The Means for Supplying Electric Energy to the Swedish State Railways.

The Swedish State Railway electrification employs single-phase, low frequency current supplied to the trolley wires at 16 000 volts. A number of investigations carried out from time to time have shown that the choice of this system has been benificial to the railway, and that no other system known as yet could have given more efficient results under the particular conditions prevalent in Sweden.

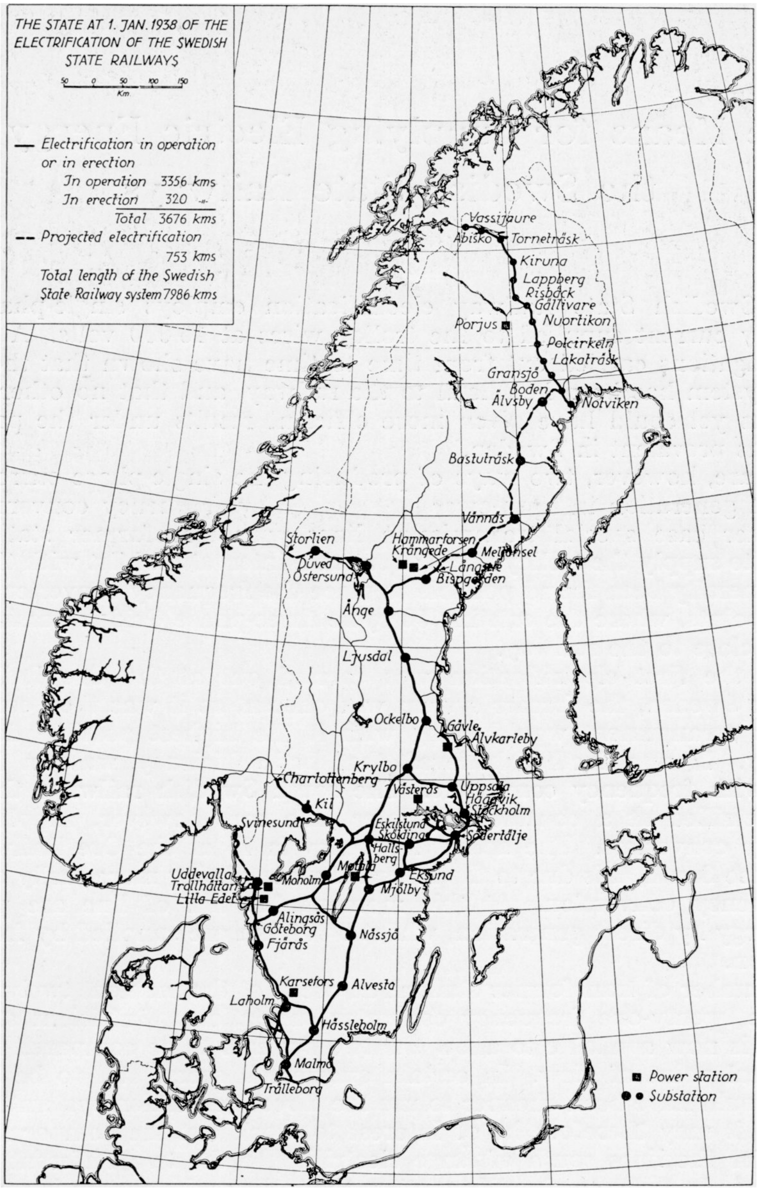
There are, however, two ways of producing the single-phase current, viz.. by direct generation in the power stations, or by frequency conversion. In the former case special transmission lines with transformer stations are required to supply the trolley wires at suitable intervals, whilst with the latter it has generally been found possible to place the frequency converter stations at such points, where the existing 50 cycle three-phase Grid is passing, or is running close to the railway.

When the first electrification was carried out at the Ore Railway in Northern Sweden, the former system was chosen, as it was then considered that this arrangement would bring with it the highest possible degree of reliability. It was further believed that bad efficiency was an inherent feature with frequency converters. The south Swedish railways that have been electrified at a considerably later date are, however, supplied over frequency converters. The actual frequency is 15 at the Ore Railway, but 1 ()•/3 in the South, this due to the latter frequency being more easily obtained by frequency conversion. At this moment 449 km of line are provided with energy by direct generation, whilst 2 907 km are supplied by frequency conversion.

