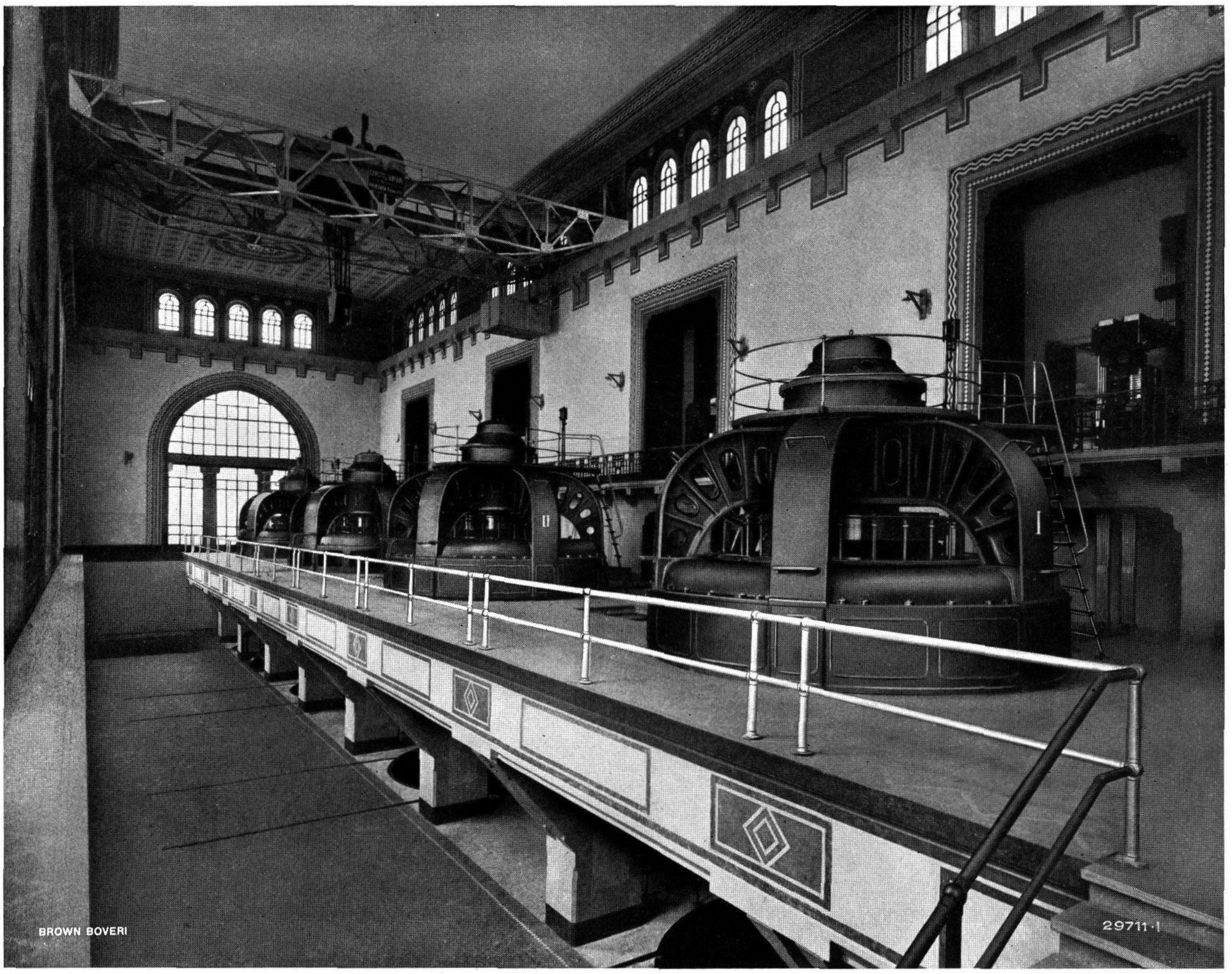
VOL. XVII JULY, 1930 No. 7

THE BROWN BOVERI REVIEW

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



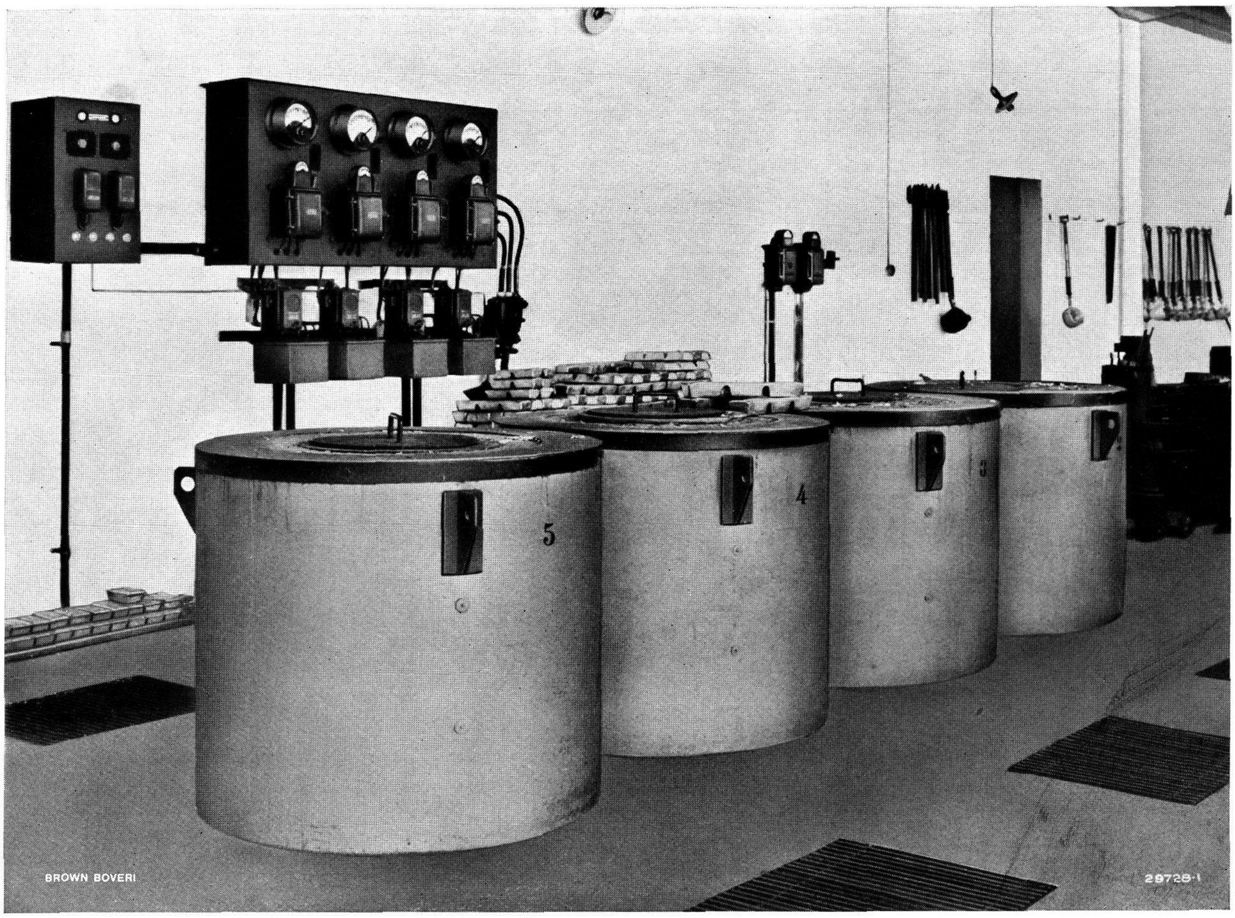
MORI POWER STATION OF THE SOC. ANONIMA ELETTRICA ALTO ADIGE, MILAN.
Four vertical-shaft direct-current generators each of 4300 kW, 350 V, 150 r. p. m.

CONTENTS:

BROWN BOVERI

ELECTRIC FURNACES FOR MELTING SOFT METALS

MADE IN STANDARD SIZES WITH AUTOMATIC TEMPERATURE REGULATION



NOVAWERKE A. G., ZURICH. BROWN BOVERI ELECTRIC FURNACES FOR MELTING ALUMINIUM.
Capacity of crucible 150 kg of aluminium. Power consumption (of each furnace) 22 kW, maximum furnace temperature 950° C. Automatic temperature regulation.

ALWAYS READY FOR SERVICE - SMALL SPACE REQUIREMENTS

CONSIDERABLE REDUCTION IN ATTENDANCE

LOW MAINTENANCE COSTS - DUE TO THE GREAT CLEANLINESS OF THE SOURCE OF HEAT THERE IS NO DIRT

BEST UTILIZATION OF ELECTRIC POWER (USE OF NIGHT CURRENT)

POWER FACTOR APPROXIMATELY UNITY

THE BROWN BOVERI REVIEW

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

VOL. XVII JULY, 1930 No. 7

The Brown Boveri Review is issued monthly. Single numbers: 1.20 francs (1 shilling). Annual subscription: 12 francs (10 shillings), postage and packing extra.

ELECTRIFICATION OF MAIN-LINE AND SECONDARY RAILWAYS IN ITALY WITH HIGH-TENSION DIRECT CURRENT.

Decimal index 621.331.024.027.3 (45).

IN the Brown Boveri Review 1929, No. 2, a short description was given of the rectifier plants for pressures above 1500 V recently supplied by Brown, Boveri & Co. to various railways in Italy. All these plants are now in service and are proving exceedingly satisfactory; they may be considered as typical of the plants which will be used in future for further electrification schemes for other main-line and secondary railways. The use of direct current at pressures up to 3000 V produced in mercury-arc rectifiers has been very widely adopted, particularly in Italy, and the development is being followed on every side with great interest. The advantages possessed by mercury-arc rectifiers over rotating machinery are recognized everywhere; they are of particular importance in high-voltage plants as very high efficiencies can be obtained.

The list, on page 216, of Italian railways recently electrified with high-tension direct current shows very clearly that in Italy the mercury-arc rectifier is now regarded as the only really suitable converter for such purposes. For the electrification of those railways marked in the table with an asterisk, rectifiers have been installed. It will thus be seen that whereas during the first period some high-voltage d.-c. substations were still equipped with motor generators, since 1926 mercury-arc rectifiers have been installed exclusively.

The cost of electrifying a railway with high-tension direct current depends on the voltage chosen and the type of converter used. Numerous calculations based on electrification schemes carried out on secondary railways have led to the following conclusions. When rectifiers are used, the total first costs (rolling stock, overhead equipment and substations) for electrification with 3000-V direct current can be reduced to about 70 % of those with rotary converters for a d.-c. pressure of 1500 V. Furthermore, experience has shown that by electrifying at 3000 V instead of 1500 V, a saving of 10 to 20 % can be effected, assuming that rectifiers are used in both cases. The reason is that by increasing the contact-wire voltage, the number of substations required for the electrification of a railway can be reduced. By choosing a higher operating voltage the overhead equipment becomes cheaper and the higher costs of the rolling stock are more than counterbalanced by the reduced costs of the substations which have to be built.

The particulars, in the table mentioned, regarding the length of the sections to be electrified and the corresponding number of substations, are of great interest. For the electrification of the railways mentioned, with the exception of the Vicenza-Recoaro-Chiampo and the Sangritana railways, only one substation has been used in every case. Secondary railways of a length not exceeding 60 km can be supplied by a single substation without the voltage drop in the contact wire sinking to inadmissable values, and also without the contact wire becoming too heavy and expensive. Noteworthy examples are the Turin-Lanzo Railway with a length of 42·5 km and a total length of track of 60 km; also the Porto San Giorgio-Fermo-Amandola Railway, the Milan-Saronno and Milan-Meda railways, the Calalzo-Dobbiaco and Ora-Predazzo railways, all of which have a length exceeding 50 km and for each of which a single substation suffices. It is only by using high-tension direct current that a single substation can be used for supplying the contact wire of such long sections.

The converters installed in the substations are asynchronous and synchronous motor generators, and also mercury-arc power rectifiers, high-voltage rotary

No.	Railway	Client	Length of railway km	Gauge mm	Max. gradient °/o	Contact-wire voltage	Number of sub-stations	Output kW	Vehicle		Weight of train		Max. speed km/h
									Loco.	Motor coach	Passenger train	Goods train	
1	Benevento-Foggia	Italian State Railways [1]	101	1445	2·3	3000	3*	6 × 1700	—	—	—	—	75
2	Turin-Lanzo	Soc. An. Ferr. Turin-Ciriè-Valli di Lanzo	42·5	1445	3·5	4000	1	2 × 650	5	2	105	250	75
3	Pinerolo-Perosa	Soc. An. Tranvia Pinerolo-Perosa, Pinerolo	20	1100	3·5	2000	1	2 × 400	4	1	—	—	40
4 5 6	Biella-Balma Biella-Vallemosso Biella-Oropa	Soc. An. Ferr. Elett. Biellesi, Biella	33·7 15	950 950	4·0 7·0	2400 2400	1*	3 × 600 + 1100	— —	9 8	60 —	— —	42 —
7	Sangritana	Soc. An. per le Ferr. Adriatico-Appennino, Milan	150	950	3·0	2600	2	5 × 600	11	6	65	107	45
8	Rome-Ostia	Ente Autonomo per lo sviluppo maritt. di Ostia	2·49	1445	1·9	2600	1	3 × 900	8	5	186	230	65
9	Spoleto-Norcia	Soc. Ferr. per Costruz. ed Eserc. di Ferr. Tranv., Milan	51·4	950	4·5	2600	1	2 × 650	—	5	80	—	45
10	P. S. Giorgio-Fermo-Amandola	Soc. An. per le Ferr. Adriatico-Appennino, Milan	59·4	950	7·0	2600	1*	2 × 700	5	3	88	107	45
11 12	Milan-Saronno Milan-Meda	Soc. An. Ferrovie Nord-Milan	44·6	1445	1·0	3000	1*	3 × 2000	3	8	106	1200	100
13	Calalzo-Dobbiaco	Soc. An. per la Ferr. delle Dolomiti, Padua	65·4	950	3·5	3000	1*	2 × 1100	2	6	70	114	45
14	Arezzo-Sinalunga	Soc. An. Ferr. per Costruz. ed Esercizio di Ferr. e Tranv., Milan	40	1445	1·4	3000	1*	2 × 600	—	5	—	—	80
15	Pescara-Penne	Impresa di Costruz. Ing. De-Agostini, Pescara	36·5	950	3·5	2600	1*	2 × 700	2	4	62	120	45
16	Vicenza-Recoaro-Chiampo	Soc. An. Tranvie Vicentine, Vicenca	51·7	1445	4·2	3000	2*	2 × 1100 2 × 700	3	7	90	185	80
17	Ora-Predazzo	Soc. Ferr. Elettr. Val di Fiemme	51	1000	—	2600	1*	2 × 910	2	3	—	—	—
18	Voghera-Varzi	Soc. An. per la Ferr. Voghera-Varzi, Milan	32·7	1445	—	3000	1*	2 × 900	2	3	—	—	—
19	Aosta-Près-S. Didier	Soc. An. Naz. Cogne, Turin	32	1445	—	3000	1*	2 × 1050	—	—	—	—	—
20	Benevento-Naples	Italian State Railways, Rome	—	1445	—	3000	2*	2 × 2000 2 × 2000	—	—	—	—	—

[1] Two substations are equipped with motor generator sets, and one with both rotary machines and rectifiers.

