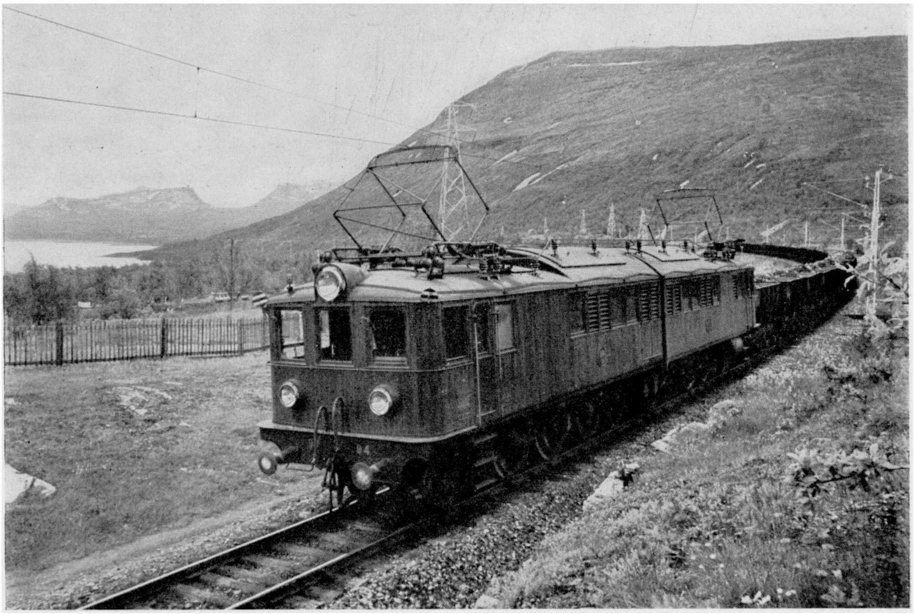
THE SWEDISH STATE RAILWAY ELECTRIFICATION



Ore train at Bjorkliden on the Kiruna—Riksgransen section of the Ore Railway.

CENTRALTRYCKERIET, STOCKHOLM 1933.

The Swedish State Railway Electrification.

The original object of electrifying the Swedish State Railways was to make them independent of foreign fuel. About 20 years ago it was, however, believed that the fuel obtainable from the Swedish woods and peat bogs would provide a valuable reserve for the railways, but the experience gained during the recent unsettled period showed that this assumption was not justified. The railway electrification, however, has proved to be not only an excellent method for utilizing the abundant supply of water power, but also a very good means for improving and increasing the railway service and consequently for competing favourably with other forms of transport.

On the map of Sweden shown in fig. 1 the heavy lines show the location of the parts of the Swedish State Railways that are to be electrified according to the present program. Of these railways in the northern part of the country the line Svartön—Riksgränsen — the Ore Railway — and in the southern part the lines Stockholm—Goteborg, Järna—Åby—Mjölby—Nassjo, Katrineholm—Aby, Orebro—Hallsberg—Mjolby, Falkoping—Nassjo, Malmo—Eslov and Arlov—Lomma were in electrical operation in May 1933.

The Swedish Parliament has further now also granted the necessary money for the electrification of the remaining lines on the program, thus lor the lines Nassjo—Eslov, Malmo—Tralleborg, Goteborg—Lomma, Angelholm—Halsingborg, Stockholm—Krylbo—Ange and Orebro—Krylbo.

In May 1933 there were thus 1 505 kilometres of State Railway-lines in electrical operation, and when at the end of 1936 all the lines now under construction are electrically operated, the total electrified length will be 2 705 kilometres corresponding to about 40 per cent of the whole system. These lines, however, have about 75 per cent of the total traffic in caraxle-kilometres. About 360 electric locomotives and 5 motor cars will be used for this traffic. The total cost of the electrification according to the present program amounts to about 240 millions Swedish kronor.

The question of different systems of railway electrification has been examined in Sweden on several occasions, but each time with the result that the single-phase system has been found preferable. The above mentioned railway elctrifications therefore are all constructed for low frequency single-phase current with 16 000 volts for the trolley-lines.

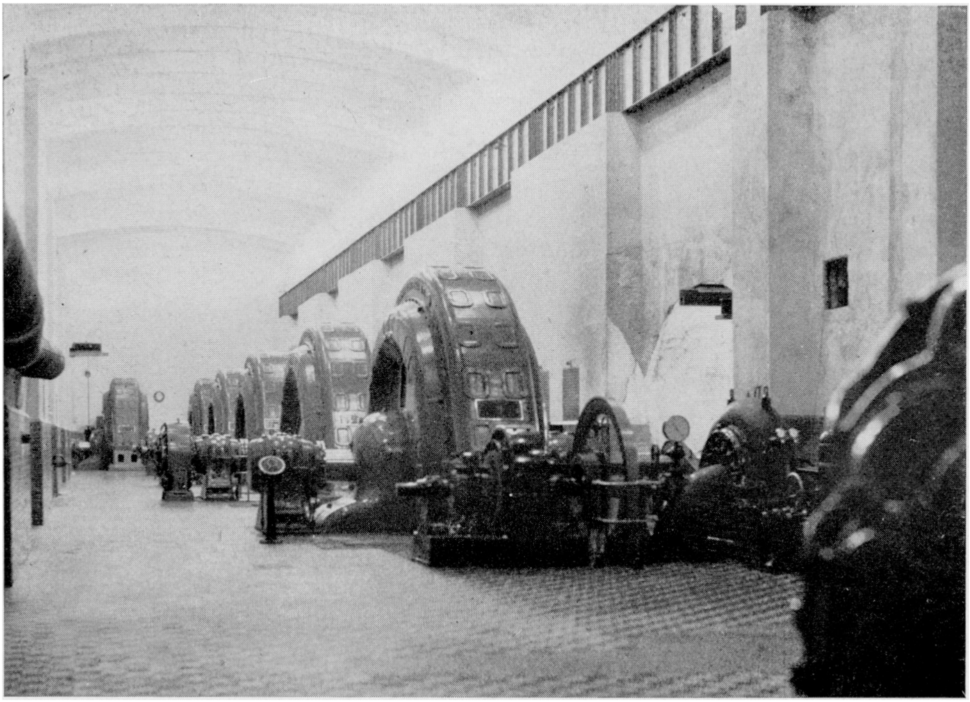
The problem of systems settled, several important questions remained, however, to be cleared up. Thus it was necessary to settle how best to produce the electrical power required for the electric operation, how to transmit it to the railways, and the measures to be taken in order to prevent interference with communication lines paralleling the railways.

The electric power required for the electrified Ore Railway is produced by separate generators in the Porjus power plant. It is generated as single-phase current at 4 000 volts and 15 cycles, which is stepped up by transformers to 80 000 volts and transmitted by transmission lines provided


Map showing the present state of the Swedish State Railway electrification
50 0 50 100 150
Km.
Jh operation-. The Ore railway Route Km 451
Stockholm (mfeborq 459
7n conilruclion: Stockholm Mo/mo 862
Stockholm -Anqe 617
Ooteborq -Ma/mo 316
Total route Km 2705
Power station
Converter station
Transtormer station
Varvii
Vgii/jour
Hundalen
Abisko
Tor net tösk
Kirunc
Lappberq
Risbäck
Gällivare
Porjus
Nuol-tikon
Polcirkrtn
Lakatraik
Grnin ijo i
loden
Notviken
Svartor
Luted
Sweden
Krångede
hojtfmartoneX
Finlan*7
Ånge
Llusc/at
Norwoi
Ockelbo
Morndat
Alvkarlel y
Kry/bo
Oppsatc
Oslo
Vp iteräs
StockJiolk n
Jrebro.
Svin und
Hallitberq™
Skildinqp
Soderfa/ji
Motala
Trollhättan
Moholr
Eksönd
Mjölby
Lilla Edet
y^Ahnqsas
Ooteborq
Nässjö
Varberq
Kanetor
Al vesta
Laholm
ben mark
Hauleholm
Malmo
Tralleborg

especially for the railway to 13 transformer stations located along the railway line, which has a total length inclusive of branch lines of 451 kilometres. The average distance between the transformer stations is 35 kilometres. In these transformer stations the voltage is reduced to the 16 000 volts required for the trolley-lines.

