AN ECONOMIC COMPARISON OF THE GENERATION COSTS OF STEAM POWER AND HYDRO-ELECTRIC POWER IN THE SOUTH

by

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Introduction

There have been many articles in technical magazines in recent years dealing with the design and unique features of both steam and hydro-electric power stations. However, very little has been written or printed on the actual operating results that are being obtained in these different atations. It is the purpose of this thesis to give an economic comparison of the generation costs of steam power and hydro-electric power in the South, and a discussion of the different factors which determine the cost.

As far as could be ascertained, the Electrical World for September 26, 1925 contains the only recent available data on the actual operating results of steam-generating stations. All data for curves pertaining to steam-generating stations except the Unit Cost of Steam-Electric Power Stations was taken from this issue of the Electrical World. The data for hydro-electric plants was obtained principally from the Electrical World and from "Hydro-Electric Power Stations" by Rushmore and Lof.

It must be remembered that the costs given herein are generation costs only, and do not include transmission and distribution.

In this introduction, the author wishes to thank Miss Rubye Wilkerson, Engineering Librarian, for her valuable assistance in finding references on this subject.

Methods of Obtaining and Source of Data for Curves Contained Herein

Curves Pertaining to Steam-Electric Plants (Coal burning only)

1. Estimated Unit Cost of Steam-Electric Power Stations. Figure 1, Page 7.

This curve was taken direct from "Hydro-Electric Power Stations", by Rushmore and Lof, Page 765. It is an estimate for the year 1923.

2. Total Operating and Maintenance Cost of Steam-Electric Power in the South. Figure 1, page 7.

This curve was plotted from data obtained from the Electrical World for September 26, 1925. For data see appendix, page 18.

3. Fixed Charges on Steam-Electric Plants. Figure 1, page 7.

This curve was calculated as follows:
The fixed charges were taken as 13% per year on the investment. This figure was given by Vern E. Alden, chairman of the Power Generation Committee of the A.I.E.E., in his comments on the data contained in the Electrical World for September 26,1925. Then, taking a plant of 20,000 Kw.:-

Unit Cost --- $100 per installed Kw.
100 x .13 ---$13.00 per Ins. Kw. per year.
1300/8760 x .218 --- .68 cents per Kw.-Hr. based on a 21.8% Use Factor*

For complete data, see appendix, page 19.

4. Total Generation Cost of Steam-Electric Power in the South. Figure 1, page 7.

This curve was obtained by adding the two preceding curves with dividers.

*Use Factor----Net Kw. Hr./8760 x Kw. Installed

5. B.T.U. per Kilowatt-Hour and Load Factors. Figure 4, page 10.

Data for this curve was taken from the Electrical World for September 26, 1925. For complete data see appendix, page 19.

6. Cost of Coal in Per Cent of Total Operating Cost. Figure 2, page 8.

From the same source as the above. Data given in appendix, page 19.

Curves Pertaining to Hydro-Electric Plants

7. Operating Expenses of Hydro-Electric Stations, Figure 6, page 13.

Data for this curve was obtained from "Hydro-Electric Power Stations", Rushmore and Lof, Page 765.

The operating expenses include general administration, labor, repairs, maintenance, and supplies. In the calculations for the cost of hydro-electric power, the operating expenses were assumed to remain constant for different use factors. This is not strictly true, but the variation is small, and, since the operating expenses comprise only about one-fifth of the total, the error introduced by this assumption is not serious. Data in appendix, page 22.

8. Unit Cost of Hydro-Electric Power Stations Figure 8, page 15.

This curve was obtained by looking up the size and cost of various Southern hydro-electric plants. References and data are given in the appendix, pages 20 and 21. The average unit cost of plants falling within certain size limits was plotted.

9. Calculated Generation Cost of Hydro-Electric Power in the South. Figure 5, page 12.

Data for these curves was calculated as follows:-

Taking a 60,000 Kw. plant

Unit Cost---$120 per installed Kw. from curve, Figure 8.

Interest and Depreciation 10%*---$120 per Kw. per year.

Taxes and Insurance ½ of 1%*-----$0.60 " " " "

Operating expenses including general administration, labor, repairs, maintenance, and supplies--$2.90 per Kw. per Yr (From Figure 6)

Total expense --- $15.50 per installed Kw. per year.

Cents per Kw.Hr. at 100% use factor 1550/8760---.1765

Cents per Kw.Hr. at 75% use factor 1550/8760 x .75--.235

Complete data in appendix, page 24.

10. Effect of Use Factor on Cost of Hydro-Electric Power Figure 7, page 14. Data in appendix, page 24.

This curve was plotted from data calculated for the preceding curves.

*This figure was given by Prof.J.A. Switzer

Discussion

The Cost of Steam-Electric Power

When comparing the generation costs of steam power and hydro-electric power, it is well to examine the different factors that go to make up the total cost of power. It will be noted from the curves in figures 1 and 5, pages 7 and 12, that the generation cost of steam power is approximately 40% greater than that of hydro-electric power. The different factors which make up the total generation cost of steam power are:-

1. Fuel cost.
2. The cost of labor, superintendence, etc.
3. The cost of maintenance.
4. Fixed charges on the investments.

The cost of coal in per cent of total operating cost is shown by the curve in figure 2, page 8. It can be seen from this curve that the fuel cost in per cent of the total operating cost increases with the increase in size of the plant. Fuel cost is the main item in the operating cost for plants above 20,000 Kw. Therefore, any change in the price of fuel produces a corresponding change in the operating expenses. This change becomes more and more marked as the size of the station increases.

Items 1, 2, and 3, are combined in curve b, figure 1, and form the total operating and maintenance cost. Data for fuel cost and total operating cost is given in the appendix. Detailed data on the different factors which make up each item can be obtained from the Electrical World for September 26, 1925.