* Rectifier substations.

converters not being utilized at all for the electrification of secondary railways in Italy. By introducing the rectifier, which for some years now has been the only type of converter used, the disadvantages of motor generators (low efficiency, complicated starting, etc.) are eliminated.

The reduction in the number of substations and the employment of mercury-arc rectifiers instead of the motor generators previously used has influenced the economical operation of electric railways very favourably. Initial costs and operating costs can thus be reduced very appreciably, and at the same time by introducing the rectifier a very high yearly efficiency can be attained. After electrification, the operating costs of the Sangritana Railway, for example, were reduced by about half, i. e., from 6 to 3 centimes per ton-kilometre.

The conditions on the Fermana Railway were still more favourable, as the substation is equipped with rectifiers. A further reduction in the operating costs and also a simplification of operation can be achieved by introducing automatic control in the rectifier substation. The first automatic rectifier plant to be installed in Italy, and which has been in service for more than a year, is that of the Fermo-Amandola Railway (Servigliano Substation.) Some particulars of this automatic plant were given in the Brown Boveri Review 1929, No. 2. It should be mentioned that the automatic gear is working to the complete satisfaction of the client, and also that the results expected have been fully realized. It has also been found that the effect of electrification on the passenger and goods traffic has been very favourable. Compared with the earlier steam service, it has been found possible to treble the number of trains running and to reduce the running times very considerably, which latter reacted very favourably upon the traffic. The diagrams shown in Figs. 1 and 2 illustrate very clearly the rapid development of the passenger and goods traffic on the Fermana and Sangritana railways as a result of the introduction of electric service. The efficiency of these railways was considerably improved by electrifying them, and it is to be assumed that the results attained in the coming years will be still more favourable.

The exceedingly satisfactory results obtained by electrifying the previously-mentioned railways with high-tension direct current have led to the electrification of other sections, according to the same system. As may be seen in the table, a direct-current pressure of 3000 V has been used throughout. The saving effected by introducing automatic operation in Servigliano Substation, which was already apparent in the first year, has convinced the managements of the Vicenza-Recoaro-Chiampo and the Voghera-Varzi railways that the provision of automatic rectifier plants is the most economical solution of the problem of electrification of secondary railways. An automatic substation has been planned for this latter railway. One of the two substations already in service on the former railway has been equipped for automatic control (Valdagno Rectifier Substation).

The North Milan Railway might be quoted as an example of railway electrification with high-tension direct current. Since the beginning of this year the suburban traffic between Milan-Meda and Milan-Saronno has been handled by electric traction. Fig. 3 shows the network of the North Milan Railway and also the sections which have been electrified up to the present. These have a total length of about 45 km. The contact wire is fed from Novate rectifier substation, which is equipped with three units of 2000 kW each. The contact-wire pressure is 3000 V.

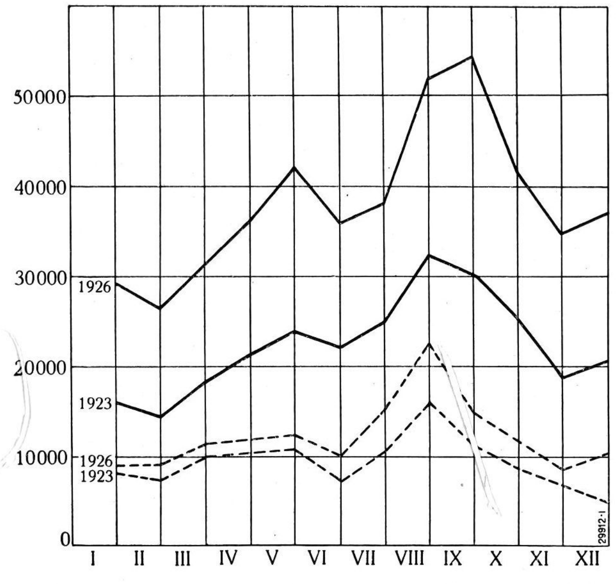


Fig. 1. — Passenger traffic on the Sangritana and Fermana railways before and after electrification.

——— Sangritana Railway. - - - - - - Fermana Railway.

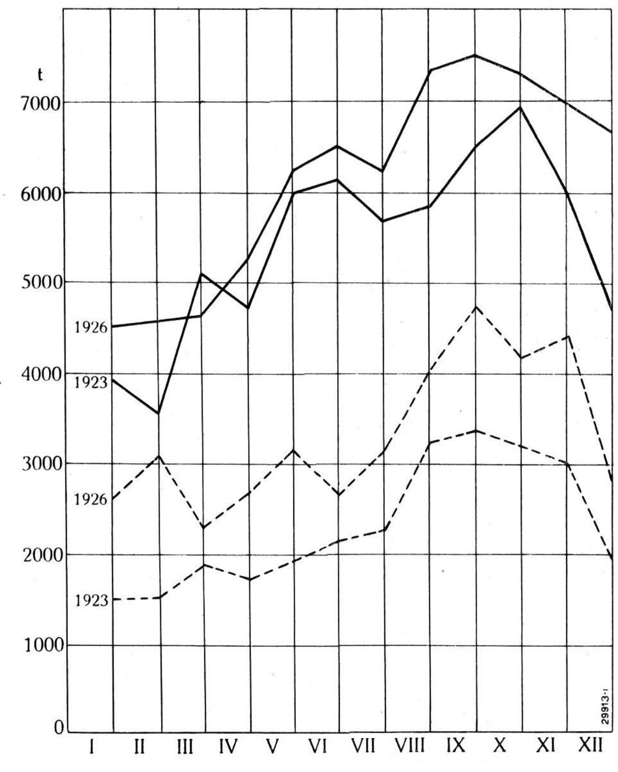


Fig. 2. — Goods traffic on the Sangritana and Fermana railways before and after electrification.

——— Sangritana Railway. - - - - - - Fermana Railway.

High-tension direct current at 3000 V is now used in Italy not only for the electrification of secondary railways but also for main-line railways. The results achieved in this connection on the Benevento-Foggia section of the Italian State Railways are very satisfactory. By way of experiment, both mercury-arc rectifiers and motor generators have been installed. The rectifiers have proved very successful, and due to their advantages over motor generators it was decided to use only this type for the extension of the electrification from Benevento as far as Naples. Three converter substations have been ordered for this section, one in Naples, one in Caserta and the third in Telese. Each plant contains rectifiers of a continuous rating of about 2000 kW at 3000 V.

These experiments of the Italian State Railways will be followed with keen interest, as the traffic on the railway just mentioned is very heavy. It also appears that in view of the extremely gratifying results, the electrification of other important sections of this railway with high-tension direct-current at 3000 V will be given careful consideration.

The special characteristics of the rectifier, e. g., small dimensions, low weight and the complete absence of rotating parts, enable light and inexpensive buildings to be used. Rectifier substations are fed by one or more incoming lines, provided with the appropriate apparatus and high-tension bus-bars, and also contain the converter sets with the apparatus for the auxiliary services as well as for the primary and direct-current sides, and also the apparatus for the outgoing feeders.

Motor generator sets with asynchronous motors are installed in the Fallo and Crocetta substations of the Sangritana Railway. The continuous rating of each set is 600 kW at 2600 V. The voltage of the incoming line is stepped down from 30,000 to 3300 V, at which pressure the asynchronous motors are fed. As is well known, converter sets with asynchronous motors reduce the power factor in the primary network, so that the use of such sets, although possessing certain advantages, is very limited. For this reason, only converter sets with synchronous motors were used for the electrification of the Turin-Lanzo, Biellesi, Rome-Ostia and Spoleto-Norcia railways. Each set comprises one synchronous motor and usually two direct-current generators connected in series, since the voltages are very high. The motors are regulated so that unity power factor is obtained. They are started at reduced voltage, for which purpose the transformers are provided with tappings. The generators (connected in series) installed in the substations of the Rome-Ostia Railway, are each designed for an output of 400 kW at 1300 V. The synchronous motor is supplied at 1000 V. The motor generators used on the Spoleto-Norcia Railway each consist of a synchronous motor of 650 kW, 3000 V, 50 cycles and a direct-current generator of 600 kW at 2600 V.

Fig. 4 shows the plan and elevation of Servigliano automatic rectifier substation of the Fermana Railway. The building consists of three parts. On the left hand side the high-tension apparatus for the incoming line with over-voltage protection is arranged and also the rectifier transformers with their oil circuit breakers.

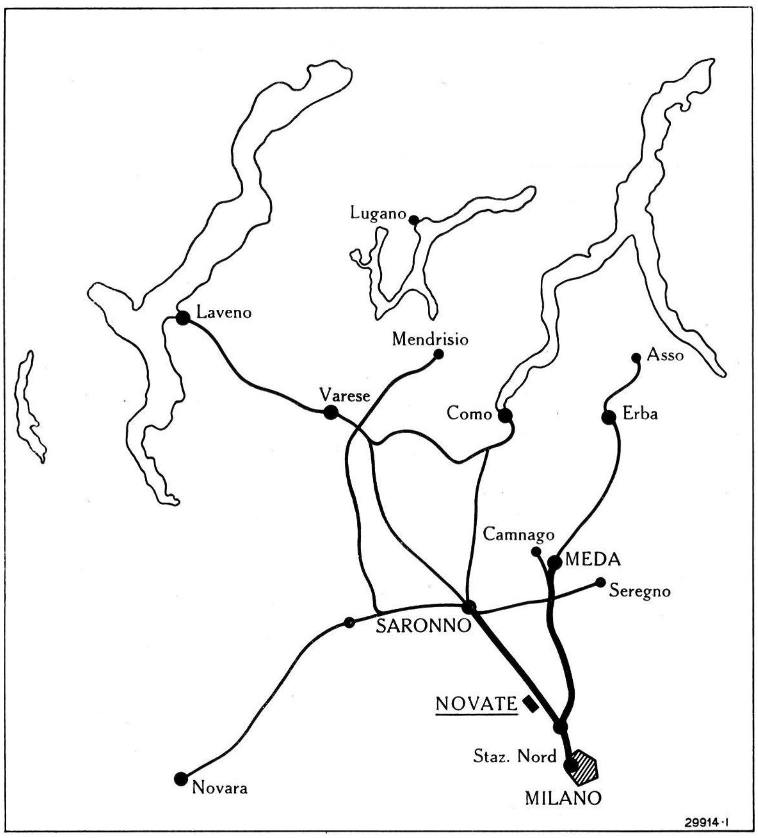


Fig. 3. — Railway network of the North Milan Railway.

The rectifiers and the switchboard are installed in the central building, while the direct-current apparatus is assembled in a special room on the right. The plant is supplied at 30,000 V, 50 cycles through a single high-tension transmission line. The contact wire is fed through three feeders protected by high-speed circuit breakers. The cathode circuit breakers are provided with reverse-current release so that in the case of a back fire in one of the rectifiers, selective tripping is obtained. It should be mentioned here that back fires in modern rectifiers are a rare occurrence, and even then merely result in the temporary shutting down of the rectifier set in question. As soon as the back fire has been cleared, the rectifier can be started up again. This only requires a few seconds, as no synchronising is necessary.

Fig. 5 shows the machine room of the rectifier plant at Novate.

The rectifiers with their air pump sets, switchboards and also some charging sets for the auxiliary accumulator battery are installed in the machine room; the closed-circuit cooling sets, which have forced ventilation, are assembled in the basement. The plant is supplied at 23,000 V, 42 cycles through two lines. The apparatus is installed in a two-storey wing of the building where the rectifier transformers with primary oil circuit breakers are also arranged. On the incoming lines and also on the primary side of the rectifier transformers, switches consisting of three single-pole oil circuit breakers are arranged. This arrangement enables the rupturing capacity to be appreciably increased. There is still sufficient space available in the high-tension room for the apparatus for two outgoing high-tension lines. Later on, these lines will be used for feeding one or two rectifier substations, which will be built when the electrification is extended. The d.-c. apparatus is also arranged in a completely separate room.

In the table given at the beginning of the article, particulars regarding the gauge, maximum gradient and also rolling stock were included, in addition to particulars concerning the electrical equipment of the substations and the length of the electrified sections. Since the electrification of secondary railways with high-tension direct current is a very recent and interesting problem, a short account must be given of the equipment of the locomotives and motor coaches, and also of the overhead equipment. On all the railways, both locomotives and motor coaches are employed, the

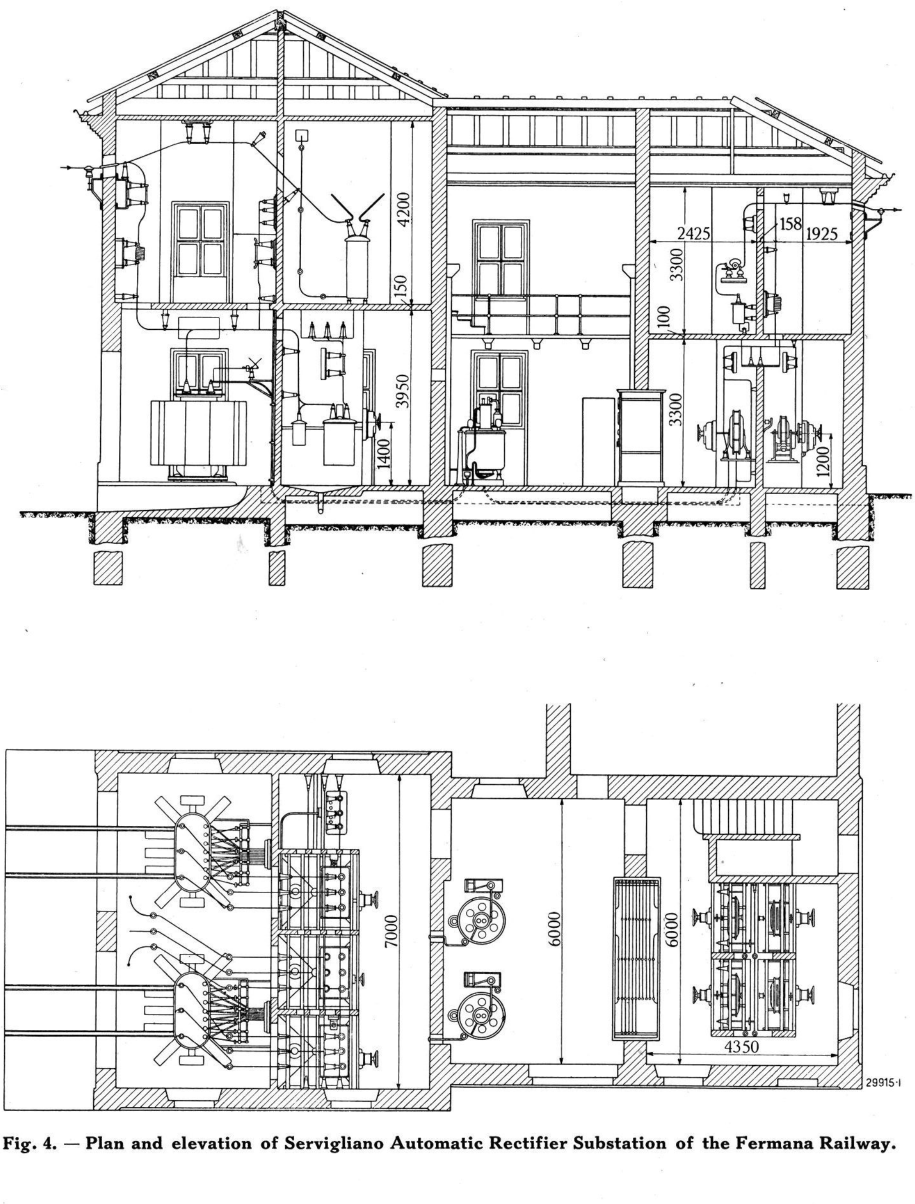


Fig. 4. — Plan and elevation of Servigliano Automatic Rectifier Substation of the Fermana Railway.