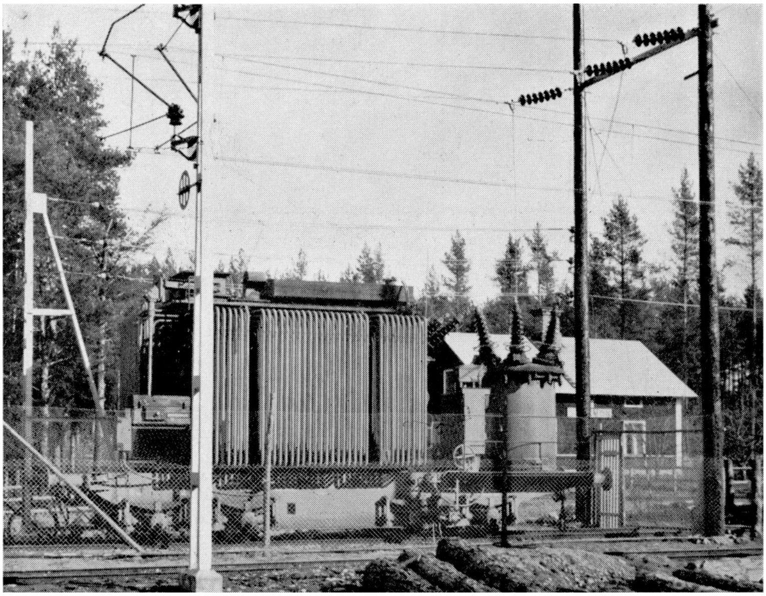
The number of transformer stations in use is at the moment twelve, whilst there are twenty-one frequency converter substations. Sufficient statistical material is now available to allow the two systems to be compared from an economical point of view. In certain quarters it seems still to be believed that it would have been cheaper to use the direct generation system throughout. and it may therefore be of interest to work out the comparative cost figures for the lines south of Ange electrified to the two different systems mentioned. In order to simplify matters the trolley wire system is considered to exist already to its present extent, and only the feeding arrangements are taken into account.

The first point to be investigated is then the question of the price per unit of energy that has to be paid for the single-phase energy.

The northern system of direct generation obtains its power in bulk from the Porjus power station, and it is hardly likely that a lower price than is



Map of Swedish State Railway electrified lines, showing location of hydro-electric power stations and substations.



Mobile transformerstation at Alvkarleo.

paid for that power would be offered by the more expensively built power stations in the South. The charge at Porjus is

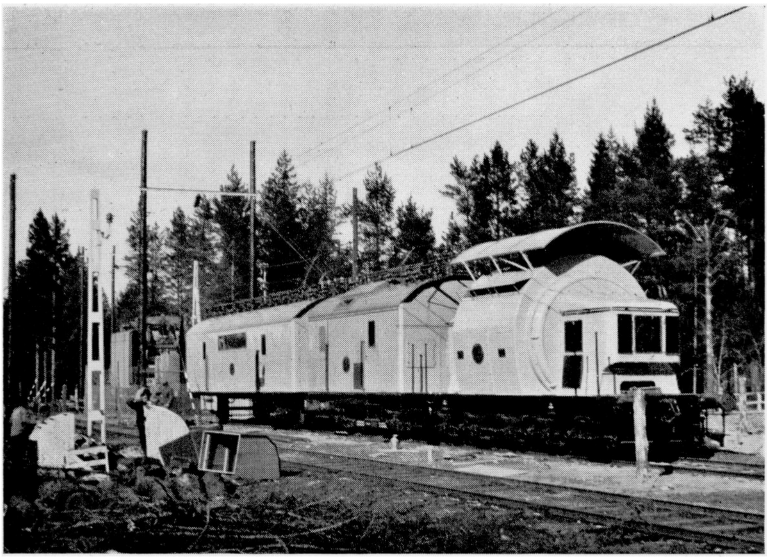
1. A fixed sum of Sw. Kr. 1 000 000 paid yearly, and permitting 35 000 000 kWh to be consumed,
2. Sw. Kr. 0.0075 for each unit consumed above this amount.

