C. can be chosen between conductor and neutral point for the D. C. transmission. To this advantage it must be added that, if an earthing of a conductor occurs on a three-phase system, of which the neutral point is not earthed, one conductor is immediately $\sqrt{3}$ more highly stressed than it is in normal service. In order to attain high efficiencies, power transmission over long distances necessarily leads to the choice of high voltages, which however are limited to 400 kV on account of corona losses. Corona and skin phenomena make expensive, hollow conductors necessary when three-phase is used while solid conductors of the same section can be used with D. C. and are fully utilized. The data collected by A. Rachel[1] shows that for three-wire D. C. connections the total conductor section is only 0·5—0·3 that with three-phase transmission. With the smaller sections of solid conductor, the masts can be made lighter as the additional pressures exercised by snow, ice and wind are lower; this means saving effected in capital outlay on the line.

According to the author just mentioned, the cost calculation for overhead lines show the great superiority of D. C. and this superiority is the more marked the greater the amount of power to be transmitted.

When the investigation of transmission systems is extended to cables, as well, the advantages of D. C. at high voltages are still greater. The line is in no way affected by charging and magnetizing currents, and can, as compared to three-phase, be used for carrying a bigger output. There being no charging currents, the insulation is less stressed and need not be so heavy, this, in turn, allows of heavier loading of the cable because the heat losses are then radiated more easily. The three-conductor system is then formed of two single-core cables the lead sheathings of which form the earthed middle conductor. To-day the technology of cable design and construction has reached a point which allows of making D. C. cables for voltages up to 200 kV; this brings big power transmission within the realm of practical realization. As compared to three-phase cables the cost of manufacture of these D. C. cables is about $^1/_2$ or $^1/_3$. Further, the utilization of high D. C. voltages and of cables for power transmission increases service reliability and lowers the upkeep charges for the transmission equipment. Transmission lines laid in cables are safe from aerial attack and, thus, assure continuity of power supply during hostilities. The lines are no longer subjected to atmospheric over voltages. The operating staff will certainly experience a feeling of relief at finding the greater part of former vexatious operating breakdowns become a thing of the past. Further, by laying the transmission lines in cables the difficulties encountered when carrying lines over rivers or arms of the sea are eliminated, while the extra expense due to specially lofty masts and special conductors is also done away with.

We think doubt can no longer exist that economically-operated big power transmission systems of the future over long distances will be by means of high-voltage D. C.

The classic 50-kV D. C. power transmission system which we owe to the genius of Thury[1] laid between Moutiers and Lyons, the voltage of which was subsequently raised to 120 kV, carries power generated by D. C. dynamos over a distance of 450 km to the consumer. This system, which works under constant current and on which the raising or lowering of the voltage is attained by the adding or cutting out of machine sets, has, as chief disadvantage, constant line losses. The power generation in dynamos calls for constant current regulation in order that all machine sets in service should work at a good efficiency also under partial load. The number of machine sets which have to be kept in reserve is, however, very low. Test equipments have been built using mutators for power transmission at constant current and making use of the experience gained on the Thury plant. However, the power transmission systems of the future will, in all probability, be made at constant-voltage, because of the intermeshing of networks; future plants will certainly be equipped with the static converters (mutators) developed in the meantime, which will be used as power-transmitting and power-receiving units. For the first time, we now have a model testing equipment built according to this system with 50,000 V mutators; this is really an important pioneering effort. The A. C. current is converted into D. C. on the site of power generation and, at the end of the transmission line it is converted again into three-phase current, under which form it is most suitable and simple for power distribution. The voltage regulation for power distribution is carried out by on-load tap-changing switches on the transformers and by grid control on the mutators. Thus, D. C. as a current system is only used, here, for the power transmission proper while power generation and power distribution is by A. C., which has well-known advantages, especially as regards voltage

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[1] A. Rachel "Elektrizitätswirtschaft", 1935.

[1] Thury, "Bull. SEV" of 1930.

conversion for numerous consumers. Existing three-phase power stations could be converted to this system for power transmissions over long distances, the consumers remaining on the existing A. C. distribution systems on which no new capital need be expended.

As controlled mutators, which are the simplest static converters for D. C. high-voltage transmissions, allow of reversing the sense of power flow, a possibility of power exchange is offered here over big distances, between different three-phase generating plants, thus realizing the coupling of different systems. This flexible coupling leaves the frequencies of the systems in question independent of each other.

High-voltage D. C. permits of transmitting big quantities of power over long distances and big savings are effected in the transmission line proper; on the other hand, there is the converter plant to be taken into account which, of course, means more outlay and which is also the source of some loss in power. With D. C., there is no wattless load to be transmitted. The wattless power required for the network supplied has got to be supplied by synchronous machines which dictate the frequency. As compared to mutators, a three-phase plant has the advantage of more simple transformer plants which, however, call for expensive switchgear when the voltage range worked to is very high. Further, it should be noted that, according to the investigations of R. Rüdenberg[1], wattless power stations must be located at distances of 200 km from one another in order to maintain stability. These, certainly, increase the cost of an A. C. transmission considerably. The advantages of D. C. shows up, most markedly, when cables are used and are the more marked the greater the amount of power transmitted. The converters are called on to fulfil special duties, because they must attain the high D. C. voltage demanded, either in one unit or in a series of units, while giving high efficiency combined with full reliability. The progress made in mutator development and the solution of the various problems set by the control equipment permit us to face the problems of the future in all confidence. Our tests already prove that, for operating voltages of 50,000-V mutators can be built for currents of 400 A making an output per mutator set of 20,000 kW. Tests are continuing along these lines and point towards higher operating voltages.

The Swiss National Exhibition gave a welcome opportunity of carrying further the preliminary work already accomplished and of making a large-scale practical test under the form of practical transmission of power by high-voltage D. C. produced in metal-tank mutators. The Zurich Electricity Works have given their whole hearted support to our efforts by placing a transmission line at our disposal. This will do much to further technical investigation work. In the plant in question, 500 kW are transmitted at 50 kV from Wettingen power house on the Limmat (near Baden) to the Exhibition in Zurich over a distance of 30 km.

Fig. 1 shows the fundamental diagram of this transmission plant. The A.C.-D.C. mutator set in Wettingen power house is connected up to the generator bus-bars through breakers and disconnecting switches. This set converts the three-phase power at 6 kV into D.C. at 50 kV for direct transmission to Zurich. The transmission line used is really the earth conductor, insulated, of the existing 50-kV three-phase transmission line. The said line goes over to cable form in the Zurich area and then becomes a single-pole overhead line again in the last section before the Exhibition. The high-voltage D.C. is then converted back to three-phase current at 6000 V and delivered to the distribution system of the Zurich Electricity Works. This conversion takes place in a D.C.-A.C. mutator set located in the substation of the Exhibition. To this end, the converter unit in question is connected to the 6-kV bus-bars of the substation through an air-blast

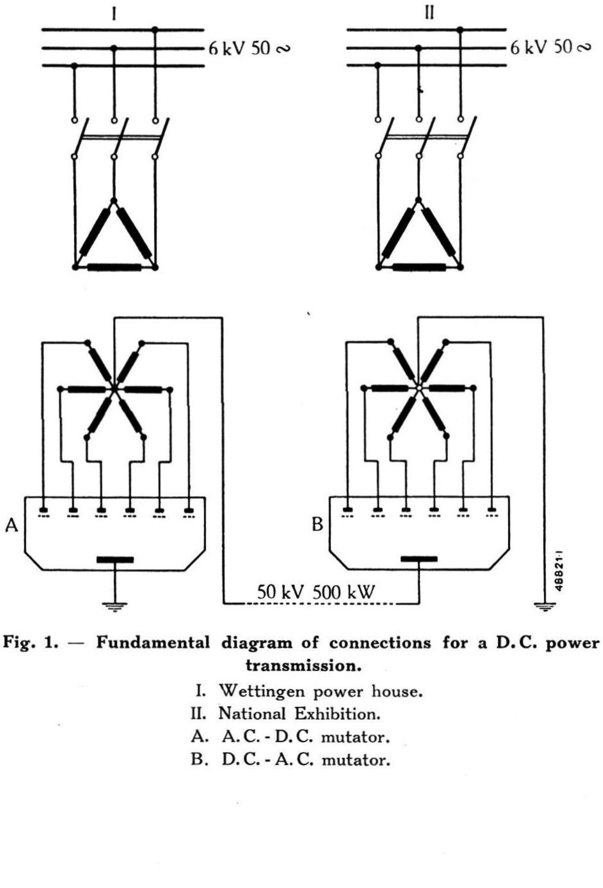

Fig. 1. — Fundamental diagram of connections for a D.C. power transmission.

I. Wettingen power house.
II. National Exhibition.
A. A.C. - D.C. mutator.
B. D.C. - A.C. mutator.

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[1] R. Rüdenberg: „Elektrische Hochleistungsübertragung auf weite Entfernung“.

high-speed circuit breaker and a compressed-air operated three-pole disconnecting switch. The earth serves as return conductor, the ordinary service earthing of the power house in Wettingen serving as earth electrode for one of the mutator sets and the rails of the tramway system, in Zurich, for the other one.

Both mutator sets are identical in design and, apart from the control circuits, have very simple connections, indeed. Each set comprises the mutator with its accessories, a main transformer and a breaker for the A. C. side, the breaker having primary-current and thermal relays to protect the set from too high overloads. There is an earthed switchboard panel to hold the various service switches and measurement instruments. Behind it, there is a highly insulated panel containing the control apparatus.

The D. C. -A. C. mutator set has been placed in the Exhibition substation and care has been given to making the layout as easy to supervise as possible. The layout of the various apparatus and conductors is easy to follow.

After extensive investigation work, grid control of mutators has been developed to the highest degree in order that, apart from voltage control, the field of D. C. -A. C. and A. C. -A. C. conversion should be mastered. It was only after the results of these tests were known that it became possible to go over to practical applications. Tests were made on a large scale to discover new fields of application and then among other results the basis was laid for this first D. C. transmission. The mutator sets, shown in Fig. 2, were first exhaustively tried out in the test rooms before being delivered for the Exhibition plant.

The high-voltage mutator, most important part of the plant, had to be considerably modified in design in order to meet the severer demands made on it; thus the new design, as shown in Fig. 3, differs considerably from former known types, the highest voltage limit of which, 60,000 V, was determined by the insulation. For the high blocking voltages existing between counter anodes we have designed special anode bushings. For the design of the valve proper we were able to make use of our own test-room results and also of practical records from numerous high-voltage mutator plants in service for wireless transmitting stations. A transformer seen in the background of Fig. 2, which was built for our test room should make possible research work in the field of higher voltages for mutators. To-day we have a complete mutator for a service voltage of 60,000 V. Thus, with this static short-circuit proof converter, we have available the basis for further study on high-voltage D. C. transmission. Needless to say that before this voltage range was reached much tenacity of purpose was necessary and many disappointments were experienced. We intend going ahead with the development of still higher voltages in a single cylinder. Here new problems will have to be solved. We would like to add here that satisfactory solutions will, certainly, be found and that we feel sure that our efforts will be crowned with that success which is the fruit of unremitting efforts and of the enthusiasm of the investigator in his chosen field.

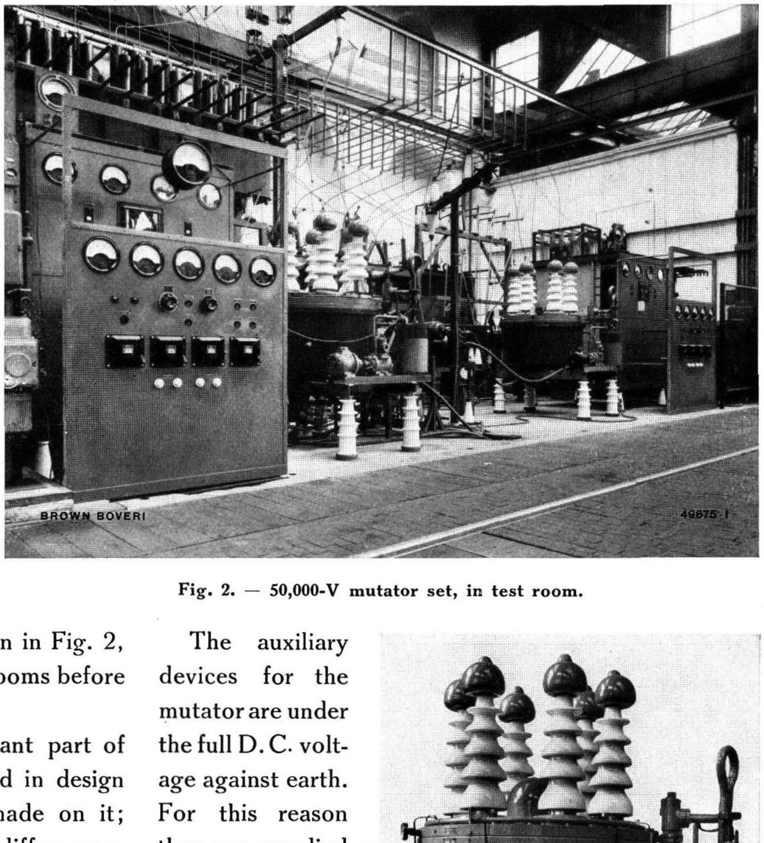

Fig. 2. — 50,000-V mutator set, in test room.

The auxiliary devices for the mutator are under the full D. C. voltage against earth. For this reason they are supplied through an insulating transformer and are mounted in an insulated switchboard panel, Fig. 4, which also holds the apparatus for grid control. This static apparatus gener-

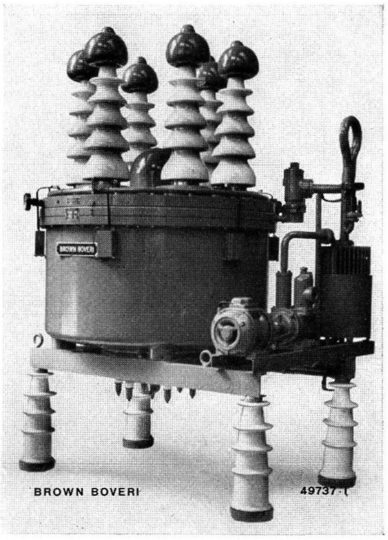

Fig. 3. — High-voltage, 50,000-V mutator.

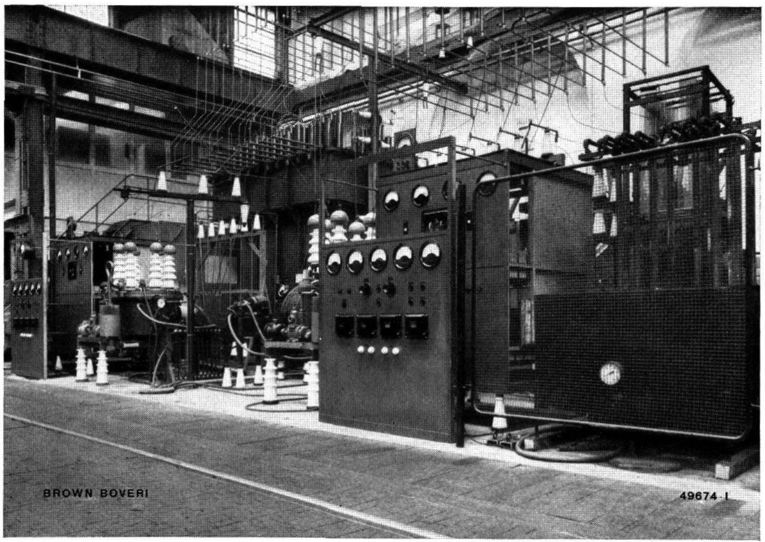

Fig. 4. — Mutator sets, 50,000 V, with switchboard panel, in the test room.

ates the steep-fronted voltage impulses which are positive in comparison to the cathode and which are produced in small current transformers, regulation of the mutator being carried out by an induction regulator which gives the requisite ingnition point. Cases of trouble are immediately cleared by well-known protective devices in conjunction with the grid relay, which effectively blocks the mutator, momentarily.

Service with the mutator sets for the Exhibition plant is very simple indeed, To begin with, by actuating the air-blast high-speed circuit breaker, the D. C.-A. C. mutator set in the substation is switched in and then by the closing of the breakers the A.C.-D. C. mutator set is put under voltage, the latter being raised through grid control until the current attains the value desired. A remote-control device also allows of controlling the latter converter set from the switchboard panel of the substation, that is from the consumer end. Short circuits on the transmission line are cleared by the mutator at the emission end by immediate action of the grid control because of the short distance covered. A break-down of the grid control apparatus results in actuating the protective relay and tripping of the breaker of the set.

The simplifications made possible in this test plant can hardly be claimed for longer transmission distances and a demand will soon be made for D. C. breakers for independent closing and opening of the converter set in ordinary operation and in cases of trouble. For this stage of developments, as well, development work has already given satisfactory results. With the introduction of the electronic valve as a D. C. high-voltage breaker the possibility of power transmission from a big generating centre point to various remote consumption points is made possible, because branches can then be laid from the D. C. transmission line.

The test plant built should give useful results during the six months it runs and allow a clearer view into the problem of D. C. power transmission. Technical men visiting the Exhibition will, certainly, be interested and this should, in our opinion, encourage further study of the problem. The successful results hoped for may be the cause of some existing enterprise deciding to make, themselves, a big scale experiment with high-voltage D. C. power transmission over a long distance and to put the results attained in this model plant to really practical use.

(MS 687) *Paul Egloff. (Mo.)*

WORK DONE BY BROWN BOVERI IN THE FIELD OF HIGH-FREQUENCY APPLICATIONS.

Decimal index 621.396.

The object of this article is to define work going on in the field of high-frequency applications, which is one we have only recently entered.

THE National Exhibition of 1939, is the first occasion on which Brown Boveri shows exhibits belonging to the field of high-frequency applications, and we think it is not out of place to give some data, here, on the subject.

Since the World War the high-frequency field has enjoyed an astonishingly rapid expansion and, to-day is penetrating into every branch of the electrical world. While Switzerland can lay claim to having played its part in the development of all the other electrical fields, a part which is no insignificant one when her small population and the poor natural resources of the country are taken into account, it must be admitted that the pioneers of high-frequency have to be sought beyond her frontiers. Up till now, nearly always, small firms took up this branch and, as is natural, they did not possess the resources allowing them to launch out on individual pioneering work to any great extent. Nearly always, the said concerns became licencees of big foreign firms, that is, when they did not limit their activities to turning out such material as was not covered by patents and the technical basis of which had become common property. The past has shown, however, that our country did not get the name it enjoys in the electrical world by following methods such as these and that real progress was only achieved by pursuing individual lines. There is nothing to be astonished at, here, because the high costs of manufacture in Switzerland make it prohibitive for Swiss products to compete in the markets of the world with others which can be turned out, practically by anyone, having the necessary standard equipment for the purpose.

