The Superpower System as an Answer to a National Power Policy*

By W. S. Murray
Consulting Engineer

The project to develop a superpower system for the region between Boston and Washington was originated by Mr. Murray during war time, who urged the late Franklin K. Lane, Secretary of the Interior, to make a survey of the sources of energy in New England and along the Atlantic seaboard as far south as Washington. In time Congress made an appropriation of $125,000 for this survey, which was recently completed for the United States Geological Survey by a special staff of which Mr. Murray was chairman. The Survey considers the economic possibilities of interconnecting existing electric power plants and systems in the zone and the building of new plants at advantageous load centers. It is estimated that this sytem will effect an annual saving of over $500,000,000 by 1930, and what is of more importance, the conservation of 50,000,000 tons of coal. The yearly profit from this development will amount to 33 perc ent of the investment—a highly attractive return. Two other articles on the significance of the superpower survey are published in this issue, one by Mr. H. Goodwin Jr., dealing primarily with the industrial features, and the other by Mr. W. D. Bearce, discussing the advantages that will result from the electrification of 19,000 miles of railroads.—Editor.

It sounds like a simple sentence to say: "Electricity is the True Agent of Power." Nevertheless when a careful analytical consideration of that sentence is made you will begin to realize that it stands for a great deal more than those simple words.

Power is the *father* of all accomplishment—moral, intellectual, and physical—and electricity as its agent is one that cannot be approached by any other. Power has become a great business in the world, and no business ever succeeded without good agents. The nearest approach to electricity as an agent of power is high pressure water and yet it can be shown that electricity is fifteen hundred times better, at least so far as efficiency is concerned, in the matter of power transmission. We have arrived at the time when 400,000 to 500,000 horse power can be transmitted 400 miles without incurring too great a commercial loss.

With regard to railways, we are not concerned with the two accepted systems of electrification but we are deeply concerned with the universal power system from which they are to receive their energy. Like the industries scattered throughout the Zone, each one of them calling for their complement of power, the railways operating therein must accordingly have their quota.

The Superpower Zone embraces the territory existing from Boston to Washington and inland from the Coast about 150 miles, a total of about 60,000 square miles. Within this area there are 23,000,000 people, practically one fifth of the total population of the United States, and there are 36,000 miles of railroad of the heavy traction type. Some of these rails have already been electrified, as for example, parts of the New Haven, New York Central, and Pennsylvania, but this is a very small percentage of the total. Within the district there are 96,000 industries, and of these 76,000 require power. Already 4,000,000 kw. of generating capacity have been installed within this Zone and produce something over 10,000,000,000 kilowatt-hours yearly.

To complete the Superpower System will require the interconnection of the power plants within the Zone. To do this our transmission experts deem it advisable to use a general zone transmission voltage of 110,000. In the case of power development extraneous to the zone and at considerable distance from it, such as in the Niagara and St. Lawrence districts, it is deemed advisable to transmit at 220,000 volts, and one of the prime objects in mind for the successful and economic handling of such a potential was that such transmissions be unhampered with the requirement of multiple switching points. In other words, that the power be transmitted in bulk from the point of development to a single point of delivery for distribution within the Zone.

Let us consider for a moment the recommendation with regard to 60 cycles as a standard for the Superpower Zone. This frequency is inevitable as the supporting data of the report will show, and it means but one thing; namely, that we must begin to live into the production and use of high-powered steam-turbine generators designed for 60 cycles. It has been and it is now my belief that the single-phase system of electric traction from an electrical efficiency standpoint is higher than that of the 3000-volt direct-current systems, when there is no intervening substation between the source of power and the traction units; but the choice of the traction system is secondary in importance to the proper choice of a standard system of power from which either system of electric traction is to derive its energy. In stating that a frequency of 60 cycles should be selected

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for the Superpower Zone, I am fully aware of the fact that this robs the single-phase system of one of its potent aids looking toward high efficiency, thus bringing the two classes of electrification more nearly together from an economical standpoint.