On top of this the Railway has to pay the rent and the cost for overhaul and amortization of the single-phase machinery in the power-house, as this machinery is owned by the Railways themselves. There are thus single-phase alternators, transformers and apparatus at Porjus, the capital charges and upkeep of which at 4 % interest works out at Sw. Kr. 159 500 per year.

During 1937 the Ore Railway experienced an exceedingly heavy traffic surpassing all previous records. It is extremely unlikely that the traffic will in the future pass this record value, and the generating costs per unit consumed for this year are therefore probably the lowest that will ever be obtained with the direct generation system. During the year 85 130 300 kWh were consumed, and for this was paid:

Fixed amount	Sw. Kr.	1 000 000
50 130 300 kWh at Sw. Kr. 0.0075	»	376 000
Machinery charges	»	159 500
Grand total	Sw. Kr.	1 535 500

or per kWh delivered at Porjus Sw. Kr. 0.01804. It is evident from the figures above that had the consumption been lower, the price per unit would have been higher. It is for instance at the more normal yearly consumption of 75 000 000 kWh, Sw. Kr. 0.01946 per unit, or about 8 per cent more.



Mobile substation at Alvkarleo.

During the same year, 1937, the electric railways south of Ange consumed:

Single-phase energy for trains . . . . kWh 348 792 000
50 cycle energy for power and lighting . . . . » 17 421 000
The total amount paid for this power delivered at tlie converter stations was . . . . Sw Kr. 9 047 881
The cost per unit was thus in this case ——————— » 0.0247

If this power was now to he generated directly at low frequency, there would he an extra outlay of capital for transmission lines and transformer stations. The 50 cycle energy required for power and lighting would probably in most cases be obtained locally, but in certain cases it may be necessary to convert low frequency power. The lowest price per unit for this energy, would for Swedish conditions possibly be Sw. Kr. 0.04, and the yearly cost would thus amount to . . . . Sw. Kr. 696 840

For the transmission of power from suitable power stations to the electrified lines south of Ange 3 000 km of transmission lines would be required, and 45 transformer stations would be necessary. As the problem of telephone interference does no longer put any limitation to the distance between feeding stations, the spacing is as compared with the Ore Railway calculated lo be increased as much as is possible from the point of view of voltage drop in the line. The transmission lines would interconnect the power stations and the transformers along the railway lines. They would cost:
3 000 km of transmission line at Sw. Kr. 11000 pr km Sw. Kr. 33 000 000
45 transformer stations at Sw. Kr. 300 000 each . . . . . » 13 500 000

Sum total Sw. Kr. 46 500 000

Substation at Uppsala.

The yearly charges calculated at 4 % interest would amount to:

Interest and amortization:		
5.2 % on Sw. Kr. 33 000 000	Sw. Kr.	1 716 000
6.6% » » 13 500 000	»	891000
Material for upkeep of transmission lines	»	100 000
» » » transformer stations Sw. Kr. 45 x 3000	»	135 000
Staff	»	500 000
Grand total	Sw. Kr.	3 342 000

When again frequency conversion is employed, the voltage can be kept constant at the converter stations, and the voltage drop which is then experienced in the trolley lines alone, allows greater distances between these stations. Only '21 stations are therefore necessary in such a case costing

Sw. Kr. 900 000 each	Sw. Kr.	18 900 000

The yearly charges calculated at 4 % interest amount to

6.6 % on Sw. Kr. 18 900 000	Sw. Kr.	1 247 400
Material required for upkeep Sw. Kr. 21X9 000	»	189 000
Staff	»	265 000
Grand total	Sw. Kr.	1 701 400

Direct generation as compared with frequency conversion thus increased the capital outlay by	Sw. Kr.	27 600 000
and the yearly charges by	»	1 640 600
lo which has to be added the cost of 50 cycle energy separately purchased, or	»	696 840
The sum left to pay for the single-phase energy, if both alternatives are to come out equal, thus works out at Sw. Kr. 9 047 881 — 1 640 600 —696 840=	»	6 710 441
The statistics of the year 1937 show that 13.3 % of the energy generated at Porjus was lost before reaching the trolley wire. The actual energy required for the South Sweden electrification at power station terminals would thus amount to 348 720 000/0.867, or	kWh	402 200 000
and if the sum mentioned above was paid for this power, the unit price would work out at	Sw. Kr,	0.0167

This is 8 % less than the lowest price that has been paid for the single-phase energy at Porjus, and it is thereby proved that the frequency conversion system is more economical under the actual conditions prevailing in the South of Sweden.