These considerations, the correctness of which will be borne out by all who know our economic conditions, form the motive which decided Brown Boveri to add the technology of high frequency to the fields already comprised in their manufacturing program. This meant the development of a purely Swiss line of investigation. On the one hand, a certain amount of work had to be done the accomplishment of which did not strictly mean the solution of quite new problems, but which opened up a field of manufacture proper to give our staff the opportunity to make contact with the practical side of high-frequency and to get into touch with those who had special problems to solve.

In the spirit of the program which we laid down there were, however, more important and far more difficult tasks to be faced, namely the tackling and solving of problems which had, either, never been solved so far, or only partly solved. Mention can be made, here, of one of the most important of these:— the development of big emitting tubes which could be dismantled and which are permanently connected up to the high-vacuum pump. The life of a tube sealed by melting is about 4000—8000 service hours and is generally determined by the life of the cathode. It is not economical to carry out repairs on a tube sealed by melting; however, with a tube which can be dismantled, the cathode can be replaced in half an hour and the tube put back to work. If the replacement of the cathode be assumed to be necessary after about 1000 service hours, the tubes can be loaded to a considerably higher specific load than in the case of those sealed by melting, this although their life is a multiple of that of the latter. The capacitance is smaller because the tubes are smaller and, they are, therefore, suitable for short wave lengths.

The field of short and ultra-short wave lengths holds, in our opinion, possibilities of development as yet unexplored and we consequently concentrated our efforts on development work in this direction. Mention should be made, here, of our delivery of a complete high-frequency equipment to the Swiss Federal Institute of Technology, Zurich, and investigation work carried out in collaboration therewith on the chamber of the Cyclotron for the physical laboratory of the said Institute. The object of the Cyclotron is to accelerate the nuclei of atoms, which carry simple and double positive elementary charges, to such speeds, that they correspond to a potential of over 10 million volts in the electrical field. Here, it is not necessary that the said voltage should really be effective, because the particles are constantly being deflected by a magnetic field and prescribe a spiral course. *Fig. 1* shows the chamber which is shaped like a box and composed of two parts, between which the electric field is active. The magnetic field is to be assumed as acting in perpendicular sense to the plane of the paper. As this magnetic field has no high-frequency oscillations to perform but can be of constant intensity, its constitution presents no new problem. The cooling of the excitation winding, however, must be an extremely intensive one, the intensity of the field being forced up to a maximum. The high-frequency emitter delivered by Brown Boveri generates the voltages to be impressed on the two electrodes, of a frequency range of 13·5 to 15·8 MHz, corresponding to a wave length of 22 down to 19 m. The power it delivers amounts to about 25 kW. The condition imposed that the peak value of the high-frequency voltage must be about 80 kV means the imposition of very severe demands on the quality of the apparatus.

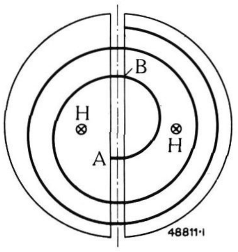

Fig. 1. — The Jonas track in the chamber of the Cyclotron.

The electrically charged particles, accelerated by the Cyclotron, serve to split atomic nuclei when they impinge thereon, high-frequency radiation appearing at the same time. According to this process, the Cyclotron will be chiefly used for the investigation of the transformation chemical elements and to generated so-termed artificial radiation phenomena. While, as already stated, the emitter tubes necessary for the Cyclotron are high-power ones, Brown Boveri also turned their attention to the development of smaller tubes for the generation of ultra-short waves, such as are required for television and ultra-short wave telephony. In order to be able to accomplish pioneering work in the field of dm and cm waves, the building of magnetron tubes was taken up and has already reached the stage of standard manufacture.

In the field of military equipment, Brown Boveri have also done some considerable work which, however, cannot be gone into, here.

The objects still to be enumerated rather belong to the field already touched on of high-frequency applications which have already reached the marketing stage of development. Here, as well, there were a number of technical details still to be settled. Brown Boveri are taking an important part in the delivery of apparatus for the police wireless installation for Zurich, to be used during the National Exhibition. The wireless transmission of orders from the central police station over a wave length of 128 m, to be received by suitable equipped officials in the town, is carried out by an emitter and receiver set delivered by Brown Boveri. The receiver set can be carried in the pocket of officials and has call relays and bells; this apparatus should awake general interest. Apart from this, the officials are able to reply by wireless to the central police station. The equipments developed by Brown Boveri to this end use ultra-short waves, between 4·5 and 5 m wave length. The decision to use such short waves, for this object, is based on experience gained by us in propagation measurements made by us in this wave length range.

Finally, high-frequency will be used in the Exhibition for transmitting switching orders in combination with the possibility of carrying on telephone conversations over a power line by means of carrier waves. This plant works over the high-voltage line with D.C. transmission between Wettingen (near Baden) and Zurich, which is described in another article of this number. The problem set here is especially difficult, for two reasons:— firstly, the high-voltage power transmission is through the earthing wire of one of the power lines of the Town of Zurich Electricity Works and, being of steel, it has a very big damping effect; secondly the transformation of A.C. to D.C. and then from D.C. to A.C. is carried out in mutators which themselves set special problems to be solved as regards the suppression of higher harmonics. Therefore, there is all reason to believe that the carrying out of this remote-control equipment will furnish valuable data for the solving of many problems which are to be met with in practice.

(MS 683) *Th. Boveri./W. Lindecker. (Mo.)*

ACTUAL PROBLEMS IN THE PRODUCTION OF POWER IN THERMAL POWER STATIONS.[1]

Decimal index 621.311.22.

This article begins with, the important efforts of the last ten years in the direction of increasing the economy of steam power stations. Then the importance and the requirements of underground thermal power stations are touched on. The special suitability of the Velox boiler in the case of the larger works of this kind is emphasized and justified. Finally, a special chapter is devoted to the most modern power generating machine, namely, the constant-pressure gas turbine, which Brown Boveri build in a series of designs, and which is especially well suited for underground installations, being so designed that no cooling water at all is necessary; thus, as regards installation site, it is more independent than any other kind of prime mover.

GENERAL NOTES.

BY far the greater part of the world's requirements for electrical power is produced in thermal power stations, and, indeed, to a predominating extent, in steam power stations. Efforts to reduce the outlay in invested capital, and to improve the utilization of the fuel, are, therefore, justified from an economical point of view. In the case of power houses serving general power demand, these efforts have resulted, amongst other things, in raising the limit of unit outputs ever higher, and in the employment of very high pressures and superheats. In this field, Brown Boveri did pioneering work in the Langerbrugge Station (S. A. des Centrales Electriques des Flandres, Belgium) as early as the year 1923, and since then have been able to complete a large number of very high pressure plants. (Approx. 70 sets for outputs up to 50,000 kW at 3000 r. p. m. and pressures above 50 kg/cm^2 abs and temperatures of 400—500° C). In this connection, special mention

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[1] While this article was being set up, we discovered that the rotor of the blower of the gas-turbine would have to be scrapped. As this is a big forging which will take some months to replace, the gas-turbine set can only be exhibited at a later date. We are exhibiting in its place a gas-turbine set, used for charging a Velox steam generator, built for a shaft output of about 1000 kW.

may be made of a set for 36,000 kW terminal output, which was placed in service in the year 1931 in the Karoline pit in Moravia (Witkowitz coal mines). It is constructed for live steam at 130 kg/cm^2 abs and 480^0 C. Up to the end of 1938, it had to its credit an operating time of 52,868 hours, the electrical output produced up to that time amounting to 507,600,161 kWh.

The recognition of the great economy resulting from combining the production of electrical power with the provision for heating requirements in industrial works, has also brought about interesting improvements in the sphere of industrial turbines. Here also, to an ever-increasing extent, very high pressures are gaining ground, because the increase in the production of valuable electrical energy thus obtained, is made available for use and in considerable quantities. In this sphere also, Brown Boveri have always occupied an authoritative position, and, thanks to great experience, are in an excellent situation to give advice to customers in the layout of a modern plant.

For several years, keen interest has been exhibited in circles concerned with power distribution, in the direct generation of very high voltages in large alternators. This interest will be fully appreciated, if consideration is given to the decrease in cost of the total installation, due to the elimination of the transformers, and to the improvement in economy, thanks to the higher overall efficiency (elimination of the losses in the transformers). Furthermore, the plant becomes simpler and more easily supervised. As early as the year 1929, Brown Boveri built a turbo-alternator for 31,250 kVA, 50 cycles, for a phase to phase voltage of 36,000 V. In the meantime, amongst others, sets of the same size for 25 kV have been built. Thanks to intensive research and development work, it is already possible, to-day, to build large units for phase to phase voltages up to 50,000 V.

The switchgear design for power stations is undergoing striking modifications, due to the demand for "elimination of oil". The realization that only the air-blast circuit breaker offers a full guarantee for the prevention of fires and explosions, has induced Brown Boveri to develop this type of circuit breaker for both indoor and open-air installation up to 220 kV. Apart from the important advantages mentioned, an even greater improvement is obtained, simultaneously, in the rupturing times. By employing these breakers in conjunction with modern Brown Boveri relays, it is possible to attain a very high degree of selectivity, so that faulty sections of the installation (outgoing lines), or feeders for supplying the station auxiliaries, are cut out before the main plant is affected by the fault. It may be definitely stated that the Brown Boveri air-blast breaker is, in this respect, superior to other types of breaker, and that its use in modern thermal power stations is becoming increasingly suitable.

The large number of actual problems relative to power production in thermal plants, in the development of which Brown Boveri is playing an active part, cannot be treated exhaustively in the space of a short article. After having first indicated some important technical advances to which a general significance attaches, we will now give more detailed data on actual problems which are of interest to a big circle of readers, and also because we are in a position to put forward interesting solutions for them.

I. BOMB-PROOF THERMAL POWER STATIONS.

One of the most actual problems of electrical power production is the installing of power stations which are proof against aerial attack. The power station buildings must either be provided with a bomb-proof concrete covering and with side walls resistant to explosive effects, or they must be arranged underground, for example, within a mountain. Such power stations have, it is true, already been built for small outputs, and provided with so-called "emergency supply Diesel sets".

As a result of the large space requirements and the high constructional costs arising therefrom, bomb-proof power stations could not, however, be introduced up to a short time ago, for medium and large outputs. Such plants should be capable of being established with the smallest capital outlay, in view of their principal duty as emergency stand-by plant with a small number of operating hours in the year. Firstly, the Velox boiler developed by Brown Boveri and recently also the constant-pressure gas turbine, make the fulfilment of this requirement possible.

For medium and large outputs (from about 5000 kW up) the steam power station using the *Brown Boveri Velox boiler* combined with turbo-sets is to be recommended.

The small dimensions of the Velox boiler and its method of operation render a separate boiler house superfluous; the boiler can be installed beside the turbo-set. Thus the whole layout, and therefore also the network of pipelines, assume the utmost

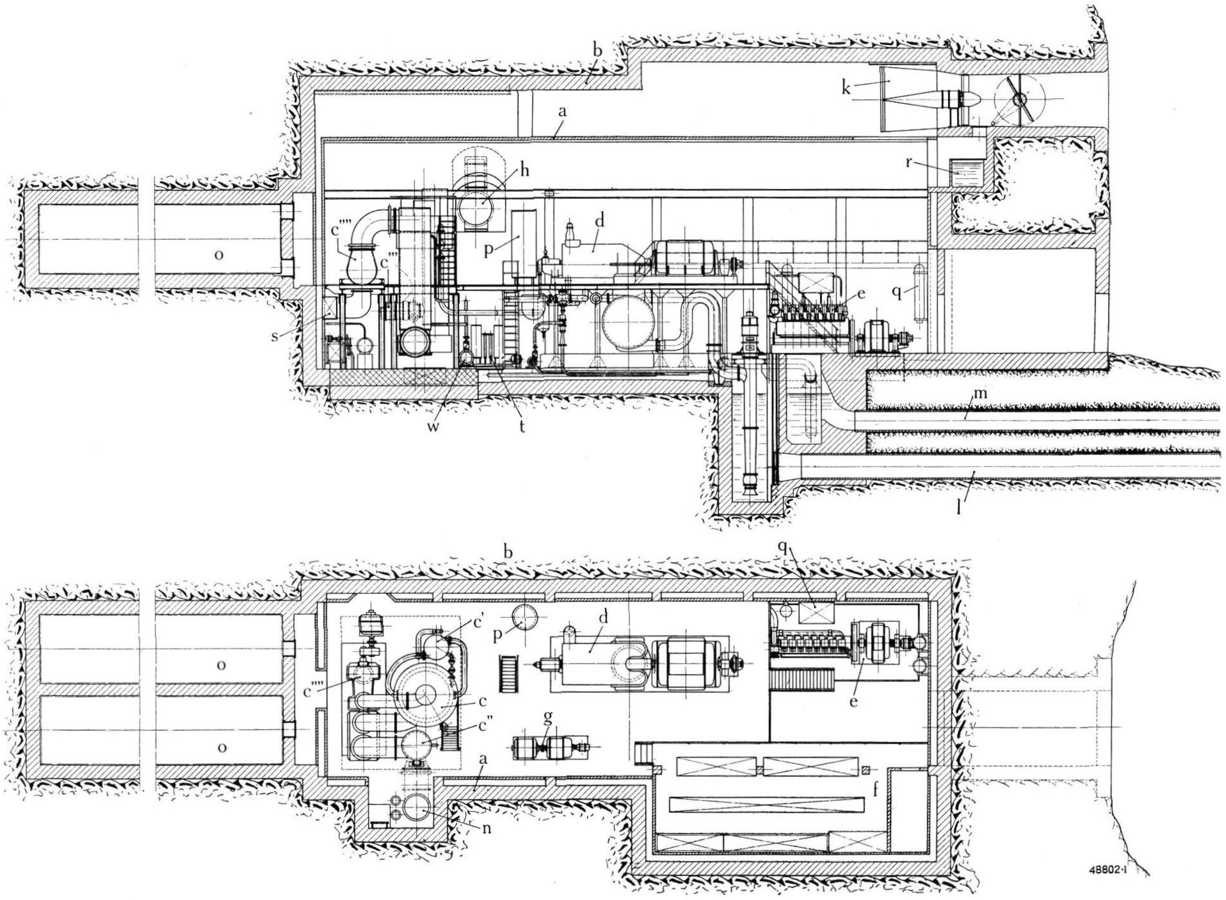


Fig. 1. — 9000-kW Velox steam power station built into a tunnel.

a. Structure.
b. Excavation of tunnel.
c. Velox boiler with steam separator (c').
Exhaust-gas heated economizer (c'').
Circulation pump (c''').
Charging set (c'''').
d. Turbo-set with generator and condensing plant.
e. Diesel-set for starting up.
f. Switchgear.
g. Ward-Leonard set of Velox boiler.
h. Feed-water tank.
k. Fan.
l. Cooling-water intake channel.
m. Overflow and outlet channel.
n. Pipe for exhaust gases.
o. Main fuel tank.
p. Auxiliary fuel tank.
q. Tank for Diesel-engine fuel.
r. Cooling-water tank for Diesel-engine.
s. Combustion air for Velox boiler.
t. Preheater for fuel and filtering equipment.
w. Feed-water pump.

simplicity. In spite of comparatively high costs for the structural part of the work, the total capital outlay is low.

Figures 1 and 2 show a thermal power station which is built into a tunnel in the mountain. The plant consists of:

1 oil-fired Velox boiler with an hourly rating of 44 t at 24 kg/cm^2 abs, 415^0 C;

1 turbo-set of 9000 kW output at the terminals, with single-cylinder turbine, three-phase alternator 9400 kVA, 6400 V, 50 cycles,

as well as the condensing plant. The preheating of the feed water to 80^0 C is carried out by means of a bled steam preheater. The make-up water for the boiler is likewise distilled by means of bled steam.

There are, further, provided:—

1 auxiliary Diesel set of 400 kW output at the terminals, for starting up the plant independently of external current supply;

1 station transformer of 600 kVA

1 machine-room crane of 20 t lifting capacity,

as well as the switch gear for the main generator, outgoing lines and station requirements.

For structural reasons, the room has been made in the form of a horizontal tunnel of about the dimensions of a double line railway tunnel. In order to exclude moisture, the useful space is separated from the real masonry lining of the shaft by means of an inner lining. Connection to the outside is ensured by a shaft of small section.

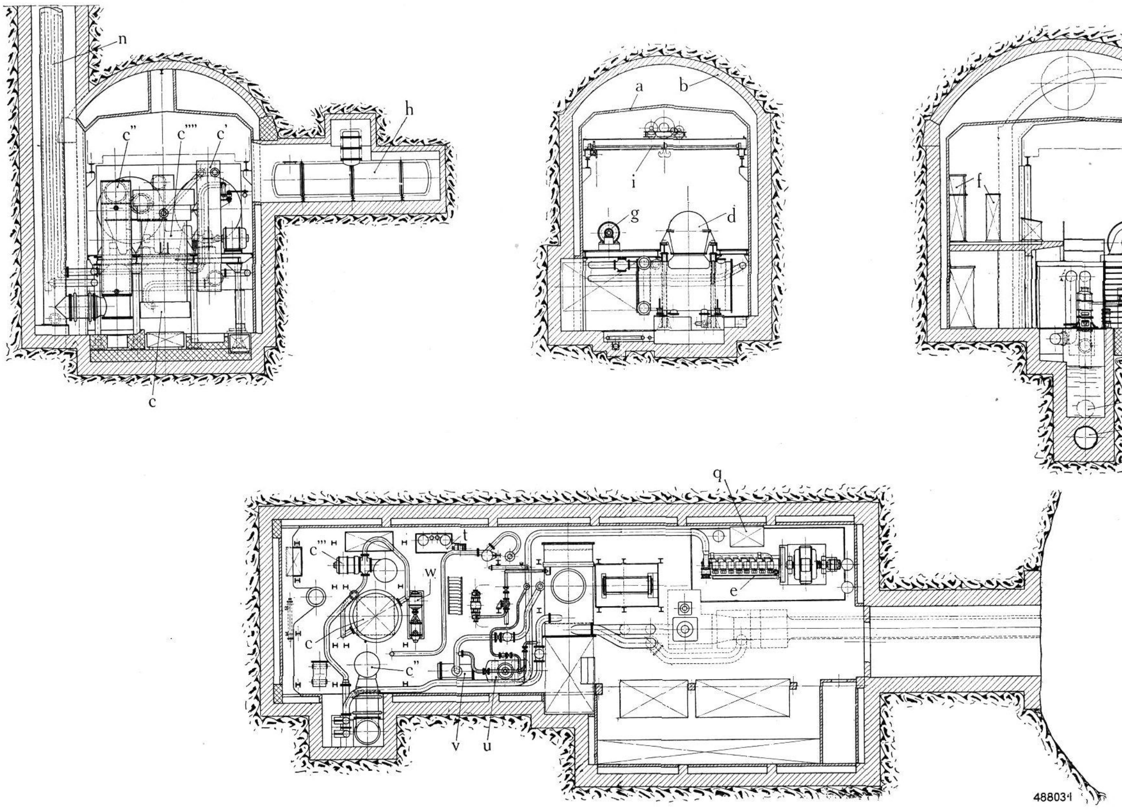


Fig. 2. — 9000-kW Velox steam power station built into a tunnel.

a. Structure.
b. Excavation of tunnel.
c. Velox boiler with steam separator (c').
Exhaust-gas heated economizer (c'').
Circulation pump (c''').
Charging set (c'''').
d. Turbo-set with generator and condensing plant.
e. *Diesel-set for starting up.*
f. Switchgear plant.
g. Ward-Leonard set of Velox boiler.
h. Condensate tank.
i. Travelling crane.
l. Cooling-water intake channel.
m. Overflow and outlet channel.
n. Pipe for exhaust gases.
t. Preheater for fuel and filtering equipment.
u. Make-up water evaporator.
v. Condensate preheater.
w. Feed-water pump.