The electrical power required for the Stockholm—Goteborg railway electrification is taken from the State high voltage three-phase transmission lines for general power distribution, at five places, where these lines had been constructed previous to the railway electrification, viz., at Sodertiilje,

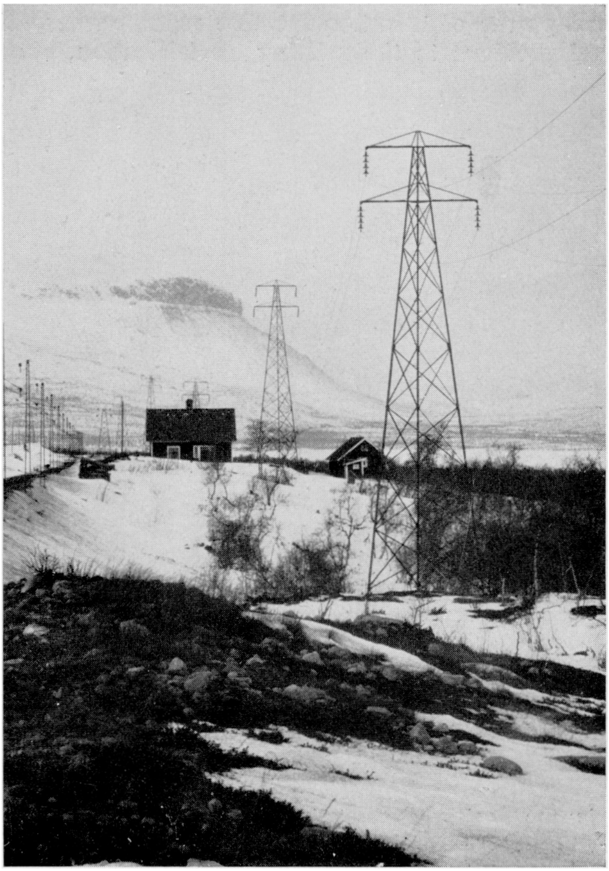


Generator room in the Porjus power station. The four generators in the middle of the picture are single-phase generators, the other two three-phase generators.

Skoldinge, Iiallsberg, Moholm and Alingsas (see fig. 1). Motor-generator stations were provided at these places, to change the available three-phase power to the low frequency single-phase 16 000 volts current required for the railway trolley lines. The single-phase current frequency of $16^2/_3$ cycles was selected in order to facilitate the conversion. The average distance between the places where the current is fed into the railway system — that is between the motor-generator stations — is in this instance 94 km, the maximum distance between two motor-generator stations being no less than 128 kilometres.

There are, therefore, considerable differences between the transmission systems for the electrifications of the Ore Railway and for the Stockholm—Goteborg line. In the former case, special generator equipment was constructed for the power plant, and special transmission lines and transformer stations erected in addition to the necessary trolley-lines. In the latter case, only motor-generator stations and the requisite trolley-lines were constructed.

The reasons for the differences between the two plants were due to the various technical possibilities at the time when the two plants were being built, in particular, the possibilities of preventing interference in communication lines parallel to the railway.

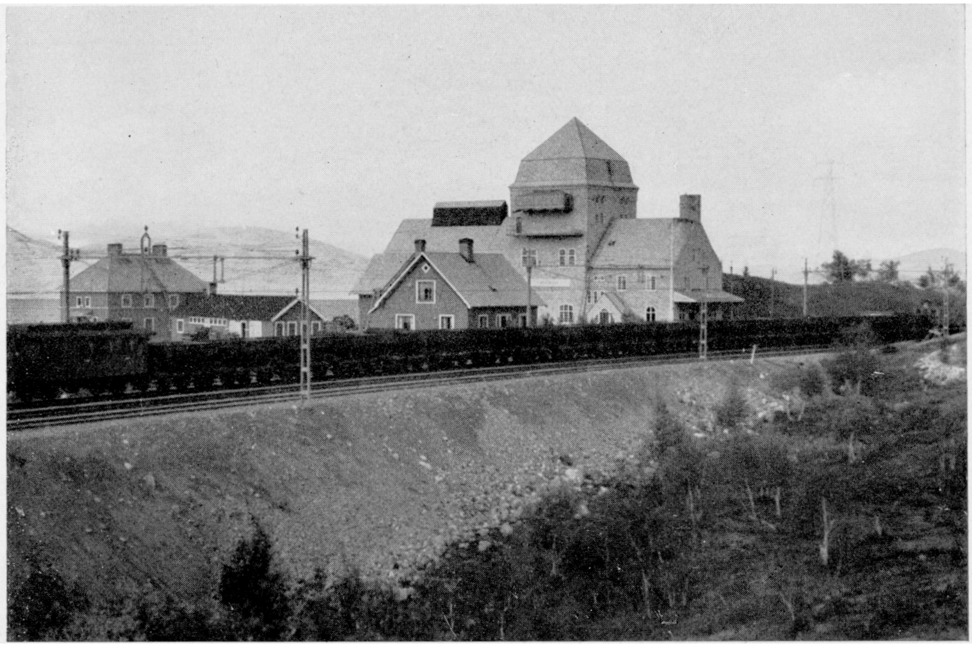


Transmission arrangement for the Ore Railway. The high tension transmission lines are for 80 000 volts.

This interference is due to voltages being produced in the communication conductors, either through (static) influence from the trolley-line voltage or through induction by the currents in the trolley-line. Interference due to (static) influence may be avoided simply by carrying the communication circuits in underground cables or by moving them 200 meters or more away from the railway. It may also be eliminated by providing some kind of static compensation. Induction interference can be avoided by means of some type of compensatory arrangements. The interference voltage due to induction may be considerably diminished by putting the communication circuits into underground cables, but it will not be entirely eliminated. If the lines are to be moved away from the railway for the purpose of avoiding inductive interference, they must be removed several kilometres, if satisfactory results are to be accomplished.

In general, there are no serious difficulties connected with the removal of communication lines, or with putting them into underground cables. Interference due to (static) influence can therefore be avoided with relatively little trouble. But the arrangements for compensating inductive interference had so far presented considerable difficulties, the more as it appeared that induction caused much larger interference voltages than had originally been anticipated.

Tests had shown that the inductive interference voltage is approximately proportional to the product of the length and the amperage of the inducing



Transformer station at the Tornetriisk station on the Ore Railway.

trolley-line section, hence, the number of ampere-kilometres. Thus on the original communication circuits, which were placed about 15 m from the Ore Railway track, interference voltages of from 4 to 10 volts per 100 ampkm have been measured. The variations in the interference voltage depend upon variations in the intermediate resistance between the rails and the earth and upon the earth resistance. The lowest interference voltage has thus been found on the Abisko—Vassijaure section of the Ore Railway, where intermediate as well as earth resistances are very high.

If the conductivity of the rails is improved, for instance, by inserting copper bonds at the rail joints, the interference voltage will be diminished. On single tracks of 40 kg rails, an interference voltage of 8 volts per 100 ampkm may as a rule be expected where rail-bonds are not employed and 6 volts per 100 ampkm, when copper rail-bonds are installed. On double

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tracks of 40 kg rails provided with copper rail-bonds, there may, as a rule, be expected an interference voltage of 4 volts per 100 ampkm. The interference voltage in underground cables may in case of double tracks provided with copper rail-bonds be expected to be 2.5 volts per 100 ampkm.

The number of ampere-kilometres may for Swedish traffic conditions amount to 20 000 per inducing section that is 400 amp. on a 50 km long

Transformer station at the Polcirkeln station on the Ore Railway.

stretch. This is consequently capable of causing an interference voltage of 1 600 volts. An interference voltage of 500 volts would occur even in case of underground cable next to double track railways provided with copper rail-bonds. Some sort of compensation was therefore essential.

The compensatory arrangement shown in fig. 2 was originally used on the Ore railway. This arrangement is designed to give compensation for inductive interference, by feeding from two sides. According to tests made, complete compensation was in this case generally obtained, when the voltage at the two trolley-line feeding points—the transformer stations—was exactly the same, say 16 000 volts at both places. But for obvious reasons this is rarely the case. Voltage drops occur in the transmission lines and in the sub-station transformers, resulting in a certain voltage difference

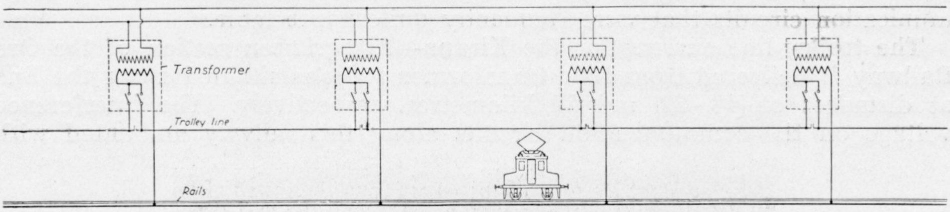


Fig. 2.