Incidentally it has been of great advantage that the capital requirement has been reduced by using the frequency conversion system which has required Sw. Kr. 27.6 millions less than the direct generation method, or 11.2 % of the total capital investment in the electrification of the south Swedish railways up to the end of 1937. Also the capital cost for the power stations has been reduced materially, as only one kind of generating equipment has been necessary. Other advantages have been that no limitations with regard to work on power stations and transmission lines have been put to the rate of electrification, as would otherwise have been necessary, and the flexibility of the system in this respect has with certainty been one of the main reasons for the extension of the original electrification plants that have followed in rapid succession making electric traction cover considerably more mileage than would otherwise have been the case.

During 1937 the total energy consumption of the electrified State Railways was

521.1	millions kWh	
85.1	»	thereof delivered at Porjus to the Ore Railway,
322.8	»	thereof delivered south of Ange as three-phase power by the Royal Board of Waterfalls,
113.2	»	thereof, also three-phase power, delivered by private enterprise, the Sydkraft.

The maximum quarter hour consumption has amounted to

at Porjus		26.4 mW
for the Royal Board of Waterfalls		64.5 »
for the private enterprise, Sydkraft		27.6 »
Added together the peaks amounted to		118.5 »
For this power has been paid a total of	Sw. Kr.	10 423 800
the Porjus part amounting to	»	1 375 700
Royal Board of Waterfalls	»	6 650 000
Private enterprise	»	2 398 100

The curves and schedules attached show the duration curves and the energy consumption of Ihe electrified railways. The actual character of the railway load is defined by this information.

Energy consumed at the frequency converter substations belonging to the Swedish State Railway electrification.

Actual figures for the year 1937.

Converter station	Energy consumed at $16^2/_3$ cycles kWh	Energy consumed at 50 cycles kWh	Loss conversion kWh	Total 50 cycle energy consumption kWh	Max. load peak at 50 cycles kW	Utilization time in hours
Ange	6 383 000	356 090	1 641 910	8 381 000	5 380	1 560
Ljusdal	10 145 000	325 150	1 886 850	12 357 000	6 800	1 810
Ockelbo	14 512 000	510 010	2 430 990	17 453 000	7 000	2 500
Krylbo	18 167 300	695 790	3 125 910	21 989 000	8 650	2 540
Uppsala	11 375 000	479 400	2 417 600	14 272 000	8 850	1 620
Alvkarleo*)	–	–	–	–	–	–
Haggvik	29 203 700	390 210	6 024 090	35 618 000	11 800	3 020
Sodertiälje	32 619 990	809 267	5 530 743	38 960 000	11 600	3 360
Skoldinge	12 069 500	438 660	2 008 840	14 517 000	6 500	2 240
Hallsberg	32 400 000	4 785 953	5 253 047	42 439 000	11 200	3 790
Moholm	15 154 800	485 390	3 281 810	18 922 000	7 380	2 570
Kil	8 121 000	631 150	2 896 850	11 649 000	6 700	1 740
Alingsås	25 487 100	648 760	5 714 140	31 850 000	10 600	3 000
Fjärås	9 728 000	277 100	2 254 900	12 260 000	5 200	2 360
Eksund	17 252 000	656 205	3 531 795	21 440 000	8 100	2 650
Mjiilbv	15 897 200	731 370	4 166 430	20 795 000	7 650	2 720
Nassjo	20 734 100	936 840	4 133 060	25 804 000	9 900	2 610
Alvesta	11 044 600	337 360	1 743 040	13 125 000	6 300	2 070
Hassleholm	12 402 700	410 420	2 514 880	15 328 000	6 630	2 310
Malmo	26 032 700	2 793 230	5 990 070	34 816 000	11 600	3 000
Laholm	20 062 000	722 910	3 596 090	24 381 000	8 400	2 890
Grand total	348 791 690	17 421 265	70 143 045	436 356 000	94 200	4 630