In this case a useful floor area of only 230 m^2, and a useful space of about 2300 m^3, suffices for turbo-set, boiler plant, switchgear and all auxiliaries. Despite this small space requirement, it was possible to arrive at a solution, in which, besides ease of supervision, a high degree of reliability is ensured. The plant has been built in the neighbourhood of a river in order to obtain the necessary cooling water for the condensation of the turbine steam. Behind the machine room is the space for the fuel tanks, which are dimensioned for about one week's continuous running. The ventilation of the station, the supply of fuel to the Velox boiler and of cooling air to the turbo-alternator, were specially arranged to conform with the conditions on site.

A similar plant for 10,000 kW output, installed by Brown Boveri, is made up as follows:—

1 oil-fired Velox boiler with a continuous rating of 52 t/h, 24 kg/cm^2 abs, 420^0 C;

1 turbo-set of 10,000 kW output at terminals, consisting of single-cylinder turbine, three-phase alternator 12,500 kVA, 6000 to 6300 V, 50 cycles, with complete surface condensing and pumping equipment;

1 transformer 12,500 kVA, 6/20 kV;

1 *station transformer* 640 kVA, 20/0·38/0·22 kV;

1 auxiliary Diesel set of 290 kW output at the terminals for starting up the station, the complete switchgear for the main alternator, outgoing lines and station supply.

This power station is to a great extent automatic; the starting up is carried out electrically in accordance with a predetermined sequence of operations. As soon as the current in the network fails, the auxiliary Diesel engine starts up automatically, the necessary pumps come on the line and the boiler compressor set is run up sufficiently for the attendant to ignite the burner. After successful ignition of the burner,

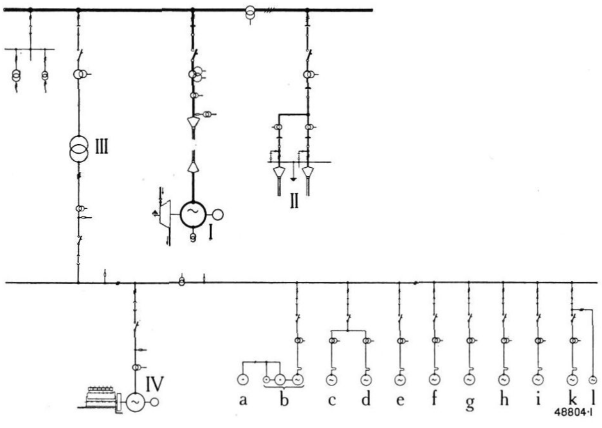


Fig. 3. — Fundamental diagram of a Velox steam power station.

I. Turbo-set.
II. Feeder to network.
III. Transformer for station requirements.
IV. Diesel set for starting up.

a. Auxiliary motor of charging set.
b. Ward-Leonard set.
c. Circulation pump.
d. Lubricating and governing-oil pump.
e. Fuel pump.
f. Feed-water pump.
g. Condensate pump.
h. Cooling-water pump.
i. Auxiliary cooling-water pump.
k. Ventilation.
l. Speed adjustment for main turbine.

the Velox boiler runs up and steam production commences. The main turbine is automatically started, held at 1000 r. p. m. for some minutes for the purpose of warming up, and then brought up to normal revolutions and paralleled onto the line.

Further, a power house for industrial purposes may be mentioned, in which the production of electrical power is combined with provision for heating requirements. This plant is also installed in a tunnel in a mountain and completely protected from aerial attack. It comprises:—

2 Velox boilers each of 18 t hourly rating, 40 kg/cm^2 abs, 400^0 C;

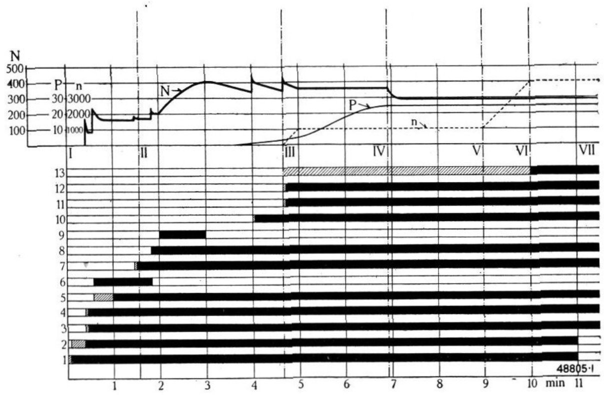
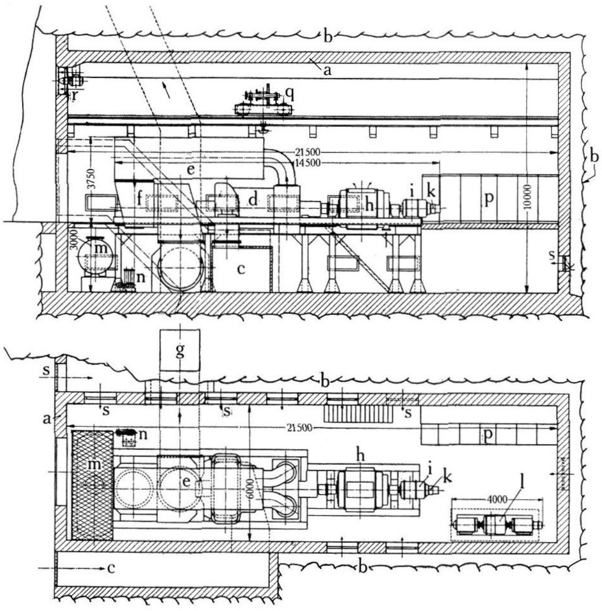


Fig. 4. — Sequence of operations in the automatic starting up of a 10,000-kW Velox steam power station in the event of the normal current supply failing.

▭. Out of service. ▨. Starting. ■. Normal service.

Upper curve.
I. Zero time.
Failure of voltage on supply system.
II. 1 min. 35 s.
Ignition.
III. 4 min. 40 s.
Starting up of main turbine by planned sequence of operations.
IV. 6 min. 55 s.
Attainment of normal pressure in boiler.
V. 9 min.
End of warming up of main turbine.
VI. 10 min.
Automatic starting of power station completed.
VII. 11 min.
Paralleling.
Synchronizing accomplished.
Stopping of the Diesel engine.
Ordinates:—
Above:—
N. Power input to auxiliaries, in kW.
p. Steam pressure in Velox boiler in kg/cm^2 gauge.
n. Speed of main turbine.

Sequence diagram.
Below:— (reading from below).
1. Actuation of low-voltage relay.
2. Automatic starting of the Diesel engine.
3. Switching in of governing oil pump.
4. Switching in of circulation pump.
5. Switching in of Ward-Leonard set.
6. Switching in of ignition.
7. Switching in of fuel pump.
8. Switching in of feed pump.
9. Switching in of the drain valve of governing oil (automatic "bringing up" of the Velox boiler).
10. Switching in the cooling-water pump.
11. Switching in the auxiliary oil pump of the main turbine.
12. Switching in the ejector- and condensate pump.
13. Starting of main turbine by planned sequence of operations.



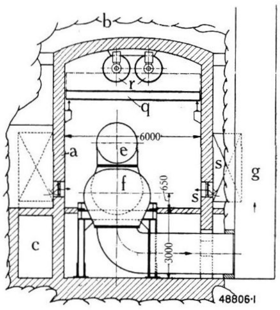


Fig. 5. — Tunnel for a constant-pressure gas-turbine power plant of the single-shaft design, output 4000 kW.

a. Structure.
b. Excavation in rock.
c. Combustion-air suction duct.
d. Air compressor.
e. Combustion chamber.
f. Gas turbine.
g. Exhaust-gas stack.
h. Generator.
i. Starting motor.
k. Exciter.
l. Diesel set for starting up.
m. Fuel tank.
n. Fuel pump.
p. Switchboard.
q. Travelling crane.
r. Fan for ventilating plant.
s. Inlet for air to plant.

- 1 turbo-set 2000 kW output at the terminals, with heat-exchange condenser and complete auxiliary equipment, as well as electrical switching gear.

Fig. 3 shows the simplified electrical connections for the auxiliaries of a Velox boiler plant.

Fig. 4 shows the simplified predetermined sequence of operations for the automatic starting up of a Velox station. The essential operations which must be carried out, are set out in function of the time. In the upper part is given the output required for auxiliaries during starting up, as well as the behaviour of the pressure in the Velox boiler and the main turbine.

The *constant-pressure gas-turbine* is especially suitable for bomb-proof plants, in the range of outputs from 1000 kW up to about 6000 kW effective output, on account of its low first cost and small space requirements. This type of machine is independent of water courses, and such a station can accordingly be built underground even in the very centre or in the immediate neighbourhood of a town. On account of its simple construction, the constant-pressure gas turbine allows of easy installation as an automatic, quick-starting, emergency standby. The predetermined sequence of operations for automatic starting is considerably simpler than for the Velox steam power station.

The constant-pressure gas turbine demonstrated at the Swiss National Exhibition, and briefly described in the following paragraphs, will later also serve as a bomb-proof, rapid-starting stand-by plant. For this purpose it will be automatically started up if the town supply or the overland transmission line fails, and is capable of generating the full output within a few minutes of receiving the starting order.

Fig. 5 shows such a station for an effective output of 4000 kW installed in a tunnel. The machine hall requires a useful space of about 900 m^3. The water requirements of the gas turbo-set amount to only a few m^3/h for the oil coolers. In cases of necessity, however, these can also be built into the fresh air passage, making the completely waterless power station an accomplished fact, and giving a still greater freedom of choice of the installation site.

II. THE BROWN BOVERI CONSTANT-PRESSURE GAS-TURBINE, A WATERLESS POWER STATION.

With some exceptions, such as windmills and small petrol engines, water finds its place in all power plants, either as working fluid or, at least, as cooling medium. Thus, what we shall describe here, the waterless power station, is fundamentally an innovation.

Solid, liquid and gaseous fuels are stored-up energy derived from the sun, which in thermal power stations is converted into mechanical and electrical energy. This conversion was successfully accomplished, for the first time, more than a hundred years ago, through the medium of steam, the potential energy of the fuel being transferred, in the steam boiler, to the feed water. Even to-day, however, despite the most refined methods, success has not been achieved in converting more than about $^1/_3$ of the energy content of the fuel into mechanical work. On account of the imperfection of the former types of steam boiler, an early attempt was made to completely avoid the use of this working medium. The problem can be considered as partly solved by petrol, gas and Diesel engines. But these machines are only capable of turning to account refined and, therefore, costly fuel, require intensive cooling and accordingly, for larger outputs, appreciable quantities of cooling water. Also the utilization of the heat content of the fuel is not much better than with a steam plant. As reciprocating engines, these combustion engines have all the disadvantages of their type. Also these plants are expensive to equip and require much attention. The ideal thermal prime-mover is doubtless the *gas turbine*, in which the energy content of the fuel is applied directly to produce a torque on the shaft.

Fundamentally, there are two ways of operating such a gas turbine. In the first way, a definite quantity of fuel is introduced and burnt in an enclosed space, previously filled with air, and the gases so obtained allowed to expand in the turbine. This results in an impulse process and the full complication of the valve control gear of a gas engine. In the second way the fuel and the required air are led in a continuous flow under pressure to the combustion chamber, in which case the turbine is capable of developing a continuous torque. The first process resulted in the explosion turbine, and the second in the constant-pressure gas turbine. The disadvantage of the latter in comparison with the explosion turbine is due to the fact that the air for combustion must be compressed to the full pressure prevailing in the combustion chamber and also before the gas turbine, and this has been, in part, overcome by the method of compression introduced by Brown Boveri. The complete plant with constant-pressure gas turbine is, as clearly shown in diagram 6, extraordinarily simple. The whole station consists essentially of the combustion chamber and the turbo

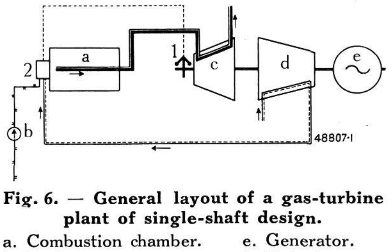


Fig. 6. — General layout of a gas-turbine plant of single-shaft design.

a. Combustion chamber.
b. Fuel pump.
c. Gas turbine.
d. Air compressor.
e. Generator.
1. Output regulator.
2. Fuel nozzle.

set comprising the gas turbine, the compressor and the electrical generator, all on one shaft. In addition, there is the device for forcing the fuel into the combustion chamber. For liquid fuel, this is a small fuel pump of a few kW output, and for gaseous fuel it is a second compressor which can be accommodated on the shaft of the main set.

In itself, this conception of the simple gas turbine plant is very old, and goes back to the beginnings of turbine design, in general; but up till to-day, the execution was wrecked, either by the high temperature of the gases, or by the poor efficiency attainable. If normal quantities of air for combustion were reckoned with, the gases would emerge from the combustion chamber at temperatures between 1200° C and 2000° C. Even to-day, our best high temperature steels still only permit of continuous working at 550° C to 600° C. In the initial stages of development, attempts were made to keep the gases at a permissible temperature by injection of water or steam, or to cool the machine parts themselves by water jackets. In this way it was unexpectedly established that, at high velocities of gas flow, the heat-transfer coefficients became extraordinarily high. An effective cooling of the rotating parts proved very difficult, however, for structural reasons. (Finally, the gas turbine again becomes a steam-driven machine, but with a somewhat lower efficiency). Consequently, Brown Boveri have completely eliminated from their gas turbine the difficult water cooling of the casing and of the rotating parts, as well as water injection, and have done what has long since been recognized as theoretically correct, but which, up to a short time ago, could never be accomplished with an acceptable efficiency, namely:— the cooling of the combustion gases to such an extent by excess air that *all water cooling is unnecessary.* As the steels of to-day permit temperatures of 550° C to 600° C, this requires excess air of about four times the quantity theoretically necessary for combustion.

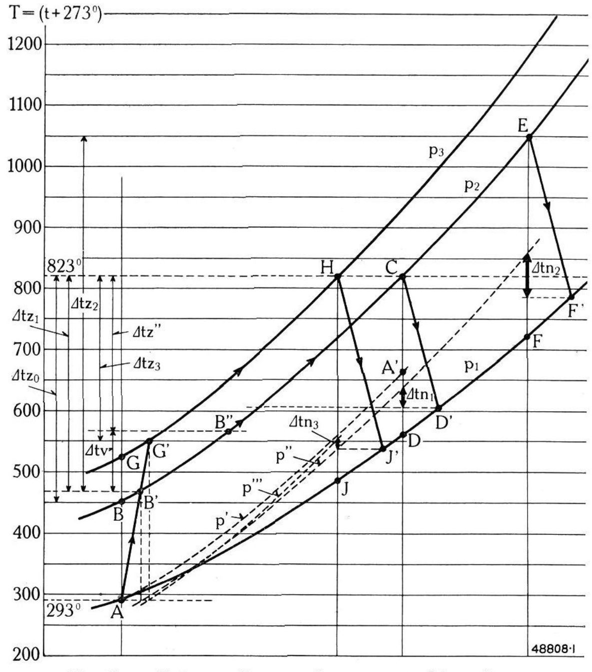


Fig. 7. — Entropy diagram for a gas-turbine plant.

The cycle of the gas turbine may be described with the help of the entropy diagram of Fig. 7, where, for the sake of simplicity, a constant c_p and an invariable gas constant are assumed. Actually, the gas changes in quantity and composition during the cycle, and this has to be taken into consideration in an exact calculation. The compressor draws in surrounding air at 20° C or $T = 293°$ C and at a pressure $p_1 = 1$ kg/cm² abs, i. e. the cycle begins at the point A. As a first approximation we shall assume the cycle to be without losses, i. e. we assume the efficiency of the compressor η_v and that of the gas turbine η_g equal to 100 %. Thus, compression takes place adiabatically up to pressure p_2 and reaches B. As a result, the work $AB \cdot c_p$ expressed in heat units, is expended. Now, sufficient heat is introduced to the combustion chamber, at constant pressure, to reach the point C, which is the intersection of the horizontal line $T = 823°$ with p_2, if we permit a maximum gas temperature of $t = 550°$ C. The corresponding quantity of heat is $\Delta t_{z0} \cdot c_p$. $CD \cdot c_p$ represents the mechanical output due to adiabatic expansion in the turbine. The available useful output accordingly becomes (if η_{el} is the electrical efficiency)

$$L_{no} = (CD - AB) \cdot c_p \cdot \eta_{el}$$
$$L_{no} = A'D \cdot c_p \cdot \eta_{el}$$

and the plant efficiency $\eta_t = \dfrac{A'D}{\Delta t_{z0}} \cdot \eta_{el}$. It is seen that the useful output is a difference, and is obtained from the divergence of the constant pressure lines p_1 and p_2, that is, with increasing temperature, the useful output increases. Actually, the compression takes place with efficiency η_v and ends at B' instead of at B, the work expended being $\dfrac{AB}{\eta_v}$. Likewise, the actual output liberated in the turbine is $CD\ \eta_g$ so that the effective useful work becomes

$$L_n' = c_p\left(CD \cdot \eta_g - \frac{AD}{\eta_v}\right)\eta_{el} = c_p \cdot \Delta t_{n1} \cdot \eta_{el}$$

Certainly, in this case, somewhat less fuel has to be supplied, in fact an amount corresponding to the quantity of heat

$$c_p \cdot \Delta t_{z_1}$$

The effective thermal efficiency $\eta\, t_1$ of this plant is, thus:—

$$\eta\, t_1 = \frac{\Delta\, t_{n_1}}{\Delta\, t_{z_1}} \cdot \eta_{el}$$

It can be at once seen, how the useful output would be increased if the temperature before the gas turbine were to be increased for example to E (T = 1050 °), that is, if more heat were to be introduced to the combustion chamber per kilogram of indrawn air. (Here the quantity of heat would be: $\Delta\, t_{z2} \cdot c_p$.) The work of compression AB′ has remained unaltered. We have then the AB′EF′ and the efficiency of the plant

$$\eta\, t_2 = \frac{\Delta\, t_{n_1}}{\Delta\, t_{z_2}} \cdot \eta_{el}$$

In the above example, compression from pressure p_1 to p_2 was assumed. What happens if compression is carried to the higher pressure p_3? The state at the outlet of the compressor corresponds to G′. As the upper temperature of 823 ° C is prescribed for us, we can still only introduce the heat $\Delta\, t_{z3} \cdot c_p$ to the combustion chamber. The outlet from the combustion chamber corresponds to H and the expansion ends at J′. It is true that the divergence of the constant pressure lines p_1/p_3 is greater than that of p_1/p_2, but the expansion line HJ′ is nearer to the compression line AG′ than the expansion line CD′. In the limiting case, the pressure ratio could be chosen so large, that a temperature T = 823 ° C is obtained by pure compression, so that no heat would be introduced by the fuel and, thus, there would be only the losses in the cycle. But also in the case of compression up to p_3, the useful output $\Delta\, t_{n3} \cdot c_p$ is, according to diagram 7, practically zero. The other limiting case is obtained when there is no compression at all, and the heat is introduced along the constant pressure line p_1. In this case, also, there are only the losses left, and the useful output is negative. Thus it is seen that there is a pressure p_2, for which the useful output is a maximum. An exact calculation would show that this maximum is, for a Brown Boveri gas-turbine plant, in the range of $\frac{p_2}{p_1} \sim 4$. So, for this reason, the constant pressure gas turbine in the National Exhibition works with a combustion chamber pressure of 4 kg/cm² abs. With this gas turbine Brown Boveri attains a thermal plant efficiency of 16·3 %. This, however, demands both from the turbine and the blower the highest efficiencies, which are attained on the one hand by the proved Brown Boveri reaction blading, and on the other hand by the multi-stage Brown Boveri axial blower.

