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SUBJECT: Sizes of U. S. Steam-Electric Plants

TO: R. B. Briggs

FROM: R. C. Robertson

SUMMARY

At the present time, plants in the 100 - 500 Mw size range are more numerous and carry the greatest portion (over 50%) of the total steam-electric plant load in the U.S. utilities industry. The contribution of plants of over 1,000-Mw capacity is increasing more rapidly than any other size classification and at present represents about 10% of the total capacity. By 1962 the TVA will have six plants with capacities of over 1,000-Mw. The largest steam-electric plant in the U.S. is the TVA plant at Kingston, Tenn., with a nameplate capacity of 1,440-Mw. Turbine-generator units are also following a trend of ever-increasing size. In present construction, the 150-200 Mw size range for units is the most common and represents the greatest contribution to capacity. Two units of 500-Mw nameplate rating each, the largest in the U.S., are on order by the TVA, and an 800 Mw unit is contemplated.

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Introduction

In evaluating reactors in long-range studies it is of interest to know the size of electric power producing stations, and units in these stations, that will best meet the future needs of the utilities industry in the United States. This information becomes particularly important when considering reactor types which appear promising only if constructed in very large sizes. It is common knowledge that larger power stations and larger turbine-generator units are being constructed as technologies are advanced, but the number of such large plants and units that the industry will support is not so apparent.

One approach to predicting these trends is to study the sizes of steam-electric plants and of turbine-generator units in the United States utility industry over an extended period, including those installations now planned and under construction. This memo reports on a brief survey of the available data, with particular emphasis on the largest plants and turbine-generator units.

The capacities are given on the basis of net electrical megawatts of total plant or turbine-generator output and in no case has this been translated into the gross thermal capacity of the associated steam generating equipment. The overall thermal efficiency of modern large steam stations is about 40%, so that a fair approximation of the associated steam generator size in thermal megawatts can be obtained by multiplying the net electrical output by 2.5; if the reactor plant produces only saturated steam a multiplying factor of about 3.5 would be more in order.

Size Distribution of Plant Capacities

The general size distribution of steam-electric plant capacities in the United States for the years 1938 through 1960 is shown in Fig. 1. The plant sizes are compared on the basis of the percentage contribution of each size classification to the total capacity of the plants included in the study for each of the years examined. The Federal Power Commission reports were the principal source of data, and while these covered 60 to 90% of the base-load utility-owned steam-electric plants in the U. S., complete listings were not available. It may be noted that the spread of the points in Fig. 1 makes the shape of the curves somewhat arbitrary.

The total power generated by plants of less than 100 Mw capacity represents a continually decreasing percentage of the total steam-electric plant generated output. It is judged that after 1960 the contribution from plants of this size will tend to level out at 5 to 10% of the total.

The increasing number of large steam-electric stations in the nineteen forties caused a reversal in the trend of importance of the 100 to 500-Mw plants, but these plants of less than 500 Mw size still carry the major portion of the total U. S. steam-electric plant load. After 1960 the 100-500 Mw curve in Fig. 1 has been indicated as leveling off at some relatively high contribution, since this size of plant will continue to meet the connected load requirements of many utility districts for several years to come. As shown in Table I, most of the new steam-electric plant capacity planned to be operational by 1960 is in this size bracket.

Table I⁽³⁾

SIZE DISTRIBUTION IN SURVEY OF STEAM-ELECTRIC PLANTS PLANNED,
UNDER CONSTRUCTION AND STARTING OPERATION BY 1960

Plant Size Mw	Number of Plants Surveyed*	Total Capacity Mw	Percentage of Plants Surveyed	Percentage of Total Capacity Surveyed
0 - 99	50	2,106	29.8	4.6
100 - 499	94	23,474	56.0	51.6
500 - 999	16	10,380	9.5	22.8
1000 - up	8	9,556	4.7	21.0
	<u>168</u>	<u>45,516</u>		

* Estimated coverage about 90%

The growth rate of plants in the 500 to 1000-Mw size range has been quite rapid during the past ten years. The percentage contribution from these plants will continue to increase, but after about 1965 the rate may tend to level off as the 1000-Mw and larger plants assume greater importance.