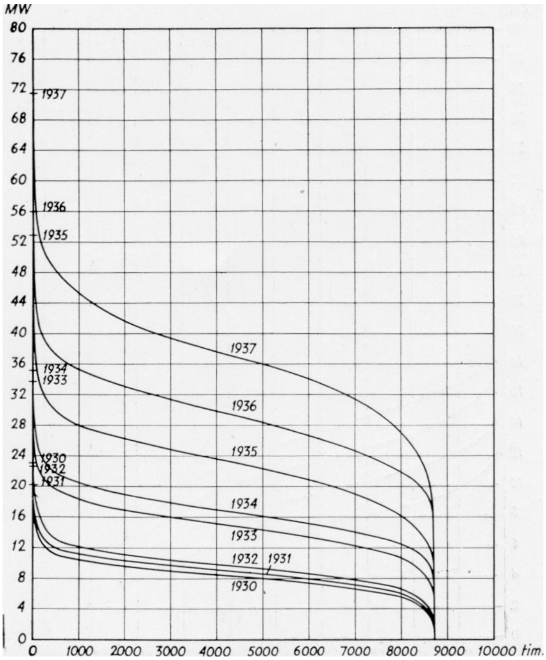
*) The Alvkarleo substation was taken in operation in April 1938.

The peak loads in the table are quarter hour demands.

Part of the energy was utilized for operating workhops 3 964 600 k\Wh at 50 cycles, and for stationary train heating arrangements 15 609 440 k\Vh at $16^2/_3$ cycles.

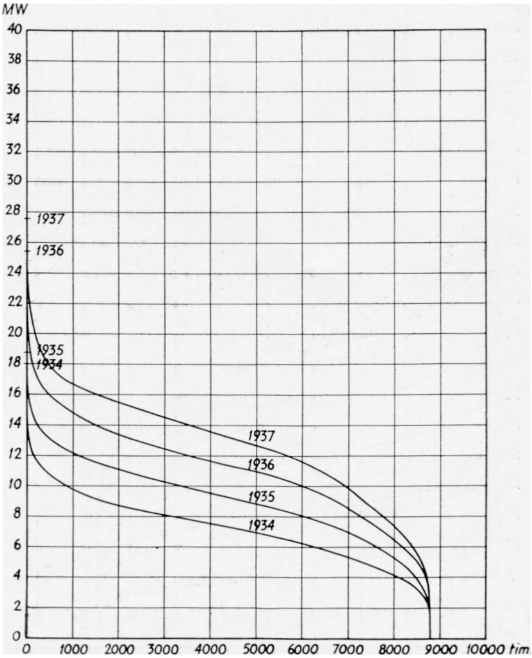
Energy consumed at the Ore Railway in 1937.

	Energy consumed kWh	kW	Utilization time hours
Transformer stations 16 kV			
Vassijaure	8 007 079	4 800	1 670
Abisko	12 054 506	5 250	2 300
Tornetrask	10 018 680	5 350	1 870
Kiruna	9 970 040	6 000	1 660
Risback	2 427 000	3 300	735
Gallivare	6 960 300	6 250	1 110
Nuortikon	4 338 600	3 700	1 170
Polcirkeln	2 963 200	2 350	1 260
Lakatrask	3 109 900	2 750	1 130
Gransjo	3 127 700	3 350	933
Boden	4 202 500	3 300	1 270
Notviken	6 648 306	3 700	1 800
Grand total kWh	73 827 811	-	
Power station 80 kV			
Porjus	85 130 300	26 400	3 220