Fig. 5. — Machine room of Novate Rectifier Substation of the North Milan Railway.

North Milan Railway are equipped for multiple unit control and are provided with safety devices. The latter were also provided on the motor coaches of the Turin-Lanzo and Dolomites railways.

Generally speaking, two essentially different types of motors are used on the direct-current railways in Italy, i.e., the totally-enclosed type and the self-ventilated type. They are axle mounted and provided with reduction gear. All vehicles are fitted with Westinghouse or vacuum brakes. In addition, in almost all cases rheostatic braking by means of resistances mounted in the motor coaches or locomotives is provided. All vehicles are directly heated by high-tension direct-current. Either accumulator batteries or converter sets supply the current for lighting. The motor coaches of the North Milan Railway are provided with batteries and charging dynamos and also the necessary apparatus for automatic charging and for regulating the voltage to a constant value. Various types of pneumatically-operated pantographs are used for collecting current. The direct-current switches with magnetic blow-out and pneumatic control are arranged in a special high-tension compartment. Details of some motor coaches already built have been given in previous numbers of this Review. Fig. 7 illustrates a motor coach of the Recoaro-Vicenza-

latter for slow passenger traffic and the former for hauling heavy passenger and goods trains. A B_o-B_o axle arrangement is used for the motor coaches as well as for the locomotives. The motor coaches on the Turin-Lanzo Railway are of the 1A-A1 type.

Fig. 6 shows a locomotive for the Benevento-Foggia section of the Italian State Railways. This locomotive has six axles with an equal number of driving motors of a total one-hour rating of 2450 H.P. at 46 km/h. The locomotive is equipped for regenerative braking, which is possible because the substations on the Benevento-Foggia section are equipped with motor generators. Passenger traffic on the North Milan Railway is handled exclusively by motor coaches, locomotives being used for hauling heavy goods trains. The maximum speed of the motor coaches is 100 km/h. In view of the special traffic conditions on the railway, very high starting acceleration was stipulated. A slow train stopping at all stations between Milan and Meda covers the distance in exactly the same time as was previously required by a through train hauled by a steam locomotive. Thus, by introducing electric operation, conditions of local traffic were appreciably improved, and as a result a big increase in the use of the railway is to be expected. The motor coaches of the

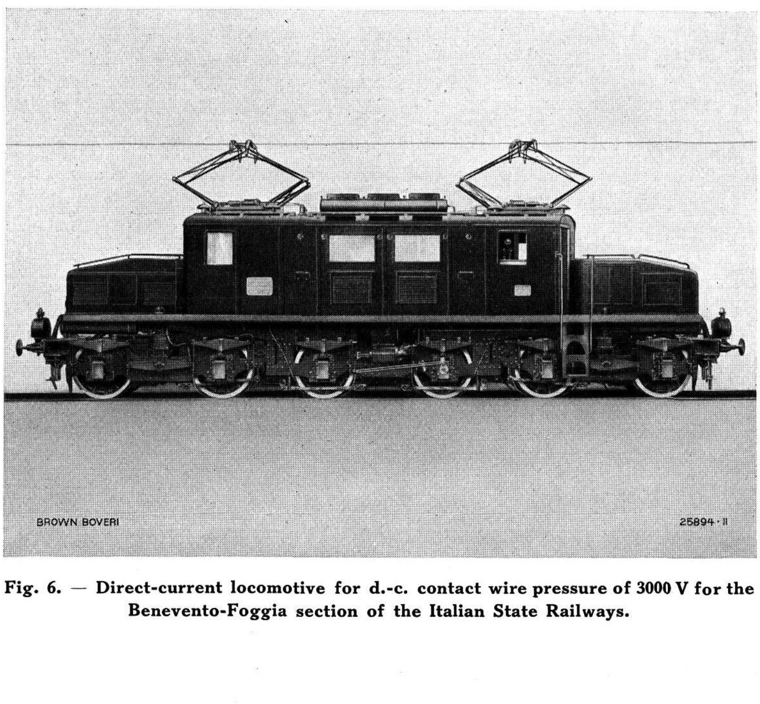


Fig. 6. — Direct-current locomotive for d.-c. contact wire pressure of 3000 V for the Benevento-Foggia section of the Italian State Railways.

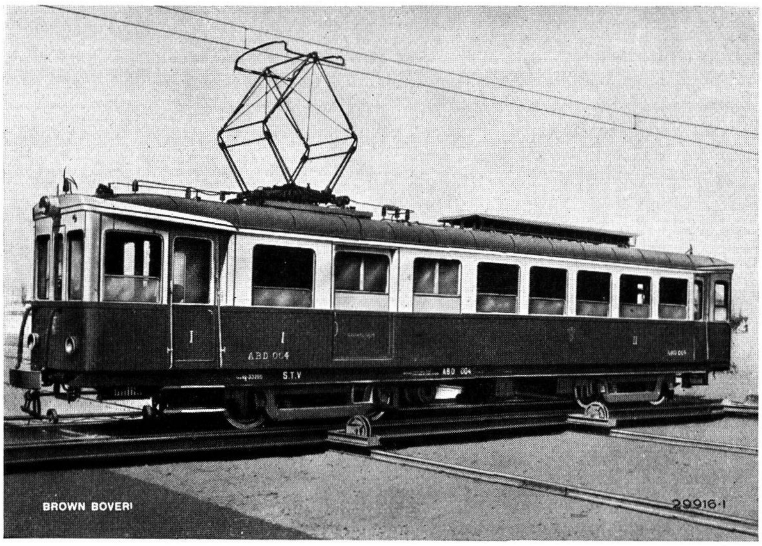


Fig. 7. — Motor coach of the Tranvie Vicentine for a d.-c. contact wire pressure of 3000 V.

Chiampo Railway and Fig. 8 the composition of a local train on the North Milan Railway. According to the maximum speed, the contact wire on railways electrified with high-tension direct-current has either simple or multiple suspension. The contact wire on the Benevento-Foggia Line and on the North Milan Railway is of particular interest, as the speed on these railways is very high and the traffic heavy. Multiple suspension not only allows a high speed but offers greater reliability, and the number of supporting points can be considerably reduced. Fig. 9 shows the contact wire of the North Milan Railway on an open section. This contact wire is provided with automatic tensioning devices, common to both contact wire and suspension wire, and also with movable supports. This arrangement is particularly advantageous because it renders the contact wire insensitive to temperature variations and the contact wire always remains at the same height.

Further advantages are: practically no alteration in the position of the wire when a train passes, and protection of the supporting insulators against the formation of soot if the service is mixed (steam and electric traction). In the central Milan station of the North Milan Railway, the contact wire has simple suspension. Feeders are arranged alongside the railway track and feed the contact wire through section switches mounted either on the poles or, where several have to be erected, in switch cabins. Each feeder is protected by high-speed circuit breakers with overcurrent release installed in Novate Substation.

As is common knowledge, regeneration cannot be utilized where rectifier substations only are provided, as rectifiers cannot pass current in the reverse direction. The Italian State Railways propose to install experimentally in Apice rectifier substation, on the Benevento-Foggia Line, equipment which will enable regenerative braking to be used on the trains even though rectifiers are the only type of converters employed. The equipment (Fig. 10) consists essentially of a loading resistor with suitable apparatus for automatically switching it in and out.

If a sufficient number of trains are ascending inclines, they absorb the energy regenerated by the trains travelling downhill. Should too much energy be regenerated, the equipment mentioned above comes into operation. Since the voltage on the bus-bars then rises, the voltage relays 3 operate and put the loading resistor in circuit. This is accomplished in steps, the number of which must always be determined according to the operating conditions. The loading resistor in the plant mentioned is of constantan

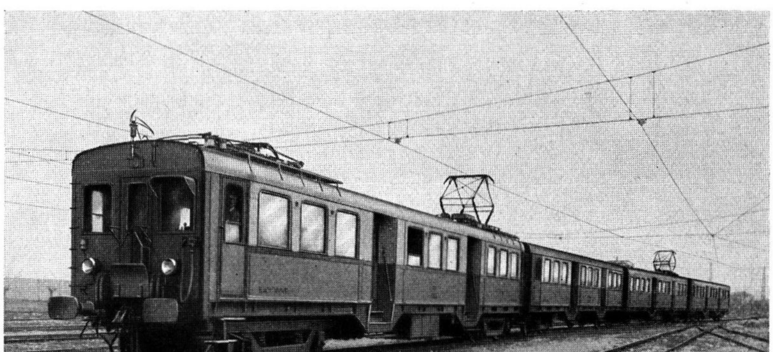


Fig. 8. — Local train on the North Milan Railway.

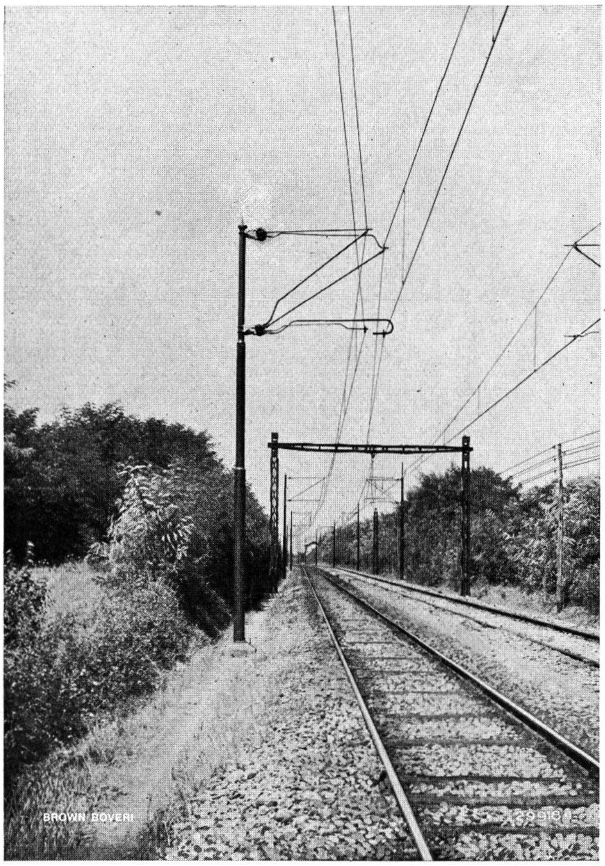


Fig. 9. — North Milan Railway. Contact wire with movable supports on an open section.

elements. It can also be in the form of a water resistance, which offers a still simpler solution. As already pointed out, this equipment will only be built in provisionally. It should be particularly emphasized that by choosing rectifiers as the converters in the substations of the Benevento-Naples Railway, the State Railways made full use of the great advantages offered by rectifiers at pressures of 3000 V. These advantages, both technical and economic, are of such a decided nature that the impossibility of using regenerative braking can well be tolerated.

In certain cases the electrification of secondary railways in Italy has been accompanied by disturbances in the telephone lines running parallel to the railway. These disturbances are chiefly due to the insufficient symmetry and insulation of the telephone wires. Where the wires have been carefully laid and transposed, e. g., as on the North Milan Railway, no trouble has been experienced with telephonic communication. Any disturbances that may occur can be immediately eliminated either by improving the lines and erecting them at a sufficient distance from the contact wire, or by using wave filters, installed in the substation. These wave filters consist of a number of resonance circuits and a choke coil (Fig. 11).

Each resonance circuit forms a short circuit for the higher harmonical currents of a given frequency, and thus reduces by a great amount the alternating-current component of the undulating voltage produced by a rectifier. The ratio $\frac{e \sim}{e' \sim}$ determines the effect

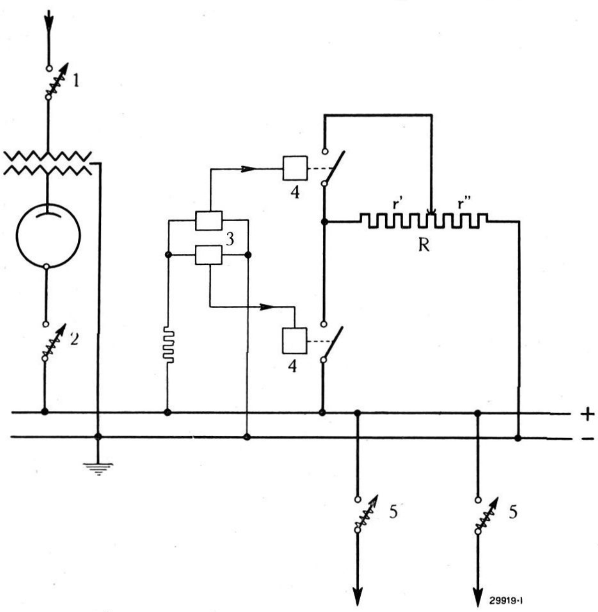


Fig. 10. — Diagram of connections for equipment for switching in and out a load resistor in a rectifier substation.

1. Oil circuit breaker.
2. Direct-current switch.
3. Voltage relay.
4. Motor control.
5. Feeder switch.

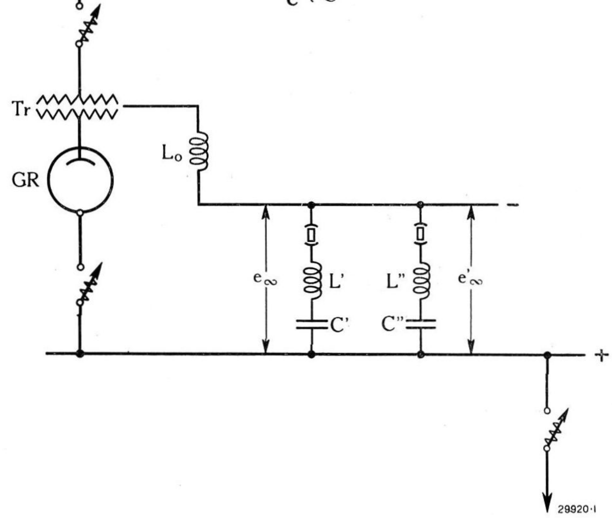


Fig. 11. — Diagram of connections of wave filter for eliminating disturbances in telephone lines.