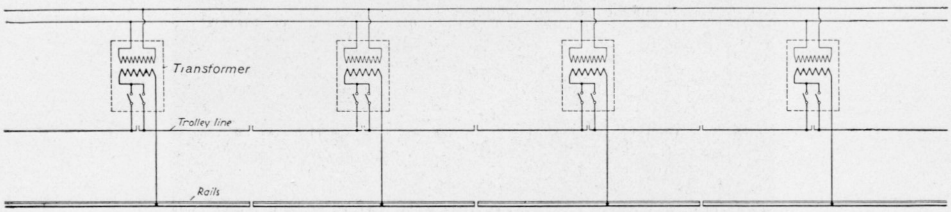


Fig. 3.

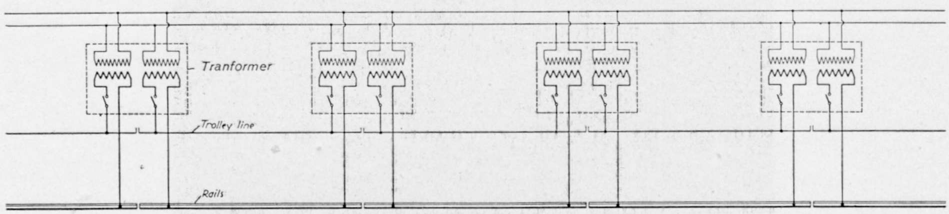


Fig. 4.

Fig. 5.

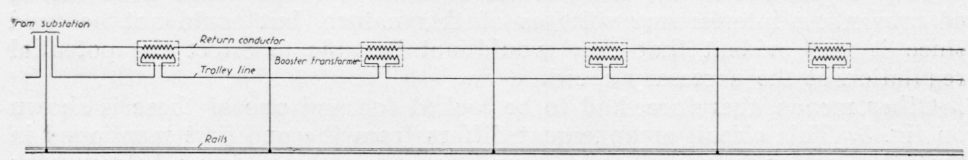


Fig. 6.

between the feeding points. This produces currents tending to establish equilibrium, which again give rise to interference effects in the communication circuits that were frequently quite appreciable.

The trolley-line current for the Kiruna—Riksgransen section of the Ore Railway is delivered from four transformer stations situated along the line at distances of 48, 32 and 29 kilometres, respectively. The interference voltage on the communication circuits along this railway amounted with

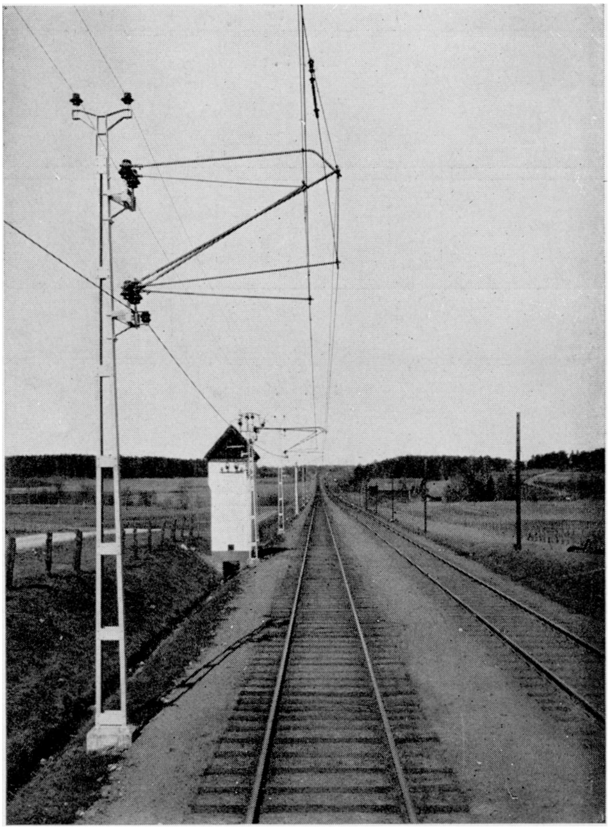


Fig 7. For the Stockholm—Goteborg line the booster transformers were arranged in small buildings as shown above.

the original circuit arrangement according to fig. 2, to 500 volts in the maximum for normal traffic and to 2 000 volts in case of short circuit. Voltage regulators in the transformer stations were proposed as a means of preventing interference voltages of this nature, but could not be used since it was evident that they would not be able to effect the potential regulation at the necessary speed.

Other means, therefore, had to be looked for and one of these is shown on fig. 3. This circuit arrangement differs from the one first mentioned in that the trolley-lines are divided up approximately midway between the transformer stations. Thus, there is in this case no compensation by twosided feeding in the ordinary sense, but the system works so that certain interference sections induce in one direction and others in the opposite direction, which, to a certain degree acts as a compensation. Much better conditions as to interference voltages in the communication circuits have by this arrangement been obtained on the Kiruna—Riksgränsen line. A maximum of 300 volts was produced with normal traffic of approximately the same volume as before, the interference from short circuits being 1 400

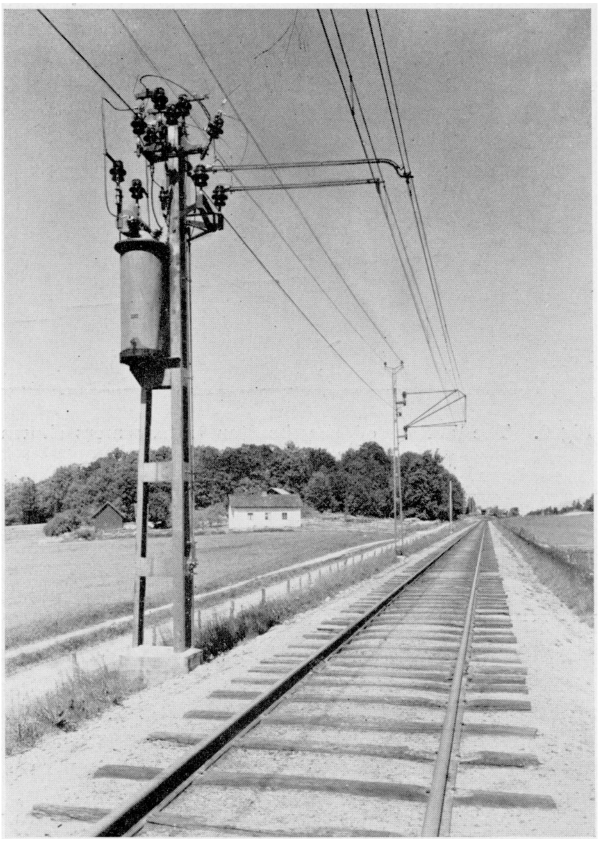


Fig. 8. For the Malmö lines and for the further electri fications the booster transformers are put on the poles as shown in this figure.

volts at the most. Obviously the division of the lines in this way also gives considerably safer operation, since a defective portion of the trolley-line can be cut out of service automatically by very simple arrangements, and consequently the defect located rapidly. But at the same time it is evident that this arrangement, also, gives no fully satisfactory results.

In order to obtain results satisfactory in this respect, the arrangement indicated by fig. 4 has been used. In this, the so-called Island-system, the distance between the transformer stations is made small, about 16 kilometres, to insure a low voltage drop in the transmission line, and in addition separate transformers are provided in the stations for each outgoing feeder to the trolley-line system. This is reported to have given entirely satisfactory results as to interference voltage in the communication lines, but the arrangement evidently entails considerable expense, and for that reason can be used in exceptional cases only.