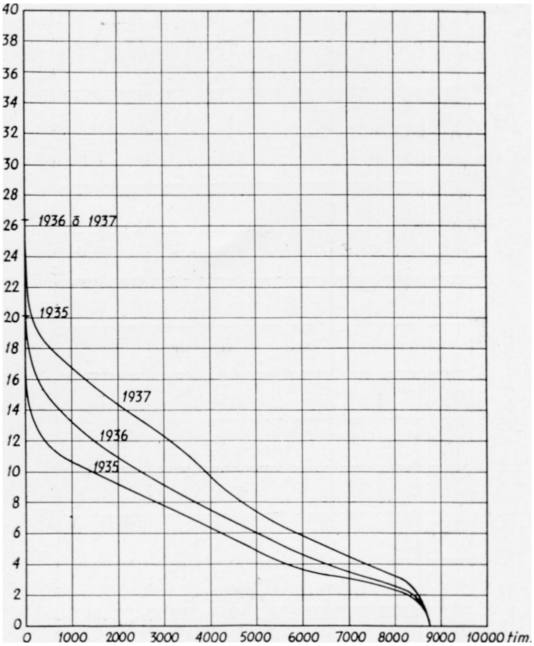
Duration curves
for the
Energy delivered to the State Railways south of Ånge by the Royal Board of Waterfalls, in the years 1930—1937.

Year	Energy consumption kWh	Maximum quarter hour consumption kW
1930	73 074 590	23 100
1931	78 277 000	20 100
1932	84 728 000	22 800
1933	130 899 000	33 800
1934	148 076 500	35 200
1935	203 427 000	50 800
1936	261 100 000	56 000
1937	322 800 000	71 200



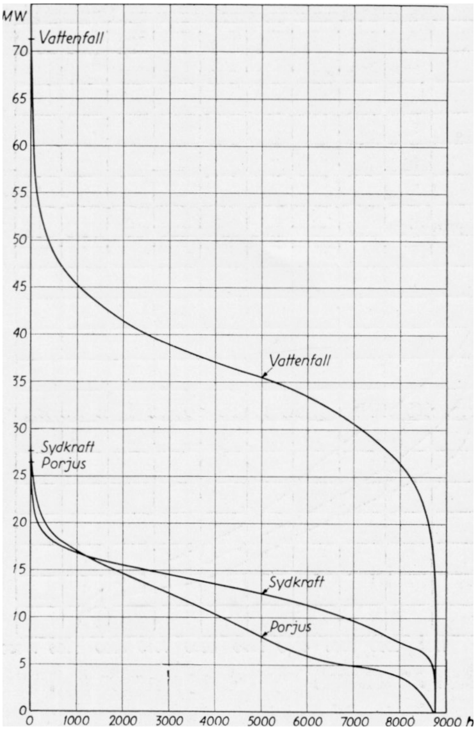
Duration curves
for the
Energy delivered to the State Railways south of Nässjö by the Sydkraft. in the years 1934—1937.

Year	Energy consumption kWh	Maximum quarter hour consumption kW
1934	63 308 000	18 000
1935	79 950 000	18 800
1936	97 795 000	25 400
1937	113 200 000	27 600