T_r. Transformer.
GR. Rectifier.
L_0. Series choke coil.
L' L". Resonance choke coils.
C' C". Capacities.

of the wave filter. The bigger this ratio, the greater the effect of the filter and thus the smaller the voltage induced in the telephone wires by the harmonics. It should be mentioned that by installing such a wave filter in Biella rectifier substation, the disturbances to the telephone communication were reduced to a negligible quantity. The official tests carried out in this plant under the supervision of the telephone authorities have shown very clearly the good effect of the wave filter. The cost of such an equipment is comparatively low and is an insignificant item in the electrification of a railway.

The total length of secondary railways in Italy is already greater than 5000 km. Of these, about 1200 km have so far been electrified — 270 km with high-tension low-frequency current, 500 km with high-tension direct current and the remainder with direct current at pressures below 2000 V.

The technical and economic results of electrifying secondary lines with high-tension direct-current are in every case satisfactory, and it is to be assumed that equal success will attend the carrying out of this large programme of electrification. The replacement of steam by electric traction, the use for this purpose of high-tension direct current, and the installation of rectifiers instead of motor generators — which previously found universal employment — are of very great importance for the secondary railways of Italy. Their electrification has not only resulted in increased traffic, but also in improved efficiency of operation. Rectifiers are proving eminently satisfactory in automatic plants, which again results in a further reduction in operating costs. They have greatly simplified the various electrification programmes, and in future will ensure that these can be carried out still more rapidly.

(MS 599) *A. Greco. (E. J. B.)*

Lonza Elektrizitätswerke und Chemische Fabriken A. G., Basle, Ackermand Power Station (Canton Valais).

THE ELEMENTS OF SURFACE CONDENSER DESIGN.

Decimal index 621. 175. 1.

THE surface condenser is employed almost to the exclusion of every other form, partly because higher vacua are obtainable with it than with direct contact condensers, but principally owing to the necessity of keeping the condensate separate from the circulating water and free from contamination with foreign matter or dissolved gases, to reduce to a minimum the unavoidable corrosion taking place in the boilers.

Surface condenser design was for a long time based more or less upon rule-of-thumb methods. For example, the ratio of cooling surface to engine horse-power in some installation considered to be satisfactory was taken as a basis in determining the size of condensers for other installations, regardless of varying conditions. This practice was particularly prevalent in the case of marine installations where it was to some extent justified because conditions varied considerably less than in the case of plants for land purposes. Even at the present time, reference is still occasionally made to surface condenser ratings in terms of the cooling surface per unit of engine power.

A more rational form of rating is the ratio of the steam quantity to the cooling surface, which can conveniently be called the *specific loading* of the condenser. The use of a value representing the specific loading in comparing condenser ratings represents an advance over the older method in that variations in engine performance and in live steam conditions are not reflected upon the condenser performance. This ratio has also been employed as a simple basis for settling the size of surface condensers, but later investigations have made it clear that to obtain the best results, the specific loading is not necessarily a constant quantity but may vary according to the conditions.

In the following study, the fundamental relations are derived upon which scientific condenser design is based, and a critical investigation is made of the influence of the various factors upon which the performance of the condenser depends.

I. GENERAL PRINCIPLES.

For each kilogram of dry saturated steam condensed, a quantity of heat r equal to the latent heat of evaporation has to be communicated to, and carried away by the circulating water, and if the circulating water quantity is n times the steam quantity, its temperature rise is given by the relation

$$r = n\,(t_2 - t_1)$$

where t_1 and t_2 are the circulating water inlet and outlet temperatures respectively, as the specific heat of water may be taken as unity over the temperature range considered.

In an *ideal* condenser, that is, one having no air leakage and possessing an infinite thermal conductivity, the temperature of the condensed steam is equal to the outlet temperature of the circulating water and the above relation may be written

$$r = n\,(t_d - t_1) \qquad (1)$$

t_d being the saturation temperature. Values of r and p_d, the absolute saturation pressure, corresponding to various values of t_d may be obtained from published steam tables or from the curves illustrated in Fig. 1, and it is therefore possible to use the above expression to obtain the relationship between n and t_1, for varying vacua, and to plot a series of curves from which, conversely, may be obtained the absolute pressures theoretically attainable in an ideal condenser for given values of n and t_1. A set of such curves is reproduced in Fig. 2; the curves show the futility of increasing indefinitely the cooling water quantity n, as, beyond a certain limit, the rate of improvement in vacuum becomes so small as not to justify the corresponding increase in cooling water quantity.

In actual practice, the absolute pressure will always be greater than that theoretically attainable in an ideal condenser, due to the following reasons:—

(a) Condenser not possessing infinite thermal conductivity;

(b) Impossibility of excluding air leakage;

(c) Existence of a pressure drop over the steam path through the tube nest.

How the above factors affect the attainable vacua is investigated in the following analysis, in which the

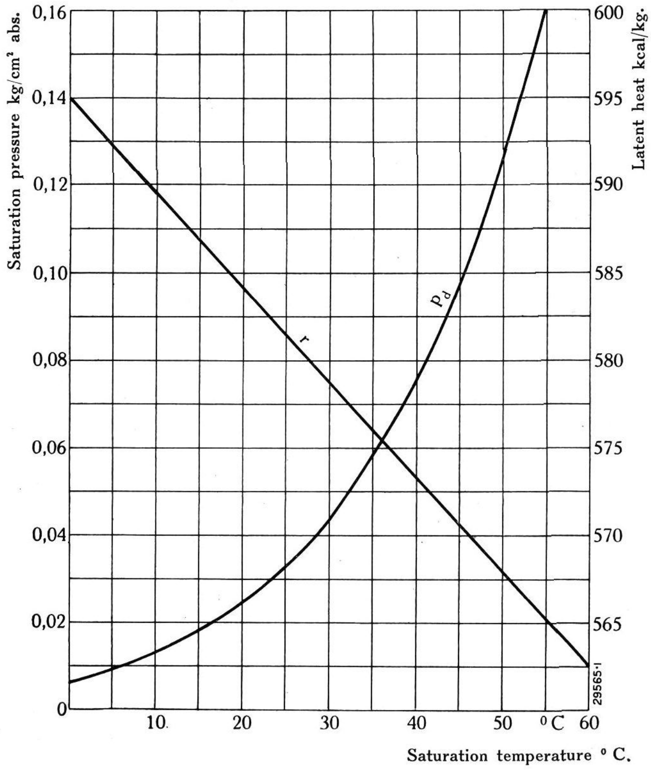


Fig. 1. — Absolute steam pressure and latent heat of steam at low pressures.

fundamental equations underlying the design of surface condensers are first derived, after which, the influence of secondary effects and the corrections thereby introduced are explained and discussed.

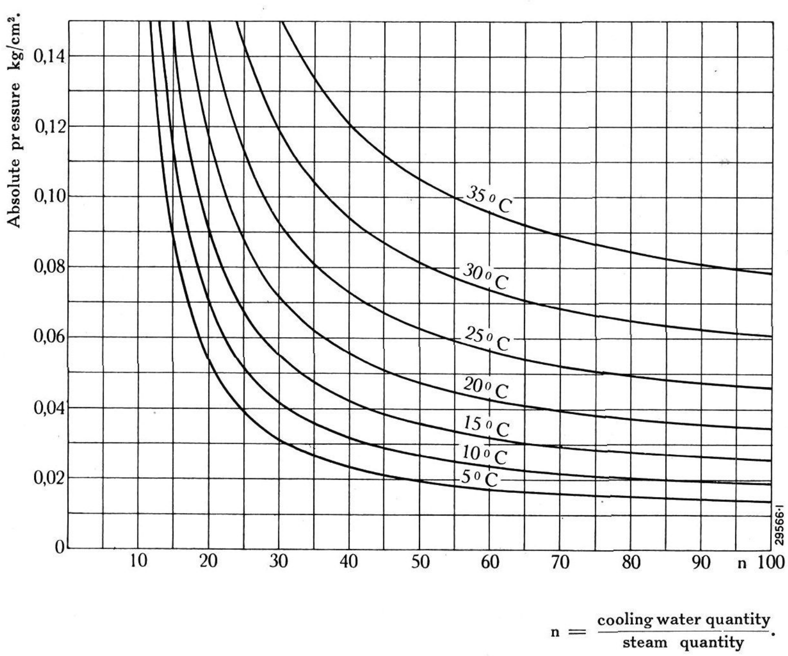


Fig. 2. — Absolute pressure theoretically obtainable in an ideal condenser, the circulating water inlet temperatures being from 5—35° C.

II. EFFECT OF LIMITED CONDUCTIVITY.

Consider the case of the elementary one-tube single-pass surface condenser represented by the diagram reproduced in Fig. 3, and let first of all the effect of air leakage be neglected, it being assumed that only dry saturated steam enters the condenser.

Let

p_d = saturation steam pressure, kg/cm² absolute.

t_d = saturation steam temperature, ° C.

r = latent heat of evaporation corresponding to the pressure p_d, k cal/kg.

t_1 = inlet temperature of cooling water, ° C.

t_2 = outlet temperature of cooling water, ° C.

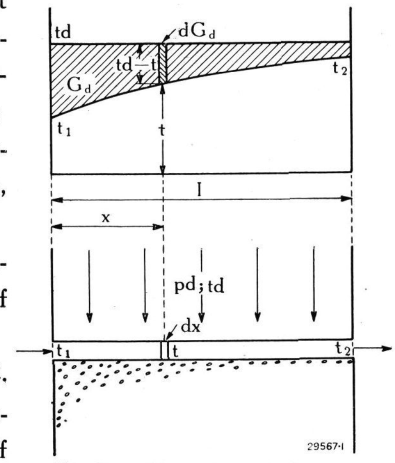


Fig. 3. — Elementary single-pass condenser.

k = thermal conductivity per unit area cooling surface from cooling water to steam, k cal/m²/° C/h.

F = total cooling surface, m².

l = length of cooling tube, m

(whence

$\frac{F}{l}$ = cooling surface per unit length of tube).

G_w = cooling water quantity, kg/h.

G_d = dry saturated steam quantity, kg/h.

$$n = \frac{\text{cooling water quantity}}{\text{steam quantity}} = \frac{G_w}{G_d}.$$

$$s = \frac{\text{steam quantity}}{\text{cooling surface}} = \text{specific loading of condenser} = \frac{G_d}{F}.$$

The heat transmitted per element of length dx at a distance x from the beginning of the tube where the cooling water inlet temperature is t_1 is

$$d\,Q = k\,(t_d - t)\,\frac{F}{l}\cdot dx = G_w \cdot dt$$

and as the heat transmitted through the tube walls must be acquired by the cooling water, we have the relation

$$G_w\,(t - t_1) = \int_0^x k\,(t_d - t)\,\frac{F}{l}\cdot dx$$

Differentiating this with respect to x to free it from the integral sign, and readjusting the terms we obtain

$$\frac{dt}{dx} - \frac{k\,F}{G_w\,l}\,(t_d - t) = 0$$

which is a simple linear differential equation of the first order, the solution of which can readily be obtained by separation of the variables and is

$$(t_d - t) = K\,e^{-\frac{k\,F}{G_w}\cdot\frac{x}{l}}$$

In this expression, K is a constant determined by the initial conditions; that is, for $x = o$, we have $t = t_1$, whence $K = t_d - t_1$, and the complete solution of the above equation is

$$(t_d - t) = (t_d - t_1)\,e^{-\frac{k\,F}{G_w}\cdot\frac{x}{l}} \qquad (2)$$

This may also be written

$$t = t_d - (t_d - t_1)\,e^{-\frac{k\,F}{G_w}\cdot\frac{x}{l}} \qquad (2\,a)$$

At the end of the tube, $x = l$, and $t = t_2$, whence t_2 is given by

$$t_2 = t_d - (t_d - t_1)\,e^{-\frac{k\,F}{G_w}}$$

Equation (2a) shows that the rise of the cooling water temperature along the tube is according to an exponential law, t_d being the limiting value which t approaches as the length of the tube tends towards infinity. The curve showing the cooling water temperature gradient is also included in Fig. 3.

The amount of steam dG_d condensed per element of tube length is given by the relation

$$r \cdot d\,G_d = d\,Q$$

or

$$d\,G_d = \frac{k}{r}\,(t_d - t)\,\frac{F}{l}\cdot dx \qquad (3)$$

It is proportional to the temperature difference $(t_d - t)$ which is given by equation (2), so that the equation gives a picture of the distribution of the condensed steam along the tube. If, in Fig. 3, the hatched area represents to some scale the total steam quantity condensed per unit of time, the distribution of the condensate along the tube is proportional to the ordinate between the horizontal line representing the constant steam temperature t_d, and the curve illustrating the gradient of the cooling water temperature t.

Substituting in equation (3) the value of $(t_d - t)$ given by equation (2) we obtain

$$d\,G_d = \frac{k\,F}{r\,l}\,(t_d - t_1)\,e^{-\frac{k\,F}{G_w}\cdot\frac{x}{l}}\cdot dx$$

or,

$$G_d = \int_0^l \frac{k\,F}{r\,l}\,(t_d - t_1)\,e^{-\frac{k\,F}{G_w}\cdot\frac{x}{l}}\cdot dx \qquad (4)$$

$$= \frac{G_w\,(t_d - t_1)}{r}\left(1 - e^{-\frac{k\,F}{G_w}}\right)$$

Putting the ratio of cooling water quantity to steam quantity $\frac{G_w}{G_d}$ equal to n, the specific loading $\frac{G_d}{F}$ equal to s and re-arranging the terms, equation (4) becomes

$$r = n\,(t_d - t_1)\left(1 - e^{-\frac{k}{ns}}\right) \qquad (5)$$

A comparison of this equation with equation (1) shows the correction introduced to account for the fact that the tube walls and surface film separating the steam and cooling water do not possess infinite conductivity. When the conductivity k becomes infinitely large, equation (5) is identical with equation (1).

In Fig. 4 have been drawn, for a cooling water inlet temperature $t_1 = 15^0$ C and for a constant specific loading $s = 50$, curves for three different finite values of the conductivity k, and for comparison purposes, the curve for infinite conductivity as given in Fig. 2 has also been reproduced.

It is particularly interesting to observe how the influence of decreasing conductivity becomes more and more marked as the conductivity gets smaller.

Equation (5) can also be used to show the effect on the theoretical attainable vacuum of varying the specific loading s. The curves drawn in Fig. 5 have been derived from this equation and are based on the assumption that the conductivity k is not influenced by the specific loading and remains constant.