To keep initial capital expenditure down, it is obviously of the greatest importance to reduce the number of transformer stations as much as possible, and other means, therefore, had to be found. The booster-transformer opens such a way. It consists of a series-transformer with two approximately identical windings, but made so large that its iron-core does not become saturated until there is a voltage of 500—1 000 volts on each of Ihe windings. The booster-transformers, that have been used on the Swedish State Railways, were originally provided with a compensating device for the magnetizing current, the number of turns in the two wind-

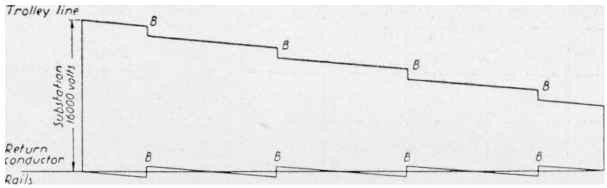
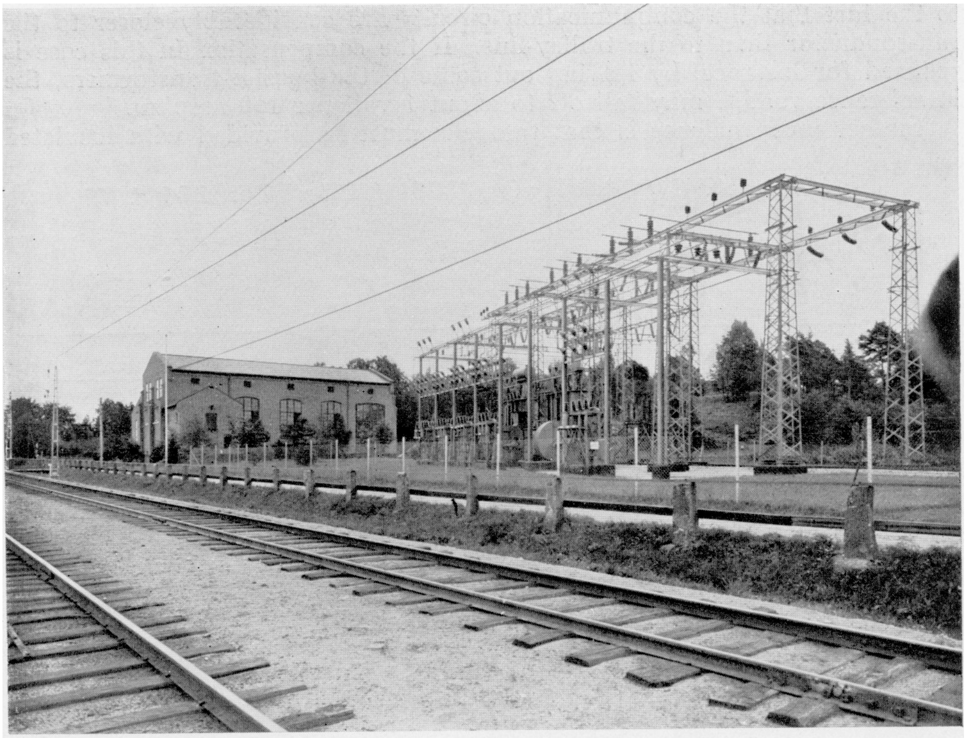


Fig 9. The action of the booster transformers shown graphically.

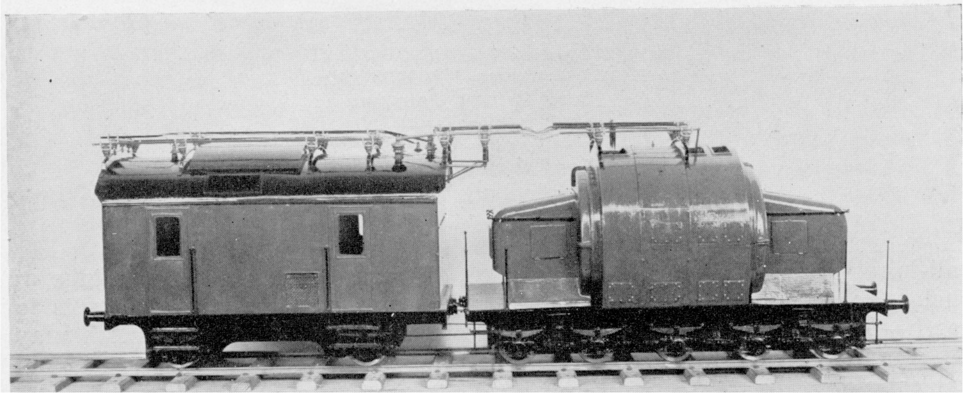
ings thereby differing by about 2 per cent. Later constructions of booster-transformers have been made with exactly the same number of turns in both windings, and the magnetizing current has been made as low as possible by using suitable transformer sheet for the cores. The magnetizing current in such cases amounts only to 0.2 per cent of the normal working current.

Booster-transformers arranged according to fig. 5 are now used on the Ore Railway. As shown by fig. 5 one of the windings of these transformers is connected in series with the trolley-line, the other in series with the rails. This reduced the interference voltage considerably, but the effect depended to a large extent upon the fact that the intermediate resistance between rails and earth was comparatively large. In the communication lines 50 metres from the railway, the induced interference voltage could in this case be brought down to 0.2 volt per 100 ampkm. The interference voltage for a section would thus be 40 volts for 20 000 ampkm, which nevertheless was considered too high. In order to lower the interference voltage to the desired degree it had therefore in this case to be stipulated that the distance between the transformer stations should be no more than 30 or maximum 40 km, which reduces the length of the feeding sections to 15 or maximum 20 kilometres, and the interference voltage in the communication lines to 12 volts per inducing section.

This arrangement of the booster-transformers, however, also entails a number of inconveniences. If, for example, the communication circuits are to be placed in cables in the roadbed, they will get an interference voltage which according to experience may amount to 2 volts per 100 ampkm, due



Transformer and motor-generator station at Alingsås. Exterior view.

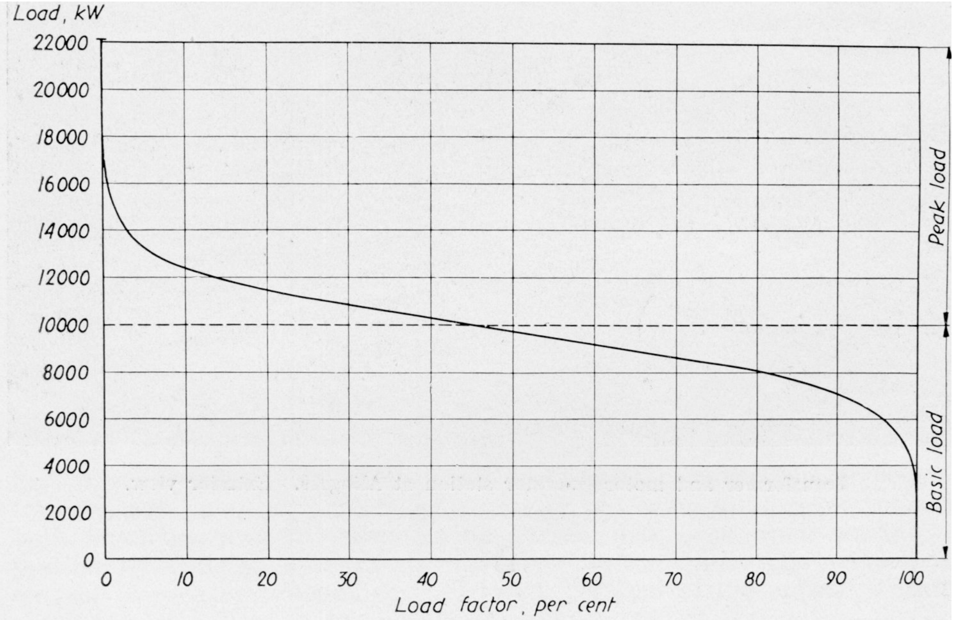


Transportable motor-generator and transportable transformer with switch gear for the new motor-generator stations.

to the fact that the communication circuits are considerably closer to the rail-conductor than to the trolley-line. If the compensation in this case is reduced for instance, by leaving out some of the booster-transformers, the interference voltage may fall off to about 1 volt per 100 ampkm.