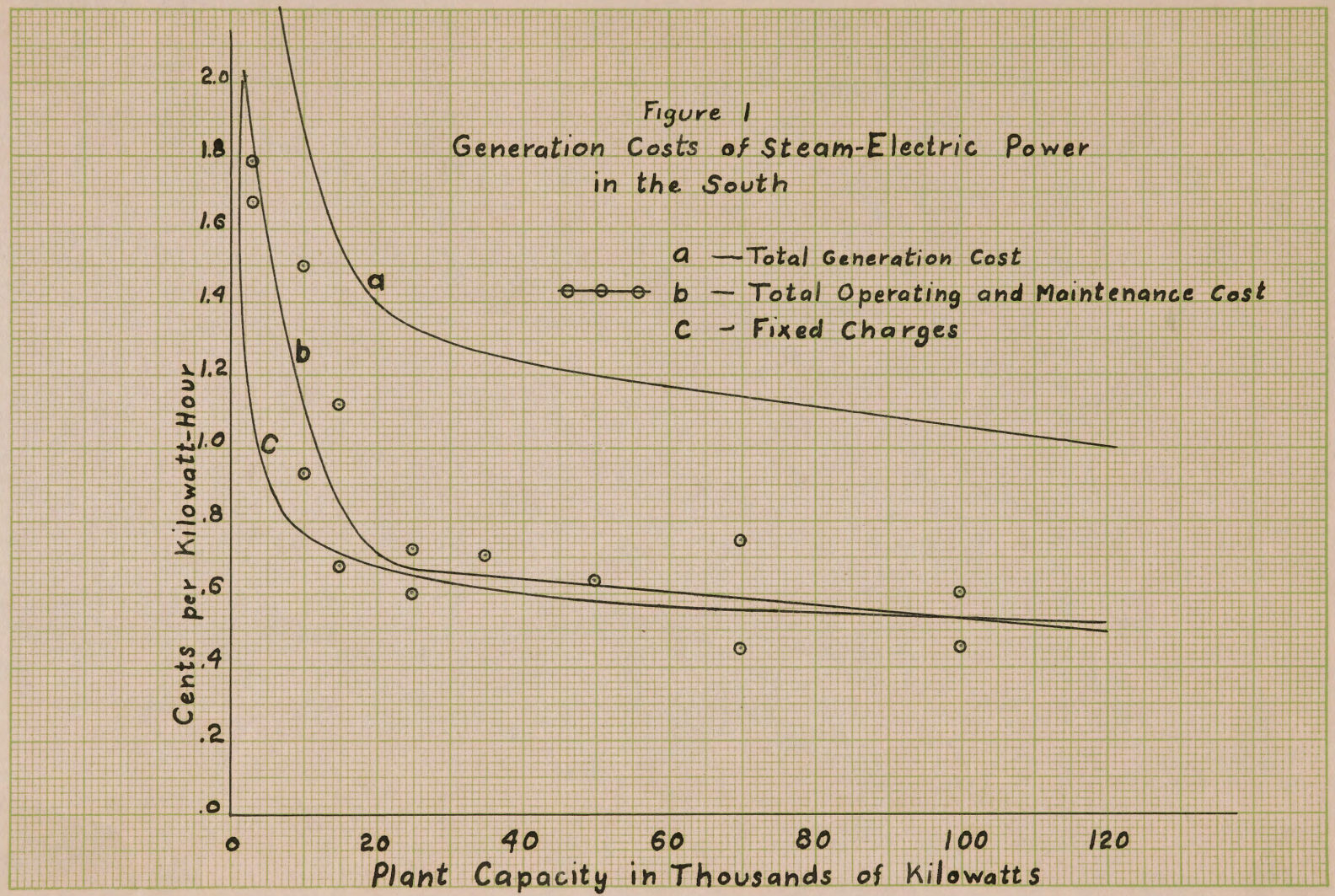
The fixed charges of a plant cover all expenses which do not expand and contract with the change in load. It will be noted in curve c, figure 1, that this item comprises approximately 50% of the total generation cost. For this reason, the load factor does not have such a pronounced effect on the cost of steam power as on hydro-electric power where the fixed charges compose approximately 80% of the total cost.

Figure 4, page 10 shows the relation of load factor to station performance. The downward trend of this curve is due to two things.*

1. In the older power systems, the base load is assigned to the newer and more up to date stations, and the older ones carry the peak loads. Consequently, their load factors are low.