By about 1960 the 1000-Mw and larger steam-electric plants will represent about 10% of the total capacity of the steam-electric plants in the utilities industry. Growth of the number of plants in this country is mainly the result of additions to existing installations. The percentage contribution from these plants is growing at a faster rate than from any other sizes, substantiating the well-established trend toward ever increasing plant sizes.

Largest Plants

By 1961-62 there will probably be 13 plants in the United States with a capacity of over 1,000 Mw; these are listed in Table II on the basis of the best information available. It will be necessary to await the publication of the 1958 FPC reports to authenticate the list of those plants now in operation or under construction; also, additional new construction may be announced in time to be completed by 1962.

As shown in Table II, the largest steam-electric plant in the United States (and probably the world) is the TVA plant at Kingston, Tennessee. This plant has a nameplate capacity of 1,440 Mw, a plant capability of about 1,600 Mw, and can carry gross average loads of about 1,700 Mw⁽¹⁾. (The distinction between nameplate capacity and capability is briefly discussed on page 5 of this memo.) This plant has the full capacity now in operation; insofar as is known, none of the plants planned to be completed by 1962 will exceed the capacity of the Kingston plant.

Table II

Largest Steam-Electric Plants in U.S. (3)(4)(5)
(Including Capacity Now Under Construction and Starting Operation by 1962)

<u>Owner</u>	<u>Name of Plant</u>	<u>Location</u>	<u>Number of Units</u>	<u>Total Capacity Mw</u>	<u>Year Operational</u>
TVA	Kingston	Kingston, Tenn.	9	1440	New
TVA	Shawnee	Paducah, Ky.	10	1350	Now
TVA	Johnsonville	Waverly, Tenn.	10	1350	1960
Detroit Edison	St. Clair	Detroit, Mich.	6	1346	1959
Indiana-Ky. Elec.	Clifty-Creek	Madison, Ind.	6	1304	Now
TVA	Colbert	Colbert City, Ala.	5	1300	1962
Pacific Gas & Elec.	Pittsburgh	Pittsburgh, Calif.	6	1300	1961
TVA	Widow's Creek	Stevenson, Ala.	7	1250	1961
Niagara-Mohawk	Huntley	Buffalo, N.Y.	?	1200	Now
Ohio Valley Elec.	Kyger Creek	Gallysolis, Ohio	5	1086	Now
Consolidated Edison	Astoria	Queens, N.Y.	4	1060	1961
TVA	Gallatin	Gallatin, Tenn.	4	1050	1959
Ohio Power Co.	Philip Sporn	New Haven, W. Va.	?	1050	1959

New units under construction by the TVA at their Shawnee, Johnsonville, Widow's Creek, Colbert and Gallatin plants will raise the capacity of these installations to over 1,000 Mw, so that by 1962 the TVA will have at least six plants in this size classification. If money is made available, either through Congressional approval of self-financing for the TVA or by other means, it is probable that another steam-electric plant of over 1,000 Mw capacity would be added to the system by 1962-63.⁽⁵⁾

Sizes of Units

The size of the turbine-generator units in steam-electric plants also follows a trend of ever-increasing capacity. The distribution of the unit sizes in new construction, as of October, 1958, is shown in Fig. 3. Well over one-half of all the new units are over 150 Mw capacity. Between the time the 1957 and 1958 surveys were made the relative distribution of sizes did not change appreciably but the overall size increased from 122 Mw to 127 Mw, for all types. Table II, which lists the largest plants in the United States, indicates the number of units in each plant, including new construction; the trend toward larger units is evidenced by the fewer number of units to be used in the newer plants.

Until the relatively recent development of hollow electrical conductors for the stator windings of the generators, permitting circulation of a coolant such as oil or demineralized water, one of the major limitations to the size of turbine-generator units was the cooling of the generator stator. Hydrogen cooling is still universally employed for cooling of the armature. It is present-day practice to serve a single turbine-generator unit with a single steam generator, with no cross-connections between other units in the plant. Development of larger sizes of steam turbines has therefore required simultaneous development of larger sizes of steam generators, but there has been so general restrictions to growth imposed by the technologies involved.