I am glad also to embrace this opportunity to say that I view with the deepest concern any tendency toward the recommendation of individual power systems for railroads. The public electric utilities should be sole producers of power from which railroads should receive their energy. The public utilities are in the power business, and know the power business, and should continue in the power business; and the railroads are in the transportation business, and should continue in the transportation business. The electrification of railroads will be retarded, their costs will be increased, and their reliability of service will suffer by the existence and construction of power plants to supply their individual needs. Per contra, the electrification of railroads will be tremendously accelerated when they know that adequate, cheap, and reliable power is made available to them by the people in the power business; and nothing can be made more patent than that this will be so when, through multiple power stations and transmissions, power can be tapped therefrom at many points along their lines.

We are on the verge of a great industrial expansion and the two great arms supporting it are power and transportation; and we must therefore develop a system of transportation which will permit the capacities of railways to expand to meet the necessity of carrying the raw and finished products, so that we can back up the production of the country to meet the world's competition.

With regard to coal let us not forget that while conserving that coal annually it will mean also the conservation of the labor of 50,000 miners who are literally throwing their work away while the world is yielding up this veritable treasure only to be wasted; and let us not forget that the investment necessary to a regional plant will effect economies, the return on which will cover that investment in three years.

Reference has been made to the savings that may be effected through the further electrification of industry and railroads. Returning for the moment to the electrification of railways, it is shown that the returns are not so great as those accruing from the electrification of industry. On the other hand, 11 to 19 per cent or an average of 14.2 for the electrification of 19,000 miles of track is no small sum; but the point here to be considered is the fact that this result is based on the existing traffic of 1919, to be much enhanced by immediately succeeding years. The thought that must be principal with us is that we must begin now to develop that system of traction which will permit a facility of expansion to cope with the quick growth of traffic requirements—and electrical movement is the only means to that end. We must speed up our main lines, yards, and terminals, and there is no hope that steam can accomplish this on our present limited track service in the zones where the density of traffic is high.

In the matter of hydro-electric power for the Superpower Zone, it is a fact that as of 1930 the ratio of hydro-electrically produced power will only be 21 per cent of the total to be generated. It is of greatest importance to note, however, that through the system of transmission interconnection, the maximum amount of water power available could be collected and so make each square mile of drainage area yield up the greatest number of kilowatt-hours. When the power of a single river is connected to the lines of a single system, the service factor of the river, especially those rivers where storage is unavailable, can not be made to correspond with the load factor of the load. Interconnection, however, of several systems permits diversity of load application and the service factors of rivers can therefore be better correlated with the loads of the several systems.

You may be interested to know how we got our appropriation from the Government. It was by a frank statement that the money would be used to show the people what might be done if we co-ordinated our power systems. We explained that we were not asking a dollar from Uncle Sam to construct the system, that it should be constructed lock, stock, and barrel by the private interests of this country, and we constantly kept in mind that good saying of President Harding that we should have "more business in Government and less Government in business" so that you must eliminate from your minds any thought that the Superpower System to be constructed will be owned or controlled by the Government.

There is no instrument that has advanced so much the possibility of superpower as the electric utilities. They are the very foundation for the coming existence of superpower and they are the logical ones to put it on the map.

We have shown how a large amount of coal, capital, and labor can be conserved. The electric utilities, like many other corporations through these difficult times, have been fighting for their very existence. Splendid management and the observance of every possible economy is bringing them through the storm, and out of this good work accomplished will arise the Superpower System to carry on to higher economy and results. Our only danger lies in the fact that we do not recognize immediately this great second period that is now upon us—not coming, but upon us—in which we can practice the economies cited. The public service commissions have a duty to perform in this great movement toward the elimination of waste and that will be in rewarding capital by giving them a proportionate per cent increase in return wherever it is possible for them by economic operation to make a reduction in rate. Today, the bogey as to a permissible cost of money has been set low. To build such a regional plant as has been described, one must buy money just as they have to buy bricks and machinery and unless a fair return is offered, capital can not be obtained. It is fair to assume that the rates on power have been scaled down by the Commissions to what in their conscientious judgment is fair and a fair plea is that additional reward be given to capital if, through the exercise of efficiency both in machinery and management, a further reduction in those rates can be made.