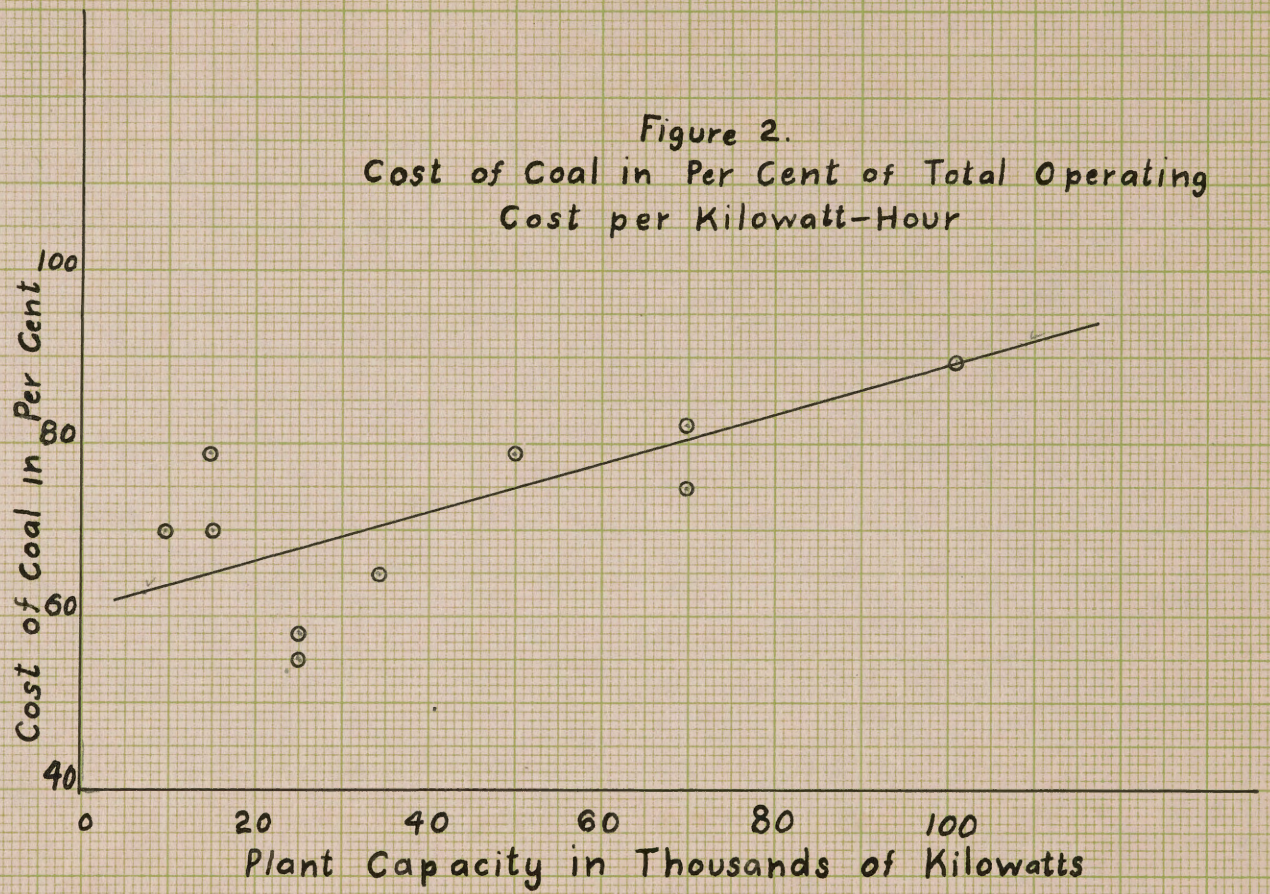
*The statement which follows was given by Vern E.Alden.

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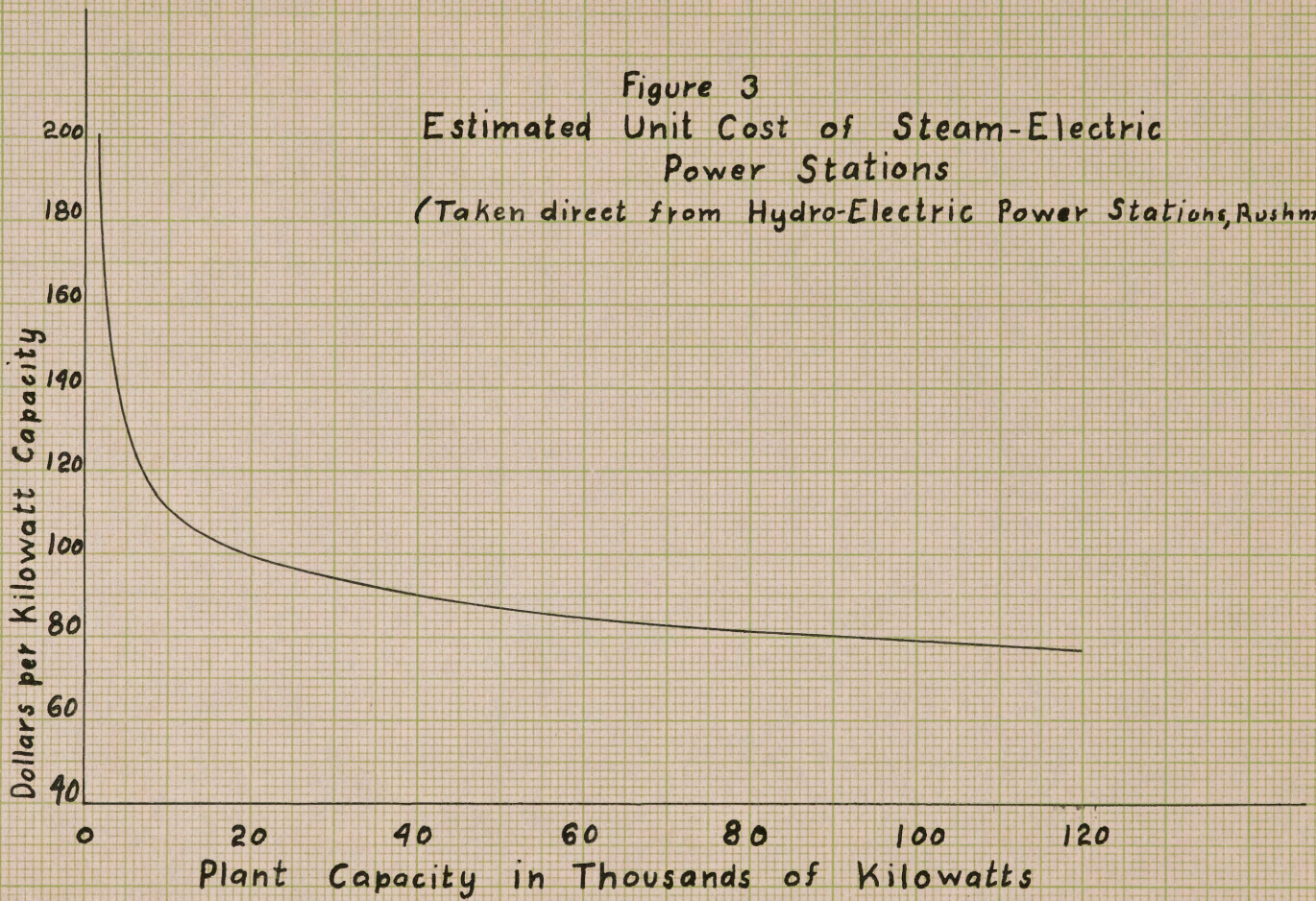
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Figure 2.
Cost of Coal in Per Cent of Total Operating Cost per Kilowatt-Hour