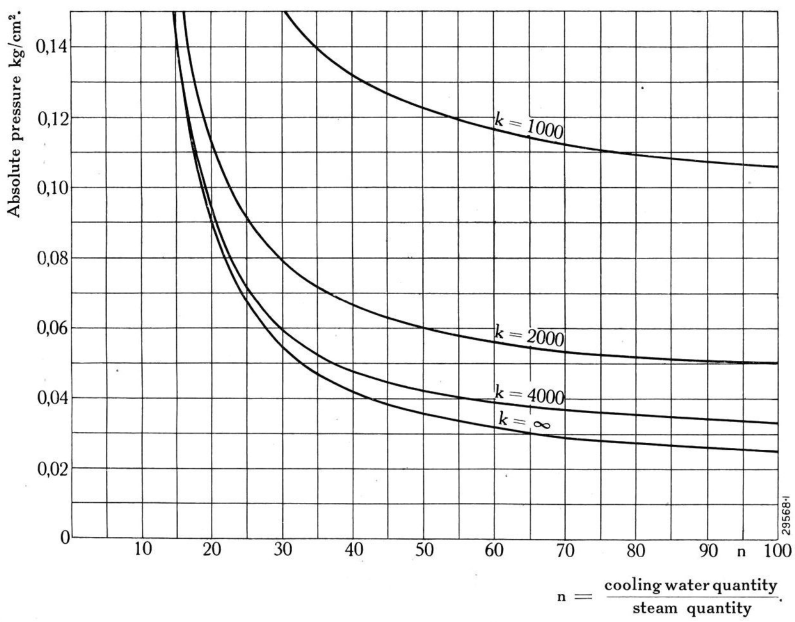


Fig. 4. — Effect of varying conductivity on the theoretically attainable vacuum, circulating water inlet temperature 15° C, specific loading = 50.

It is sometimes convenient to consider the heat transfer taking place in the condenser as resulting from a hypothetical mean temperature difference between steam and cooling water $(t_d - t_m)$. On this basis the total heat transmitted is given by the relation

$$Q = k F (t_d - t_m) \qquad (6)$$

and as this must equal the heat given out by the condensation of G_d kilograms of steam as determined by equation (4), we may write

$$k F (t_d - t_m) = G_w (t_d - t_1) \left(1 - e^{-\frac{kF}{G_w}}\right)$$

and therefore

$$(t_d - t_m) = \frac{G_w}{kF} (t_d - t_1) \left(1 - e^{-\frac{kF}{G_w}}\right) \qquad (7)$$

but from equation (2)

$$(t_d - t_1)\, e^{-\frac{kF}{G_w}} = t_d - t_2$$

also

$$\frac{kF}{G_w} = \log \frac{t_d - t_1}{t_d - t_2}$$

and therefore the mean temperature difference as given by equation (7) becomes

$$t_d - t_m = \frac{t_2 - t_1}{\log \frac{t_d - t_1}{t_d - t_2}} \qquad (7\,a)$$

For many purposes, the mean temperature difference may be, and frequently is taken as

$$(t_d - t_m) = t_d - \frac{t_1 + t_2}{2}$$

although the departure of the value given by this expression from that obtained from equation (7 a) becomes appreciable for the smaller values of $n = \frac{G_w}{G_d}$, and $s = \frac{G_d}{F}$.

It is also interesting to note that, since from equation (2)

$$\frac{kF}{G_w} = \log \frac{t_d - t_1}{t_d - t_2}$$

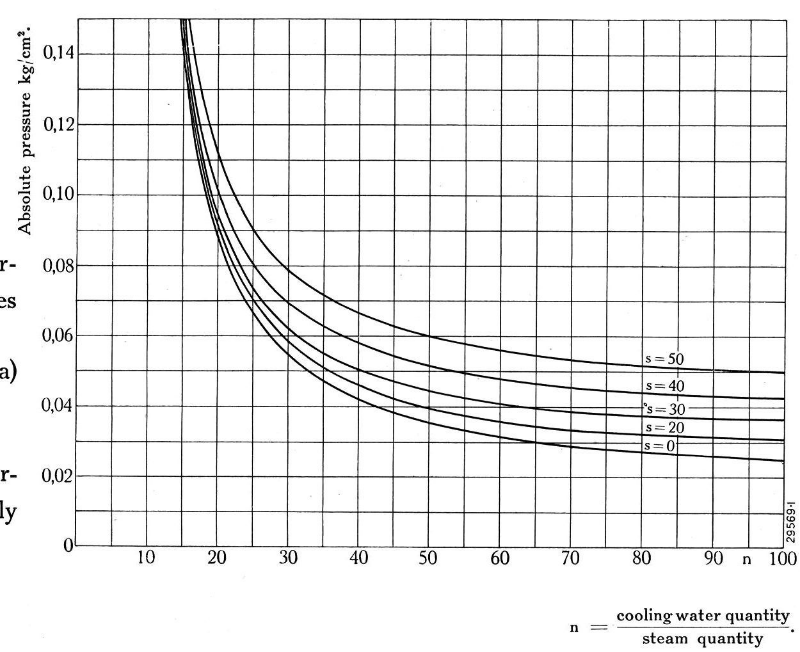


Fig. 5. — Effect of varying specific loading on theoretically obtainable vacuum, circulating water inlet temperature 15° C, conductivity = 2000.

the cooling surface, F, is given by the relation

$$F = \frac{G_w}{k} \cdot \log \frac{t_d - t_1}{t_d - t_2} \qquad (8)$$

or

$$F = \frac{n\,G_d}{k} \cdot \log \frac{t_d - t_1}{t_d - t_2} \qquad (8\,a)$$

III. INFLUENCE OF AIR.

No condenser is entirely free from air leakage; furthermore, not only the connecting piece between the turbine and the condenser, but, under normal operating conditions, also a considerable part of the turbine itself is under vacuum, so that even with steam free from non-condensable gases coming from the boilers, there is considerable probability that the exhaust steam is discharged to the condenser with an appreciable air content.

The accurate determination of the loss of vacuum due to the presence of air is exceedingly difficult, if not impossible; but it is essential, if a good design of condenser is to be evolved, that the theory of the phenomena taking place be carefully investigated and properly understood.

Fig. 6 represents a simple form of surface condenser, where, for convenience, such air as finds its way into the condenser is supposed to be admitted at the top, mixed with the exhaust steam. The condensate collects in the hot well at the bottom, and the non-condensable gases are drawn off, also at the base of the condenser.

Had the air pump suction been situated at the top of the condenser, a fraction of the mixture of air and steam would have been withdrawn, whilst the air in the remainder of the mixture entering the tube nest would have found no means of escape and the condenser would gradually have become "air-locked", that is, filled with air, the pressure in the condenser rising until it equalled the total pressure of the mixture at the inlet so that no more steam could pass on into the tube nest to be condensed there.

According to Dalton's law, the pressure of a gas mixture is equal to the sum of the partial pressures of the gases constituting the mixture; hence, if at the entrance the partial pressures of steam and air are p_{d1} and p_{l1}, respectively, and at the air pump suction they are p_{d2} and p_{l2}, the total pressure at the condenser inlet is

$$p_1 = p_{d1} + p_{l1}$$

that at the air suction is

$$p_2 = p_{d2} + p_{l2}$$

and the pressure drop over the tube nest is

$$\Delta p = p_1 - p_2$$

The mixture of air and steam entering at the top meets the first tube rows and the steam begins to condense. As the mixture progresses through the tube nest, more steam condenses until, at the base, there is only so much water vapour as corresponds to a partial pressure equal to the saturation pressure of the condensate. In the meantime, owing to the handling capacity of the air removal pump being very small for gases at low densities, air is not at first withdrawn as fast as it enters the condenser, but accumulates at the bottom until the pressure is high enough to enable the air pump to exhaust it at the same rate as it enters, whereupon a steady state is reached. Let the partial air pressure dependent upon the handling capacity of the air pump be p_{l2}, the saturation pressure corresponding to the temperature of the condensate p_{d2}; the total absolute pressure at the base of the condenser is then

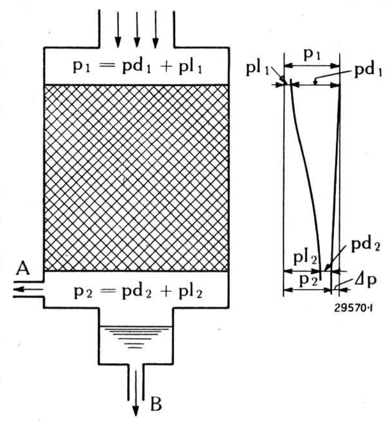


Fig. 6. — Diagram illustrating distribution of the air in a simple surface condenser.
A = Air pump. B = Extraction pump.

$$p_2 = p_{d2} + p_{l2}$$

and the total absolute pressure at the entrance to the condenser is

$$p_1 = p_2 + \Delta p$$

In modern condensers, Δp is kept small and, for present purposes, it may be neglected so that

$$p_2 \cong p_1$$

whence

$$p_{d1} + p_{l1} \cong p_{d2} + p_{l2}$$

or

$$p_{d1} \cong p_{d2} + (p_{l2} - p_{l1})$$

This indicates that the partial steam pressure at the condenser inlet is greater than that corresponding to the condensate saturation temperature by an amount about equal to the rise of the partial pressure of the air caused by the handling capacity of the air pump being limited according to the density of the gases exhausted.

The partial pressure of the air grows as the mixture descends the tube nest, increasing from its value p_{l1} at the condenser inlet to the value p_{l2} at the air outlet in the manner shown by the curve also included in Fig. 6.

In order to obtain the best possible vacuum at the condenser inlet, for a given circulating water inlet temperature and quantity, every possible effort should be made to reduce the air leakage to a minimum. In the first place, the absolute pressure at the inlet, which is the magnitude with which the user is mainly concerned, is given by

$$p_1 = p_{d1} + p_{l1}$$

from which it is evident if p_1 is to be kept low, that p_{l1}, which depends on the air quantity entering the condenser, must be kept as small as possible. The second consideration is to provide an air pump of adequate capacity so that the difference between the partial steam pressure at the inlet and the saturation pressure of the condensate due to the concentration of air at the bottom of the condenser as given by the relation

$$p_{d1} \cong p_{d2} + (p_{l2} - p_{l1})$$

is also kept as small as possible by keeping down the value of $(p_{l2} - p_{l1})$.

The size of the air extraction pump and its power requirements depend on the total gas quantity handled; hence if water vapour as well as air is drawn off, a larger air pump requiring greater operating power is necessary than if only air were being exhausted. Looking upon the subject in another manner, a better vacuum will be attainable with a given size of pump if care is taken to reduce to a minimum the amount of water vapour being evacuated with the air. This consideration has led to the adoption of special precautions to make the partial steam pressure p_{d2} at the air suction as small as possible. The first precaution consists in arranging the flow of the cooling water to traverse the condenser in the opposite direction to that of the steam-air mixture. This arrangement, which is known as the *counter-flow* principle, is responsible for a low partial steam pressure at the air exhaust because the steam at this point meets the coldest circulating water and accordingly the condensate and corresponding saturation temperature are lower than if the steam were here in contact with tubes traversed by water already warmed by passage through some other part of the tube nest.

As the partial steam pressure above the condensate is dependent on the temperature of this latter, it has been estimated that an improvement would result from passing the coldest circulating water through tubes actually immersed in the condensate in order to "super-cool" it, reducing its temperature and therefore vapour pressure, and condensers have actually been built provided with this feature. Experience has shown, however, that this resulted essentially

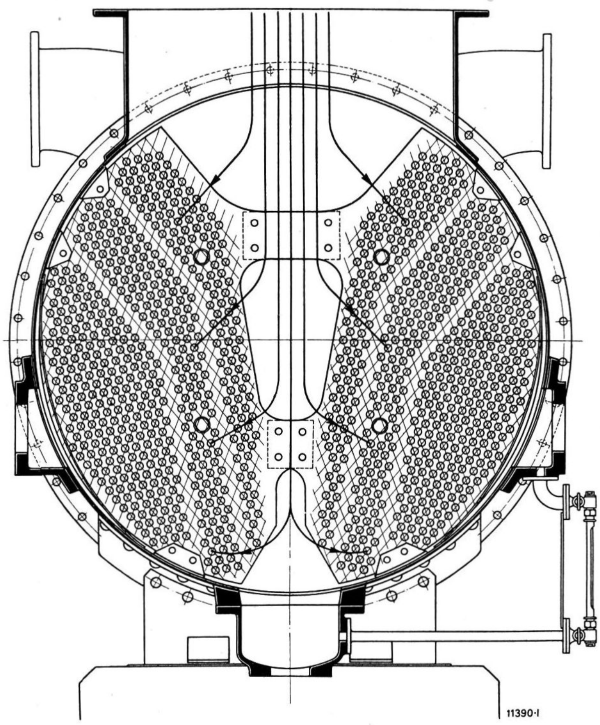


Fig. 7. — Section of Brown Boveri type-OV condenser showing position of air suction branches.

in a reduction of thermal efficiency due to the reduced temperature of the condensate when returned to the boilers as feed water, so that improvements were sought along other lines. In good modern condensers, the air suction is still in the neighbourhood of the coldest circulating water, but some distance away from the hot-well so as to allow an appreciable fall in temperature and therefore of water vapour pressure between the hot-well and the air outlet. The manner in which this is achieved in the Brown Boveri type-OV condenser is clear from the sectional drawing reproduced in Fig. 7. This condenser owes its name to the figure assumed by the tube distribution in the condenser shell, which is such as to give the incoming steam the easiest possible access to the cooling surface and so keep down to a minimum the internal pressure drop. The design illustrated has three water passes: the circulating water flows first through the two outermost passes in parallel, returning through the intermediate passes and finally going down the two innermost passes, and leaving the condenser at the top. The air suction outlets are arranged on each side a little below the centre where, due to the combined effect of the counter-flow principle and the arrangement of the tubes, the steam is most rarified and the air density correspondingly high. With this design, the condensate temperature under normal conditions is only about 1 ^{0} C less than that corresponding to the absolute pressure at the condenser inlet so that there is no tendency to lower the cycle thermal efficiency by super-cooling the condensate returned to the boilers. It is also clear from the drawing that there is constant circulation throughout the entire condenser and that there is no spot where non-condensable gases may accumulate and form air-locks, thus reducing the effective cooling surface.

IV. INFLUENCE OF PRESSURE DROP OVER THE TUBE NEST.

It has been seen above that the absolute pressure at the condenser inlet, which is the value determining the quality of the condenser performance, was equal to the saturation pressure of the condensate in the hot-well, augmented by the partial pressure of the air at this point, plus the pressure drop over the tube nest, or,

$$p_1 = p_{d_2} + p_{l_2} + \Delta p$$

The saturation pressure of the condensate in the hot-well is fixed by the quantity and inlet temperature of the circulating water so that in order to maintain a low absolute pressure at the inlet, it is evident that Δp as well as p_{l_2} must be kept as small as possible. In modern turbines, the steam always possesses an appreciable discharge velocity to enable it to clear the last row of blades, and its momentum can be made use of — by skillfully designing the path to the cooling tubes in such a way as to avoid eddies — to carry it into the tube nest. The pressure drop is then largely overcome by the velocity head of the discharged steam. Reference to Fig. 7 shows how effectively the velocity head is made use of in the Brown Boveri type-OV condenser to distribute the steam uniformly to the tube nest.

V. SECONDARY EFFECTS.

These are by far the most difficult to gauge and in condenser design it is only possible to make allowance for them after experience has been gained by exhaustive tests under conditions similar to those for which the proposed design is intended.

Among the more important secondary effects may be enumerated:

(a) Variation of the thermal conductivity coefficient k.

(1) According to the velocity of the cooling water through the tubes;

(2) With the viscosity, that is to say temperature of the circulating water;

(3) According to the condition of the tubes, whether new or with slight organic film, or with sludge and scale deposits;

(4) With varying specific loading and density of the steam;

(5) With varying air content.