In the case of the New York, New Haven & Hartford Railroad, the load factor on that system is excessively high, due to the high ratio of passenger tonnage to freight tonnage. One of the last contracts I made for the New Haven Road was that with the New York Edison Company in which a load factor of 70 per cent was guaranteed. In the early days of 1905 when the New Haven road was electrified, we had to put 100 per cent of their dollars into the line, and 100 per cent for power into locomotives, and 100 per cent into power stations. In other words, they had to do the whole thing. Now, when we electrify, let us eliminate for the railroads the 100 per cent for the power station; let us eliminate from an investment point of view the 100 per cent for the locomotives by standardizing equipment and securing their purchase through equipment trust bonds and thus leave only 20 to 25 per cent capital requirement on the part of the railroads for the construction of their distribution and contact systems. We must construct these great power stations and transmission systems so that power shall be available to the railroads just as it is to us when we go over to a socket to turn on the light in a room, and it must be adequate, reliable and cheap.

Discussion of Address by W. B. Potter

Mr. Murray mentioned that the return on the investment would be something over 14 per cent as the result of the reduction in cost of operating railroads electrically as compared with steam. That figure is rather interesting. He mentioned a range between 11 and 19 per cent and I think that these figures are not so very far from many of the investigations we have made.

There is, however, another element entering into the economies of electrical operation which I think well worth emphasizing. The value of property is what you can get out of it, and if you can increase the amount of traffic over a railroad by 5 per cent you have increased the value of the property 5 per cent. Many of the railroads, in normal times at least, operate at nearly their full capacity, and electrification would mean an increase in the amount of tons they could handle. As to passenger service, it means trains more nearly on time. The reliability of electric power is proved, as compared with steam. While it is true that each steam unit is an independent source of power, at the same time broken down locomotives on the track are quite apt to interfere with passenger service.

The bringing together of all those little isolated plants seems to me like bringing together rainfall into Niagara—both are waterfalls. One has value, it is true, but of no particular value to move the industries of the world. But the bringing together of these individual power plants, and the creation of this superpower scheme, makes for the district covered by it a unified source for maintaining industry that could not be met throughout the world.

If the co-operation of the various interests involved is as successful in carrying out the undertaking as Mr. Murray has been in securing the co-operation of those with whom he has been associated in the preparation of this report, we can ask nothing further.

Discussion by A. H. Armstrong

The question of power supply is of first importance in every proposed railway electrification and I cannot too strongly endorse the valuable work done by Mr. Murray and his Commission in their careful analysis of power requirements and their recommendations for the future. Electrical engineers must fully recognize the utmost importance of continuous power for electrified railways, as no one cause would so quickly discredit the success of electrifications as unreliable power.

To supply that security against breakdown, which is so necessary to electric railway operation, imposes an almost prohibitive burden upon the railway company itself, if a power house containing ample reserve is installed by the railway company and used exclusively for its own purpose. The load factor of an electrified road under favorable conditions may be as high as 70 per cent but in many instances where electrification is fully justified the load factor may fall below even 40 per cent. If in addition to the variation in the daily load there is added ample provision for seasonal variations, such as grain movement in the fall on our western roads, and also there are provided reserve units in addition, it becomes apparent that the total investment in a railway power station is so great that the burden of its fixed charges seriously impairs the economic advantages of electrification.