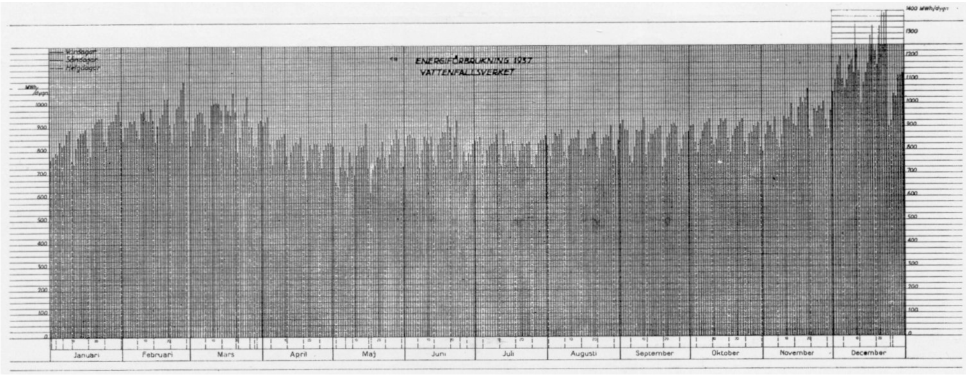


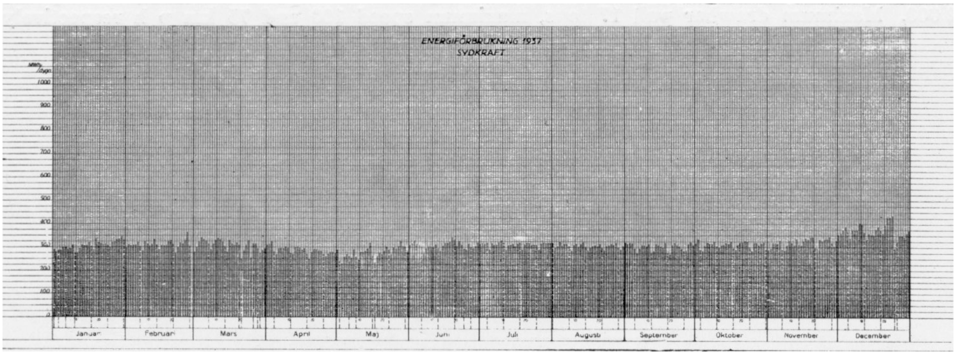
**Duration curves
for the
Energy delivered at Porjus to the Ore Railway
in the years 1935-1937.**

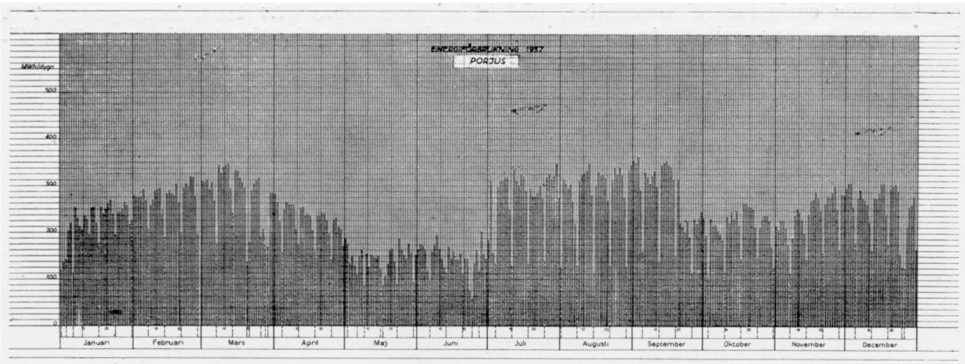
Year	Energy consumption kWh	Maximum quarter hour consumption kW
1935	54 428 700	20 100
1936	68 445 000	26 400
1937	95 400 000	26 400



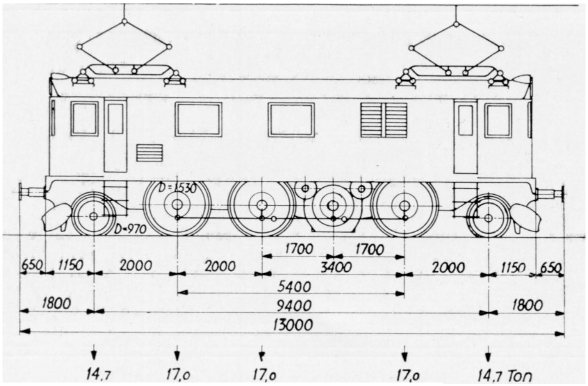
Duration curves
for the
Three Energy Supplies to the Swedish State Railways
intheyear1397



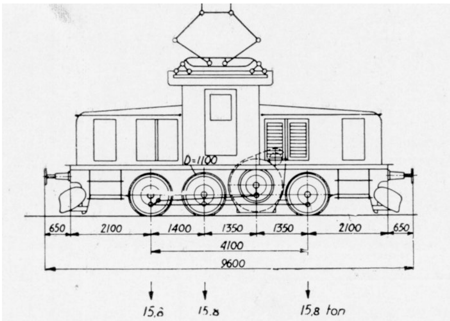




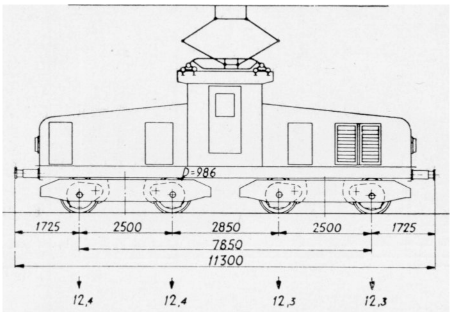
Diagrams showing the quantities of electric energy in inWh daily delivered to the Swedish State Railways in 1937 by the three suppliers the Royal Board of Waterfalls, the Sydkraft and Porjus. As will be seen from these diagrams the energy consumption varies most at the Ore Railway—the lowest diagram—depending upon the variations in the export of ore. The load for the railways in Ihe southern part of the country—the diagram in the middle—is as will be seen very even.