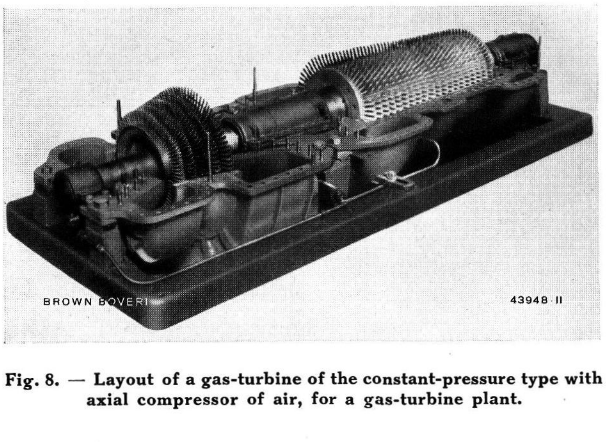


Fig. 8. — Layout of a gas-turbine of the constant-pressure type with axial compressor of air, for a gas-turbine plant.

A modern gas-turbine set, comprising a Brown Boveri reaction turbine and a multi-stage axial compressor, with the high efficiencies necessary in this case, are shown in Fig. 8. From this photo only the combustion chamber and the electrical generator, which is coupled with the compressor, are missing. This is, in essential, the complete turbo-plant in the simplest form, the so-called single-shaft design.

The exhaust gases leave the turbine at a comparatively high temperature, corresponding to D′ in the diagram of Fig. 7. This heat is lost if it cannot be used for heating purposes. Even in a pure power plant, however, a part of this heat can be recovered by passing the exhaust gases through an air preheater connected between the compressor and the combustion chamber. In this case the air entering the cycle AB′ CD′ of Fig. 7 already has a temperature B″ so that the heat $\Delta\, t_v \cdot c_p$ is recovered. Thus, only the heat $\Delta\, t_z'' \cdot c_p$ has still to be supplied by the fuel, whilst otherwise everything remains the same. With this air preheating, thermal efficiency of the plant increases to:—

$$\eta_t = \frac{\Delta\, t_{n_1}}{\Delta\, t_z''} \cdot \eta_{el}$$

Even with very large air preheaters and the use of the counterflow principle, B″ will be lower than the temperature D′ of the turbine exhaust gases. For practical reasons, 3000 m² is not exceeded for the air preheater, or, based on the above mentioned 4000-kW unit of the National Exhibition, 0·75 m² per kW, with which an efficiency $\eta_t = 23\,\%$ is attained.

With the single shaft unit shown in Fig. 6, the compressor always delivers the same quantity of air by reason of the constant speed, so that at partial load the gas temperature, and with it also the efficiency, rapidly fall away. This can be remedied if the two shaft arrangement of Fig. 9 is chosen.

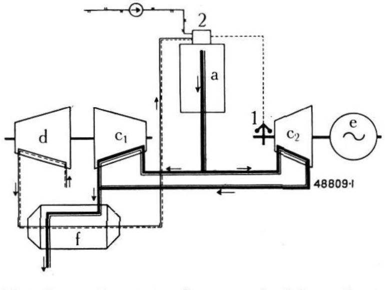


Fig. 9. — Layout of a gas-turbine plant with preheating of combustion air, in double-shaft design.

a. Combustion chamber.
b. Fuel pump.
c_1. Turbine of compressor } Air set.
d. Compressor
c_2. Useful power turbine } Useful power-supply set.
e. Generator
f. Preheater for air.
1. Output regulator. 2. Fuel nozzle.

With the use of liquid or gaseous fuel, the gas turbine plant presents no structural unknowns to Brown Boveri. The parts have long ago been perfected and tested out; Brown Boveri has after all built about 80 compressor sets with gas turbines and the same number of combustion chambers for Velox plants, quite apart from hundreds of exhaust-gas turbines for the purpose of supercharging Diesel engines. Further, Brown Boveri and one of their licensees, in the last three years, have already supplied or have under construction, more than a dozen gas turbine plants for power raising. Most of the sets are running in American oil refineries and are, indeed, in continuous service, some already for over two years. Fig. 10 shows such a plant, which can produce a useful output of 2000 kW for normal pressure drop. If the dimensions of the set are compared with its useful output, the set is found to be very large. But one should turn back once more to Fig. 7 and remember that the output of the compressor is probably three times that of the turbine, four times, the useful output, which is obtained as the difference between the two. Consequently, limits are imposed on the gas turbine as regards output from a unit. For the state of development reached to-day, their use lies in the output range from 1000 to 6000 kW.

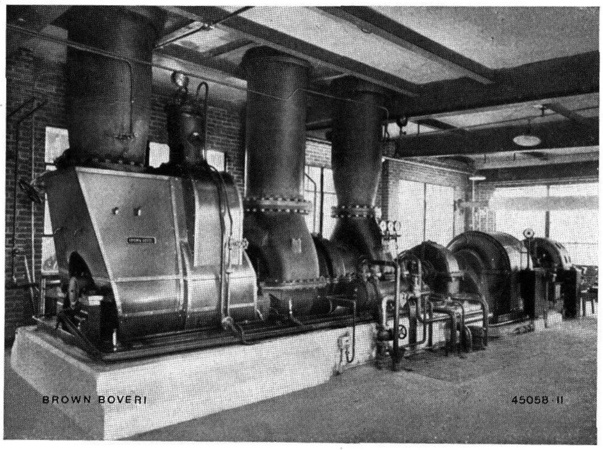


Fig. 10. — Single-shaft gas-turbine plant with reduction gearing, of 2000 kW, placed in an American oil refinery and having been in continuous service since 1937.

Comparative figures show that the gas turbine plant, in initial outlay, is by far the cheapest power plant. If, on the other hand, the initial outlay, respectively the writing-off cost of the plant and, on the other hand, the fuel costs together with the outlay, for staff maintenance, lubrication, etc., are taken into consideration, the total power production costs of such a station may be obtained. Calculation shows that for small number of operating hours, up to about 350 hours per year, which correspond to requirements for standby plants, the single-shaft gas turbine is the most economical one.

(MS 679) *Ad. Baumann./W. Broggi. (Mo.)*

THE BROWN BOVERI AIR-BLAST HIGH-SPEED CIRCUIT BREAKER AND ITS IMPORTANCE FOR THE PROTECTION OF NETWORKS.

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We will endeavour to show, in this article, how, by using modern air-blast high-speed circuit breakers and high-speed distance relays, the stability of high-voltage networks can be maintained, in the face of every kind of disturbance likely to arise.

ELECTRIC power generating and distributing plants have grown to be an important factor in national economy, especially in highly industrialized communities, and the capital invested in plants of this kind represents a respectable fraction of the national wealth of these countries. Especially, in the case of thermal generation of power, but also in that of hydraulic generation of power, developments of recent years have tended toward perfecting the machines used and, to-day, machines are available which allow of rational generation and distribution of electric power combined to great reliability in service. The result is that break-downs or stoppages in power delivery due to faults of the machines, themselves, have become of infrequent occurrence.

In order to allow of localizing defects, as far as is possible, power generation is frequently divided up among the independent generating units of a power station, a practice which, however, may give rise to difficulties to the consumer if the unit supplying his particular system is the one to break down. To-day, however, this class of disturbance can be considered as eliminated, through the utilization of mutators, brought to a high degree of perfection by Brown Boveri and which permit of the flexible coupling of systems working under different frequencies. Synchronization of different systems, which was often a wearisome operation, has thus been done away with and an exchange of power between systems in any sense desired, with practically no losses, has become possible. This flexible coupling of systems, brought about by relatively simple technical means, allows of combining power-generation and power-distribution networks of the most varied characteristics, thus assuring very economical power generation and distribution.

The increasing utilization of electricity for making high-grade industrial products demands, however, that the supply of power be kept up, under all conditions.

The linking up of the different power-generating and power-distributing systems is generally carried out by overhead lines for high and very high voltages. Unfortunately, cases of disturbances on overhead transmission lines are very frequent and it has not yet been found possible to build these lines both economically and also so that lightning or other phenomena will not cause troubles on them. Usually the latter take the form of short circuits of a transient nature. Data collected on Swiss 50-kV and 80-kV systems and on American and South-African 132-kV systems concur to show that only about 7 % of all cases of trouble are of a permanent nature. Of the remainder about 21 % are two- or three-pole arcing short circuits and 72 % are earth faults.

The duty of network protection is to suppress short circuits, which are not of a permanent nature, and to cut out the faulty section by a selective process, when the short circuit thereon is of permanent nature.

In networks in which the neutral point of the system is earthed through an extinguishing coil, single-pole arcings to earth, which, according to the statistics just given, make up about 72 % of all disturbances, can be extinguished without interrupting service on the system. On the other hand, the extinguishing coils cannot cope with two- and three-pole short circuits.

All short circuits which cannot be eliminated by extinguishing coils must be cut out by the selective process, in which the problem of time plays the biggest part. For a considerable period, now, the development of breakers and relays has been towards the shortest inherent tripping times attainable, because this is the only way of limiting to a minimum damages caused by short circuits. With efficient oil circuit breakers and good relays it proved possible to cut out every short circuit occurring within 0·5 to 1·5 s. Although these rupturing times are sufficiently short for *independent systems,* it was found that, to allow a case of trouble to last as long as this on an *extensive distribution network,* was inadmissible, with regard to the stability of the network operation. During a short circuit, hunting is set up between the various generators working on the network, the individual machines are accelerated and slowed down again, causing circulating currents to flow between the power stations. Usually, these circulating currents cause the protective relay to act and thus cause indiscriminate cutting out of parts of the system. Of course, stability is not disturbed, to this degree, by every case of short circuit encountered. In order, however, to eliminate all phenomena of this nature and under all circumstances, a certain duration of the short circuit must not be exceeded. Recent investigations[1] have shown that only fractions of a second are admissible and that the stability is progressively less affected the shorter become the tripping times of breakers and relays. The next development of modern air-blast high-speed circuit breakers will be towards bringing down the inherent tripping times of these to a few hundredth parts of a second.

However, with the selective cutting out of a short circuit, the duty of an efficient network protection is not absolutely accomplished. Normal operations should be re-established when the disturbance, as is generally so, is of a transient character, this means that the line in question must be switched in again as soon as possible.

Pioneering work[2] carried out by Brown Boveri has fully revealed these processes and thus shown the way to new methods to be followed. These investigations have shown that the deionization of the path of an arc, that is to say the prevention of arc reignition, is assured, in all cases, after the lapse of 0·2 to 0·25 s, according to the conditions pertaining to the system. Thus, the three-pole cutting out of a defective line for a short period of this duration suffices to prevent an arcing short-circuit reigniting. During this short period of time, however, the various machines on a given system will not fall out of step. As in most earthed networks, the majority of disturbances are to be traced back to single-pole earth faults, the

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[1] Dr. W. Wanger:— "The stability of three-phase networks with a description of some experimental tests carried out on small and medium-power machines", see The Brown Boveri Review, 1937.

[2] H. Thommen:— "The further development of the air-blast high-speed circuit breaker up to the highest voltages encountered in service and for outdoor erection. Increased protection of systems by short rupturing times and rapid reclosings in cases of short-circuit trouble." The Brown Boveri Review of March, 1939 (see, also, Bulletin SEV 1939, special paper).

investigations were also extended to single-phase ruptures of a line in which only the phase affected is cut out. In this case, the deionizing of the short-circuit arc on the overhead line is made more or less difficult according to the size of the network by the capacitive influence exercised by the two sound phases left in operation, so that considerably longer interruptions are necessary. Contrary to three-pole ruptures, however, the time of interruption of the faulty phase, when that phase alone is ruptured, can be allowed to be considerably longer without endangering the stability of the network. Tests carried out have shown that no falling out of step of machines is to be feared on a system on which one or two phases are still operating, even if the time of interruption attains 0·7 s, and it is to be expected that even considerably longer interruptions could be tolerated without deleterious heating of the machines by the reverse field which is created when three-phase machines are run as single-phase units.

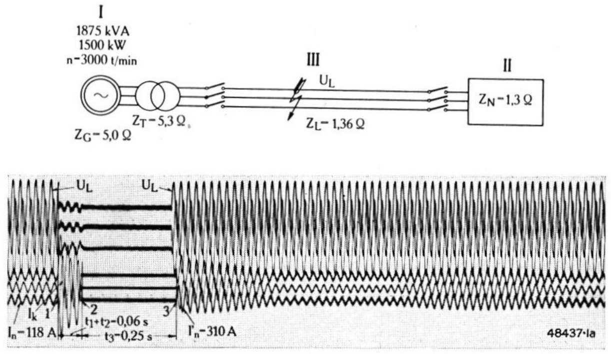


Fig. 1. — Oscillogram of a three-pole opening and reclosing operation when an arcing short circuit occurs on a transmission line.

I. Generator with transformer.	1. Beginning of short circuit.
II. Network.	2. Rupture of short circuit.
III. Transmission line.	3. Reclosing.

Voltage on transmission line 8·8 kV.

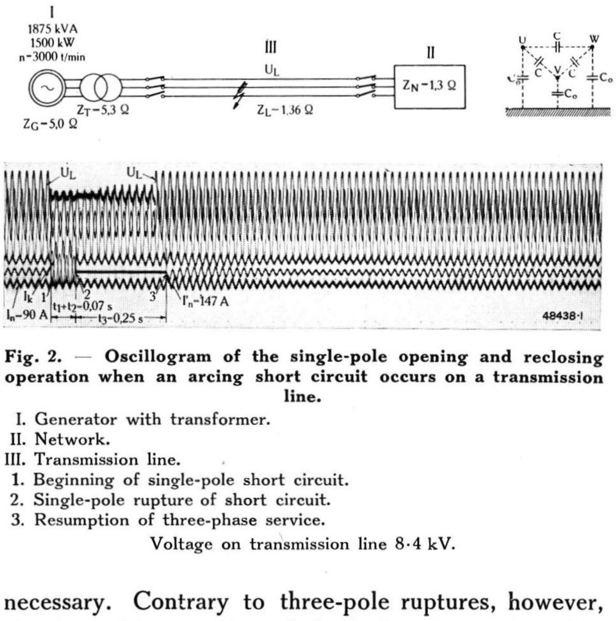


Fig. 2. — Oscillogram of the single-pole opening and reclosing operation when an arcing short circuit occurs on a transmission line.

I. Generator with transformer.
II. Network.
III. Transmission line.
1. Beginning of single-pole short circuit.
2. Single-pole rupture of short circuit.
3. Resumption of three-phase service.

Voltage on transmission line 8·4 kV.

Figs. 1 and 2 show conditions when three-pole and single-pole ruptures occur on a line as a result of arcing short circuits.

The foregoing considerations show that, in the case of breakers with reclosing devices, the overall rupturing time which must be adhered to in order to assure as continuous service as possible, are of the order of a tenth of a second. Only air-blast high-speed circuit breakers and high-speed distance relays allow of meeting these requirements, generally. The Brown Boveri air-blast high-speed breaker and high-speed distance-relay protection have been developed with the special aim of attaining the shortest rupturing times possible.

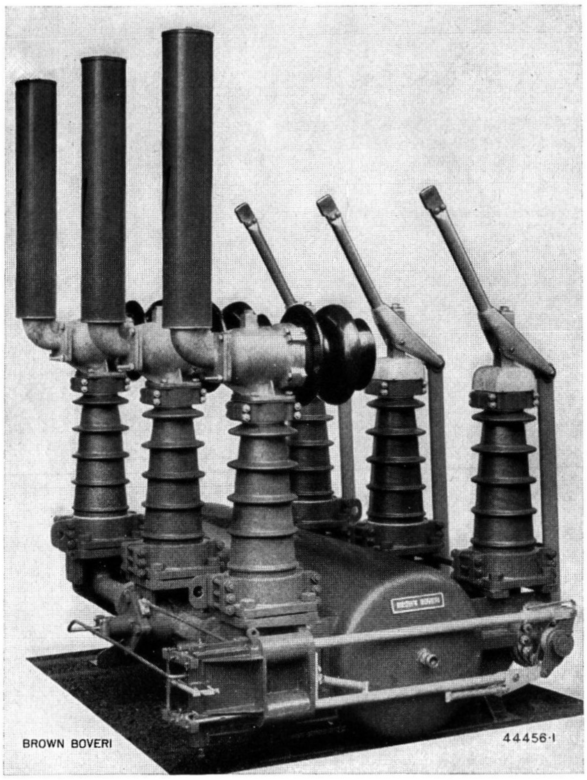


Fig. 3. — Air-blast high-speed circuit breaker, 64 kV, for indoor erection.