Another inconvenience is that the rails must be provided with insulated

LOAD CURVE FOR 1932 OF STOCKHOLM - GOTEBORG LINE



Tola/ load - 22100 kW
, energy- 85000000 kWh
Load factor- ˆˆ per cent
Basic load - 10000 kW
. energy- 79000000kWh
Load foelor • 90 per cenl
Peak load -- 12100 kW
•• energy •= 6 000 000 kWh
Load factor- 5n per cenl

Fig. 10.

rail-joints where the track transformers are connected up. The voltage at such places will usually amount to a maximum of 60 volts—+30 volts to earth—but in case of short circuits, voltages of 500 volts and more may occur and these are capable of causing trouble in communication or signal cables laid in the road-bed. The connection between the track transformers and the rails may, moreover, be severed by exterior causes, whereby relatively high voltages are produced in the ground, which according to experience may also have harmful effects on communication and signal circuits in cables at this place. Furthermore, the insulated rail joints may be easily short-circuited by the steel wires used for signals or by spikes wrongly driven in or even as a result of the lengthwise expansion of the rails in warm weather, which may squeeze the insulating material between the railends to pieces. Evidently, in each of these events the track transformers will be short-circuited and their compensatory effect destroyed. Insulated rail-joints are therefore not practicable, and are to be avoided wherever possible.

Ordinarily the intermediate resistance between rails and earth on the Stockholm—Goteborg line w^Tas only one fifth of that on the Ore Railway. An arrangement of track transformers there, such as was used on the Ore Railway would, therefore, not as a rule have had the required effect. Another consideration was that the communication circuits of the Stockholm—Goteborg line were to be put into cables in the road-bed and that the State Telegraph Hoard owned a great number of telegraph lines with earth return along this railway, the conversion of which to metallic circuits would have entailed consideiable expenditure. If these were to remain as earth return circuits, the total interference voltage would have to be reduced to 15—20 volts.

When electrification work was to be started in 1920 on the Stockholm—Goteborg line, another condition was imposed, namely, that it was desired that the electrical power for the railway electrification should be tapped from the State three-phase general power distributing system, which had already been built along this railway line. For reasons of economy this would not have been possible, if the distance between the railway feeding points had to be limited as before to 30—40 kilometres.

During the period from 1920 to 1923, however, progressive research work had been undertaken. This had shown that the problem of preventing interference was capable of a much better solution than hitherto thought feasible. It had, moreover, been possible to test the new system in practice, whereby very good results were obtained. The electrification of the Stockholm—Goteborg railway could therefore be undertaken on the basis of a much larger distance between the feeding points, making it possible to utilize the existing three-phase system for supplying the required electric power, with economically satisfactory results. The distance between the feeding points, as constituted by the motor-generator stations, constructed for that purpose, was then as mentioned before, 128 km at the most.

The circuit arrangement, which has made this possible, is to be seen in fig. 6. It will appear from this diagram that this arrangement provides for an insulated return-conductor, which acts as a compensatory line to offset the inductive effects of the current in the trolley-line. It has, for that reason, been placed on the trolley-line poles in a suitable position, and it carries a current which is practically the same as that in the trolley-!ine. Suitable constructed booster-transformers, fig. 7 and 8, are inserted in the trolley and return-circuit at definite intervals in order to accomplish this effect, and the return-conductor is connected to the rails midway between these booster-transformers. In the beginning the distance between the booster-transformers was only about 1.4 kilometres, but now, since experience is available, it has been possible to increase this distance to about 5 kilometres.

This arrangement has given very satisfactory results. Ry carefully adjusting the position of the return conductor, the interference voltage produced in communication cables in the road-bed can in this case be brought down to 0.02 volt per 100 ampkm. Despite the fact that a close adjustment of the return-conductor for the whole line was regarded as practically superfluous, the interference in Ihe cable in the road-bed was found to be no more than 10—16 volts under normal operating conditions, and 47 volts

Fig. 11. Trolley-line construction for the latest electrifications.

in case of the most severe short-circuit. It has, therefore, been possible to use single wires in the railway cable for telegraphy with earth return, a fact which presents considerable advantages. Interference voltages of more than 0.5 volt under ordinary circumstances, or more than 3.6 volts in the most severe case of short-circuit, have not been observed on the Telegraph Board circuits, which are carried in and along the highways parallel to the railway.

The action of the booster-transformers is to transfer the voltage drop in the rails or the return conductor gradually to the trolley-line as graphically is represented by fig. 9.

The motor-generator system for purposes of railway electrification offers the advantage that short-circuits in the trolley-line system are not felt in the three-phase system, and that in case of short-circuit the current in the trolley-line can be kept at a relatively safe level, which makes it possible to make the booster-transformers of moderate sizes. The synchronous motors also are used for the purpose of voltage regulation in the three-phase system, which of course is another great advantage.

A 3-wire system at 32 000 volts was proposed for the trolley-lines, when

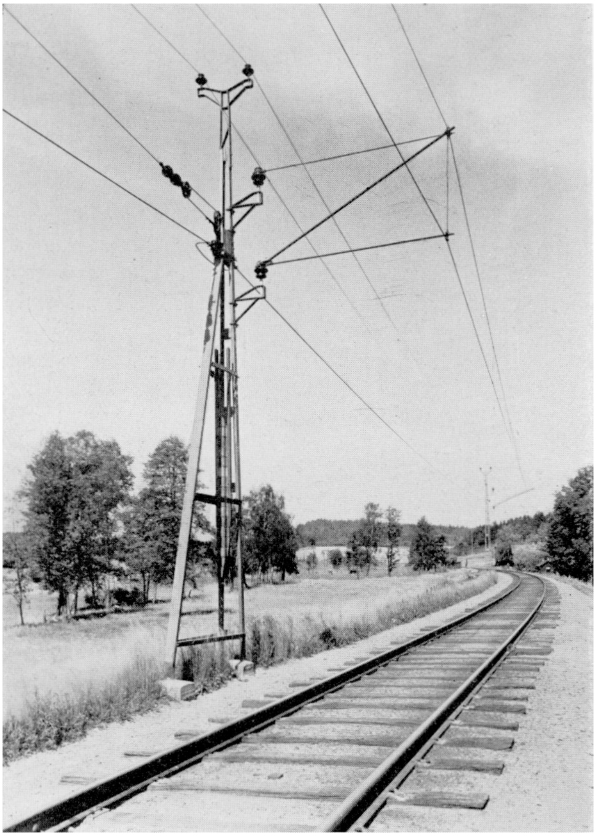
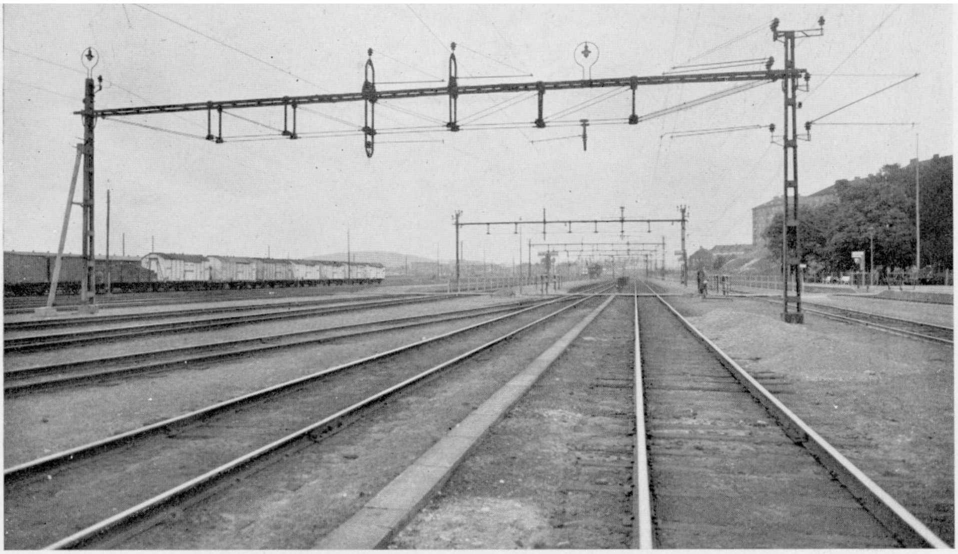


Fig. 12. Arrangement for keeping the mechanical tension in the trolley-line constant.

the electrification should be extended down to Malmo, but a careful study of this matter showed that such a system should have been much more complicated and not more economical than the simple transmission system already in use on the Stockholm—Goteborg line.