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Figure 3
Estimated Unit Cost of Steam-Electric Power Stations
(Taken direct from Hydro-Electric Power Stations, Rushmore & Lot)

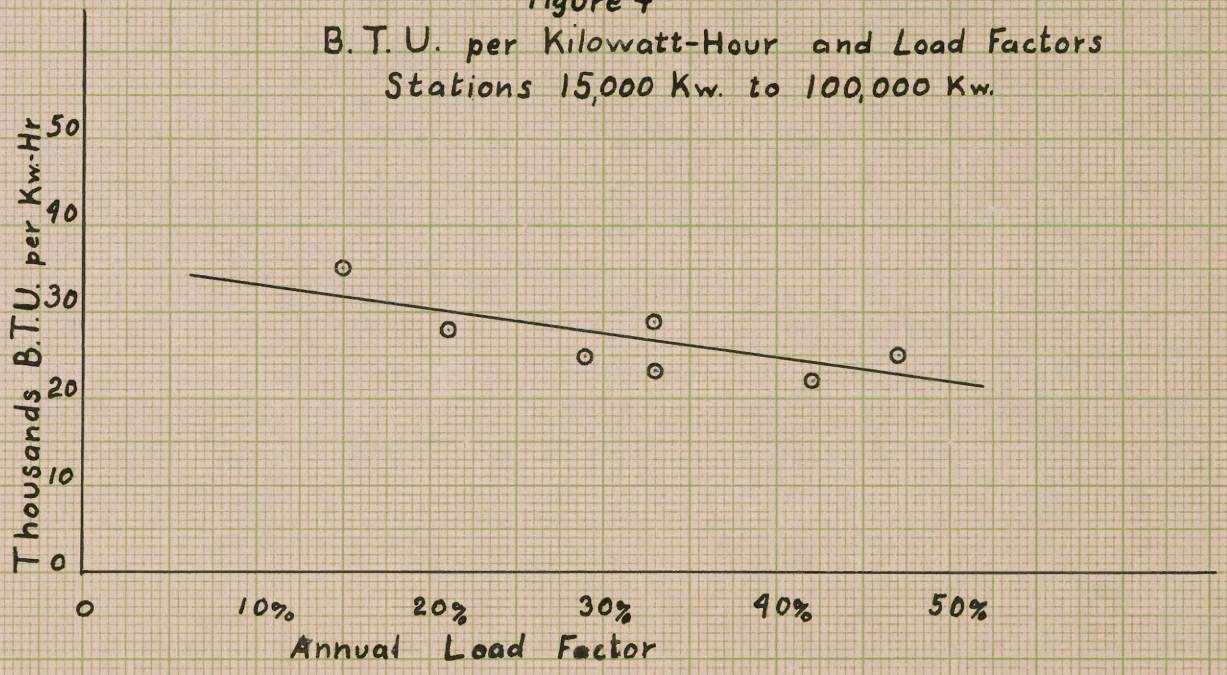


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Figure 4

B. T. U. per Kilowatt-Hour and Load Factors

Stations 15,000 Kw. to 100,000 Kw.



2. Due to the low load factor, the turbines and auxiliaries must be started and stopped frequently and the boilers must be frequently banked. This accounts for the higher B.T.U. consumption at low load factors.

The first item probably has more to do with the slope of the line than the second. The effect of a change in load factor in a single station would not be nearly so marked.

The Cost of Hydro-Electric Power.

The cost of hydro-electric power is made up of two parts:-

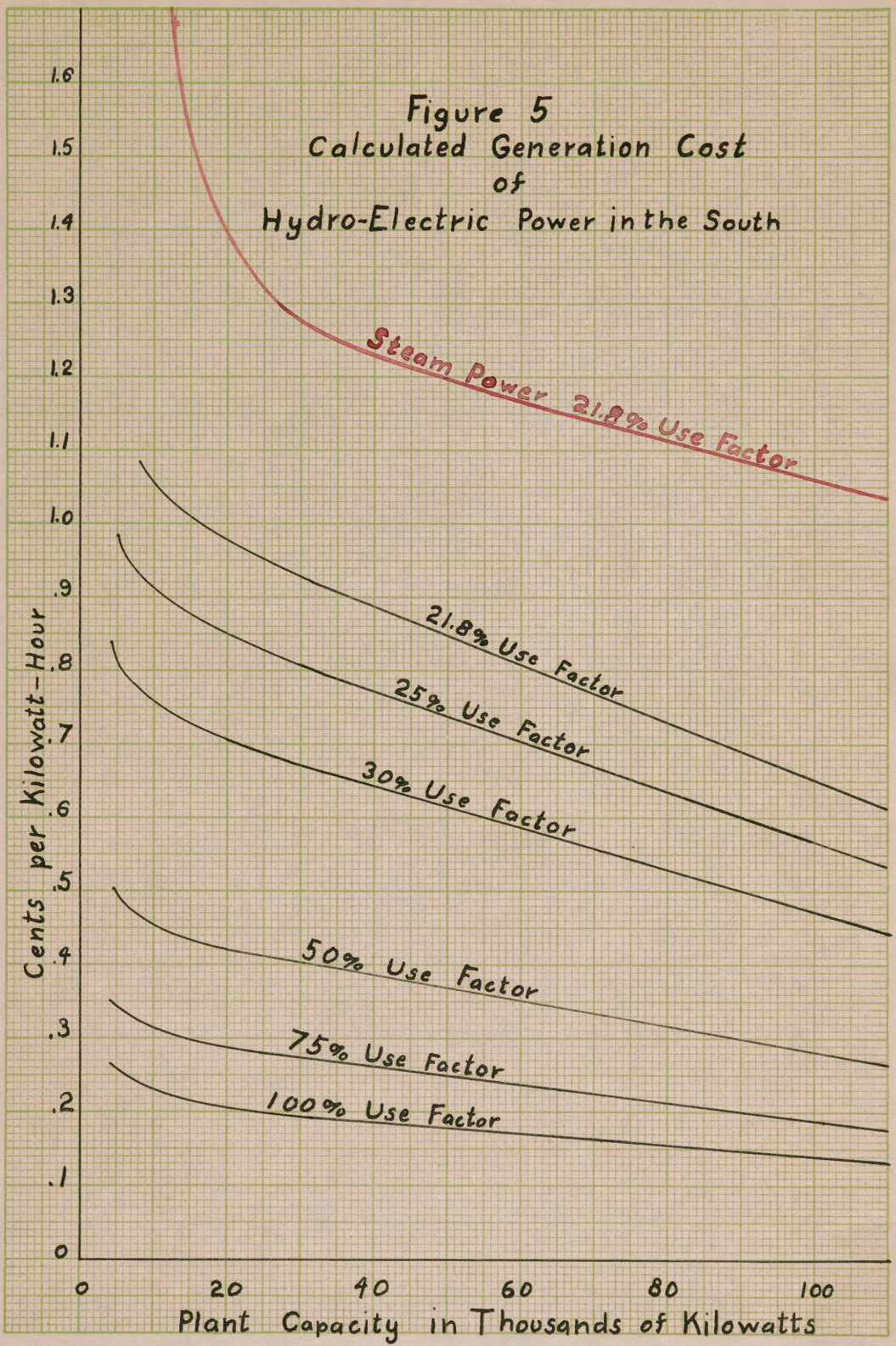
1. Fixed charges
   a. Interest on investment.
   b. Taxes and insurance.
   c. Depreciation.
2. Operating expenses
   a. General Administration.
   b. Labor.
   c. Supplies.
   d. Maintenance and repairs.