Locomotive type D. Used for hauling passenger trains weighing 600 tons, or freight trains weighing 900 tons, exclusive of locomotive. Weight of locomotive 80,4 tons, horse-power 2 000. Maximum drawbar pull 17 tons, maximum speed 100 and 75 km p h respectively. Number in operation and under construction 281. 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 47.4 tons, horse-power 700. Maximum drawbar pull 16 tons, maximum speed 40 km p h. Number in operation 45. Dimensions in mm.



Locomotive type Ud. Used for light passenger and freight trains of a maximum weight of 400 tons for passenger and 600 tons for freight trains, exclusive of locomotive; also used for shunting; an all round locomotive for all kinds of services on lines where the track does not allow more than 12.6 ton axle pressure. Weight of locomotive 49.4 tons, horse-power 1 200. Maximum drawbar pull 11 tons, maximum speed 90 km p h. Number in operation and under construction 62. Dimensions in mm.

The sections mentioned below of the Swedish State Railways have been operated electrically "since the following dates:

1915	January 19	Kiruna—Riksgriinsen	129	km
1920	March 12	Kiruna—Gallivare	100	»
1921	February 8	Gallivare—Ripats	20	»
	August 1	Ripats—Kilvo	18	»
	October 1	Kilvo—Nattavara	9	»
1922	March 20	Nattavara—Boden	121	»
	June 21	Boden—Lulea—Svarton	36	>
1923	February 10	Gallivare—Malmberget	7	>
	March 26	Gallivare—Tingvallskulle—Koskullskulle	9	»
1926	March 15	Katrineholm—Falkoping	209	»
	April 30	Sodertalje—Katrineholm	98	»
	May 10	Falkoping—Goteborg	114	»
	» 15	Stockholm—Sodertalje	38	>
1932	July 27	Hallsberg—Orebro	25	»
	> 27	Katrineholm—Norrkoping—Krokek	61	
	August 9	Jarna—Krokek	96	»
	December 16	Falkoping—Nassjo	113	»
	18	Norrkoping—Mjolby	78	»
1933	January 12	Hallsberg- Mjolby	96	»
	April 2	Mjolby—Nassjo	89	»
	» 4	Malmo—Eslov och Arlov—Lomma	39	»
	July 23	Nassjo—Alvesta	87	»
	September 2	Eslov—Hassleholm	50	»
	October 1	Alvesta—Hassleholm	98	»
	December 4	Malmo—Trelleborg	31	»
1934	October 1	Orebro—Krylbo	132	»
	December 1	Lomma—Angelholm	72	»
	12	Stockholm—Uppsala	66	»
	16	Uppsala—Krylbo	95	»
1935	July 2	Angelholm—Halmstad	66	»
	November 28	Krylbo—Bollnas	157	»
	December 14	Hassleholm—Veinge	72	»
1936	April 2	Bollnas—Ange	167	»
	October 6	Halmstad—Goteborg	151	»
	November 20	Sodertalje—Eskilstuna	100	»
	December 2	Skebokvarn—Stalboga	23	»
1937	January 8	Halsingborg—Angelholm	26	»
	» 18	Laxa—Kit	120	»
	April 24	Kil—Charlottenberg	83	»
	May 21	Astorp—Molle	37	>
	June 1	Kil—Fryksta	3	>
	September 6	Orebro—Svarta	49	»
	November 10	Tomteboda—Vartan	8	»
	13	Skovde—Karlsborg	44	»
	December 6	Uppsala—Gavle	114	»
		Total	3 356	km

The electrification of the sections mentioned below is in erection, and will be put in operation at the following dates:

1939	May	Goteborg—Uddevalla	87	km
		Ange—Ostersund	102	»
		Bracke—Langsele	131	
		Total	320	km

Stockholm. May 1938.