After a certain size is reached, say 200 to 300 Mw, the first cost of a turbine-generator of a unit per kw of capacity does not decrease significantly; at the present time domestic prices (f.o.b.) are about \$30 per kw and foreign bids have ranged between \$17 and \$22 per kw.⁽⁵⁾ The large units are attractive primarily in that less operating crew per kw of capacity is needed and that building costs are also somewhat less.

A utility system should have sufficient reserve generating capacity to absorb the loss of output of any one of its units; a rule-of-thumb is that no single unit should be larger than 10% of the dependable total capacity of the utility system. This factor has limited the size of units in many utility districts, but the TVA with a combined hydro and steam-electric capacity of over 11,000 Mw, is in a very good position in this respect and is leading the world in installation of the very large units.

The TVA now has two 500-Mw units on order. One of these, manufactured by General Electric for the Widow's Creek plant at Stevenson, Alabama, will be operational by September 1, 1960; the other, manufactured by C. A. Parsons, Ltd., is to be installed at the Colbert plant at Colbert City, Alabama, and is scheduled for operation September 1, 1962. Both are of the cross-compounded type and will have steam conditions of 2,400 psia and 1,050 °F with reheat to

1,000 °F and each require approximately 3,900,000 lbs steam per hour. The Widow's Creek steam generator is being built by Combustion Engineering and the Colbert unit by Babcock and Wilcox; the latter will be of the "once-through" type and will not employ the conventional boiler drums.

The largest units in the United States are the two 500-Mw machines just mentioned. However, bids were received by the TVA last week for a number of sizes of turbine-generator units, and included was a 600-Mw unit by General Electric and an 800-Mw unit by Westinghouse. The bid price was about \$30 per kw; more detailed information was not available at the time of this writing. A steam generator to supply the 800-Mw unit is stated to be in the realm of present technology. (5)

Data Used in This Study

The data for the plotting of the 1938 through 1957 points in Fig. 1 were taken from the Federal Power Commission reports. (2) The curves were extended through 1960 by adding the new plants planned to be operational by 1960, as reported in Power magazine, (3) to the 1957 FPC values. Extensions of the curves past 1960 are purely speculative. The information on large steam-electric plants listed in Table II was combined from data published in Power (3)(4) and from conversations with TVA personnel. (5)

The TVA listings and the Federal Power Commission reports are on the basis of rated capacity, or nameplate data of the turbine-generators, whereas the data taken from Power is stated to be on the basis of the capability of the units. The capability rating is generally about 10% greater than the rated capacity and refers to the fact that the machine can be operated continuously at this overload without exceeding the manufacturer's guarantees. It is prevailing practice to operate large units at capability, or even in excess of it, so that confusion exists as to the basis to be used for reporting the capacity of a steam-electric station. The difference is not of great importance when studying the trends in plant sizes, but the listed capacity of a particular plant must be accepted with caution in this respect.

The extent of the coverage of the Federal Power Commission reports is shown in Table III. These data indicate how the coverage has increased through the years and also the relative importance of private industry-owned-steam-electric plant capacity. As previously stated, this study does not include these plants, but lists only the utility-owned, base-load type steam-electric plants. The average size of steam electric plants in the utility industry is much larger than the overall average of all steam-electric plants in the U.S., as shown in Fig. 2. This graph also illustrates the growth rate of the over-all average size of steam-electric plants in the U.S.

The size distribution of steam-electric plants as determined from the FPC data is indicated in Tables IV through VI, which also show the number of plants included in the study for each of the years 1938, 1943, 1948, 1953 and 1957.