Although the first thought of the railway operator is to look favorably upon an independent power supply entirely under railway control, a study of existing installations discloses the fact that some of our largest electrified roads depend in whole or in part upon power purchased from public utility companies. This tendency toward the purchase of power has become clearly defined during the past few years and indicates the necessity of adopting a uniform frequency of supply, in order to benefit to the fullest extent from the interconnection of power stations and systems. The recommendation of Mr. Murray and his Commission that 60 cycles be recognized as the standard frequency of power supply in the United States is in full agreement with the trend of sales of turbines and transformers manufactured by the General Electric Company during the past ten years, which clearly discloses the rapid ascendency of 60-cycle apparatus. However much disagreement there may be as to so-called systems of railway electrification, electrical engineers should be in fullest accord as to the benefits of adopting 60 cycles as the standard frequency for all future power installations.

Similar action has been taken in many foreign countries upon the recommendations of railway electrification commissions appointed by the Government to study the matter of electrifying the railways in their respective countries. In England, France, Belgium, Holland and other countries a standard of 50 cycles has been adopted for power generation and transmission, and the distribution of power at a uniform frequency throughout the country will constitute one of the greatest factors in bringing about electrification of railways. The report of Mr. Murray and his Commission may therefore be looked upon as the first serious attempt to bring about equal benefits in this country by recommending the standardization of 60 cycles, which is already so firmly established. Although this Commission lacks any power to enforce its recommendations in this respect, it is to be hoped that the soundness of its findings will be recognized by all electrical engineers and every individual effort be made to standardize a universal 60-cycle power supply.

Discussion by O. F. Allen

The total power so far used, or even contemplated for the next few years, in the centers of population of Europe, is so small compared with the tremendous problem Mr. Murray has studied, there is nothing to say on that phase of it.

It will perhaps be of interest to you if I relate one illustration of the European situation. An Italian railway now electrified delivers freight to a French railway operating by steam. I asked the engineer of the French railway if they were going to electrify under the existing industrial and economic conditions, and if they could afford to electrify. He replied: "We cannot afford not to electrify, as with the electrified lines the Italians are giving us freight faster than we can handle it. As we have a contract with them for several years to run to take the freight we have either got to double our lines or electrify them, and it is cheaper to electrify than to double track."

Another phase over there is that following the terrible destruction from the war, they have been able to study the combination of heavy traction and power plant development. The two things are going hand in hand. In France they are building quite substantial power plants up to over 200,000 kw. each, and they are laying out 220,000-volt transmission lines. It is hoped to build them in three to five years. They are combining so that they can use all their power plants in all industries, and are not seriously considering any plants of small size. The railroads are considered customers for power plants as much as other industries. They are treated as part of the power scheme. and this will help railway electrification in France,

Discussion by H. R. Summerhayes

We have already in New England a superpower system on a smaller scale: New England power companies operating a large number of hydro-electric stations. The New England situation is bringing into being an interconnecting system among many power companies, operating on a sufficiently large scale, and showing the practicability of the system Mr. Murray proposed.

There is a similar situation in the southeastern states. While they do not transmit power from one end of the system to another, the power generated at one end of the system may be carried part way and the power generated at this intermediate point transmitted further on so that finally the surplus power at the lower end of the system relieves the situation at the upper end.

Last year, under the pressure of economic necessity, that is, because of shortage of water, a number of the systems surrounding San Francisco were hastily tied together by links of transmission systems and put on one load despatcher with a resulting saving of a great amount of fuel.

In the larger system there are still some engineering problems to be met. One little difficulty is frequency, and in that I heartily subscribe to Mr. Murray's declaration that 60 cycles will be the universal frequency for the power network. When we come to the transmission of power it at first appears that a lower frequency may be desirable for a straight-away transmission, but in working out the network 60 cycles may actually become cheaper. It is, surely, preferable on account of the necessity of standard frequency and on account of the very much lower cost of 60-cycle machinery. We must remember that in the utilization of machinery—motors, transformers, etc.—in the distribution system, they represent a much greater investment than the generating apparatus.

"General Views of Grand Central Terminal Area from 50th Street Before and After Electrification"

What the Superpower Survey Means to the United States

By H. Goodwin, Jr.