Fig. 3 shows a standard Brown Boveri air-blast high-speed circuit breaker for 64 kV. Thanks to its design, it is fundamentally adaptable to all kinds of mounting. The disconnecting switches which form part of the breaker are clearly visible and show immediately if the breaker is open or closed, which adds much to the safe operation of the plant, further these free air gaps add to the isolating qualities of the breaker and effectively eliminate any tendency to creeping phenomena between the open contacts. Overhauling of the arcing contacts is an easy matter as it suffices to unscrew four bolts on the extinction chamber to make them accessible to the operator. The very short inherent rupturing time reduces wear on the contacts by burning, to a minimum. Compressed air is used throughout to actuate arcing contacts and disconnecting contacts. Here, relatively big forces stored up under the form of compressed air are caused to act on small masses, thus producing quick switching action. At the same time, use is made of the high dielectric strength of compressed air in order that, during the opening process in the extinguishing chamber, full insulation is quickly attained between the two contacts which are opening and great reliability of the rupturing process is assured.

With the rapid reclosing device, the rupture of the arc track is only performed by the arcing contacts actuated by compressed air, very short opening time being attained thanks to the big power stored up in the compressed air and the small masses of the contacts to be accelerated. The compressed air which then flows out gives reliable insulation during the break, thanks to its high electric insulating strength this despite the very short distance between the contacts of one phase. The opening time of the arcing contacts is so chosen that the defective line remains sufficiently long under no voltage to allow deionization of the arc track at the point where the fault has occurred and is made sufficiently short to avoid the falling out of step of machines connected to the network, a subject mentioned before. The total, or overall, switching time calculated from the moment the impulse is given by the protective relay up to the extinction of the arc is, then, only 0·05 s. As the inherent time of the distance relays for successful reclosing is also very short, the time, reckoned from the setting up of a faulty (short circuit) arc to the reclosing of the breaker on the line after successful extinction of the said arc, is so short that, for by far the greatest number of service faults, there is no danger of the stability of the network being effected.

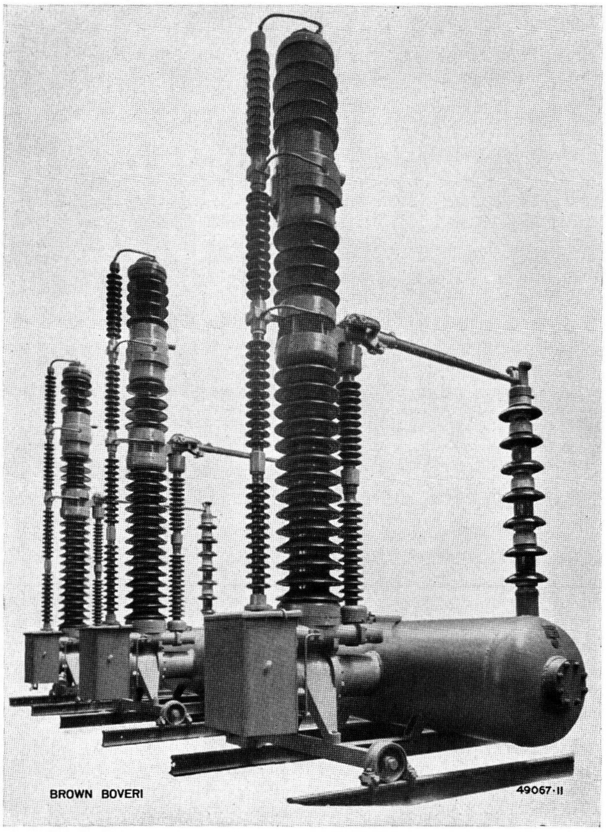


Fig. 4. — **150-kV air-blast high-speed circuit breaker set for outdoor erection and with device for rapid reclosing.**

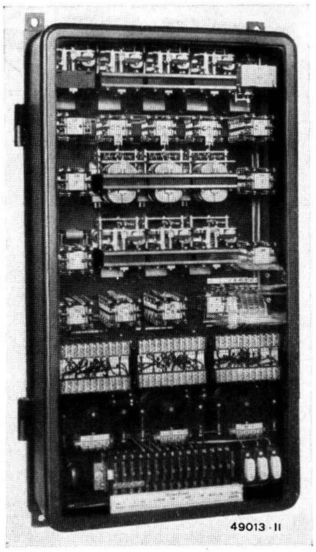


Fig. 5. — **Three-pole high-speed distance-relay protection.**

With air-blast high-speed circuit breaker for high voltages in which each of the poles has its own pneumatic control gear, it is possible to attain one-pole quick reclosing such as is desired in the case of the cutting out of one phase only, when a single-pole short circuit occurs.

Measures are taken, both for three-phase and single-phase switchings with air-blast high-speed circuit breakers, so that if the trouble be of permanent character, that is to say if after rupturing the arc and subsequent reclosing of the breaker a further rupturing impulse is imparted to it, it should then always open on all three poles, the quick-acting reclosing device being then blocked.

Fig. 5 shows a Brown Boveri quick-acting distance-relay protective equipment. When a short circuit occurs, the protection is caused to act through the agency of an impedance pick-up organ. The measuring relays then determine whether the short circuit has occurred within the section supervised L_1 (Fig. 6) or beyond the same.

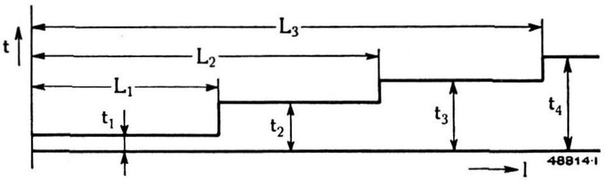


Fig. 6. — **Distance-time characteristic of the high-speed distance-relay protection.**

l. Distance.
t. Time.
t_1 to t_4. Time steps.
L_1 to L_3. Supervised sections.

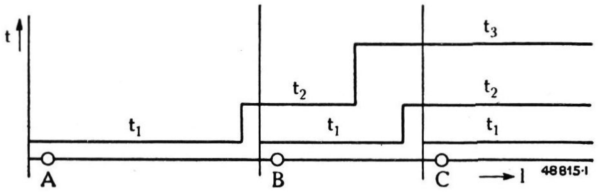


Fig. 7. — **Standard graded plan for selective protection.**

I. Distance.
t. Time.
A, B, C. Distance relays.
t_1 — t_3. Time steps.

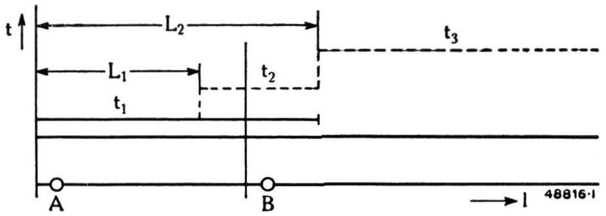


Fig. 8. — **Graded plan of a selective protection with reclosing feature.**

I. Distance.
t. Time.
A, B. Distance relay.
t_1 to t_3. Time steps.
L_1 to L_2. Supervised sections.

If the short circuit has arisen within the section in question, the tripping contact is closed; if beyond the section the measuring relays remain inactive until they are set after the lapse of time t_2, through the agency of a precision time mechanism. From this moment, the measuring relays supervise the section L_2. If the short circuit is located within L_2, the tripping contact is closed, if beyond L_2 the measuring relays remain inactive. This process can take place several times in succession, even until up to 5 sections have been successively supervised (it would be easy to show that, generally, at least 4 steps should be provided for).

For selective protection, without reclosing, the length L_1 is chosen equal to 85% of the section to be protected (Fig. 7).

Short circuits inside this length are tripped within time t_1, equal to 0·1 s. For short circuits in the remotest part of the section, time t_2 is valid. The shortest time t_2 which can be set for relay B, for example, is determined by the condition that, in the case of a short circuit just after C, relay C should trip before relay B. For this reason t_2 is made up of the following time elements:—

a) Time t_1 of relay C.
b) Rupturing time of breaker C.
c) Fall back time of relay B.
d) Margin of time precision to be allowed for relays B and C.

If we assume for *a* 0·1 seconds, for *c* and *d* together also 0·10 seconds and for *b* 0·05 seconds, it will be seen that the short circuits on the remotest part of section B C are cut out at both ends in 0·25 seconds.

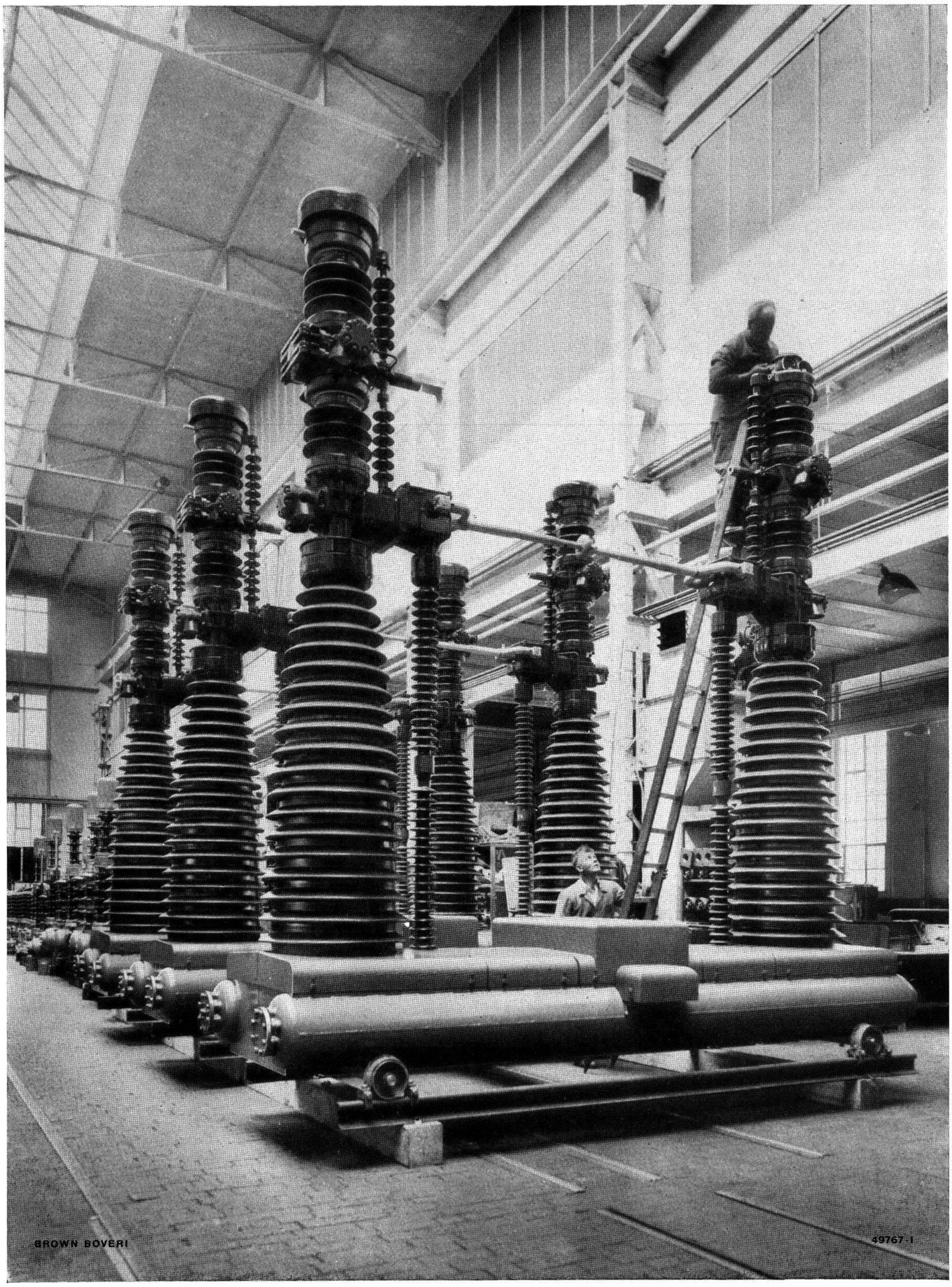
The total (overall) tripping time of the Brown Boveri network protection made up of air-blast high-speed circuit breakers and high-speed distance relays thus fulfils the conditions requisite to the maintenance of stability on the network.

For the selective protection with reclosing feature the breakers inserted at both ends of the section which has developed a defect must trip simultaneously and as quickly as possible. In the arrangement shown in Fig. 7, this condition is not satisfied for short circuits occurring at the end of the section. In principle, simultaneous tripping can be attained by remote transmission of the tripping impulse through a high-frequency channel. However, the arrangement which will now be described allows of doing without high frequency.

On Fig. 8, the section A B and the distance-time characteristic of the distance relay are shown in A. This relay is so set that it takes up supervision of section $L_2 > AB$ at the first pick-up impulse. Short circuits anywhere on A B will be tripped within time t_1, and reclosing can be carried out. When the second pick-up impulse occurs, the relay must work according to the dotted characteristic, that is to say in the same way as in Fig. 7. In the case of short circuits at the beginning of section B C, the relay A will, however, trip unnecessarily. As, however, breaker A immediately recloses, this tripping of relay A does not cause any disturbance of service. If, however, the short circuit persists, it is breaker B and not breaker A which opens and the short circuit is selectively cut out.

Thus, the Brown Boveri distance-relay protection in conjunction with the Brown Boveri air-blast high-speed circuit breakers form a really ideal solution of a network protection. Further developments along the same lines will bring other improvements. This protection provides that stability so necessary for a satisfactory industrial exploitation of networks. It also reduces to a minimum damage to line equipment and to plants, due to arcing short circuits.

R. M. Wild./J. Schneider. (Mo.)



Set of three-pole air-blast high-speed circuit breakers for 220 kV, 630 A, 2500 MVA.

PROGRESS IN THE TRACTION FIELD.

Decimal index 625.28.

As far as we can judge, the three factors dominating the future of the traction field are:— speed, comfort and economy. For Brown Boveri designers, these factors define the development program to be followed in the technology of railway vehicle design, as well as in the thermal and electrical field. Definite progress along these lines has already been made, namely:— in the design of light and high-speed vehicles, in that of new types of bogies and in individual axle drives, in control and circuit-breaker construction, in the bringing out of new kinds of steam generators, also in cable railway design and in the field of train lighting. Some of these new developments are shown in the National Exhibition of 1939.

THE two terminal stations of the first railway built in Switzerland were Zurich and Baden (1847), both of which are towns with a tradition for initiative and progress.

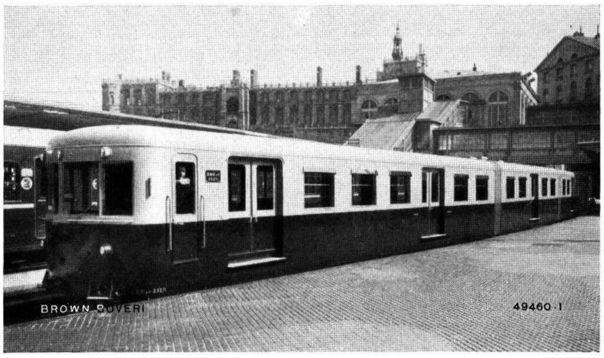


Fig. 1. — Micheline No. 136, the first rail vehicle in the world mounted on pneumatic tires.

Thirty-two years later, electrification of the railways can be said to have begun and dating from an exhibition year. In 1899 the first standard gauge electric railway in Europe, the Burgdorf-Thun Railway was equipped electrically by Brown Boveri. The three-phase motor, a creation of C. E. L. Brown, based on the discoveries of Ferraris and Tesla, was just beginning its triumphant progress throughout the world and this was the type which was chosen for the railway in question as driving motor, on account of its simplicity, reliability and the little supervision it called for. The two-pole contact overhead line was considered as a disadvantage which could justifiably be disregarded in view of the multiple advantages inherent to this type of driving motor. It was only realized to the full, in later years, that the three-phase motor of constant speed was less suitable to traction requirements than the one with approximately constant output, that is to say a motor of series characteristic. However, this first standard-gauge railway in Europe fulfilled a requirement, the advantage of which was only properly estimated tardily, but all the more forcibly for that reason: it utilized electric power in that form in which it was quite commonly generated in Switzerland, at that time:— namely, under the form of three-phase current at 40 cycles.

Since the completion of this first standard gauge electric European railway with its two locomotives, Brown Boveri and their concessionaries have turned out or equipped over 1500 electric locomotives with a total one-hour rating of over 2 million H. P.; to these must be added 3500 electric motor coaches with a total one-hour rating of 700,000 H. P.

Since the first three-phase railway many others have been built. Some are still running while others have been transformed. Most of the electrified railways, to-day, are operated with single-phase or direct-current, with a traction motor of series characteristic. Dr. Behn-Eschenburg established the basis of single-phase traction at low frequency when he brought out his motor with phase-displaced commutating field. However, single-phase operated railways must draw the power they require either from rotary converter sets of rigid type (Sweden) or of flexible type (Switzerland, Germany, Norway) and, probably, in future will do so, more and more, from mutators with grid control for reversed operation, the power in question being tapped from the available three-phase systems of power-supply authorities. If this is not done, then they must generate current themselves in single-phase generators, which of course, can be housed in the same generating stations as three-phase generators, allowing of common utilization of the water power available (Switzerland, Germany).

For their present-day form and development, the D. C. railways have the mutator to thank. This converter is the only one with which it is practicable to convert three-phase current into high-voltage D. C. current, in an economical manner and thus to allow of ranging the railways in the general power-supply system of the country. Originally, the mutator is an American invention. Its development, however, was carried out in Switzerland by Brown Boveri. It is impossible to surpass the simplicity of the present-day traction mutator. It shows low losses, can be heavily overloaded, can be regulated over a wide range and, to-day, the problem of using it as a D. C. - A. C. converter, as well, has been satisfactorily solved, thus allowing of reverse conversion from D. C. to three-phase current, so useful on those D. C. railways, the motor coaches of which are built for recuperative braking.