The operating expenses comprise approximately 20% of the total cost of hydro-electric power. This expense decreases with the increase in size of the plant if it is calculated per unit of capacity. The reason for this is that very little more labor and administration is required for a large plant than for a small one. The curve for the operating expenses of hydro-electric plants is given in figure 6, page 13.

The fixed charges make up about 80% of the total cost of hydro-electric power. This item therefore is the controlling factor in the cost. For this reason, the use factor has a very marked effect on the cost per kilowatt-hour, since 80% of the expense goes on regardless of the amount of power generated. The amount of fixed charges per installed kilowatt per year decreases with the increase in size of the plant. This is due to the fact that the power of a turbine increases approximately as the 3/2 power of the head, but the total installation cost usually increases at a lower rate. For this reason, the unit cost decreases with the increase in head or capacity. This is shown by the curve in figure 8, page 15. The unit costs given by this curve will appear to be rather low. The reasons for this are twofold:-

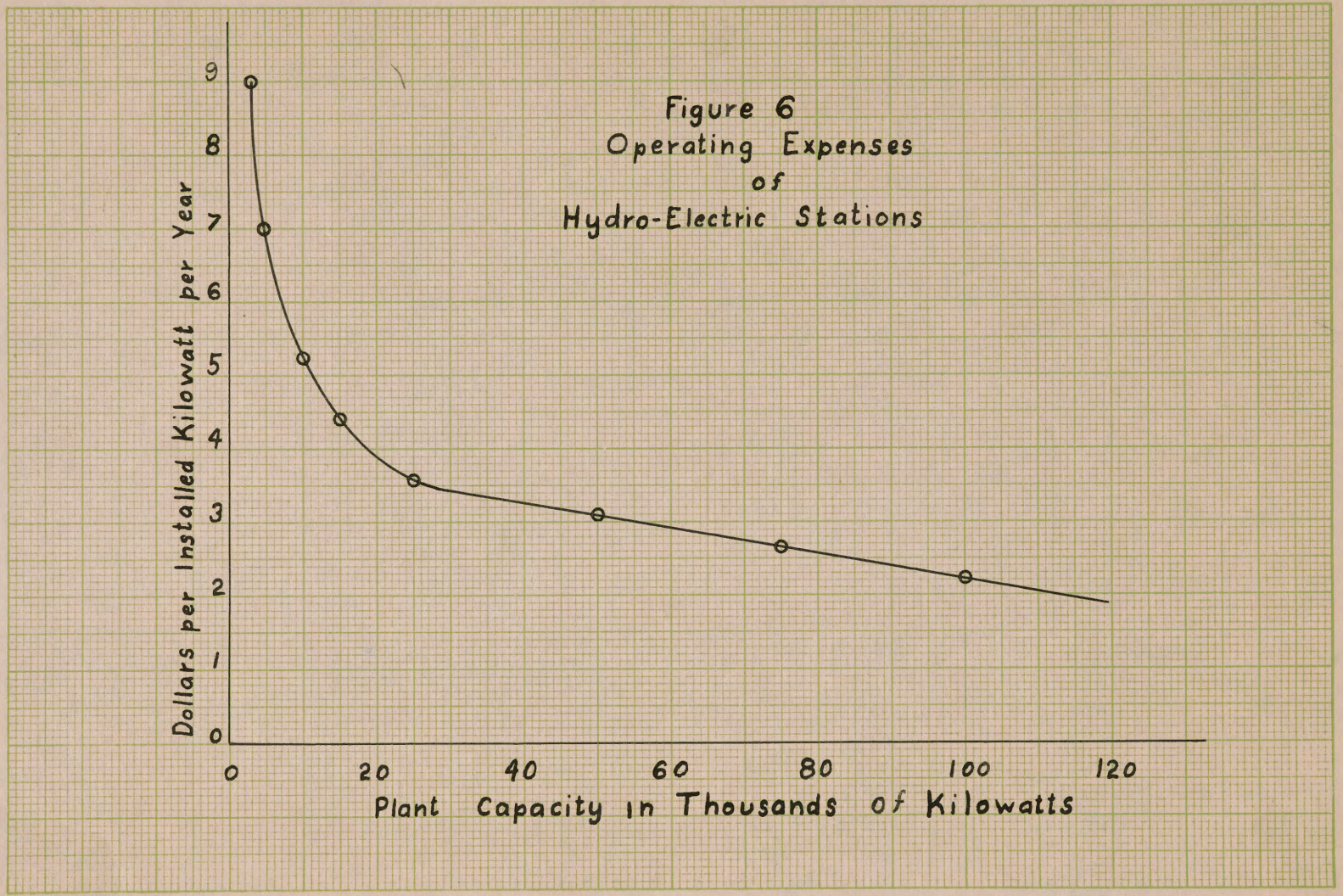
1. Most of these plants were constructed before the War when construction costs were much lower than they now are.