Consulting Engineer, Philadelphia

Mr. Goodwin was a member of the committee that made the Superpower Survey for the U. S. Geological Survey, and is specially qualified to discuss its import. While the investigations of the Superpower Survey were to a large extent local, the fundamental economic principles and deductions will apply to almost all sections of the country; hence the findings and recommendations are of concern to the whole country, and Mr. Goodwin has elected to discuss its significance from this broad standpoint.—Editor.

The Superpower Survey has been discussed in its preliminary stages so frequently in the technical press that it should be necessary here only to remind the reader of it before proceeding to the discussion. It is described very well by the title of the report which has been issued as professional paper No. 123, of the U. S. Geological Survey, entitled: "A Superpower System for the Region between Boston and Washington."

The Superpower System is, of course, electrical, a network of moderately high voltage supplied by economical generating stations at strategic points for generation. The region studied runs inland about 150 miles, covering the intense industrial area of the North Atlantic Seaboard. The survey was made by a special staff under the U. S. Geological Survey.

But the Superpower Survey was more than is at first suggested by the title of the report. It was the first effort to determine with any real accuracy the power, fuel and electrical requirements of a large section of

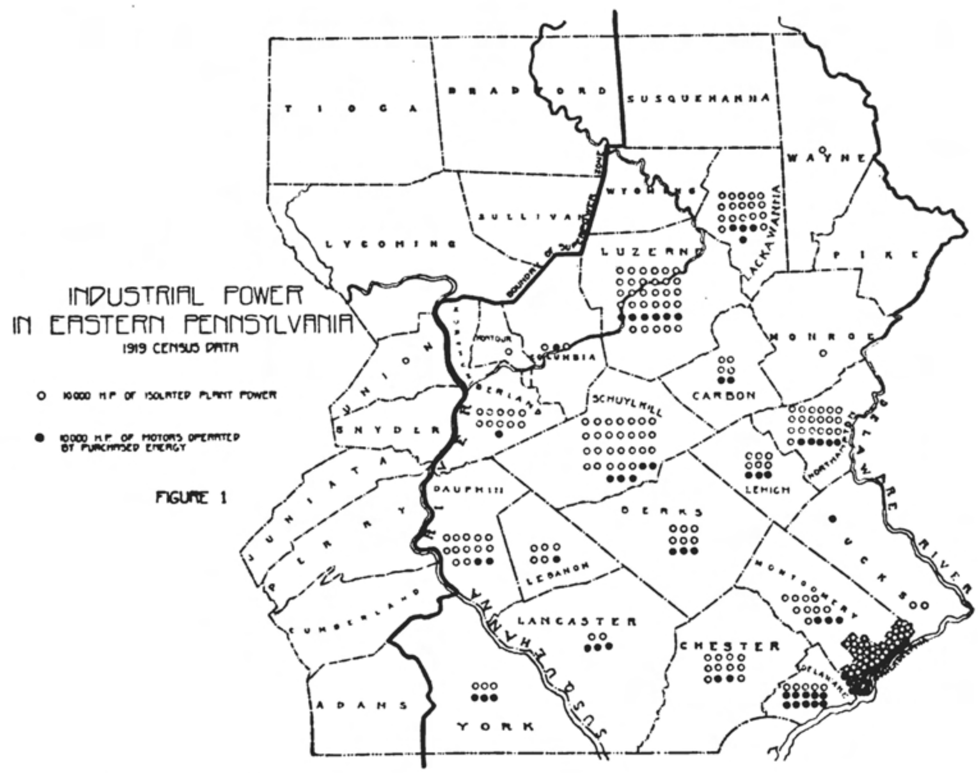

Fig. 1. Map Showing Distribution of Industrial Power in Eastern Pennsylvania

our country. The tremendous growth of the electrical industry in all its branches is a matter of record. The possibilities of the future have been an open subject for prediction and prophesy by those so inclined. Some prophets have been so enthusiastic and have spoken in such glittering generalities of the "unlimited possibilities" of the electrical future, that those who must supply the funds for the development have been inclined to discount the glowing statements. These financiers have seen other propositions developed to a saturation unappreciated by their enthusiastic advocates and have seen them crumble with the effort at over development. So a great progressive move is made by the Superpower Survey in the definite study of a large territory to determine the proper ultimate practical development, and a plan to reach that development as soon as conditions will permit.