(b) Reduction in effective cooling surface due to air concentration at the air suction outlets.

(c) Cooling by radiation from the condenser shell and adaptor piece between turbine and condenser.

It is outside the scope of this article to enter into the complicated and in many cases incomplete theory of all the above-mentioned effects, but no study on this subject should be concluded without drawing attention to them and briefly discussing their action, as their influence on the performance of the condenser is far reaching.

The fact that the thermal conductivity coefficient varies according to the velocity and viscosity of the water in the tubes, indicates that equation (5) is only true provided allowance is made for the variation of k with n. Experience shows that the thermal conductivity coefficient varies approximately as the square root of the water velocity, but it is rarely advantageous to raise the water velocity above 2 m/sec, as the gain in vacuum is then offset by the increased power requirements of the circulating pump, the resistance to flow varying as the square of the water velocity.

The attainable vacuum is very largely influenced by the condition of the tubes. For example, the thermal conductivity coefficient k for tubes having a moderate coating of sludge and scale may be only half the value for new tubes, and the effect of this on the attainable vacuum can readily be appreciated by reference to the curves in Fig. 4. Furthermore, with any but the purest glacier or rain water, after only a few days service, a thin organic film forms on the inside of the tubes. It can hardly be detected by an ordinary inspection, yet it is responsible for an appreciable reduction in the conductivity coefficient when compared with results obtained with new tubes in the laboratory. It is evident that allowance must be made in the condenser design to enable the vacuum guarantees to be attained with this film and even with thin deposits. It is, however, of the greatest importance that sludge and scale be periodically removed by a thorough cleaning of tubes, as the vacuum falls off increasingly rapidly with decreasing conductivity. (See curves Fig. 4.)

The conductivity also varies according to the specific loading s, being better for larger values of the specific loading and greater steam densities than for lower values of these quantities. The curves plotted in Fig. 5 are drawn on the assumption that the conductivity k is not dependent on these factors but is taken as a constant value equal to 2000 kcal/^{0}C/m^2/h, and they are subject to correction accordingly.

The presence of air mixed with steam reduces the conductivity coefficient, in that air is entrained with steam condensing on the tubes, slowly escaping from the water film on the tube surface and forming an insulating layer. Towards the air outlets, the tube surface is almost entirely inaccessible to steam due to the concentration of air at these points, resulting in a reduction of the effective cooling surface.

The cooling by radiation from the condenser shell and connecting piece between turbine and condenser, unless the latter is very long, is commonly neglected, or more correctly, this effect is retained as a margin to offset possible inaccuracies in calculation due to lack of exact knowledge.

VI. CONCLUSION.

It will be seen from a perusal of this article, that although condenser design is not an exact science, due to the numerous phenomena which cannot

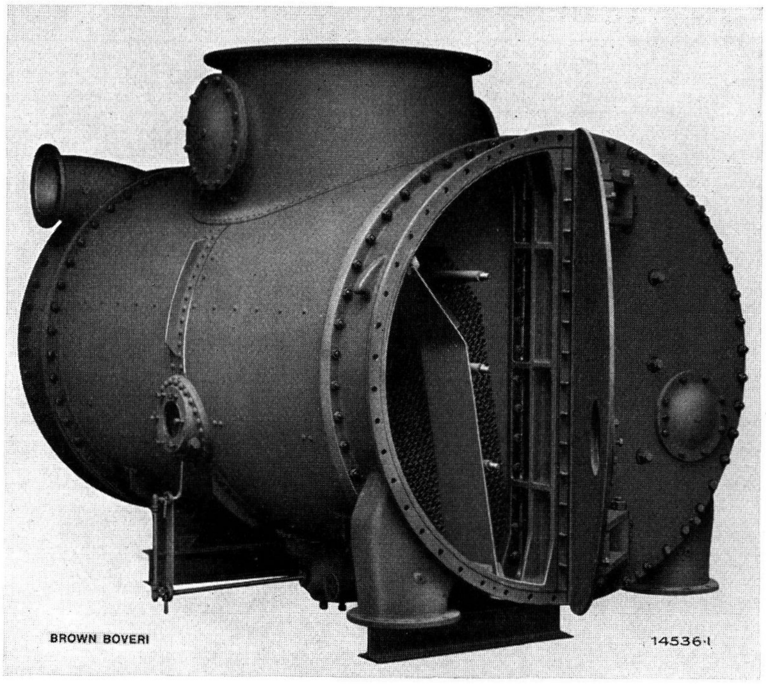


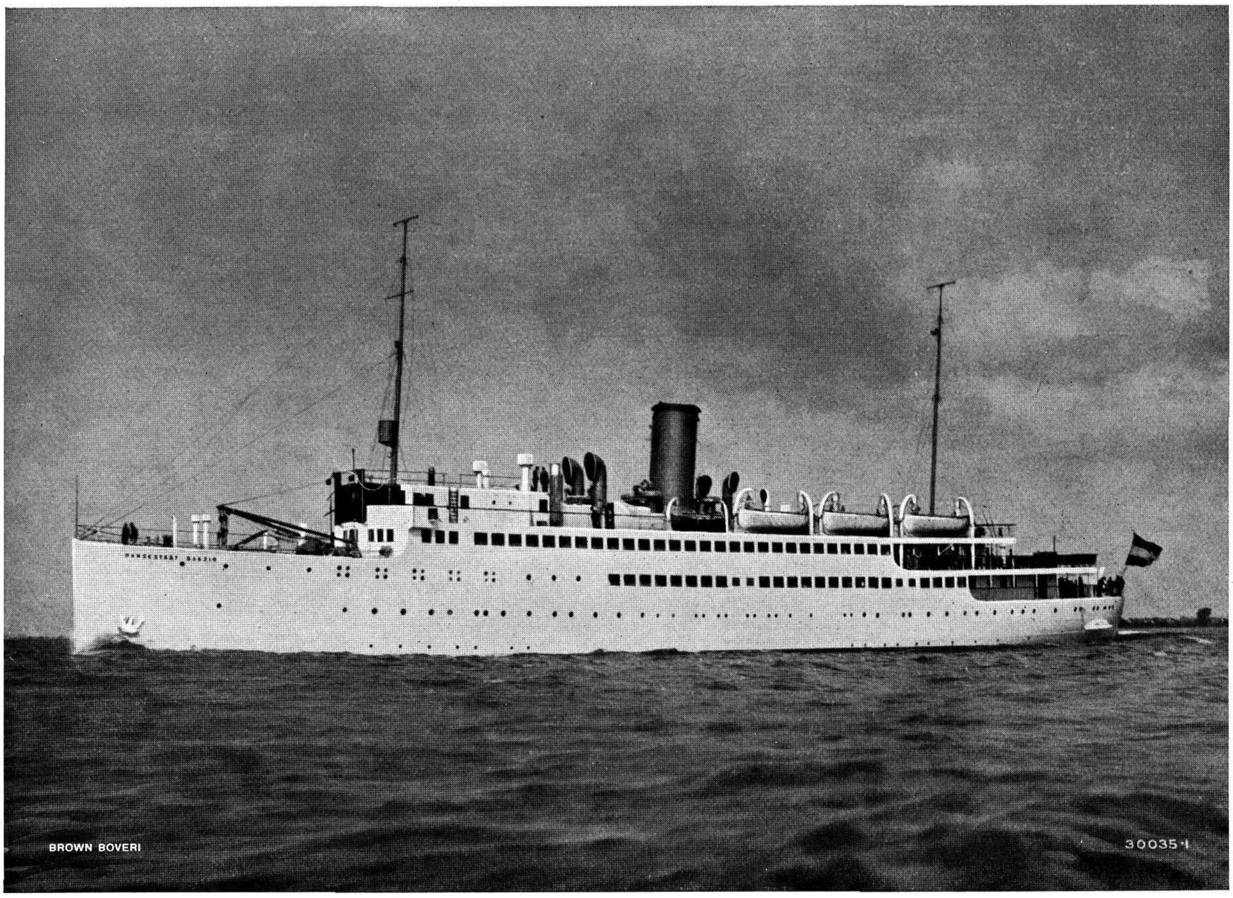
Fig. 8. — View of typical Brown Boveri continuous service condenser.

accurately be expressed in the form of mathematical relations, it is based, in the case of modern practice, on sound scientific reasoning. The fundamental equations derived in the first part of this analysis, when corrected according to knowledge derived from experience, form the basis for determining the main dimensions for any given set of conditions.

An example of the difficulties with which the condenser designer has to contend is afforded by the subject of air leakage. The amount of air entering the condenser has a very large influence on the attainable vacuum, yet there is no method by which it can be calculated and for otherwise identical installations very different vacua may be produced in the condensers, simply due to different air leakages. Not infrequently a condenser installation has to be entirely overhauled to reduce the air leakage to reasonable proportions.

Another difficulty is that the condenser designer is usually given only the total steam flow to the condenser corresponding to a certain vacuum and is not told the value of the dryness fraction, that is, he is not given the proportion of water in the steam discharged from the turbine. To allow for this, he reduces slightly the value of the latent heat corresponding to dry saturated steam, assuming a constant average value which may be taken as generally applicable in all cases; in this connection attention is drawn to the fact that in this study all calculations have been made and curves drawn based on dry saturated steam. They are easily corrected for wet steam as this latter may be considered as a mixture of dry saturated steam and water from which it is only necessary to subtract the water as given by the dryness fraction.

(MS 596) *H. S. Hvistendahl.*



The twin-screw motor vessel "Hansestadt Danzig" with engines supercharged on the Büchi system and equipped with Brown Boveri turbo-scavenging blowers.

MERCURY-ARC POWER RECTIFIERS FOR WIRELESS TRANSMISSION PLANTS.

Decimal index 621. 314. 65 : 621. 396.

Among the numerous difficulties which have had to be surmounted in the rapid progress of wireless telegraphy and telephony within the last few years, one remained which proved to be a very serious obstacle. This difficulty lay in the generation of power in the form of high-voltage direct current for supplying the amplifiers of the transmission plants. The d.-c. pressures involved were of the order of 10,000 to 30,000 V.

The first solution to which wireless engineers resorted, in order to overcome this difficulty, naturally took the form of special motor generator sets, coupled in series to obtain the requisite voltage. The resulting considerable demand for motor generator sets for this purpose led to important developments in their design, so that modern sets can be built for pressures up to 15,000 V d.-c. in one unit.

This solution could not, however, be considered as satisfactory, owing to certain inherent characteristics of motor generators which prevent them from complying with the demands placed upon them when applied to wireless transmission. The principal disadvantage of motor generator sets lies in the comparatively long time necessary to start them up, whereas it is essential that spare sets should be capable of being put in service within a few seconds, as otherwise large portions of a speech in course of transmission would be completely cut out upon the occurrence of trouble in the machine used for supplying the amplifiers. This disadvantage would be all the more serious nowadays as orators frequently speak in a public hall and not at the wireless station, so that they would be unaware of the trouble.

The next solution attempted by wireless engineers took the form of thermionic rectifiers, which at first sight seemed very satisfactory, as they could be put in service at a moment's notice and were capable of withstanding short circuits. The disadvantage of this solution lay in the enormous cost of upkeep of these rectifiers due to their life being limited, on an average to 5000 hours, i. e., to approximately one year of wireless service. Lesser disadvantages such as a low efficiency of about 80 % and the large floor space required, due to the necessity for a large number of rectifiers in parallel, should also be mentioned.

The most modern solution of the problem has been provided by the decision of Marconi's Wireless Telegraph Co. Ltd., London, to install a Brown Boveri mercury-arc power rectifier in their research laboratories at Chelmsford, England. The rectifier and rectifier transformer were designed for an output of 400 kW at d.-c. pressures of 9000, 10,000 and 12,000 V. This solution of the problem would seem to be ideal, as a power rectifier can fulfil all the requirements placed upon it by wireless service: it is capable of withstanding short circuits without the slightest trouble, as there are no windings to burn out; it can be set in service immediately, merely by closing the oil circuit breaker, and it possesses a high efficiency.

The plant was first placed in service on September 16th, 1929, and operated entirely satisfactorily from the start. The average load on the set was 230 kW at 13,000 V. The pressures of 9000, 10,000 and 12,000 V are adjusted at no load by taps on the transformer, but lower or higher values can be obtained at Chelmsford by varying the primary voltage. It is particularly worthy of note that although the set was only designed and tested for 12,000 V, it functions perfectly satisfactorily in practice at 13,000 V.

Another point of interest is that the set was often run for several hours at loads as light as 30 kW at 7500 V, which means that the direct current only attained 4 A, i. e., a magnitude not even sufficient to warm the anodes; despite this the set did not develop the slightest trouble.

It is also worth mentioning that the mercury-arc rectifier presents no greater difficulty in the smoothing of its output than the thermionic valve rectifier. At Chelmsford, the same ripple-eliminating system is used for the arc as for the alternative thermionic rectifier and no difference in the smoothed output is noticeable whichever of the two rectifiers is in operation. Judging by these operating data, it would seem that power rectifiers will undoubtedly be used extensively in future for wireless purposes.

A superficial examination of the adaptations which are necessary in high-voltage plants may be of interest. The rectifier transformer is of normal design with the exception that the secondary six-phase side must be specially insulated. The absorption choke coil being placed in the negative pole, which is earthed in wireless plants, does not need very abnormal insulation, although the voltage across this coil amounts to a quarter of the d.-c. voltage, i.e., the coil must be designed for pressures of the order of 3000 V. The rectifier itself must be of special design in order to obtain the requisite spacings between anodes, between anodes and cylinder, as well as between anodes and cooling dome.

Water cooling of the rectifier is not necessary, as radiation and convection suffice to lead away the losses. The high-vacuum pump must of necessity be cooled by water, which fact presented some difficulty, as this pump is at the same potential as the rectifier, i. e., 12,000 V against earth. In order to eliminate any danger of short circuits through the cooling water, it was decided to wind the rubber inlet and outlet pipes around porcelain pillars, thus obtaining a long column of water, insulated from earth, of sufficient resistance to prevent corrosion or leakage. In the event of the current on high-voltage rectifiers being increased above 50 A, it will be possible to use these pillars for insulating the cooling system of the rectifier itself, which would be connected in parallel with the cooling system of the high-vacuum pump. In Fig. 1, which shows the layout of Chelmsford Substation, these pillars may be seen to the left of the rectifier.