It is hardly to be expected that the system applied in Germany on the Höllental Railway and in Hungary on the Budapest-Ostbahnhof-Hegyeshalom line section, using single-phase 50-cycle current on the contact wire, will have much future, elsewhere. Although it is quite true that this system allows of tapping the power required for the railway direct from the three-phase supply at 50 cycles, the same thing can be

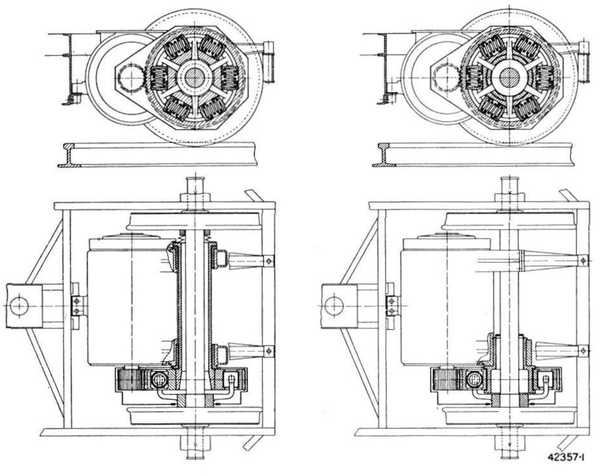


Fig. 2. — Brown Boveri spring drive; on left with quill; on right with short quill; driving motor rigidly mounted in bogie frame.

done when D. C. traction is used, by means of stationary mutator stations which operate very economically, a solution which is finding increasing favour to-day. The equipment of locomotives and motor coaches for the straight application of D. C. makes these vehicles lighter, simpler and cheaper than units of the same power for single-phase, 50 cycles, because, in the latter, a transformer and mutator or big phase converter for the full locomotive output has to be built in as well as the traction motors. In the case of 50-cycle commutator-type traction motors the electric equipment is also heavier than that of D. C. vehicles and it is more difficult to build motor coaches of this type.

The design of the electric vehicles of the future would seem to be dominated by the three following factors: — *higher speeds, more comfort, more economical operation.* These factors demand lower weights and less noise. They define for Brown Boveri the lines of future development.

The needs of the coming epoch will not be satisfied by bigger dimensions or record outputs of individual machines. The real demands are for qualitative improvements.

We believe in increasing speeds of electric trains with lower axle loads, the stressing of the rails growing more than proportionately with the speed. The tare of trains built up till to-day is much too high, being, on an average, for passenger service, 5—10 t train weight per passenger carried per annum. We are strongly in favour of high-speed, light trains both as motor-coach trains and locomotive-hauled trains. Here the principle factor is high travelling speed. This means big initial acceleration and big brake retardation combined to as considerable reduction of weight as possible. We are now putting this program into practice. In the case of vehicles carried on pneumatic tires, the necessity of having light weights is specially important. In France, Michelin turned out the lightest train composition in the world; this is the electric *Micheline* a three-unit coach train, No. 136, the electrical equipment of which was delivered by the Compagnie Electro-Mécanique, our French concessionary. With a seating capacity of 180 and a maximum number of passengers of 256, including those standing, the tare is only 32 t or 178 kg per seat, while the one-hour rating per ton tare is 24 H. P.

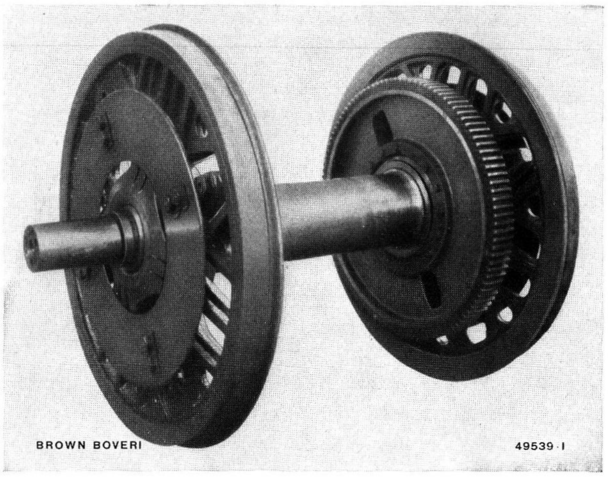


Fig. 3. — Brown Boveri spring disc drive without articulations, bearings or parts in friction, no upkeep needed.

Only the most ingenious design and strong construction of all parts, with all due regard for safety, but without exaggeration of the quantity of high-grade light metal used, allow of solving such problems successfully and economically.

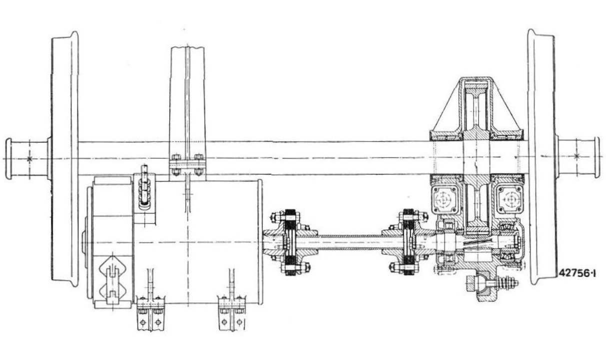


Fig. 4. — Drive by short cardan shaft, for tramway coaches. Driving motor rigidly mounted in frame.

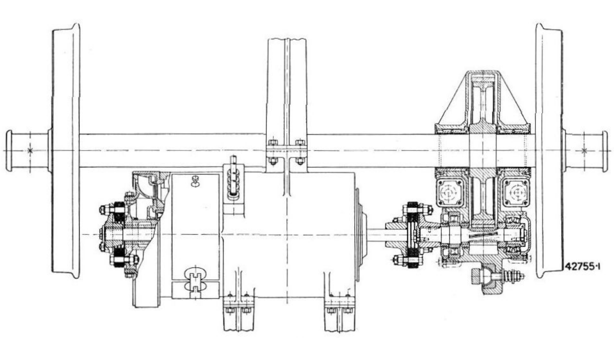


Fig. 5. — Drive by long cardan shaft, for tramway coaches. Driving motor rigidly mounted in frame.

From the mechanical point of view there are two factors which influence primarily the design of electric coaches: the drive and the bogie.

The drive should be of the individual axle type using springs to transmit the torque from gear wheel to driving wheel. This drive is simple and requires little or no upkeep. Brown Boveri have brought out two fundamentally new types of drive. The *Brown Boveri spring drive* has the cups of the springs located in the big gear wheel where they do not take up otherwise valuable space and where the rubbing surfaces are not exposed to soiling and are protected and lubricated automatically by the oil from the gear wheel. The spring cups are compressed by a spider transmitting the power of the driving motor to the driving wheel. It is quite feasible with this drive, to allow the big gear wheel to rotate on a fixed short length of quill instead of using a quill passing all through, of fixed or rotating type with heavy axle bearings. This allows of using the drive with the shortest possible centre distance of motor axle and wheel axle and the biggest reduction ratio, thus making it feasible to have fast-running, small and light driving motors. The space in the middle of the axle is free. This is, thus, easily accessible, contrary to other drives with quill carried through. This allows of putting in combined bogies of the Krauss-Helmholtz type in the usual, simple design.

This drive is used on the double motor coach Type Re 4/8 No. 301 of the Swiss Federal Railways and on the Diesel-electric locomotive Type Am 4/4 No. 1001 of the Swiss Federal Railways, shown in the Railway Traction section of the National Exhibition.

The Brown Boveri spring drive is very suitable to small driving wheels. It has been used, now, for about 5 years, on the 7 "Red Arrow" coaches of the Swiss Federal Railways, among others, and also abroad. The drive can also be used for big driving wheels on a locomotive. It has been chosen by the Swiss Federal Railways for all the light and express vehicles to be built according to last year's program.

The *Brown Boveri spring disc drive* requires no supervision at all. It is now being tried out on a Swiss Federal Railway locomotive, Type 2-C_o-1. This is an articulated drive with two concentric quills. The mobile couplings are formed of two flexible steel discs. There are no surfaces in friction, no journals nor bearings. There are no lubricating points in service and nothing to keep up. This drive will suit locomotives having big wheel diameters.

For tramways and suburban railways, flexible drives with short and long cardan shafts have been created, with the driving motor located in the bogie in the longitudinal axis of the latter, especially for narrow-gauge vehicles. All these drives allow of using big reduction ratios. They lead to high-speed small and light totally-enclosed motors, spring mounted, and also allow of noiseless driving. Up to date, they have given an excellent account of themselves.

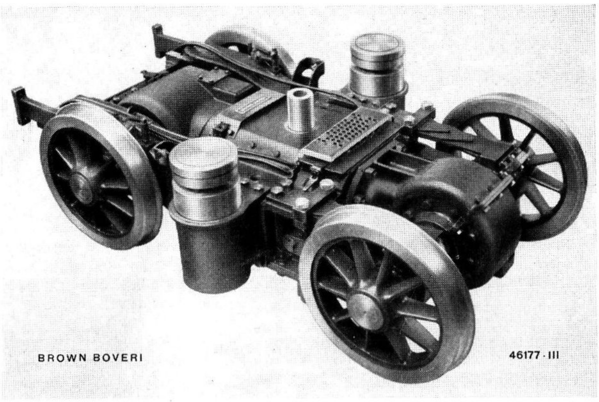


Fig. 6. — "Simplex" bogie. The motor itself forms the bogie frame and carries the bogie pivot and lateral spring supports of the coach body.

An especially light type of *bogie* has been brought out under the name of *Simplex.* The design was studied primarily in conjunction with a coach works. It has rubber cushions between the wheel proper and the wheel tire. The housing of the motor is in the longitudinal axis of the bogie and is, itself, designed as bogie frame. It is carried on 3 points on the two driving axles which are driven through bevel gears. Two supporting points of the motor are on the swinging axle and one point is on the oscillating axle. The swinging axle is coupled to the motor shaft through a Brown Boveri spring drive. There are lateral spring cups to carry the coach body. The bogie pivot is on the top of the motor housing.

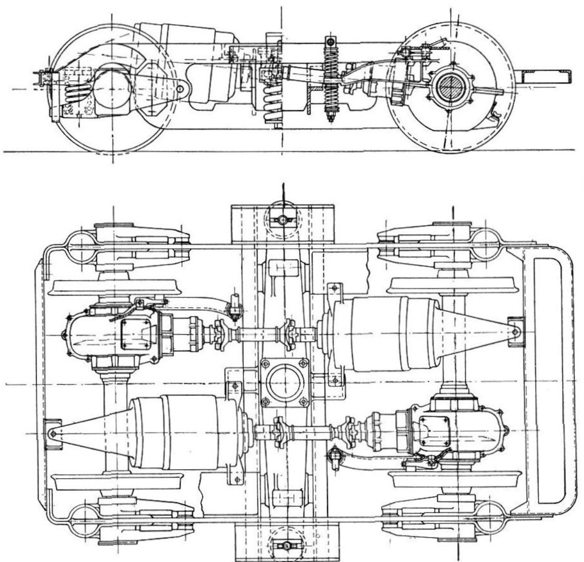


Fig. 7. — Bogie with driving motors rigidly mounted in longitudinal axis, with cardan drive.

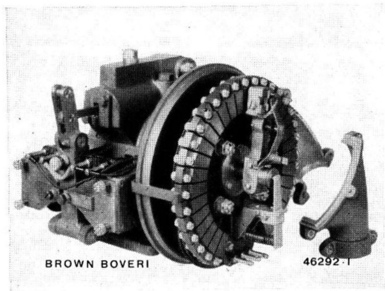


Fig. 8. — Brown Boveri servo field-regulator for Diesel-electric coaches.

This bogie design has the advantage — apart from lightness and simplicity — of having the masses concentrated at the centre. The bogie is easy to guide. Its construction permits of many developments. Thus, for example, both axles can be provided with spring drive. When it is also equipped with a swing bolster, the design becomes especially advantageous for high speeds. Thus, locomotives have been designed with this bogie for 180 km/h maximum speed, 3000 H.P. at 1500 V D.C. and a weight of 65 t.

On the electrical side, as well, there are some interesting improvements introduced by Brown Boveri to be recorded. The *current collectors* have been streamlined designed, for speeds up to 160 km/h and having a weight of 160 kg as compared to over 500 kg, formerly. Here, the static system of current collector design was applied.

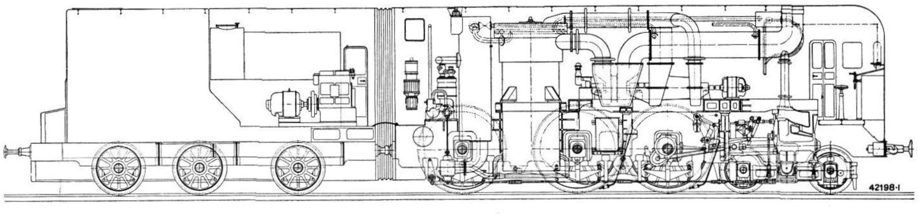


Fig. 9. — Locomotive with Velox steam generator, 2000 H. P., for fuel-oil firing. French State Railways.

The main circuit breaker of the future will be the *air-blast high-speed breaker* for vehicles as well as for stationary plants. This breaker has been developed by us after thorough investigations carried out over a very wide range. With this design, we again attain much lighter weights, about $^1/_3$ of that of the earlier standard locomotive oil-filled single-phase breaker, this combined with a high degree of operating reliability.

Driving motors for D. C. coaches have, now, been designed and built for as low specific weights as $3^1/_2$ to 4 kg per H.P. one-hour rating.

In order to attain higher starting accelerations without disagreable repercussions on the passengers or skidding of the wheels, we invented and developed the *spiral transformer.* In its latest design, it has placed in the Swiss Federal Railway double high-speed motor coaches Type Re 4/8 No. 301. The secondary windings are wound on spirally (copper ribbon) and the current collector on the secondary side of the transformer slides along the edge of this bare copper winding. We have also designed braking resistances on this principle which allow of a continuous regulation of the electric braking smoothly (without steps).

Special attention was devoted by us to the development of *trolley-buses,* vehicles which are becoming of increasing importance for the future of tramway service. Like the *Micheline,* it has the advantage of running on tires and that of drive by electric motor. An especially light multi-step control, based on the system breaker principle has been developed. A coach of this kind belonging to the Town of Winterthur tramway service is shown in the "Street Traffic" section of the Exhibition. The controller of this bus weighs less than 50 kg, with 21 travelling steps and 21 braking steps.

In the field of thermally driven vehicles, Diesel-electric locomotives and motor coaches deserve special attention. Our *servo field-regulator control* has proved its qualities and is by far the most suitable type of control for all units of this kind. It regulates the electric power delivered by the generator, at any service speed, to a constant amount of fuel injection per cylinder of the Diesel engine. This control is built into the Swiss Federal Railway locomo-

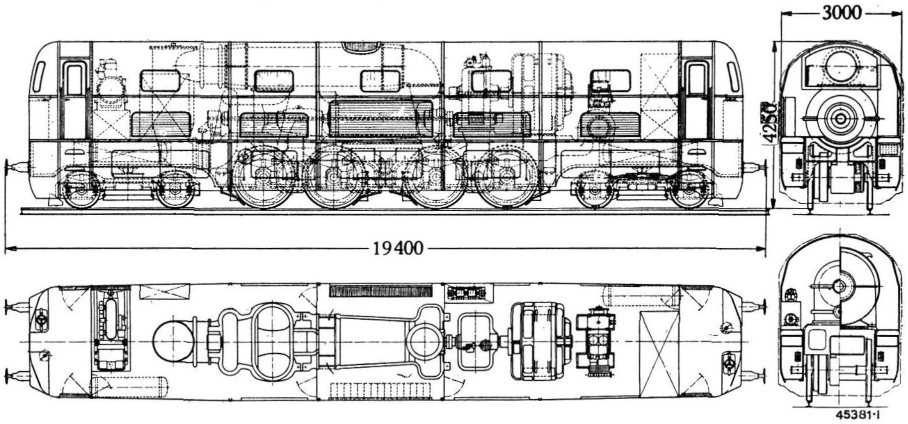


Fig. 10. — Proposed design of gas-turbine locomotive without water, with electric transmission; fuel-oil firing. Output 3000 H. P.

tives Type Am 4/4 No. 1001, one of which is exhibited in the "Traffic" section of the Exhibition.

The Compagnie Electro-Mécanique, France, built a *Velox locomotive.* The Velox steam generator with its very advantageous qualities, such as light weight, big specific output, rapid generation of steam and adjustability to load fluctuations, high boiler efficiency and fuel-oil firing make it a very attractive steam generator for using on locomotives.

The Velox locomotive had hardly grown out of its infancy when the *gas-turbine locomotive* appeared on the horizon of thermal vehicles. It may be designated as a Velox machine which does not require any water. It takes from the standard Velox the combustion chamber, the gas turbine and the compressor, but no water, steam or seals for these elements are required. Here the slogan *lighter* is very much in evidence. The transmission of the output will principally be an electrical one in one of the forms we have experience in building.

Our firm has always held a leading position in the design *of mountain railways* of funicular, aerial cable railways, sledge railways and ski lifts.

Models are shown in this section of the exhibition of the latest types of light motor coaches, which are those built for the Glion–Rocher de Naye rack railway and the light and express motor coach, now in process of construction, for adhesive drive on the Rhaetic Railway. There is also a model of the most efficient funicular cable railway in operation to-day, namely the Parsenn line. Brown Boveri also built the main drive of the aerial railway to span the lake of Zurich, the towers of which are in the grounds of the exhibition itself.

In the field of *train heating and lighting* which is one of our specialities, considerable progress can be recorded in air heating, while in train lighting new regulators and dynamos with their drives, including cardan-drives have been brought out (see the postal coach exhibited in the "Railway Traffic" section).

The preceding short article has only touched on some of the more important milestones on the road of traction progress. We have many other developments in view but they are not yet sufficiently advanced to be exhibited in 1939. The 1914—1939 period was one of encouraging developments in the traction field and we think it permissible to assert, here, that *the name BROWN BOVERI continues to be a guarantee of quality and progress.*

(MS 680) *E. Schroeder. (Mo.)*

1200-H. P. Diesel-electric locomotive Bo—Bo, weight in service 65 t, Series Am 4/4 No. 1001 of the Swiss Federal Railways. Trial run with light trailer coaches on the Winterthur—Schaffhausen line section.

THE FLEXIBLE COUPLING OF SYSTEMS, BY MEANS OF MUTATORS, RESTORES HIS INDEPENDENCE TO THE STATION OPERATOR, WHILE INCREASING THE ECONOMICAL OPERATION OF THE SYSTEMS.

Decimal index 621.311.161:621.314.65.

The service results now available from the first three-phase three-phase mutator plant operating in the Lütschental substation (Switzerland) go to show that the problem of the flexible coupling of two three-phase systems has been satisfactorily solved, further, that the regulating conditions inherent thereto are fulfilled in simpler and more satisfactory manner than is possible with rotary machinery.

THE progressive paralleling of power stations and the linking up of entire groups of power houses goes far to limit the independence of operation of the stations entailed, on account of the identical frequency which is thereby imposed on all systems concerned. It is true that the power output of each individual machine can be set, at will; nevertheless, it is generally impossible to deliver given loads to determined external points with simultaneous satisfaction of local requirements, and low transmission losses, without the help of a central despatching station. If, on the contrary, the parallel connection of a generating set with others is made through a flexible-coupling plant, that is to say a plant which allows power transmission, within a certain range, in both senses, independently of the exact frequency relationship between the systems, all difficulties of the kind under consideration are avoided. Plants of this kind, with rotary machines which have, partly, to be commutator units, have been built and are running.