But any initial, progressive step like this is more than a local benefit; it is a great step in advance for the whole country. The underlying economic principles are the same no matter what section is considered and the means for working out those principles will show greater similarity than diversity of local conditions would at first make apparent. So the Superpower Survey should interest every progressive individual throughout the length and breadth of our country.

Therefore the title of this article has been chosen to be: "What the Superpower Survey means to the United States." This title embraces all that is to be said, though on account of the size of the subject it is unfortunate that the article cannot include all that might be said under such a title.

Natural Divisions

Any such proposition as a Superpower System may for one purpose or another be dealt with from various aspects: executive, legal, financial, commercial and engineering.

We should have a full appreciation of these various aspects, and carry on our work in any one so as to aid those who are engaged

TABLE I: MECHANICAL POWER SUPPLY EQUIPMENT

Divided by Character of Pow

Character of Power Supply	Plant Size H.P.	ESTABLISHMENTS		POWER SUPPLY EQUIPMENT									
					Prime Movers								
		Number	Average H.P.	Aggregate H.P.	Total H.P.	Steam Engines		Steam Turbines		Internal Combustion Engines		Waterwheels	
						No.	H.P.	No.	H.P.	No.	H.P.	No.	H.P.
	No Power	407	—	—	—	—	—	—	—	—	—	—	—
Steam Power Only	1/200	452	71	32166	32166	535	31713	9	453	—	—	—	—
	201/500	87	333	29030	29030	174	27045	16	1985	—	—	—	—
	501 and above	72	1920	138052	138052	337	70878	79	67174	—	—	—	—
	Sub Total	611	326	199248	199248	1046	129636	104	69612	—	—	—	—
Purchased Electric Power Only	1/200	3701	26	95580	—	—	—	—	—	—	—	—	—
	201/200	142	312	44489	—	—	—	—	—	—	—	—	—
	501 and above	103	1050	118676	—	—	—	—	—	—	—	—	—
	Sub Total	3946	655	258745	—	—	—	—	—	—	—	—	—
All Other Power	1/200	1341	40	54293	38753	319	16741	7	286	960	15827	167	6899
	201/500	165	320	52501	32872	215	24069	12	785	56	2978	75	5040
	501 and above	155	2290	354363	208708	465	111465	54	77578	63	10622	71	9043
	Sub Total	1661	278	461157	280333	999	152275	73	78649	1079	29427	313	19982
Total (Power)....		6218	148	919150	479581	2045	281911	177	148261	1079	29427	313	19982
Grand Total.....		6625	—	919150	479581	2045	281911	177	148261	1079	29427	313	19982

in the others. In this light the Superpower Survey considered commercial and engineering matters only. There are details to be worked out in regard to executive, legal and financial matters. While there are no insurmountable difficulties, it will be evident that some matters could be simplified by proper technical development, both engineering and commercial.

It is here then that the report should engage the attention of most. The results of the Survey should not merely interest us as finalities; instead, with the breadth of view which these results will impart, each one should survey his territory in like manner to see how the findings may be applied.

The division of the work of the Survey is a fundamental that was proved to be sound. Therefore a statement of it is more than narrative; it is a necessary concept for the full appreciation of the work accomplished. There were three sections of the work, viz.:

Railroads
Industries
Power and Transmission.

It was required of the first two sections to determine the amounts of the railroads and industries that might be economically electrified and the saving to be accomplished thereby. Of the third section it was required to design a system to interconnect the present utilities and carry the load determined by the other two sections. It is thus seen that commercial matters were involved in the work of the first two sections and engineering in all three.