The auxiliary services of the rectifier, such as the motor of the rotary vacuum pump, the vacuum measuring device, etc., all come under a pressure of 12,000 V against earth. All these pieces of apparatus are therefore mounted on insulators and fed from an insulating transformer of 220/220 V, the secondary winding of which is insulated against earth and against the primary winding for 12,000 V. The vacuum indicator, rotary switch for the vacuum pumps, drop disc relays to indicate excessive temperature on the rectifier cylinder, alarm bell connected to these relays, etc., are all mounted on the switchboard. This latter is insulated from earth and placed behind

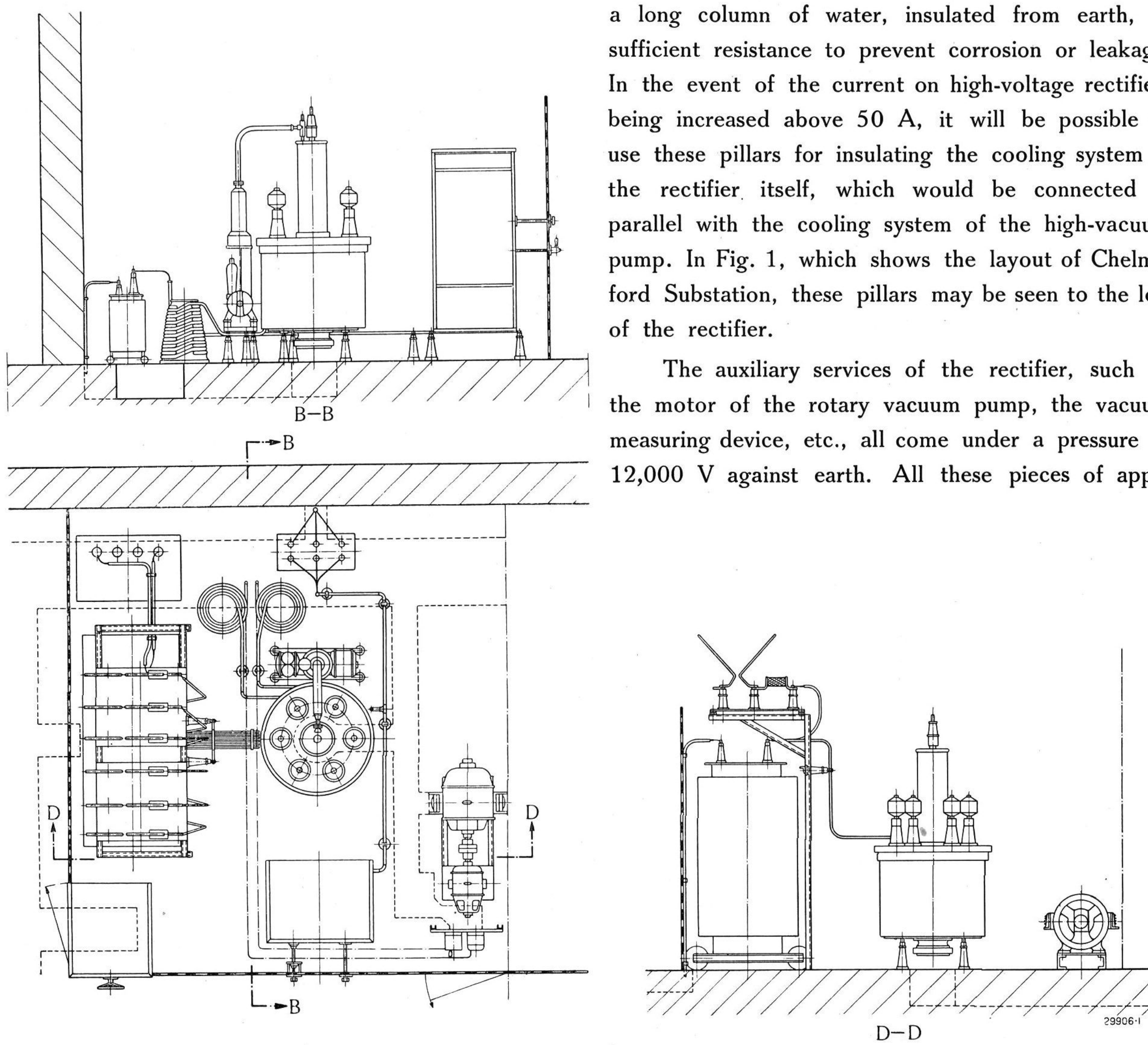


Fig. 1. — Layout of the high-voltage rectifier substation at Chelmsford.

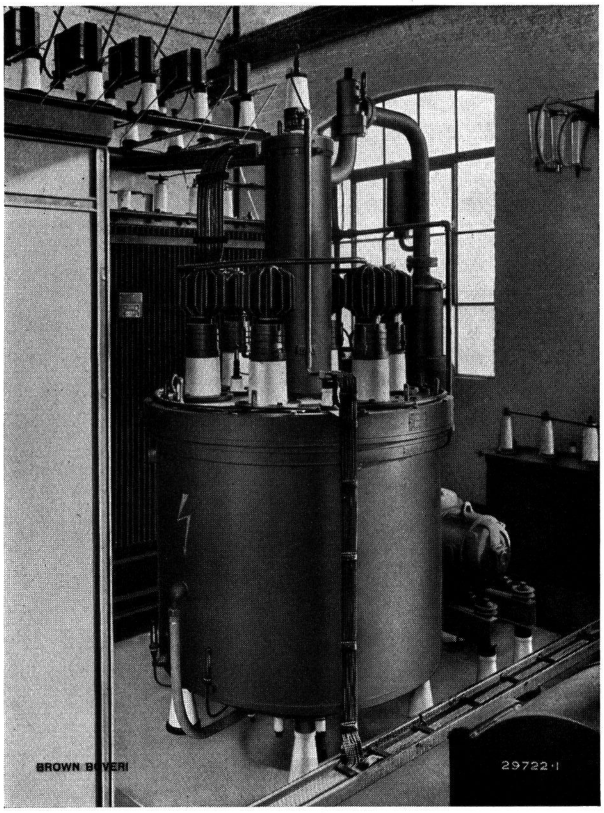


Fig. 2. — The high-voltage rectifier at Chelmsford.

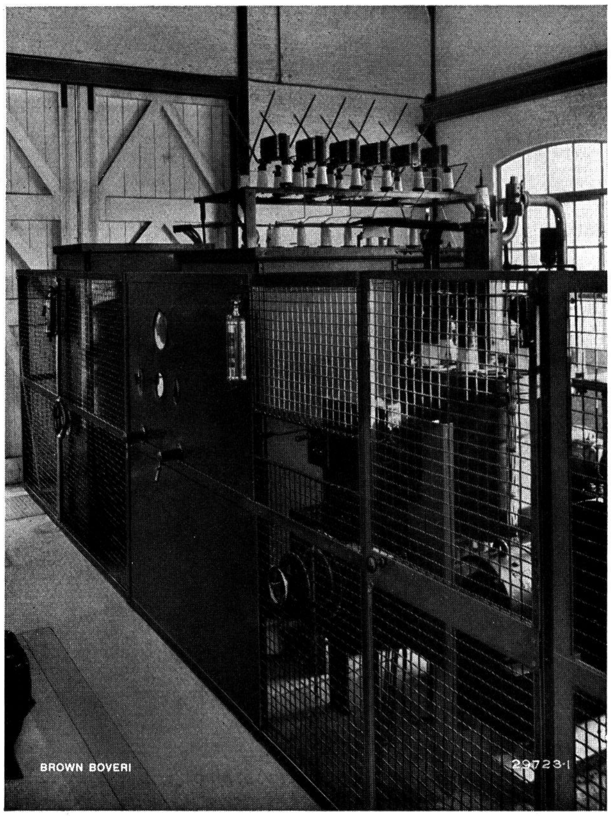


Fig. 3. — Switchgear of the plant. The rectifier can be seen in the background.

a protective screen in order to prevent any risk of persons coming into contact with it when reading the instruments.

The small motor generator set seen on the right of Fig. 1 is for obtaining a constant a. c. pressure of 220 V for the auxiliary services. In normal stations this set would not be necessary, as the auxiliary supply would be obtained from an auxiliary transformer connected to the constant primary voltage. In Chelmsford, the application of an auxiliary transformer is impossible, due to the variations in the primary supply voltage for test purposes. Figs. 2, 3, and 4 are photographs of the plant at Chelmsford.

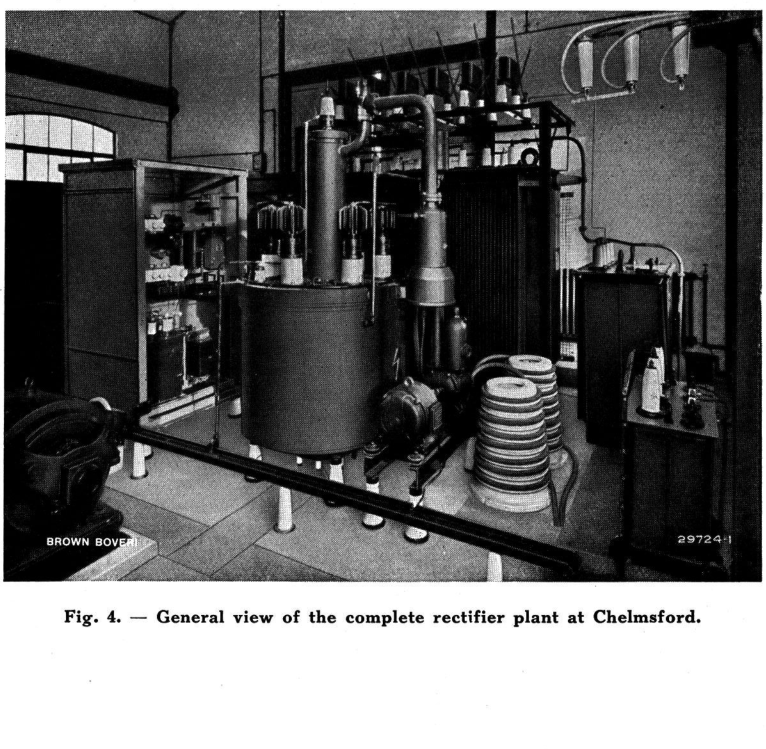


Fig. 4. — General view of the complete rectifier plant at Chelmsford.

The plant has proved conclusively that there are no insurmountable difficulties in applying mercury-arc rectifiers to d.-c. pressures above 10,000 V.

The new broadcasting station at Warsaw is to be equipped with two Brown Boveri rectifiers, each of which must be capable of giving an output of 500 kW at 10,000 to 15,000 V. As this is a very important station, two rectifier sets are provided, one of which acts as a complete stand-by for the other. The plant should be in operation by the autumn of this year.

(MS 604) *H. C. Beck.*

NOTES.

The new power plant of the Cía. Italo-Argentina de Electricidad, Buenos Aires.

Decimal index 621. 311 (82).

DUE to the rapid growth of Buenos Aires, a big increase in the demand for electricity has taken place, and as a result the Cía. Italo-Argentina de Electricidad decided to build a new power station.

In their Pedro Mendoza Power Station, the company already possessed a plant capable of developing about 100,000 kVA. This power station, completely equipped by Brown, Boveri & Co., contains seven turbo-alternator sets: three of 5000 kVA, two of 10,000 kVA, and two of 30,000 kVA each. These seven sets work in parallel on to a bus-bar system of 7000 V, at which pressure the current is distributed.

The new super power station will be built in three stages. During the first stage, three 37,600-kVA turbo-alternator sets will be installed. These have now been under construction several months. In order to meet future developments, as far as they can be judged at the present time, a 50,000-kVA turbo-alternator set will be installed during each of the successive stages. The pressure of 7000 V will not, however, be sufficient for the distribution of the large powers which will shortly be encountered. Each generator will therefore be connected up to a transformer for raising the pressure to 27,500 V. Transmission lines operating at this tension will be used for connecting the new power station to the main substations and also to the power station at Pedro-Mendoza. The elementary diagram of connections of the new 27,500-V plant is shown in Fig. 1. It has been decided to build two main substations, namely, "Estados Unidos" and "Tucuman". Both are situated in the town at about seven kilometres from the new power station.

The power station lies on the bank of the Río de la Plata, on ground reclaimed from the river. Building operations were commenced over a year ago. The water level in the Río de la Plata varies heavily according to the prevailing winds, but throughout its whole length the river is very shallow. In the vicinity of Buenos Aires, the solid ground suitable for supporting the foundations is only covered by a layer of clay, so that it is readily accessible for all kinds of harbour-building operations. The town of Buenos Aires has decided to extend its harbour to the north by continuing the promenades, some of which are already completed, along the river. The new plant, to be known as the "Nuevo-Puerto Power Station", will be built in this quarter. It will be directly accessible to vessels bringing fuel (coal and mazout), while a railway siding will enable material to be brought by rail. A detailed description of the power station will be published at a future date.

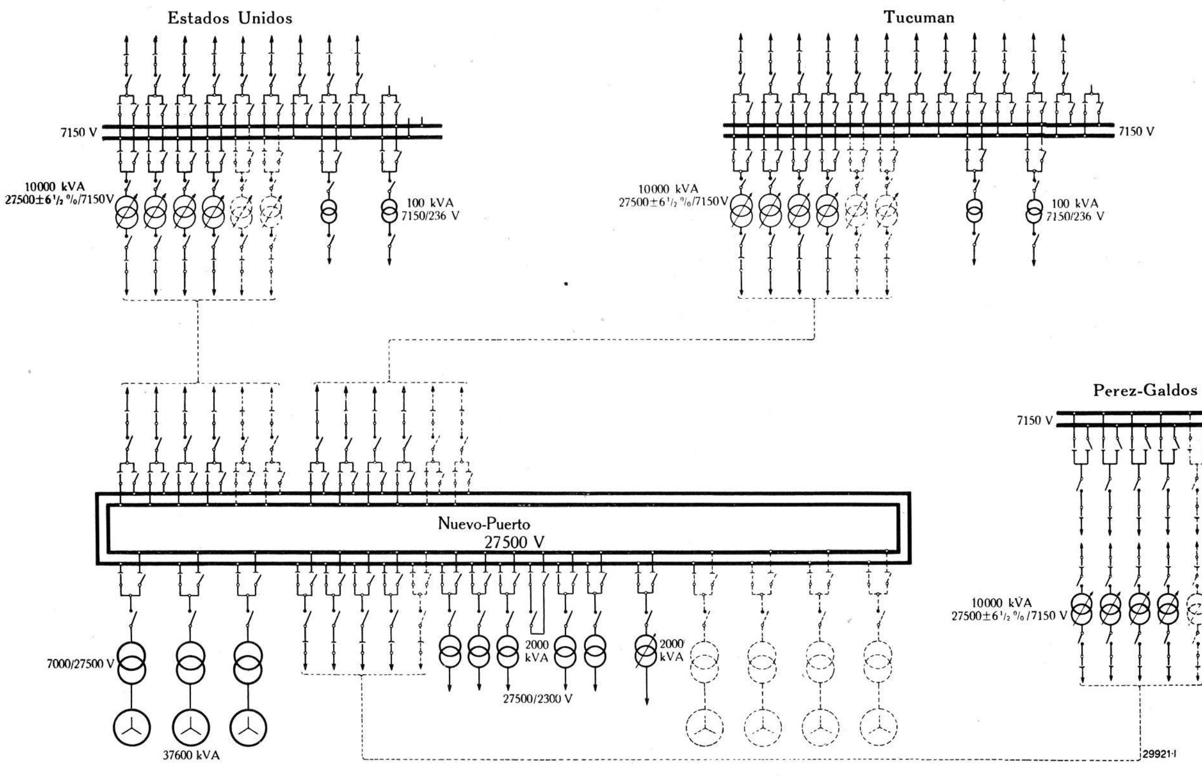


Fig. 1. — Cía. Italo-Argentina de Electricidad, Buenos Aires. Elementary diagram of connections of the new power plant.