2. Most of the stations which have been built up to date are ones which called for the smallest investment per unit of capacity.

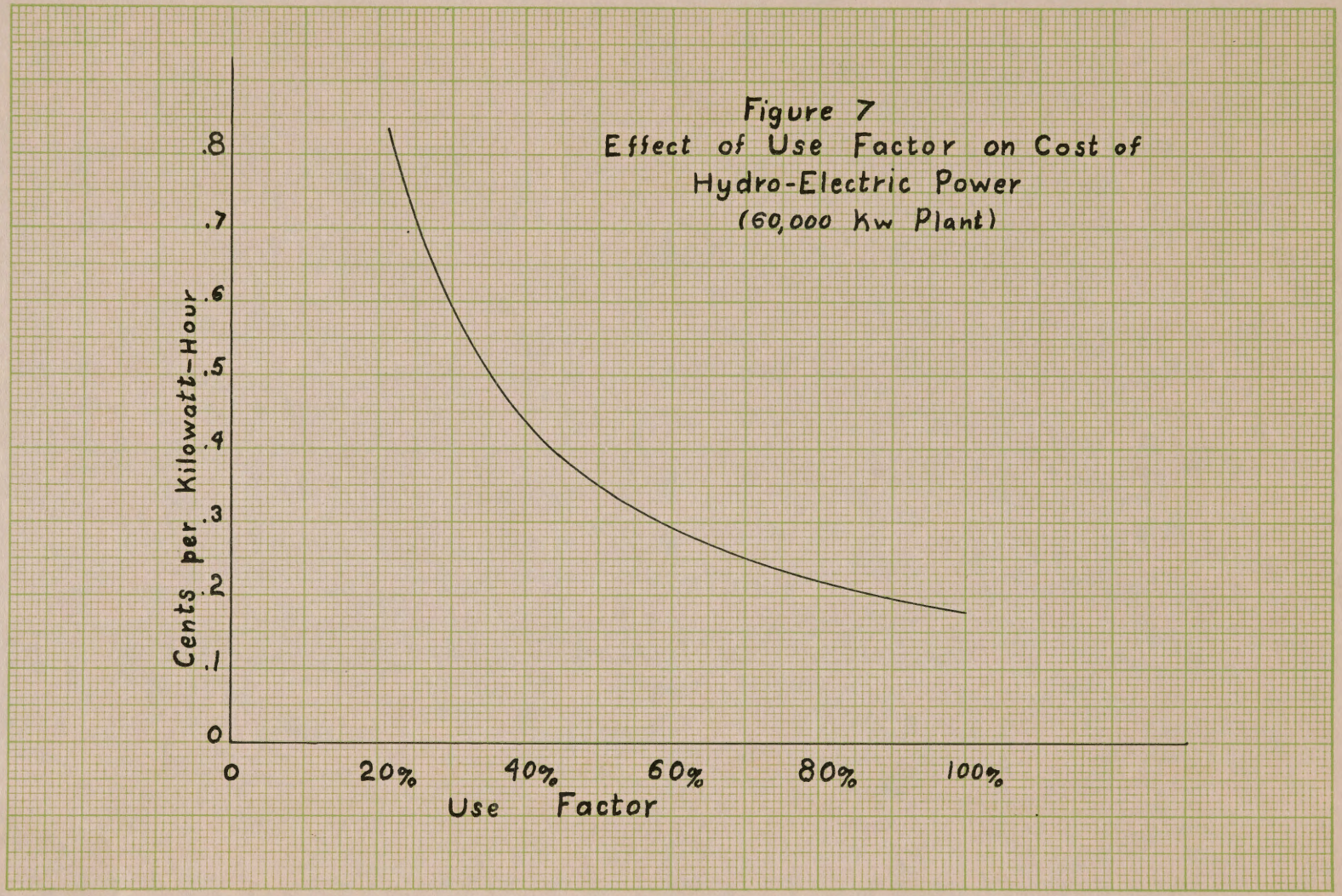


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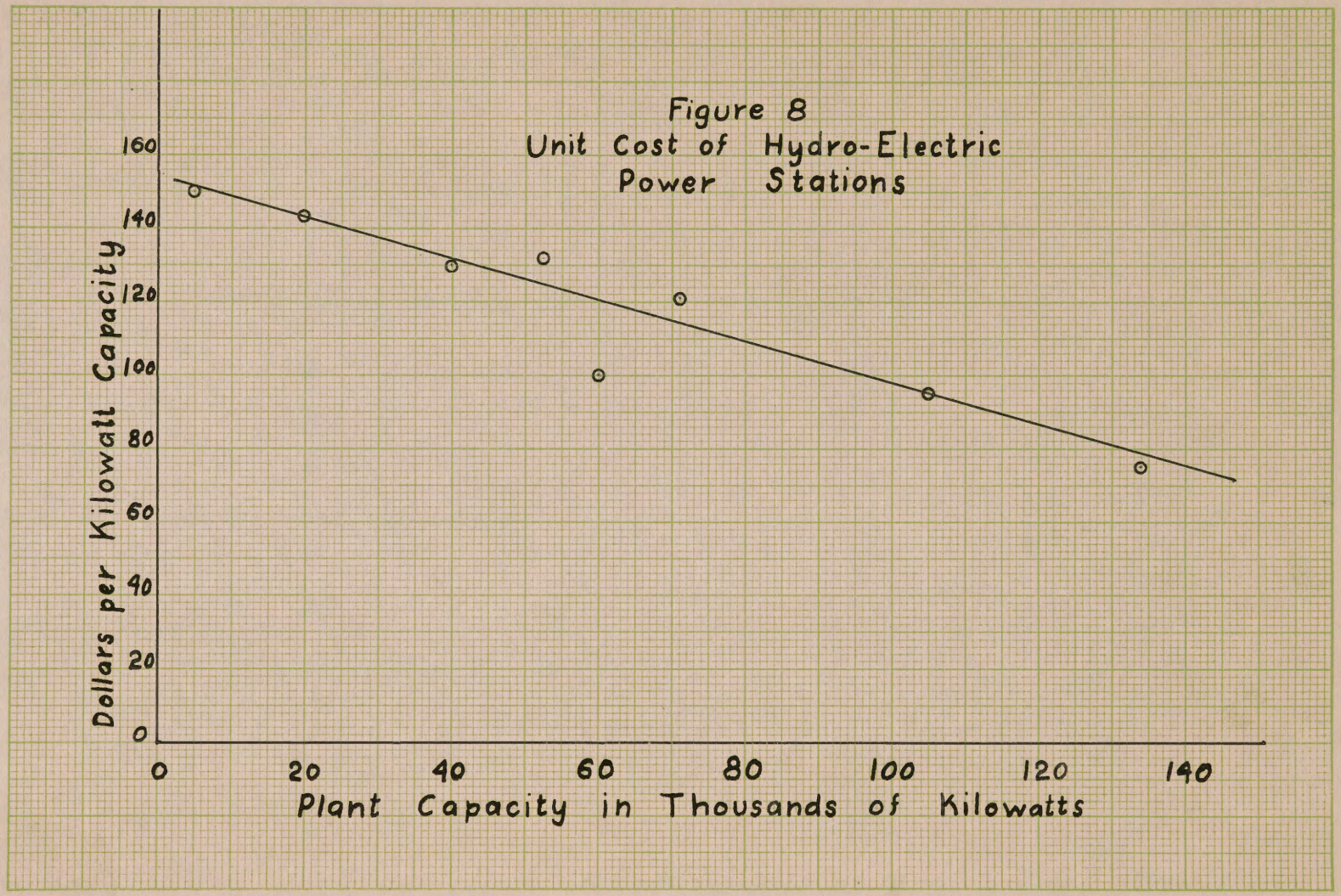
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Conclusions

It cam be seen from the foregoing discussion that hydro-electric power can be generated much cheaper than steam power in the South. From this, it would seem that hydro-electric power alone is the most economical. This, however, is not the case. If hydro-electric power alone were used in a system, the primary power of the system would have to equal the maximum peak load of the primary power consumers. In this condition, all the water except that needed to develop the primary power is wasted, except that used to develop secondary power. If the system load factor is not favorable, less water than that required to develop the primary power continuously will be used. All these factors reduce the number of kilowatt-hours which can be produced by a plant, and thus very much increase the cost of power.

On the other hand, if the hydro-electric plants are used as base load plants, and steam plants are kept in reserve to carry the peaks and low water periods, the output of the hydro-electric plants can be greatly increased, and thus lower the generation cost. This method is used by all the large Southern Power Companies and is undoubtedly the most economical method of producing power in the South.

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Electrical World, Vol. 83, page 1234.

Electrical World, Vol. 85, page 119.

Electrical World, Vol. 87, page 56.

Electrical World, September 26, 1925.

American Hydro-Electric Practice, Taylor and Brymer.