The circuit arrangement described above for the trolley-lines of the Stockholm—Goteborg line has thus proved to be eminently satisfactory, and will therefore be used for all future electrifications of the Swedish State Railways.

By thus arranging the power supply the State Railways are ordinary consumers of three-phase current from the general transmission system, and are therefore able to increase or decrease their consumption of energy according to the traffic conditions without having to take into consideration to such an extent the capacity of the generating plants and the size of transmission lines, as would have been necessary if the single-phase power had been separately generated. The equipment of the power plants for the three-phase distribution system has of course to be increased for this purpose, but not in proportion to the additional railway load, owing to the levelling of the load curve obtained by superimposing the railway load on the industrial load.



Arrangements for trolley lines in the yards.

The price that was at first asked for a supply was, however, comparatively high, in spite of the fact that the State Railways were very large consumers —the consumption for the electrification of the line Stockholm—Goteborg amounting to about 70 million kWh per year. For three-phase power, delivered at the five converter stations for this line at 6 300 volts, the figure was 3.75 ore (0.5 d.) per kWh. In order to reduce this figure, investigations were carried out to discover the ordinary market price of electric power used as it would be for railway operation. The load conditions of the railway operation were thereby also studied, and it was found that these were considerably more favourable than had hitherto been assumed. This was to a large extent due to the fact that it had been possible to change over most of the freight operation to night service on account of the increased speed of the freight trains. The price of power was subsequently discussed, and the following tariff was agreed upon:—

1) An annual charge, corresponding to the cost for transmission, of 740 000 kronor (£40 600), and, in addition,

2) An annual charge for contracted or basic load of kronor 97.50 (£5 7 s.) per kW (15 minutes' demand), and

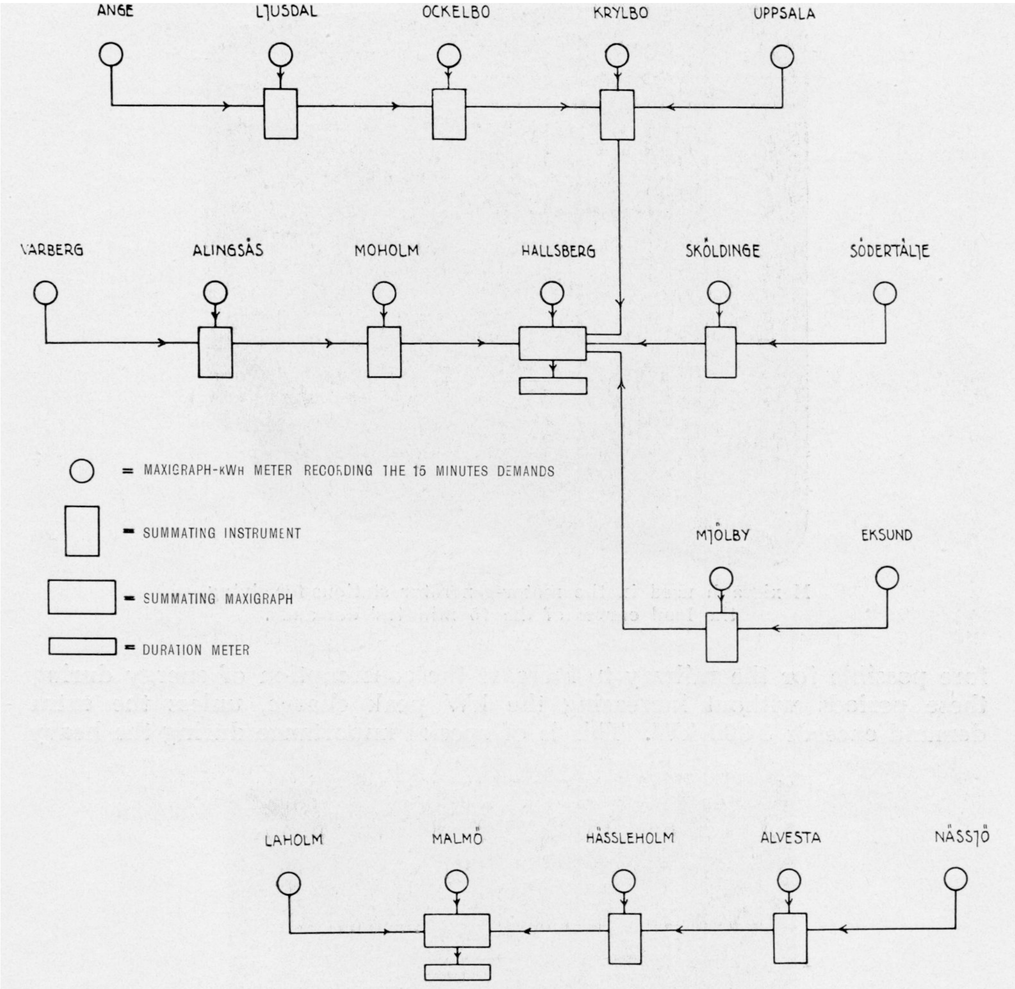
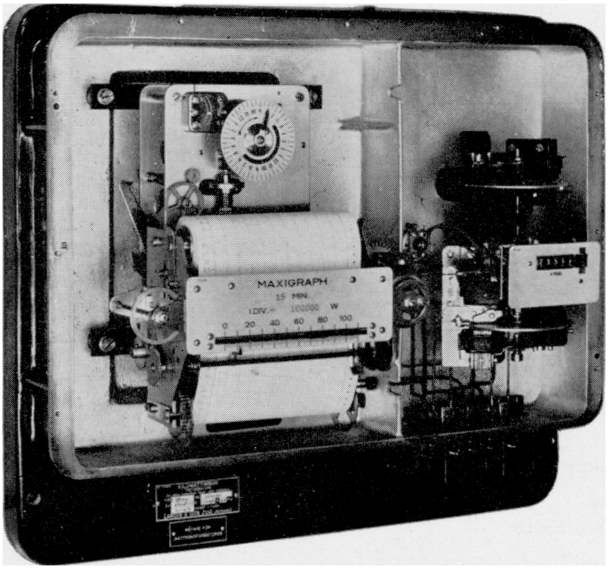


Fig. 13. Arrangement for summating the load of the motor-generator stations.

3) An annual charge for peak load above the contracted basic load of kronor 35 (£ 1 18 s. (5 d.) per kW, measured over 15 minutes by a maximum-demand meter, and, in addition, a charge for peak energy of 2.5 ore (0.33 d) per kWh.

In 1930 the first 9 000 kW were contracted for as basic load, and the rest of the 15 minutes' maximum demand was charged as peak load. The basic power can be increased or decreased, according to agreement with the suppliers, 6 months in advance. In 1931 it was 9 600 kW, in 1932 10 000 kW and in 1933 16 000 kW. The load curve for 1932, with all the 15-minutes' demands measured and plotted according to lengths »the duration curve» is shown in fig. 10.

On Sundays, holidays and during each night between 9 p. m. and 7 a. m. 3 000 kW is deducted from the maximum-demand reading, and it is there-



Maxigraph used in the motor-generator stations for giving the load curves of the 15 minutes' demands.

fore possible for the railway to increase the consumption of energy during these periods without increasing the kW peak charge, unless the extra demand exceeds 3 000 kW. This is of special importance during the heavy

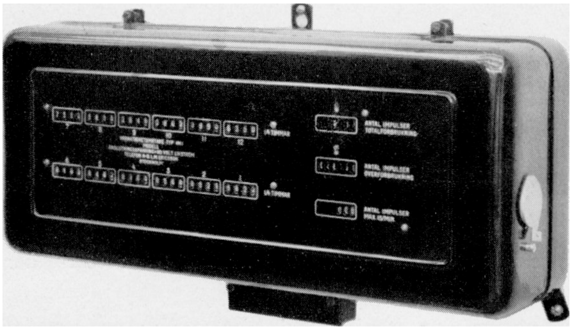
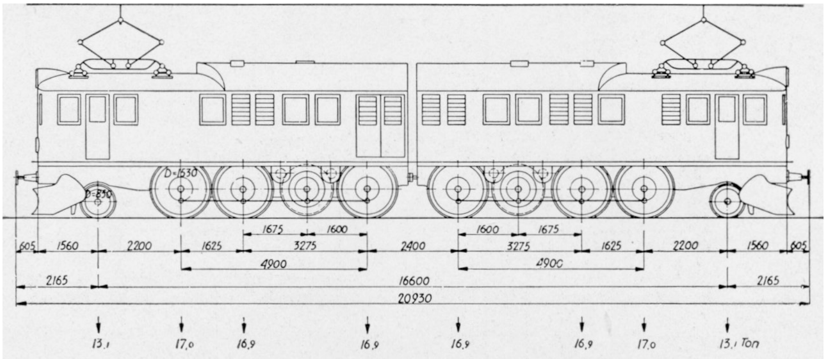


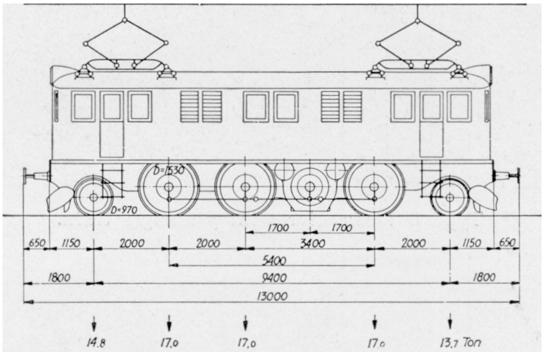
Fig. 14. Duration meter, used for summating the load of the motor-generator stations.