Fig. 1 shows an elementary diagram of connections of the power station. The auxiliary services, although naturally of great importance, are not indicated, as this article is merely concerned with a brief description of the main features of the plant.

The bus-bars of Puerto-Nuevo Power Station form those of the whole 27,500-V network, and are connected to the Tucuman and Estados Unidos substations through 10,000-kVA transformers equipped with tapping switches. These transformers step down the pressure to 7000 V for feeding the existing network and the one which it is intended to build.

Both power stations — Puerto-Nuevo and Pedro-Mendoza — are connected through similar 10,000-kVA transformers with tapping switches. The voltage must be kept constant at the bus-bars of Puerto-Nuevo station, while the tapping transformers in the various substations enable it to be regulated according to the loading at various times of the day.

Briefly, the plant to be installed during the first stage is as follows: —

(1) *Nuevo-Puerto Super Power Station.*

3 turbo-alternator sets, each of 37,600 kVA, 7000 V, 3000 r. p. m., and each with a 7000/27,500-V transformer of equal rating. All the 27,500-V bus-bars have already been provided, so that no interruption of the service will be occasioned when the 50,000-kVA sets are installed subsequently.

Eight 27,500-V, 200-A outgoing lines, four to Estados Unidos substation, and four to Tucuman substation. Four 27,500-V outgoing lines for connecting the Nuevo-Puerto and Pedro-Mendoza power stations.

All the auxiliary services at 2300 V, 440—225 V alternating current, 225 V direct current.

One cable-testing device for the 27,500-V cables.

The control room for the whole power station.

(2) *Estados Unidos Substation.*

4 tapping transformers, each of 10,000 kVA, 27,500 $\pm$ 6·5 %/7150 V with complete equipment.

25 outgoing lines operating at 7150 V for feeding the town mains.

The auxiliary services comprising two 7150/236-V transformers, and the appropriate low-tension distribution plant.

(3) *Tucuman Substation.*

This installation will be identical with Estados Unidos Substation, except that 30 outgoing lines are provided for in the first stage instead of 25.

(4) *The Perez-Galdos coupling station.*

4 tapping transformers, each of 10,000 kVA, 27,500 $\pm$ 6·5 %/7150 V, with complete equipment.

4 cables of 7150 V connecting up with Pedro-Mendoza Power Station.

When the super power station has been put into service, it is very probable that the Pedro-Mendoza one will be used only as a stand-by. The 7000-V network which it previously supplied will then be fed by the Nuevo-Puerto plant.

(5) *Transformers.*

As already indicated, three 37,600-kVA transformers will be installed in Nuevo-Puerto Power Station. The three other stations will be equipped altogether with twelve similar transformers, each of 10,000 kVA. The ratio of transformation has been chosen so that the voltage drop in the network and transformers is taken into consideration, alike whether the transformers are used for stepping the voltage up or down. This is necessary because at first the 27,500-V network will be fed from Pedro-Mendoza.

All the 10,000-kVA transformers are equipped with remote-controlled tapping switches. During the first stage these tapping switches will be connected in groups of four, each group being controlled by a single switch. To prevent the differences in voltage being too great when changing from one tapping to the next, the three phases are switched separately, one after the other, so that the individual changes in voltage are only equal to one third the voltage difference if all three phases were switched simultaneously.

The 37,600-kVA transformers have external oil cooling, while those of the 10,000-kVA type have natural cooling.

(6) *Over-current protection.*

Each generator-transformer set is provided with differential-relay protection against short circuits between phases and faults to earth, as the neutral points of the generators, and also the high-tension sides of the transformers, are earthed through resistances. In addition, the generators are equipped with three-phase over-current relays and current-limiting regulators.

As a protection against short circuits in the 27,500-V and 7000-V networks, all the outgoing lines are equipped with selective relays. Since the neutral point on the high-tension side is earthed, one selective relay per phase is required. On the 7150-V side, however, two relays per three-phase feeder suffice, as the neutral point is insulated. The introduction of selective protection requires that this shall be provided throughout the whole network, and thus calls for a careful study of the network conditions; this is now being carried out.

(7) *Control room.*

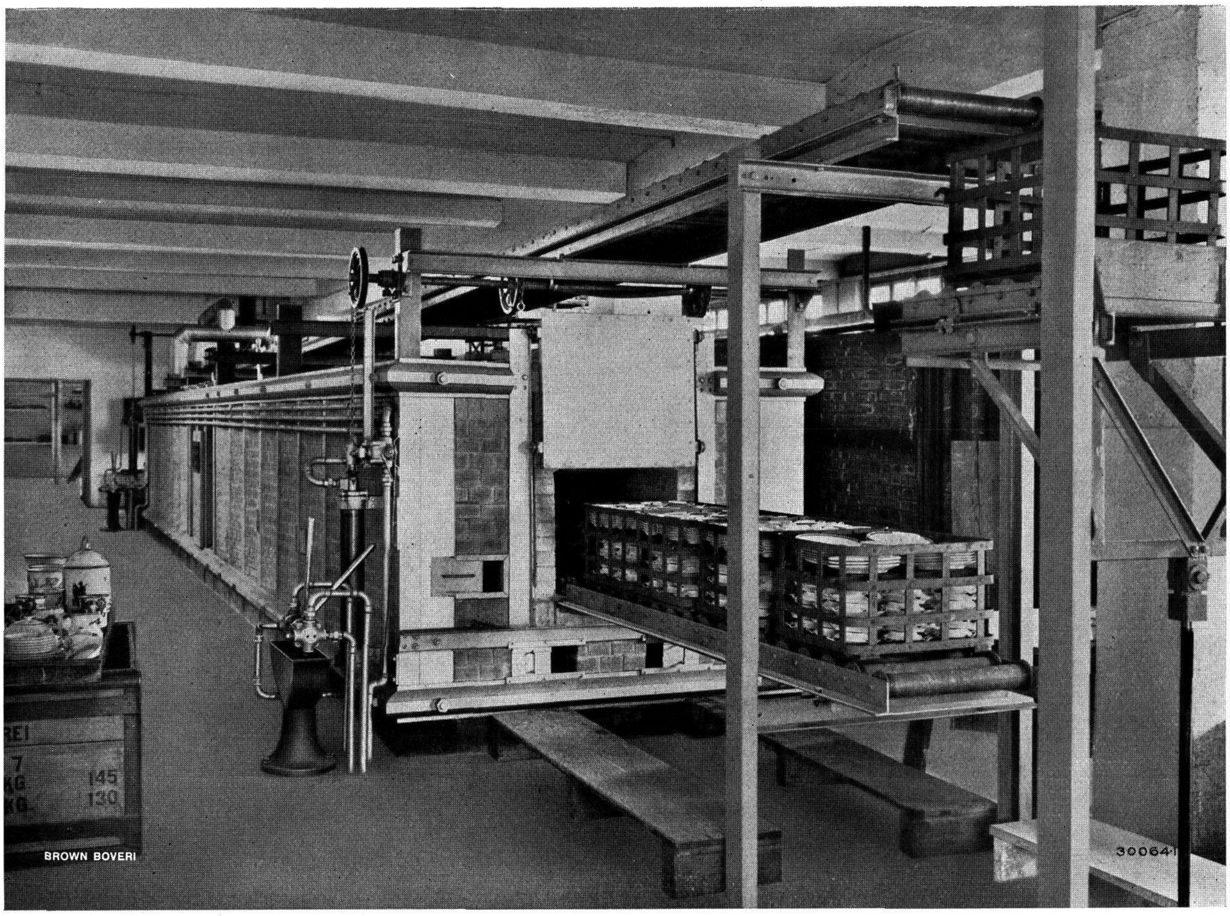
In view of the great importance of the new installations, very particular attention was paid to the design of the control rooms of the power stations and substations.

The Cía. Italo-Argentina de Electricidad, one of the largest power supply companies in South America, desired that the control rooms should be equipped on the most modern lines. The type of control equipment, incorporating the safety switching supervisor developed by Brown, Boveri & Co. within the last few years, has therefore been installed. This system has the great advantage of showing in the control rooms in a simple and reliable manner the condition of the network and also, at the same time, the voltage and loading of all the parts of the network. The most important feature of a protective system is that it should positively prevent incorrect switching operations from being made. The effects throughout the network which will be produced by any operation made from the control room are automatically tested before the operation is carried out. Should the operation be such as to cause an alteration in the voltage in the network, this is indicated in a clear manner in the light diagrams. By means of an interlocking system which works compulsorily, only those operations can be made which are entirely permissible, i. e., which are without danger to the plant.

The light diagram in the control room of Puerto-Nuevo Power Station contains not only the diagram of connections of the station, but also of the whole 27,500-V network, the positions occupied by all the oil circuit breakers and isolating switches in this part being automatically signalled. In the control rooms of the Estados Unidos and Tucuman substations, however, only the positions of the circuit breakers of the feeders are signalled.

It is intended to put the new plant into service in the autumn of 1931.

(MS 611) *R. Decoppet. (E. J. B.)*

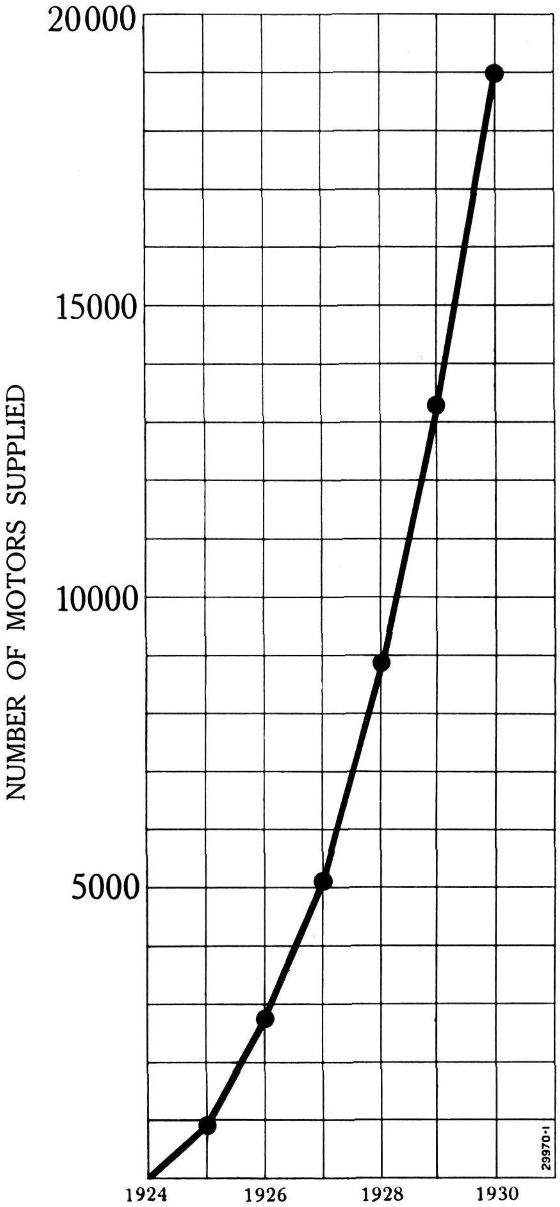


Porzellanfabrik Langenthal A. G., Langenthal (Switzerland). Furnace for burning the decorations on to porcelain.
Power consumption 130 kW. Overall length of furnace 14 metres. Length of heating space 2 metres. Capacity 3 to 4 tons of porcelain per 24 hours.

Published by BROWN, BOVERI & COMPANY, LIMITED, BADEN (Switzerland). Printed by Kreis & Co., Basle, Switzerland.

37 000

MOTORS WITH CENTRIFUGAL STARTERS ARE NOW IN SERVICE.



MOTORS SUPPLIED BY OUR MUNCHENSTEIN WORKS

OF THESE

18 957

HAVE BEEN SUPPLIED BY OUR MUNCHENSTEIN WORKS

18 000

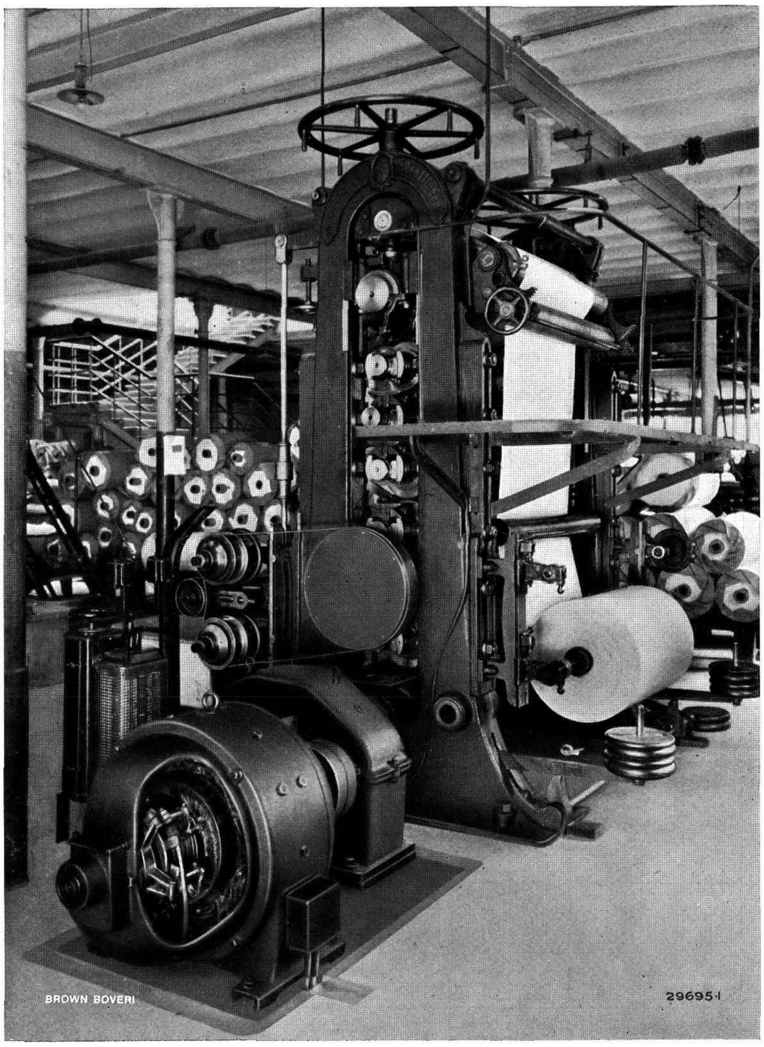
BY THE WORKS OF OUR CONCESSIONAIRES

QUOTATIONS AND DESCRIPTIVE MATTER ON REQUEST

BROWN, BOVERI & COMPANY
LIMITED
BADEN (SWITZERLAND)

WORKS: BADEN AND MUNCHENSTEIN (SWITZERLAND)

SPECIAL DRIVES



BIBERIST PAPER MILL, BIBERIST (SWITZERLAND).
Variable-speed direct-current motor driving an eight-roll calender through reduction gearing.
For feeding-through, the motor is connected to an auxiliary low-voltage supply.

CALENDER DRIVES