Engineering, News Record, Vol. 91, Page 116.

Hydro-Electric Power Stations, Rushmore and Lof.

APPENDIX

Operating Performance of Steam-Generating Stations in the South.

From the Electrical World, Vol. 86, No.13, Sept. 26,1925.

Plant Number	Installed Generator Rating Kw.	Annual Plant Use Factor * Per Cent	Total Operating and Maintenance Expence, Cents per Kw.-Hour.
1	1,000	20.7	5.0502
2	2,000	22.3	2.0724
3	3,000	18.8	1.6790
4	3,000	16.6	1.7949
5	10,000	7.9	1.4888
6	10,000	24.6	.9313
7	15,000	26.1	1.1060
8	15,000	33.7	.6867
9	15,000	16.9	.7990
10	25,000	28.6	.5930
11	25,000	24.9	.7130
12	35,000	14.0	.7034
13	50,000	26.6	.6242
14	70,000	31.8	.4530
15	70,000	3.1	.7460
16	100,000	37.2	.4514
17	100,000	15.3	.6528

Average Use Factor---21.8%

* Use Factor---Net Kw.-Hour/Kw. Installed x 8760

Fixed Charges of Southern Steam-Electric Plants

Size of Plant Kilowatts	Unit Cost Dollars per Ins. Kilowatt	Fixed Charges 13%. Dollars per Installed Kw. per Year.	Fixed Charges. Cents per Kw.-Hr. 21.8%L.F.
5,000	130	16.90	.885
10,000	110	14.30	.749
20,000	100	13.00	.680
40,000	90	11.70	.612
60,000	85	11.07	.579
80,000	82	10.70	.560
100,000	80	10.40	.545
120,000	78	10.12	.530

Cost of Coal in Per Cent of Total Operating Expense.*
Load Factors and B.T.U. per Kilowatt Hour.*

Size of Plant Kw.	Coal Cost Cents per Kw.-Hour	Total Oper. Cost. Cts. per Kw.-Hr.	Coal Cost in % of Total Op. Cost	Load Factor Per Cent	B.T.U. per Kw.-Hr.
100,000	.357	.3997	89.4	29	25,000
70,000	.415	.555	74.8	42	22,000
70,000	.311	.378	82.2	33	29,000
50,000	.4613	.5825	79.1	47	25,000
35,000	.389	.6062	64.1	15	35,000
25,000	.325	.582	55.8	33	23,000
25,000	.403	.687	58.5	21	28,000
15,000	.4948	.622	79.4		
15,000	.684	.973	70.2		
10,000	.557	.7926	70.2		

* From the Electrical World, September 26, 1925.