Christmas train service, and the new agreement has resulted in an average charge for the total consumption for the Stockholm—Goteborg line of 2.7 ore (0.36 d.) per kWh. Due to this reduction in the price of power the electrification has proved to be considerably more economical.

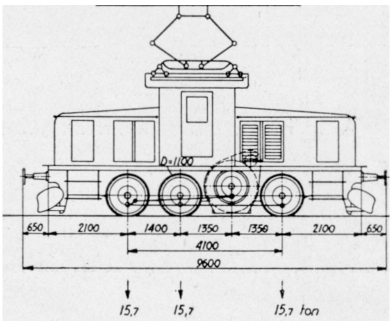
When the whole electrification program is completed the energy con-



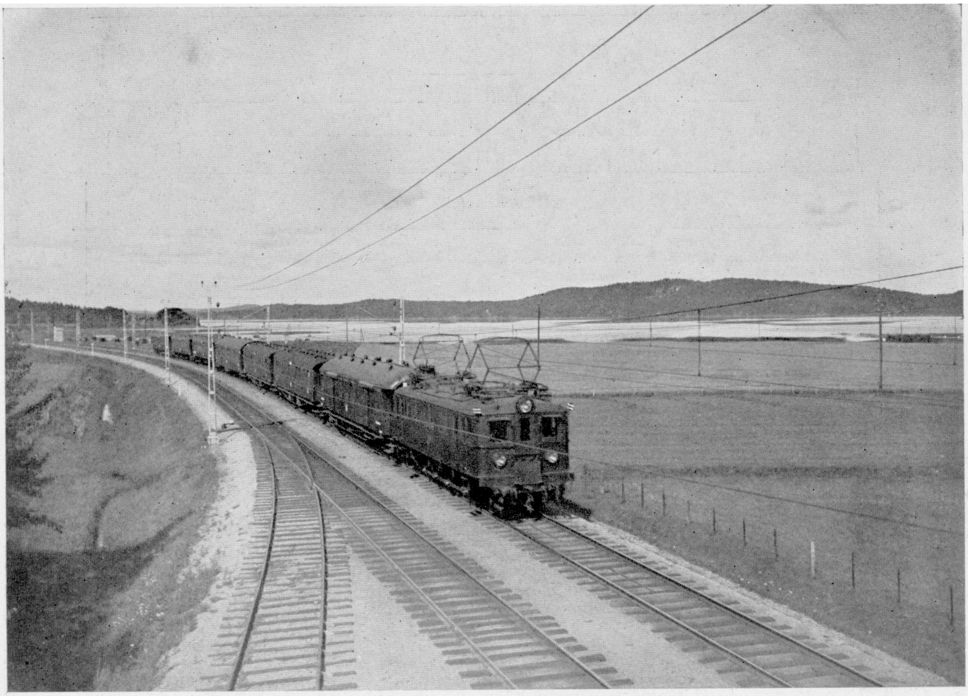
Locomotive type Ocf. Used for hauling ore trains weighing 1 900 tons, exclusive of locomotive. Weight of locomotive 127,**8** tons, horse-power 2 900. Maximum drawbar pull 30 tons, maximum speed 37 m. p. h. Number in operation 21. All dimensions in mm.



Locomotive type D. Used for hauling passenger trains weighing 550 tons, or freight trains weighing 900 tons, exclusive of locomotive. Weight of locomotive 79,5 tons, horse-power 1 660. Maximum drawbar pull 17 tons, maximum speed 60 and 45 m. p. h. respectively. Number in operation and under construction 235. All dimensions in mm.



Locomotive type Ub. Used for shunting service and local freight trains of a maximum weight of 600 tons, exclusive of locomotive. Weight of locomotive 47,1 tons, horse-power 700. Maximum drawbar pull 16 tons, maximum speed 28 m. p. h. Number in operation and under construction 45. All dimensions in mm.

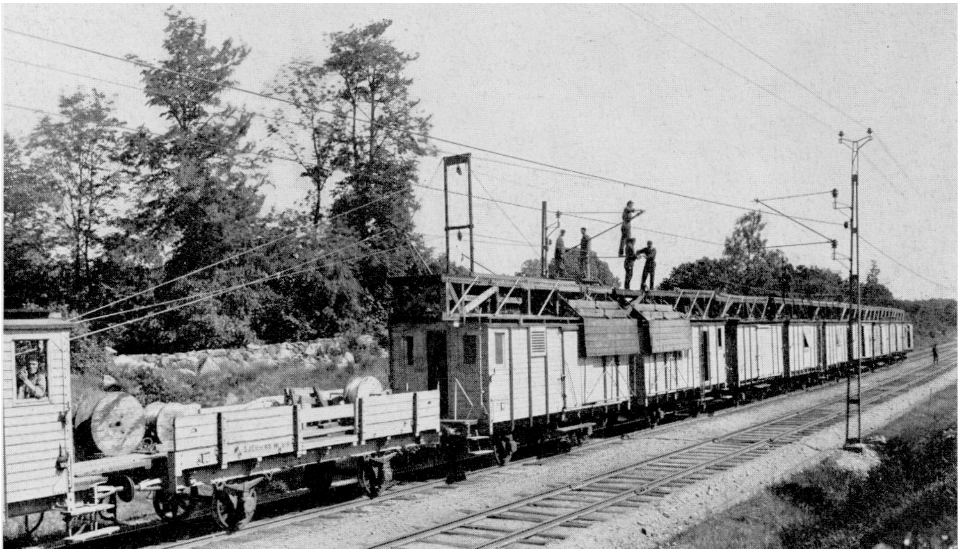


Type D locomotive with passenger train.

Type Ub shunting locomotive with train.

Arrangements and steel towers for the lighting of yards. Day-time.

Arrangements and steel towers for the lighting of yards. Night-time.



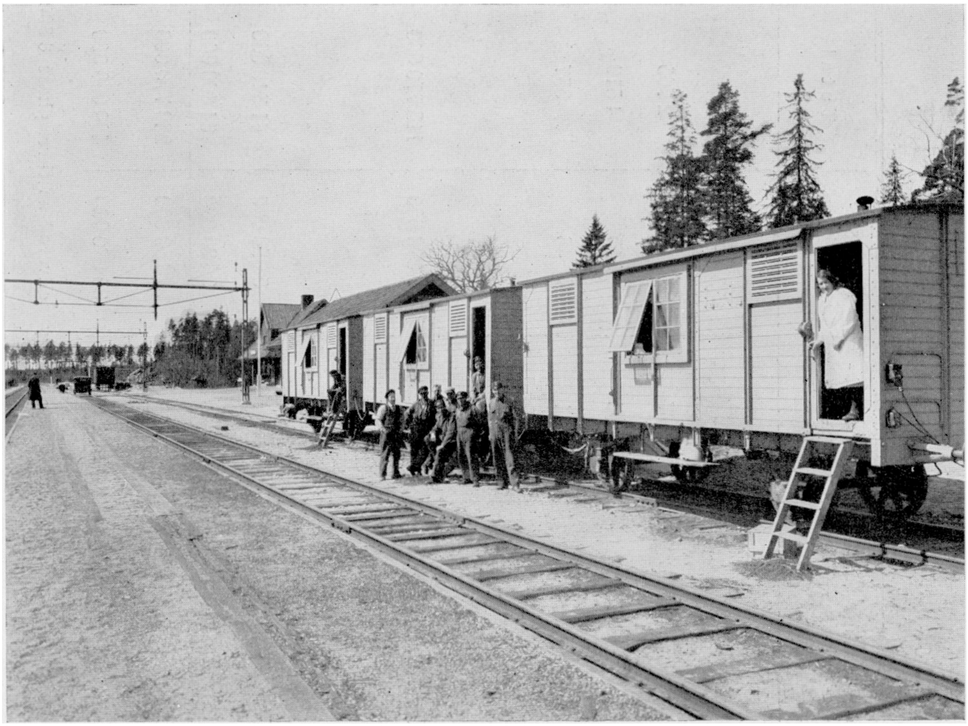
Erecting train for the trolley lines.

sumption will be increased to about 300 million kWh for all the lines south of Ange, and then the price of current will be decreased to about 2.1 ore (0.28 d.) per kWh.