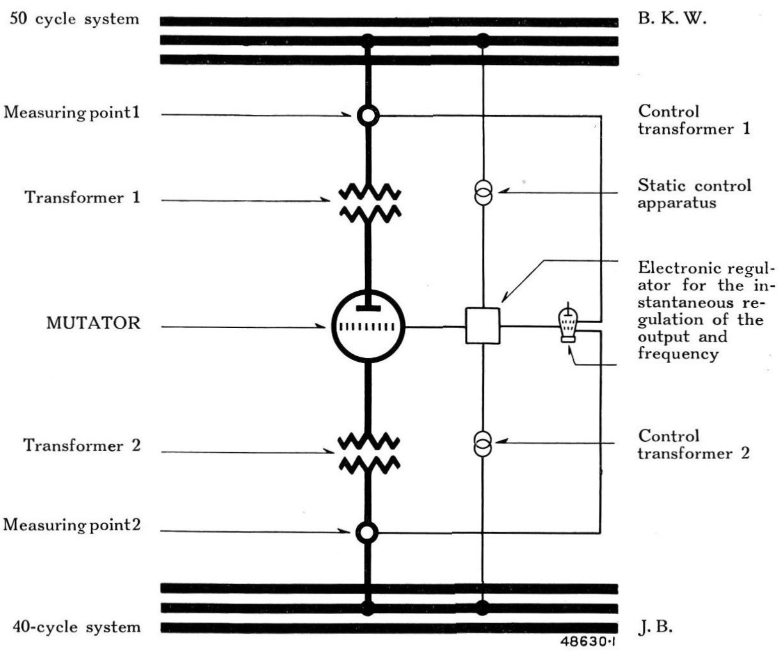


Fig. 1. — Simplified diagram to explain the three-phase—three-phase mutator and its regulating system.

A practical solution of the problem of the flexible coupling of two three-phase systems, allowing a regulated exchange of power between them to any extent desired, by means of a single mutator unit, has now been found. The first plant of this kind is that coupling the 40-cycle three-phase system of the Jungfrau Railway (J. B.) (Switzerland) to the 50 cycle three-phase supply system of the Bernische Kraftwerke (B. K. W.). This plant allows the Jungfrau Railway to tap power from the B. K. W. supply system or else to restore power thereto, according to circumstances. The mutator plant is located in the Lütschental power house of the Jungfrau Railway and is built for a power rating of 1600 kW.

The following factors had to be taken into account when the mutator set was built.

1. The pressing need to have the plant in service by the 1st of January, 1939 because experience had shown that, in winter, the amount of water available for power generation is small and because the power required to run the Bernese Oberland Railway, Wengernalp Railway, Jungfrau Railway and the Mürren Railway is at a peak, at that period, owing to the winter sport traffic.

2. The novelty of the whole scheme and the doubts expressed by the clients as to the possibility of getting the plant working satisfactorily in good time.

We owe a debt of gratitude to the Jungfrau Railway Company and their executives for the confidence shown in us, here. Our firm was, thus, given an opportunity of demonstrating a new application of the mutator which represents a considerable technical step forward and this in a plant running in Switzerland and thus very accessible to us and others for closer study.

To the great satisfaction of the clients it was found possible to get the plant running by the 23rd of December, 1938. The amount of water available from the rivers Schwarze Lütschine and Weisse Lütschine between Christmas and New Year was so low that

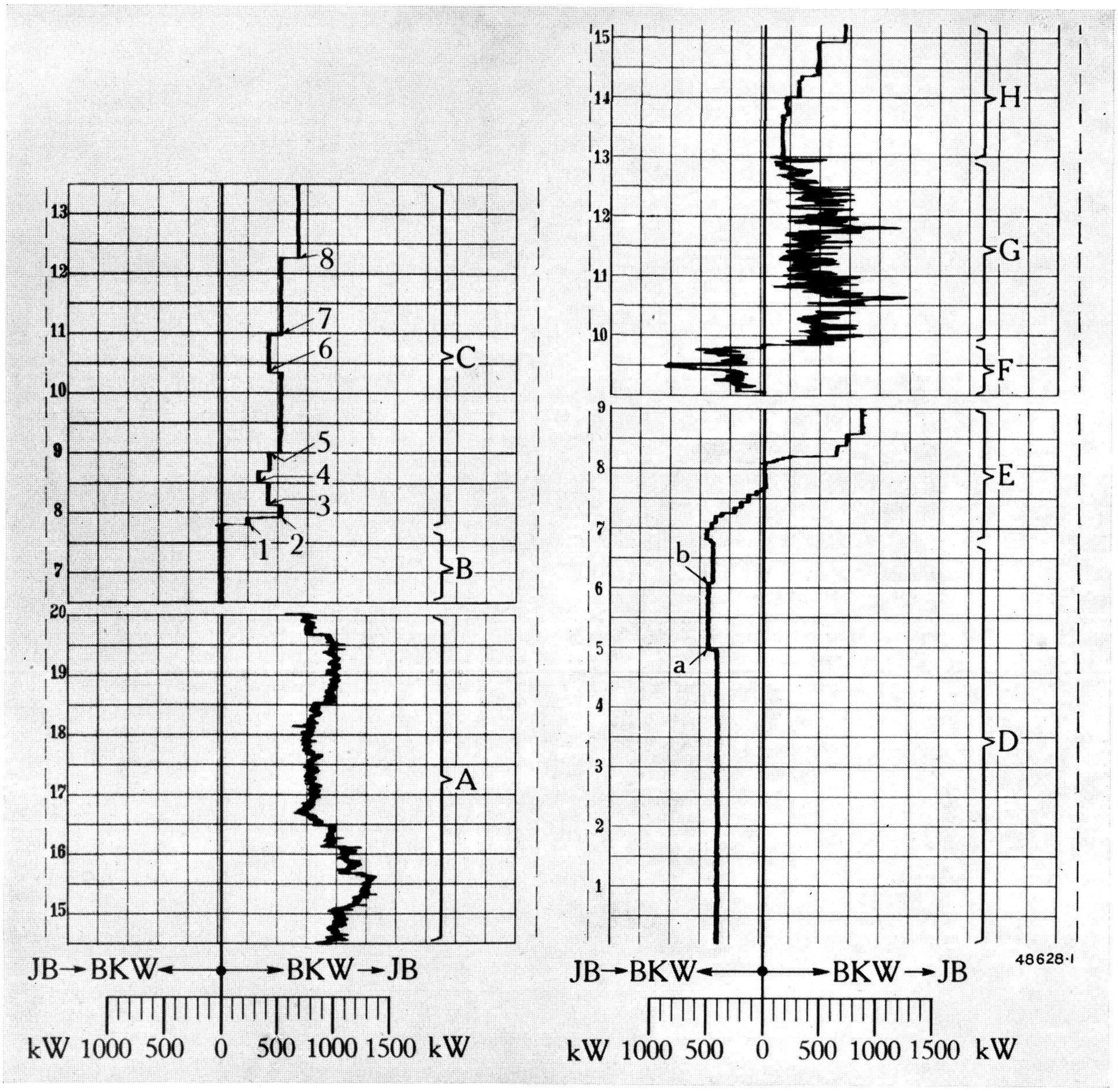


Fig. 2. — The Lütschental three-phase three-phase mutator.

Strips from the recording wattmeter connected at metering-apparatus point 2 of Fig. 1.

A. Power tapped from the B.K.W. system with regulation of load by hand.

B. Plant cut out.

C. Power tapped from the B. K. W. system with automatic load regulation by electronic regulator. By acting on the regulator, another load was adjusted to, on points 1, 2, 3, . . . 8.

D. Power delivered to B. K. W. system with automatic load regulation by electronic regulator. The load adjusted to was changed on points a and b.

E. Regulation downwards of the load in finely-graded steps and transition from power delivery to power absorption.

F. } Regulation to constant frequency of the 40-cycle system by the G. } electronic regulator.

H. Regulator to constant load.

the new plant was, really, indispensible for keeping up service. The operating personal of the station especially appreciate the rapidity with which the plant can be started up, the simplicity of supervision, the absence of any synchronizing operations, the new type of very precise regulation of load and the high efficiency.

With the help of Fig. 1 we give a summary explanation[1] here, of the working principle of the three-phase—three-phase mutator with its load regulating equipment, this in single-pole diagram.

The load from the B. K. W. system passes through metering apparatus 1 to transformer 1. From here six phases lead to the mutator and to transformer 2. The latter then delivers the power over metering apparatus 2 to the Jungfrau Railway system. In similar manner, power can be made to flow in counter sense. A static control apparatus[2] is used for the

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[1] Compare with The Brown Boveri Review of December 1934, p. 214, and Bulletin SEV of November 1936, p. 690.

[2] Compare with The Brown Boveri Review of May/June 1938, pages 103 and 124.

control of the grids, it impresses on the grids voltages of definite characteristics dependent on the frequencies of the two systems coupled. Therefore the control apparatus is fed from both control transformers 1 and 2. The setting of the regulation is automatic by means of an astatic regulator working with standard electronic tubes. The grids of the electronic tubes are so influenced by current and voltage from metering apparatus 1 that the regulator sets the control to constant power delivery of the mutator. This type of regulation and control has the advantage that it is of instantaneous-reaction character and is, thus, superior in speed of action and in precision to all standard regulators working to a mechanical principle.

Fig. 2 gives some cuts from the strip of the recording wattmeter inserted at metering-apparatus point 2. The piece A shows the characteristic of the power transmitted from the Bernische Kraftwerke system to that of the Jungfrau Railway when the control apparatus is being manually regulated. As is seen, it is quite possible to set the power output desired within given limits but, nevertheless, the said power is subjected to heavy fluctuations. The cause of the load fluctuations is the variations of the voltages of both systems and not variations of the frequencies, as is the case with conversion by means of rotary machines. The piece C of the recording strip shows the regulation by electronic regulator to constant load. On positions 1, 2, 3 . . . 8 the load taken through the mutator is altered by action of the station operator on the regulator. It will be noted how well the load adjusted for is maintained.

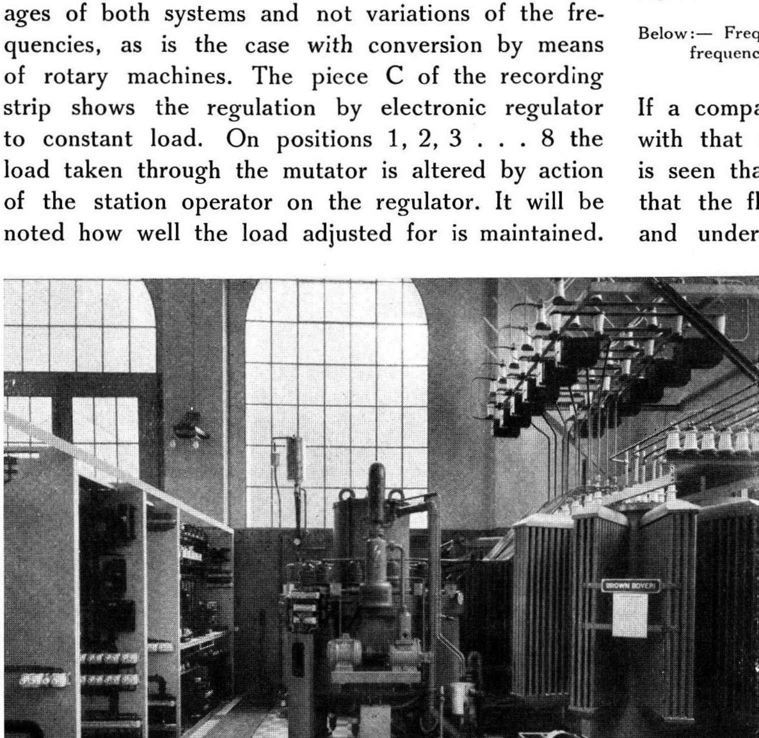


Fig. 4. — Partial view of Lütschental mutator plant.
From right to left:— transformer for 40-cycles, mutator, control and measurement panels of the switchboard.

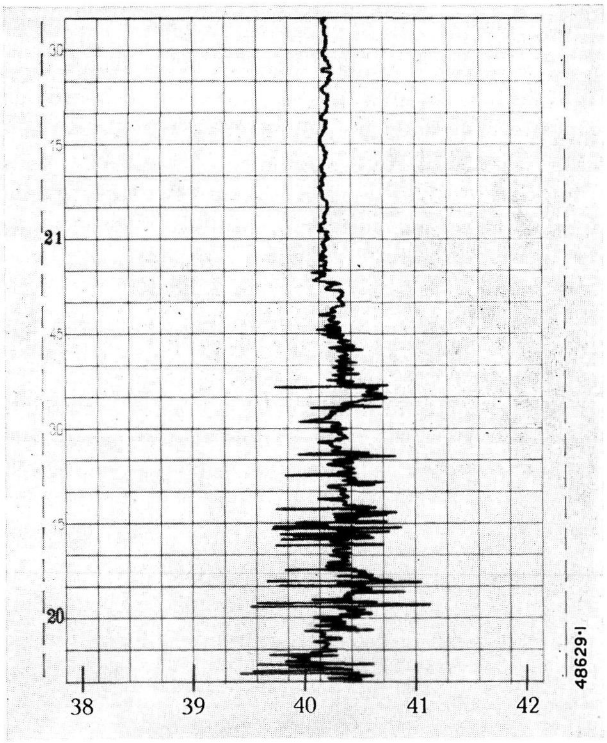


Fig. 3. — Strips of the recording frequency meter on the 40-cycle side of the Lütschental mutator.
Below:— Frequency set by turbine governors. Above:— Influence of frequency regulation by electronic regulator is clearly seen.

If a comparison is made of the thickness of the line with that at B when the plant is out of service, it is seen that it is the same in both cases. This means that the fluctuations caused by the continuous over and under regulating movements of the regulator are very small indeed, a result only possible thanks to the instantaneous reaction of the regulator. The piece D of the strip represents a long running period with power delivery in counter sense, that is from the railway system (J. B.) to the power-supply system (B. K. W.). At points a and b the load was set for other values. Here, as well, the fine astatic straight-line character of the regulation is a striking feature. At E, according to service requirements, the load was regulated down to zero in steps which could be as fineley graded as desired and, shortly afterwards, the plant was put back to work but with power delivery from the Bernische Kraftwerke to the Jungfrau Railway.

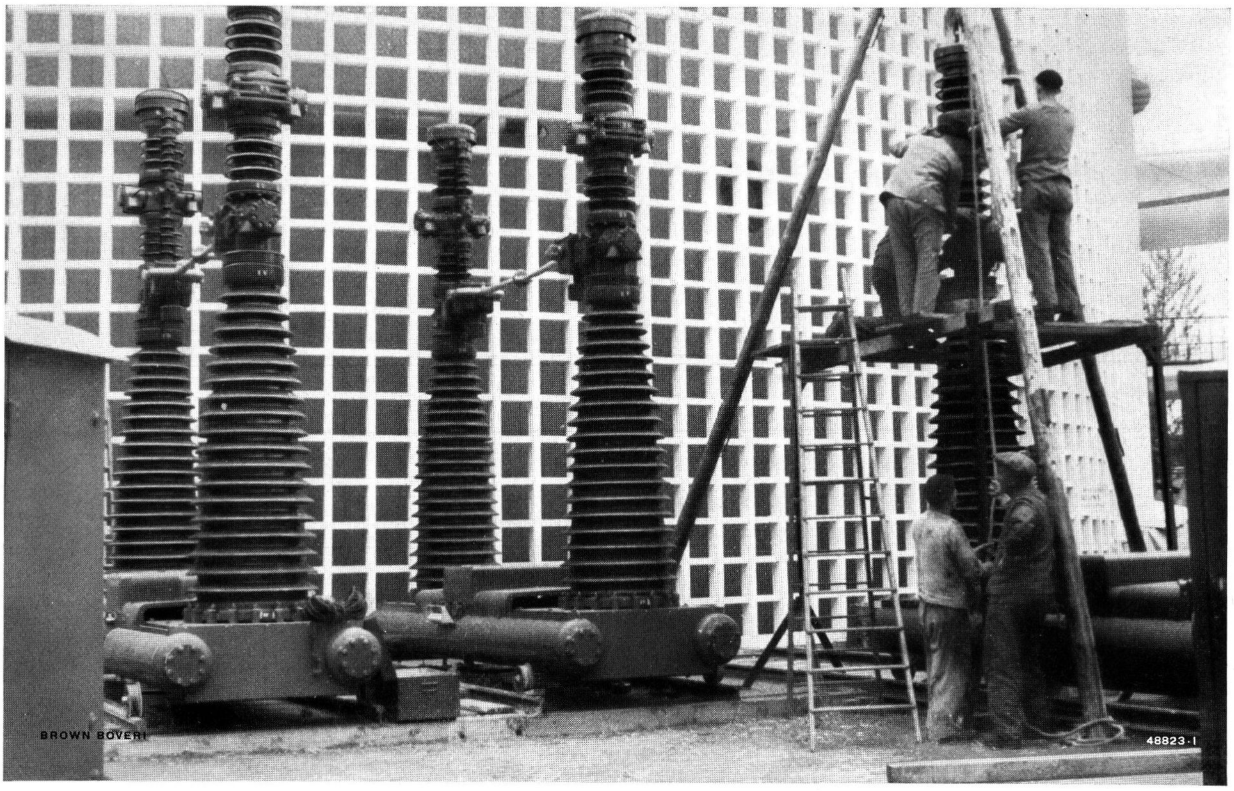
Another kind of regulation has been combined to the same regulating equipment, in the Lötschental plant. This is the regulation seen at F and G to constant frequency on the 40-cycle Jungfrau railway system. In this case, the plant has to take over the load peaks of the system, which is possible when the load quota set for the mutator suffices for maintaining the frequency. The degree of irregularity (or static) of the mutator regulator and of the governors of the prime movers of the generators determine the distribution of the peak power between mutator and generators. The electronic regulator of the mutator is so made to suit the turbine governor that the distribution of the load peak between mutator and generators desired by the client is attained. Fig. 2 shows how, at the transition from F to G, the transmission of the load from the sense Jungfrau Railway to Bernische Kraftwerke system to the opposite one is carried out. The points between G and H on the strip show how easy it is to change over the regulator from regulation to constant frequency to regulation to constant load, during service. Frequency regulation takes place, according to Fig. 1, a regulating component dependent on the frequency being led from the metering-apparatus point 2 to the electronic load regulator.

Fig. 3 shows a part of the frequency recording strip, the lower part of which shows how the frequency fluctuates when it is only regulated by the turbine governors. The upper part shows how evenly the frequency is maintained by the mutator regulator. The superiority of regulation by the electronic regulator of the mutator is due to its instant reaction character. The mutator takes up the load surges of the system before the speed of the generators has fallen to any appreciable degree.