COMMERCIAL PHASES

From the beginning it was evident that, regardless of engineering analyses or possible economies to be obtained, the final supply of power to any establishment would necessitate negotiations exactly similar to those now conducted by the new business departments of the central stations. Therefore, every effort was made to develop the data in the best form to aid the central stations in connecting the load that it was shown should be supplied by them.

AND FUEL USED IN FOUNDRIES AND MACHINE SHOPS

er Supply. 1919 Census Data

Operated by Purchased Energy				ELECTRIC MOTORS				FUEL USED			
Total H.P.	Electric Motors No.	Electric Motors H.P.	Other H.P.	Total No.	Total H.P.	Run by Current Generated in Establishment No.	Run by Current Generated in Establishment H.P.	Coal: Anthracite Long Tons	Coal: Bituminous Short Tons	Coal: Total Equivalent Bituminous Short Tons	Coke Short Tons
—	—	—	—	—	—	—	—	4230	3304	7114	1077
—	—	—	—	1213	8713	1213	8713	69628	153924	216564	48561
—	—	—	—	1900	19738	1900	19738	40664	105987	141987	24465
—	—	—	—	9491	133800	9491	133800	243808	598265	817865	113638
—	—	—	—	12604	162251	12604	162251	354100	858176	1176416	186664
95580	13971	95580	—	13971	95580	—	—	66177	102742	162242	109625
44489	4158	44489	—	4158	44489	—	—	24835	58478	80778	31114
118676	10144	118676	—	10144	118676	—	—	32453	147478	176578	63708
258745	28273	258745	—	28273	258745	—	—	123465	308698	419598	204447
15540	1654	13033	2507	2331	17617	677	4584	43195	101056	140056	38735
19629	1726	19454	175	2686	30564	960	11110	40088	137558	173558	39182
145655	9093	145455	200	14068	206497	4975	61042	152280	931306	1068000	95199
180824	12473	177942	2882	19085	254678	6612	76736	235563	1169920	1381614	173116
439569	40746	436687	2882	59962	675674	19216	238987	713128	2336794	2977628	564227
439569	40746	436687	2882	59962	675674	19216	238987	717358	2340098	2984744	565304

How often has a central station desired to know the amount of load that might possibly be connected in its particular territory? Or, lacking that, even the total power in use in the territory? This is the situation that presented itself to the Survey, except that it was magnified for the whole zone. Since practically none of the central stations could supply this information other means were adopted. It was decided to obtain the information directly from the railroads. But the industries still presented a great problem. The last census for manufacturers was that for 1914. The census bureau was questioned about the 1920 census then in the process of collection. The reply was that with the co-operation of the Survey they believed they could furnish the information desired.

Industrial Power

The original intention was to get just the regular information on power and fuel used by the industries in the Superpower zone. The work in the census bureau was under the direction of Mr. E. F. Hartley, Chief Statistician for Manufacturers. He entered into the proposition with great spirit and exhibited the strongest desire to make the census bureau of the greatest commercial service. The result is that instead of having just an ordinary summary of the power and fuel used by the industries, there is presented in the Superpower report the greatest, in fact, the only analysis of industrial power and related fuel use on a large scale that has ever been made.

As an example, Table I shows the mechanical power supply equipment and fuel used in machine shops. The report will contain over fifty such tables, general and detail, covering all branches of manufacturing and mining. The value of these can be appreciated by a little study of this sample. Table I shows by the column headings the various types of prime movers and electrical equipment used, and also the fuel. Looking down the left side it is seen that all the items are divided by character of power supply, and then subdivided by plant size. It is to be noted that the fuel associated with each power group is shown separately; for instance, plants operating entirely on purchased electrical power have in this industry 142 establishments with 201 to 500 horse power. The total rating of the motors is 44,489 horse power.

In these establishments there is used for other purpose than power production 24,835 tons of anthracite and 58,478 tons of bituminous coal, which is equivalent to 80,778 tons of bituminous total. This table deserves the study of every man interested in industrial power, so that when the report comes giving similar tables for all industries he may be able to grasp them quickly and understand the analyses worked out from them. From these tables the Survey determined by analysis and consultation with experts in the different industries the additional amount of power that might have been supplied to each and all the industries.