The transmission plant of the Stockholm—Goteborg line has been constructed according to the experience gained on the Ore Railway and at other places, and arranged with a view to obtaining the greatest reliability of operation and the greatest possible reduction in cost of supervision and maintenance. Power for lighting, signals, and other purposes is also transmitted by a high-tension transmission line run along the top of the trolley-line poles. All stations and trackmen's houses receive their power from this line. The cost of this power has thus also been reduced.

The trolley-line is arranged as shown by fig. 11. The trolley-wire is 80 mm^2, and the catenary cable 50 mm^2, both of copper and both automatically kept under constant mechanical tension by weights. The return cable on the small insulators at the side is 130 mm^2. At the top of the poles there are the two 30 mm^2 copper wires for transmitting 50 cycle 10 000 volt single-phase power for lighting and other purposes. The arrangement for keeping the mechanical tension of the trolley-line constant is shown bv fig. 12.

For the electrification of the Stockholm—Goteborg line 5 motor-generator stations were erected, and when the further electrification now in construction is completed, the number of these stations will be increased to 18. Of these stations 13 will be supplied by the State Water Power Board and the



The home for the erecting crew.

5 in the southern part of the country by a private company, the Southern Power Company.

The motor-generator stations all receive three-phase energy with 50 cycles and in most cases 6 300 volts through underground cables from adjacent transformer stations. These are fed from the big three-phase transmission lines in the country, which have potentials of 50 000, 70 000, 130 000 and 220 000 volts.

The stations have each two or three motor-generators, each consisting of a 6 300 volts synchronous three-phase motor driving a synchronous single-phase generator, which delivers 3 000 volts at $16^2/_3$ cycles. On the single-phase side each motor-generator can continuously deliver 2 400 kVA, and can for short periods stand over-loads up to 6 000 kVA. The motor and the generator are both mounted on the same shaft with only two bearings, one at each end of the set. On the extreme ends of the shaft are mounted the two exiters for supplying the required magnetizing current.

In the stations there are also arranged single-phase transformers of sizes corresponding to the generators, which raise the single-phase voltage to 16 000. Circuit breakers and other apparatus for starting and operating the motor generators and for the outgoing feeders for the trolley-lines are placed along the walls in the station. The trolley-line sections are fed through underground cables except for the first constructed 5 stations. A switchboard is also arranged in the stations with all the apparatus and instruments that are necessary for the control and operation.

Table I.

The electrification of the Swedish State Railways.

	The Ore Railway	The Stockholm—Göteborg lines	The Stockholm—Malmö lines	The Stockholm—Ånge lines	The Göteborg—Malmö lines	Total
Electrified lines						
Construction years	1910—1922	1923—1926	1931—1933	1933—1935	1934—1936	
Electrified route-kilometres	451	459	862	617	316	2 705
» track-kilometres	599	880	1 590	935	515	4 519
Number of electric locomotives	62	64	104	81	46	357
Cost of electrification						
Transmission plants Swed. kronor	28 540 000	19 630 000	32 900 000	20 900 000	11 800 000	113 770 000
Alterations to telephone, telegraph, lighting, signals, tracks and bridges » »	1 380 000	10 230 000	13 200 000	10 900 000	5 630 000	41 340 000
Locomotives » »	20 700 000	14 740 000	21 800 000	17 700 000	9 720 000	84 660 000
Total Swed. kronor	50 620 000	44 600 000	67 900 000	49 500 000	27 150 000	239 770 000
Annual consumption, kWh	95 000 000[1]	75 000 000	125 000 000	70 000 000	35 000 000	400 000 000

[1] Delivered as single-phase 4 000 volts at the generators in the Porjus power plant. All other energy delivered as three-phase 6 300 volts at the substations.

Table II.

Traffic in train-kilometres and caraxle-kilometres for parts of the Swedish State Railways in 1933.

	Km	Train-km in 10^3 total	Train-km in 10^3 per route-km	Caraxle-km in 10^3 total	Caraxle-km in 10^3 per route-km	Caraxles per train
Total for all the State Railways	7 144,7	35 673	4,99	1 130 870	158,3	31,7
For those parts of the State Railways,						
1) that are to be steam-operated	4 439,7	13 299	2,99	277 029	62,4	20,8
2) that are to be electrified	2 705,0	22 374	8,27	853 841	315,6	38,2

All of the control gear for the converter stations is semi-automatic and operated from the switchboard by means of control-handles. The circuit breakers for the outgoing feeders to the trolley-lines are of the reclosing type, and operate with very high speed. They thus break a short-circuit automatically in half a cycle (a 33rd of a second) and then again close the circuit after 30 seconds, if the short circuit is away. If that is not the case, the circuit breaker makes another attempt after 3 minutes, and if it fails even then an alarm signal is given to indicate to the station operator that the case has to be investigated.

The 7 motor-generator stations, that will now be constructed at the lines Stockholm—Ange and Goteborg—Malmo, will be arranged with transportable motor-generators, transformers and starters, whereby many advantages will be obtained.

To measure the sum of the supplied energy to all these stations has been quite a problem, which, however, also has been solved in a very satisfactory manner. The motor-generator stations are for this purpose connected together by a pair of signal wires in the telephone cable in the road-bed, as shown by fig. 13. For every 50 kWh consumed in a station a current impulse is sent through the signal wires to the next station. In this station there is a summating instrument that adds the incoming impulses and the impulses from the station, and sends them further through the signal wires to the next station. Finally the impulses thus arrive to a station, where the metering for the whole system is arranged. For this purpose is used a so-called »duration-meter», which receives the sum of all the impulses. This instrument is arranged so that it gives the total kWh consumption, the kWh consumption corresponding to the peak load and the maximum demand for 15 minutes, all in figures just as on an ordinary kWh meter. The instrument also gives the so-called »duration-curve», fig. 14. Through this arrangement very little clerical work is needed for calculating the cost of the electrical energy for the railway-operation.

The number of electric locomotives in use on the Ore Railway is now 62. There are 11 different types of locomotive. Four of these types are used for passenger service, three for freight and shunting service, and four for ore-train service. If the plant had to be built at the present time, however, only three types would be used, one (type D) for passenger and freight trains, one (type Ub) for shunting, and one (type Of) for ore trains.

On the lines in the southern part of the country only two types of electric locomotive wyill be used, type D for passenger and freight trains, and type Ub for shunting. On these lines 235 type D locomotives and 45 type Ub locomotives will be employed.

Types D, Ub and Of locomotives are all built with the driving motors fixed to the locomotive frame and geared to a jack-shaft, from which the power is transmitted to the driving wheels by means of coupling rods. Flexible electrical connections and flexible air-ducts are consequently not required for the motors. The type D locomotive has two motors and the type Ub one motor of the same type. The Of locomotive has four motors of about the same type.

The electrification of the Swedish State Railways will according to the existing program be undertaken in 5 parts, for which the costs and some other details are given by table I. Of these parts number 1 and 2 and part of number 3 are in operation as mentioned above. The whole part 3 will be in operation in October 1933, and at the end of 1936 the whole electrification program will be completed.

Table II gives a comparison of the traffic conditions for the parts to be electrified with the other parts of the State Railways.