Fig. 4 shows a view of a part of the plant, one of the transformers, the mutator and the rear of the switchboard for service and regulation being shown.

The utilization of the three-phase—three-phase mutator is not limited to the flexible coupling of three-phase systems of different frequencies. Thanks to this satisfactory new type of regulation, it is to be foreseen that this system will also be used for the flexible coupling of three-phase systems of the same frequency. The results given show how advantageously the power exchange from system to system by means of a three-phase—three-phase mutator may be carried out. The task of assuring increasing collaboration between systems, in the field of power production, without depriving the different generators of their independence entirely, has come a step nearer to accomplishment, by the method just described.

(MS 685) *Ch. Ehrensperger. (Mo.)*



220-kV air-blast high-speed circuit breakers for outdoor erection, being put up in the Swiss National Exhibition, in Zurich.

A WALK ROUND THE NATIONAL EXHIBITION.

Decimal index 606.4 (494).

To complete the preceding articles which cover special fields of manufacture, we give here a summary description of Brown Boveri's participation in the Swiss National exhibition.

IN the preceding articles, the reader will find some data on special fields of manufacture which we think justified in designating as outstanding accomplishments among Swiss industrial products. Obviously, the said articles do not cover all our exhibits and we would like to give the reader a more complete impression of our participation in the Exhibition, by means of a general survey.

Under the form of this National Exhibition, the Swiss people has striven to give as impressive an example as possible of its creative power. This demonstration coincides with a period in which the smaller nations must feel a sincere desire to express their right to independent existence. Thus, we Swiss found ourselves confronted with a big task of collaboration in which all parts of the country and all professions have their share, according to their importance. With this aim, there goes the desire that the Exhibition should not be simply a collection of exhibits of a few chosen firms, but should be the work of the whole people expressed along given leading lines. Only very exceptional products can be permitted to exceed the general framework laid down, while all the other objects shown conform to the general preconceived theme.

The central point of Brown Boveri participation is to be found in the section "*Electricity*". Here, in the Exhibition substation, is the end of the *direct-current high-voltage power transmission from Wettingen to Zürich,* by which 500 kW are transmitted from Wettingen at 50,000 V, through the agency of mutators, to be delivered in Zürich to the exhibition power supply system. An article of this number is devoted to this most modern of power transmission systems, which we think has a big future before it. It is a pioneering effort, only comparable to the Lauffen-Frankfort power transmission first demonstrated at the Frankfort exhibition of the year 1891. The same can be said of the *air-blast high-speed circuit breakers,* the latest models of which, for a rated voltage of 220,000 V are shown, in outdoor mounting.

As regards power generation, Brown Boveri exhibits a large number of illustrations of the latest machines and also the rotor of a *turbo-generator* of the latest design. This goes to show that, although Switzerland is the land of water power, the design and construction of steam turbines and of turbo-generators plays a very important part in its export industry. The new *Brown Boveri primary regulator* is shown in the same hall. It is combined with a Bell turbine governor and is for the speed regulation of hydro-electric sets. This primary regulator has already given an excellent account of itself in practice.

The Distribution Group is very advantageously laid out. Beside the 220-kV air-blast high-speed circuit breakers are placed *air-blast high-speed circuit breakers* for 50 and 11 kV, the latter being lodged in an armoured switching cell of the truck type. The 60-kV *compressed-air voltage transformer* is an application of compressed air in the place of oil for this class of apparatus, as well, the tendency being to banish oil from switchgear plants, altogether. The field of the *quick-acting automatic regulator* is represented by the simple standard regulator type and also by the high-capacity voltage regulator for use on big generators. The various applications of the quick-acting regulator are shown, especially for voltage regulation and power factor regulation, etc. The exhibits are so mounted that the regulators can be demonstrated easily and clearly to those interested. The *relay* field is chiefly represented by a demonstration switchboard with quick-acting distance protection, this in combination with the 220-kV air-blast breaker, already mentioned. Other relays are exhibited separately and also on a model of the system of the Electricity Works of the Town of Winterthur. As regards *transformers,* we find two units for automatic voltage regulation, Type TQ, very suitable for automatic and smooth regulation of the voltage, especially on small supply systems. In connection herewith, we come to *lightning arrestors* of the well-known Resorbit type.

Another room in the Electricity section is devoted to the applications of electricity. Here, Brown Boveri exhibit, as biggest piece, a *Frigibloc refrigerating plant* with a refrigerating capacity of 330,000 kcal per hour which is used for the air conditioning of a part of the hall. There are various welding sets and welding transformers shown which show that the field of electric welding is still in a phase of vigorous development. There is an interesting exhibit under the name *"Electricity as a working force"*. The object here is to show the technic of electric drives in its most important aspects and with interesting applications to industry, the visitor being able to establish, unaided, a number of connections which demonstrate important processes such as the smooth continuous *regulation of speed* on a *three-phase shunt commutator motor* and the maintenance of whatever speed is set for. Further, it is possible to demonstrate how the maintenance of a given speed ratio between two motors can be kept at the value desired. Devices of this kind are used, to-day, on the sectional drives of paper-making machines and also in rolling-mill drives. Here the increasing utilization of the fundamentally simple, strongly-built and economical *squirrel cage motor* is also demonstrated, while the star/delta starting of such units can be shown to interested parties. These Brown Boveri star/delta starters have a simplified contact system which, starting from the cut-out position, can be switched over to starting and running in two time steps. For operating this apparatus, only one switching order or impulse "switch in" is necessary, either imparted by hand or by push-button; the switching over from starting to running position is automatic and governed by a time switch. This gives the power supply company a guarantee that the starting of motors on its system will be properly carried out and that current surges resultant therefrom will be kept down to a minimum. The *geared motor* shown is an example of what may be termed a harmonious combination of a high-speed squirrel-cage motor and a planet gear built by the von Roll'sche Iron Works in Klus (Switzerland). This combination allows of satisfying two important requirements of industrial drives, namely:— a high-speed driving unit and a low-speed driven machine. Exceptionally powerful automatic *electric braking* is demonstrated on a squirrel-cage motor exhibited and this, in conjunction with a light blocking device such as is used on certain machine tools as safety device. By depressing a push-button the motor is switched in. If the visitor moves his hand through the space under the influence of the light rays, the motor is instantly stopped. Braking is, here, by direct current made to circulate for a short period through the stator winding. Finally, the *thermal releases* of our directly heated type, so indispensable for the reliable protection of motors, is shown on a demonstration model. A new type of lifting gear is also exhibited. This, the electro-hydraulic thrustor, is here shown as brake lifting device for a shoe-type of brake.

An interesting application of heat generated by electricity is shown under the form of an *electric boiler plant*, this boiler gives the necessary steam for a press for making gramophone plates.

In the High-frequency Group Brown Boveri shows some interesting objects belonging to the *high-frequency field*. A special article of this number is devoted to this subject.

In the section *"Iron, metals, machines"*, Brown Boveri will have a big exhibit under the form of a *combustion gas-turbine plant* of 4000 kW output. This machine, described elsewhere in this number, should have a big future before it, especially in the export field. In the same section, we show some interesting material belonging to the field of *arc welding* and welding demonstrations are made before visitors. Elsewhere, the visitor will see an *arc melting furnace* for steel of a capacity of 3·6 t. Its daily production in practical service is 30 t of steel (24 working hours). The electrodes are automatically controlled by an electro-hydraulic regulating gear. Unfortunately, it is not possible to show this furnace working, as this would be a difficult and costly matter to do so in an exhibition, but the electrode regulation is shown in action. In the field of electric furnaces, Brown Boveri exhibits the electric equipment for a low-frequency induction furnace for non-ferrous metals, especially for brass alloys. Together with Messrs. Sulzer Bros. we exhibit an entirely automatic *Diesel-electric emergency set*. These sets are being used increasingly to-day in big buildings such as warehouses, hospitals, administrative blocks, etc.

There are also a number of our driving motors exhibited here in conjunction with a variety of driven machines.

In the section *"Strength and health"*, a Brown Boveri *hot-water electric boiler* is shown for the laundry of a hospital.

In the *Aluminium Pavilion* we exhibit a welding set for the welding of aluminium and a resistor type of furnace with graphite crucible for melting aluminium and its alloys. The heating capacity of this furnace is 16 kW.

In the *Chemistry Pavilion* we exhibit *a mutator for a high-frequency furnace.*

We also have some exhibits in the *"Building"* section. In the ceramic pavilion of this section we have an *electric furnace for the biscuit firing and glazing of artistic porcelain* and for the burning in of colours on porcelain and glass, for operating temperatures up to 1000° C. Beside it, we exhibit a model of a big electric *tunnel furnace* for the biscuit firing and high-temperature firing of hard porcelain. The original has now been in operation for some time in the Langenthal Porcelain Works (Switzerland). The operating temperature is up to 1410° C.

In the section *"Traffic and Transport"*, Brown Boveri has numerous exhibits. Here there is a *double high-speed motor coach Type Re 4/8 No. 301 of the Swiss Federal Railways*, which will be used for excursion trips during the Exhibition. There is also a new *1200 H.P. Diesel-electric locomotive Type Am 4/4 No. 1001* belonging to the Swiss Federal Railways, the electrical equipment and individual axle drive of which are by Brown Boveri. This unit has Büchi charging of the Diesel engine by means of a Brown Boveri exhaust-gas turbine. There is also a survey or view coach Type B 4 for the Brünig line equipped with *Brown Boveri railway lighting gear.* A railway postal coach Type Zi 4 of the Swiss Post, Telephone and Telegraph Administration is also shown, this coach has *electric heating, ventilation* and *lighting* by Brown Boveri.

The Winterthur Tramways show an interesting *Trolleybus.* Units of this type have been running for some time, now, between, the Winterthur railway station and Wülflingen. The electric equipment and the pneumatic door-actuating gear of this modern vehicle are built by us.

In the section *"Aviation Industry"*, Brown Boveri show an *exhaust-gas turbo-blower for an aeroplane engine.* This unit has already run with an aeroplane engine, the exhaust-gas turbine operating with temperatures up to 1000° C. It is, unfortunately, not yet widely known that we have done a lot of pioneering work in this most significant field of aeroplane-engine charging, which is of very great importance to Swiss aviation.

Note should also be made that we delivered the *main drive for the Zürich aerial railway* across the lake, with a motor of 90-kW output and its control gear.

In various other sections, such as "Clothes make the man", "Our Wood", "Agriculture", "Graphical Arts", Brown Boveri show the *application of their electric motors for a variety of machines driven,* the three-phase shunt commutator motor with smooth speed variation and economical operation is of especial interest, here.

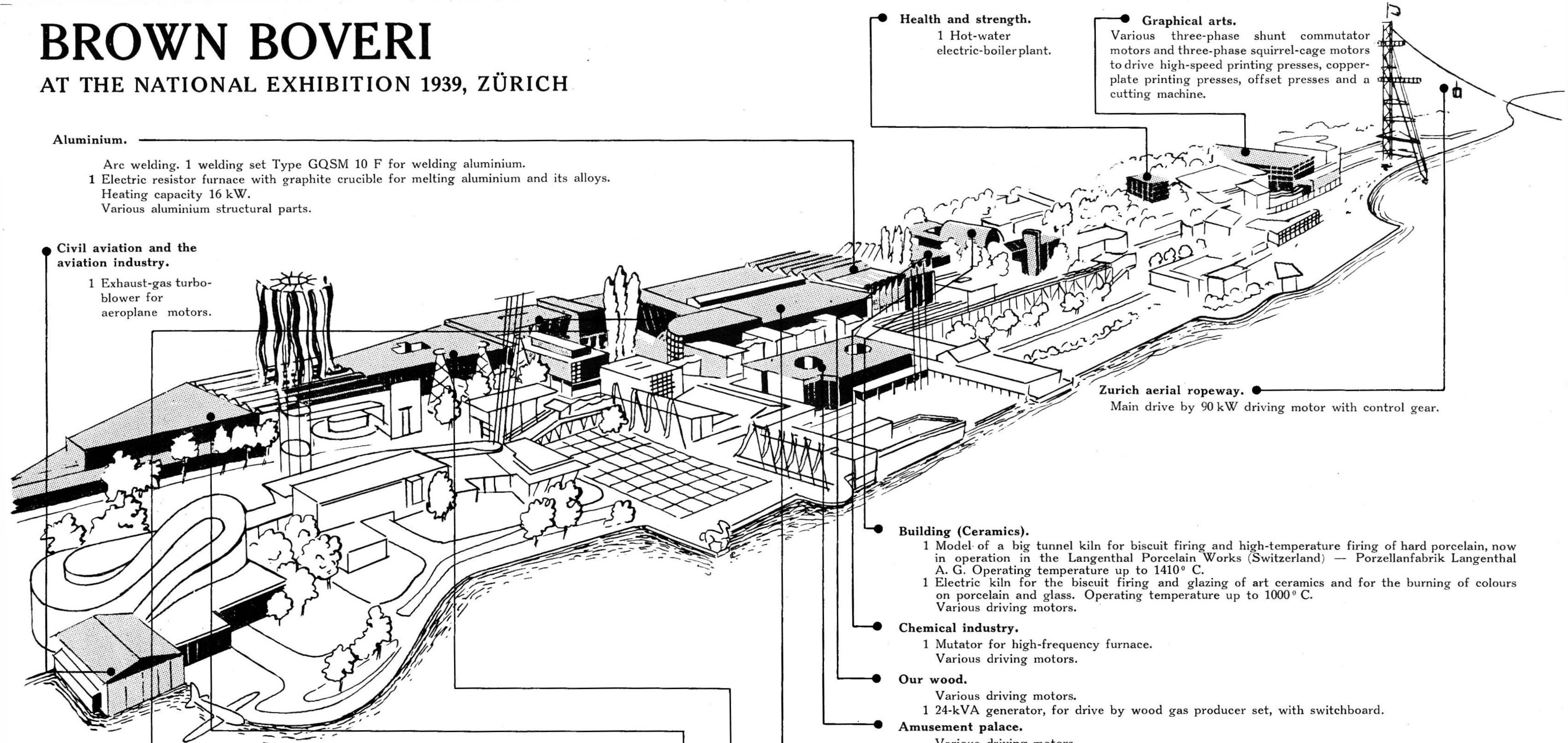
A plan of the Exhibition is given on the back page of this number with clear indications of where Brown Boveri products are exhibited. We trust that visitors to the Exhibition will carry away with them the impression that our firm has done its full share in making this work of national collaboration a success.

U. Vetsch. (Mo.)

Published by BROWN, BOVERI & COMPANY, LIMITED, BADEN (Switzerland). Printed by Kreis & Co., Basle, Switzerland.
Obtainable through A. Francke A. G., Berne and Rouge & Cie., Lausanne (Switzerland).

BROWN BOVERI

AT THE NATIONAL EXHIBITION 1939, ZÜRICH



Aluminium.

Arc welding. 1 welding set Type GQSM 10 F for welding aluminium.
1 Electric resistor furnace with graphite crucible for melting aluminium and its alloys.
Heating capacity 16 kW.
Various aluminium structural parts.

Civil aviation and the aviation industry.

1 Exhaust-gas turbo-blower for aeroplane motors.

Electricity.

D. C. high-voltage transmission at 50,000 V, 500 kW, by mutators, from Wettingen Power Station to the National Exhibition.
1 220-kV air-blast high-speed circuit breaker set with plant for generating compressed air.
High-frequency material. Model of the high-frequency part of a Cyclotron, police transmitter various electronic tubes in operation with demonstrations of high-frequency effects.
Frigibloc plant, 330 000 kcal/h refrigerating capacity, for air conditioning.
1 Turbo-rotor for 2500 kVA, 3000 r. p. m.
1 Photo cabinet with illustrations from the field of power production.
1 Primary governor for speed regulation of hydro-electric sets.
Arc welding. 3 welding sets and 2 welding transformers. 1 Relay panel.
2 Transformers for automatic voltage regulation Type TQ.
Over-voltage protection (Resorbit lightning arrestor).
Various relays in the system model of the Winterthur Electricity Works.
Exhibit on the theme:— "Electricity as a driving force".
1 Demonstration switchboard panel for quick-acting automatic regulators.
1 High-capacity voltage regulator.
1 Demonstration switchboard panel with quick-acting remote protection, for 220 kV air-blast high-speed circuit breakers.
1 50-kV air-blast high-speed circuit breaker.
1 Metalclad switching cell with 11 kV air-blast high-speed circuit breaker.
1 On-load disconnecting switch.
1 60-kV compressed air voltage transformer.
1 Demonstration switchboard panel for small contactors.
1 Electric boiler plant for producing steam.

Agriculture.

Health and strength.

1 Hot-water electric-boiler plant.

Graphical arts.

Various three-phase shunt commutator motors and three-phase squirrel-cage motors to drive high-speed printing presses, copper-plate printing presses, offset presses and a cutting machine.

Zurich aerial ropeway.

Main drive by 90 kW driving motor with control gear.

Building (Ceramics).

1 Model of a big tunnel kiln for biscuit firing and high-temperature firing of hard porcelain, now in operation in the Langenthal Porcelain Works (Switzerland) — Porzellanfabrik Langenthal A. G. Operating temperature up to 1410° C.
1 Electric kiln for the biscuit firing and glazing of art ceramics and for the burning of colours on porcelain and glass. Operating temperature up to 1000° C.
Various driving motors.

Chemical industry.

1 Mutator for high-frequency furnace.
Various driving motors.

Our wood.

Various driving motors.
1 24-kVA generator, for drive by wood gas producer set, with switchboard.

Amusement palace.

Various driving motors.

Iron, metals, machines.

1 Combustion gas turbine plant of 4000 kW effective output.
1 Diesel-electric emergency set.
Arc welding. 1 Arc-welding set Type GQSM 20 g and 1 welded anode plate of a mutator.
1 Electric arc-type melting furnace for making steel, of a useful capacity of 3.6 t, daily production 30 t of steel in 24 hours. Automatic electro-hydraulic regulation of the electrodes.
1 Electric equipment for a low frequency induction furnace for melting non-ferrous metals and special brass alloys.
Various driving motors.

Clothes make the man.

About 50 individual drives of textile machines, of which 2 automatic by shunt commutator motors governed by spinning regulators for ring-spinning frames.

Communication and transport.

Double high-speed motor coach Re 4/8 No. 301 of the Swiss Federal Railways.
1200 H.P. Diesel-electric locomotive Am 4/4, No. 1001 of the Swiss Federal Railways with Büchi supercharging of the Diesel engine by means of a Brown Boveri exhaust-gas turbo-blower.
Railway postal coach Z 4 i No. 923 of the P.T.T. with electric heating, ventilating and lighting equipments by Brown Boveri. [railway lighting equipment.
View coach B 4 of the Swiss Federal Railways for the