Installed Cost of Southern Hydro-Electric Plants.

Plants Having from 1,000 to 10,000 Kilowatts Capacity.

1. Electrical World, Vol. 75, Page 527.
2,250 Kw. Installed. Cost $320,000 or $142 per Ins. Kw.

2. Electrical World, Vol. 75, Page 933.
746 Kw. Installed. Cost $140,000 or $188 per Ins. Kw.

3. Electrical World, Vol. 81, Page 1229.
10,000 Kw. Installed. Cost $500,000 or $50 per Ins. Kw.

4. Electrical World.
2,000 Kw. Installed. Cost $425,000 or $212 per Ins. Kw.

Average Cost --- $148 per Installed Kilowatt.

Plants Having from 10,000 to 30,000 Kilowatts Capacity.

5. "American Hydro-Electric Practice", Taylor and Brymer.
23,000 Kw. Installed. Cost $2,000,000 or $87 per Ins.Kw.

6. Electrical World, Vol. 85.
15,000 Kw. Installed. Cost $3,000,000 or $200 Per Ins.Kw.

Average Cost --- $143 per Installed Kilowatt.

Plants Having from 30,000 to 50,000 Kilowatts Capacity.

7. 36,000 Kw. Installed. Cost $6,000,000 or $167 per Ins.Kw.

8. 34,000 Kw. Installed. Cost $4,500,000 or $132 per Ins.Kw.

9. 45,000 Kw. Installed. Cost $1,250,000 or $28 per Ins. Kw.

10. Electrical World, Vol. 83, Page 1234.
30,000 Kw. Installed. Cost $6,000,000 or $200 per Ins.Kw.

11. Electrical World, Vol. 75, Page 527.
45,000 Kw. Installed. Cost $9,000,000 or $200 per Ins.Kw.

12. Electrical World,
43,000 Kw. Installed. Cost $5,000,000 or $117 per Ins.Kw.

13. "American Hydro-Electric Practice", Taylor and Brymer.
40,000 Kw. Installed. Cost $70 per Installed Kilowatt.

Average Cost --- $130 per Installed Kilowatt.

Plants Having from 50,000 to 70,000 Kilowatts Capacity.

14. Electrical World, Vol. 85, Page 119.
52,000 Kw. Installed. Cost $4,000,000 or $77 per Ins.Kw.

15. Electrical World, Vol. 87, Page 56.
60,000 Kw. Installed. Cost $6,500,000 or $108 per Ins.Kw.

16. Engineering New Record, Vol. 91, Page 116.
66,000 Kw. Installed. Cost $10,000,000 or $150 per Ins.Kw.

17. "Hydro-Electric Power Stations", Rushmore and Lof, Page 751
60,000 Kw. Installed. Cost $66 per Installed Kilowatt.

Average Cost --- $100 per Installed Kilowatt.

Plants Above 70,000 Kilowatts Capacity.

18. "Hydro-Electric Power Stations", Rushmore and Lof.
72,000 Kw. Installed. Cost $8,750,000 or $121 per Ins.Kw.

19. 105,000 Kw. Installed. Cost $10,000,000 or $95 per Ins.Kw.

20. Electrical World, Vol. 87, Page 56.
134,000 Kw. Installed. Cost $10,000,000 or $75 per Ins.Kw.

Operating Expenses of Hydro-Electric Plants.

From"Hydro-Electric Power Stations", Rushmore and Lof.

Installed Capacity Kilowatts	Operating Expenses, Dollars per Ins. Kilowatt per Year.
2,500	8.76
5,000	7.10
10,000	5.26
15,000	4.38
25,000	3.51
50,000	3.07
75,000	2.63
100,000	2.19

Operating and Maintenance Costs of
Southern Hydro-Electric Plants.

Capacity in Thousands of Kilowatts	Cost of Installing Dollars per Kilowatt*	Interest and Depreciation 10 Per Cent
5	151	15.10
10	144	14.40
20	141	14.10
30	137	13.70
40	131	13.10
50	125	12.50
60	120	12.00
70	114	11.40
80	108	10.80
90	102	10.20
100	97	9.70
110	91	9.10
120	86	8.60

Capacity in Thousands of Kilowatts	Taxes and Insurance ½ of 1% $ per Ins. Kw. per Yr.	Operating Expenses per Ins. Kw. per Yr.	Total Expenses per Installed Kilowatt per Year
5	.755		22.65
10	.72	6.80	20.32
20	.71	5.20	18.66
30	.69	3.85	17.79
40	.66	3.40	16.96
50	.63	3.20	16.20
60	.60	3.07	15.50
70	.57	2.90	14.72
80	.54	2.75	13.94
90	.51	2.60	13.12
100	.485	2.41	12.46
110	.455	2.27	11.66
120	.43	2.10	10.98
		1.95	

*See Figure 8, page 15.

Generation Cost of Hydro-Electric Power in the South.

Cost per Kilowatt-Hour.

Installed Capacity Kilowatts	USE FACTOR 100%	75%	50%	30%	25%	21.8%
5,000	.258	.344	.516	.86	1.03	1.19
10,000	.231	.308	.452	.77	.925	1.062
20,000	.2125	.284	.425	.71	.85	.98
30,000	.2025	.2725	.409	.676	.818	.94
40,000	.193	.258	.386	.644	.772	.89
50,000	.185	.247	.370	.616	.740	.852
60,000	.1765	.235	.354	.588	.705	.815
70,000	.168	.224	.336	.560	.672	.775
80,000	.159	.212	.318	.530	.636	.734
90,000	.150	.200	.300	.500	.600	.690
100,000	.142	.190	.284	.474	.568	.655
110,000	.133	.177	.266	.444	.532	.614
120,000	.125	.166	.250	.416	.500	.575

APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

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May 28, 1926

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