The size distribution of plants and the total capacities included in the 1960 study are shown in Table IX, which combines the data from the FPC reports (2) and from Power magazine. (3)

TABLE III
RELATIVE COVERAGE OF THE FPC COST BOOK SERIES

<u>Total Steam-Electric Power Industry</u>				
	<u>1938</u>	<u>1947</u>	<u>1956</u>	<u>1957</u>
Number of plants	1,165	1,045	1,037	1,039
Installed capacity, Mw	26,066	36,035	92,591	99,500
Average plant size, Mw	22	35	89	96
Annual plant factor	35%	55%	59%	57%

<u>Steam-Electric Plants Covered in FPC Cost Book Series</u>				
Number of plants	151	200	463	480
Installed capacity	15,404	23,609	81,677	88,704
Percent of total industry represented	59%	65%	88%	89%
Average plant size, Mw	102	118	176	185
Annual plant factor	38%	61%	62%	61%

TABLE IV⁽²⁾

SIZE DISTRIBUTION OF STEAM-ELECTRIC PLANTS IN 1938 FPC REPORT

Plant Size Mw	Number of Plants Reported	Total Capacity Mw	Percentage of Plants Reported	Percentage of Total Capacity Reported
0 - 99	103	4,742	68.2%	30.8%
100 - 499	46	9,266	30.5	60.3
500 - 999	2	1,375	1.3	8.9
1000 - up	<u>none</u>	<u> </u>		
	151	15,383		

TABLE V⁽²⁾

SIZE DISTRIBUTION OF STEAM-ELECTRIC PLANTS IN 1943 FPC REPORT

Plant Size Mw	Number of Plants Reported	Total Capacity Mw	Percentage of Plants Reported	Percentage of Total Capacity Reported
0 - 99	109	4,575	58.9	22.3
100 - 499	74	14,589	40.0	71.2
500 - 999	2	1,335	1.1	6.5
1000 - up	<u>none</u>	<u>-</u>	-	-
	185	20,499		

TABLE VI⁽²⁾

SIZE DISTRIBUTION OF STEAM-ELECTRIC PLANTS IN 1948 FPC REPORT

Plant Size Mw	Number of Plants Reported	Total Capacity Mw	Percentage of Plants Reported	Percentage of Total Capacity Reported
0 - 99	123	5,291	56.4	20.2
100 - 499	92	18,748	42.2	71.6
500 - 999	3	2,136	1.4	8.2
1000 - up	<u>None</u>	<u>-</u>	-	-
	218	26,175		

TABLE VII⁽²⁾

SIZE DISTRIBUTION OF STEAM-ELECTRIC PLANTS IN 1953 FPC REPORT

Plant Size Mw	Number of Plants Reported	Total Capacity Mw	Percentage of Plants Reported	Percentage of Total Capacity Reported
0 - 99	177	8,149	48.4	15.6
100 - 499	182	39,850	49.7	76.0
500 - 999	7	4,445	1.9	8.4
1000 - up	<u>None</u>	<u>-</u>	-	-
	366	52,444		

TABLE VIII⁽²⁾

SIZE DISTRIBUTION OF STEAM-ELECTRIC PLANTS IN 1957 FPC REPORT

Plant Size Mw	Number of Plants Reported	Total Capacity Mw	Percentage of Plants Reported	Percentage of Total Capacity Reported
0 - 99	204	9,039	41.9	10.1
100 - 499	247	55,131	50.7	61.9
500 - 999	32	19,712	6.6	22.1
1000 - up	<u>4</u>	<u>5,180</u>	0.8	5.8
	487	89,062		

TABLE IX

SIZE DISTRIBUTION OF STEAM-ELECTRIC PLANTS ESTIMATED FOR 1960
BY COMBINING DATA FROM TABLES II AND VII

Plant Size Mw	Total Capacity Mw	Percentage of Total Capacity
0 - 99	11,145	8.2
100 - 499	78,605	58.2
500 - 999	30,092	22.8
1000 - up	<u>14,736</u>	10.8
	134,578	

ORNL-LR-Dwg.-37240
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Figure 1

Size Distribution of Steam-Electric Plant Capacities

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Figure 2

Average Size of U.S. Steam-Electric Plants

ORNL-IR-Dwg.-39355
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Figure 3

Size Distribution of Turbine-Generators in the Units
Planned, Under Construction and Starting Operation as of Oct., 1958.

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