The tables, of course, apply only to the Superpower zone, but a thorough study of them should give a new sense of proportion useful in any territory. In fact it is probable, having sufficient familiarity with the special data for the Superpower zone, that useful approximations could be made from the general census tables for the other sections of the country.

TABLE II: MECHANICAL POWER SUPPLY EQUIPME

Divided by Plant Size.

Plant Size H.P.	ESTABLISHMENTS REPORTING POWER		POWER SUPPLY EQUIPMENT									
				Prime Movers								
	Number	Average H.P.	Aggregate H.P.	Total H.P.	Steam Engines		Steam Turbines		Internal Combustion Engines		Waterwheels	
					No.	H.P.	No.	H.P.	No.	H.P.	No.	H.P.
1/200	338	42	14173	7794	151	6341	2	24	21	195	41	1234
201/500	37	305	11316	6124	111	5985	0	0	2	4	2	135
501 and above	38	5550	211730	170869	327	103481	42	18588	23	48500	4	300
Total	413	575	237219	184787	589	115807	44	18612	46	48699	47	1669

Distribution of Industrial Power

But this is not all that the census did for the Survey and engineers. After each industry had been analyzed the power was tabulated by counties, subdivided by plant size. Table II shows Northampton County, Pa., as a sample. The division of power by plant size in each county was only made for the Superpower zone. But the 1920 census will show for the first time the power in each county in the United States, tabulated with the same column headings as Table II.

It is interesting to remark that these special tabulations were made economically possible by the introduction into the census of manufacturers of electrical tabulating machines.

To illustrate the distribution of power graphically, Fig. 1 shows a map of the section of Pennsylvania in the Superpower zone. Indicated thereon by open circles is the total rating of prime movers and by solid circles the motors operated from purchased electric energy. On the completion of the 1920 census of manufacturers it will be possible to construct such a map for the whole country or any portion of it.

Growth of Industrial Power

But of course, the load that might have been carried in 1919 is not sufficient information on industrial power. It was not then connected to central station systems and may not be till those systems are extended. Also the Superpower System must be constructed to care for increases for a number of years to come. This then brings in the question of growth of industrial power. The past growths were determined as a basis. The curves in Fig. 2 show by solid lines the form of the growth. The first point of interest is that if the central stations ("Purchased H.P.") continued to grow at the rate they have in the past, their load would soon exceed the total power of all the industries—an obvious impossibility. The dot and dash line shows the amount of power that might

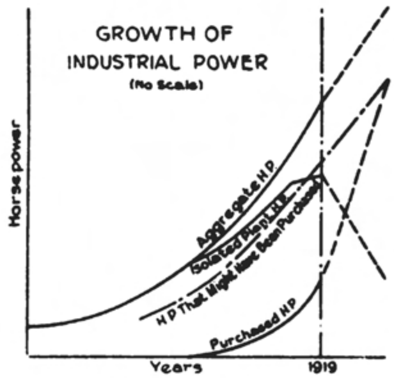

Fig. 2. Curves Illustrating Growth of Industrial Power

have been carried at any time as determined by the Superpower analysis of the industries. It is the object of the Superpower to have all this connected by 1930. This means that the central station curve will continue up as shown. But look at the "Isolated Plant" curve and note what the result is there. It means that this curve must turn down and show a more rapid rate of decrease of power than the maximum rate of increase. During the past few years the central stations have shut down much isolated plant power and taken practically all the increase, but enough new plants have gone in so that the total isolated plant power has been held practically constant. Now the real fight begins. Iso-

NT USED IN NORTHAMPTON COUNTY, PA.

1919 Census Data

Operated by Purchased Energy				Electric Motors				Number of Establishments Reporting No Power
Total H.P.	Electric Motors		Other H.P.	Total		Run by Current Generated in Establishment		
	No.	H.P.		No.	H.P.	No.	H.P.	
6379	1392	6379	0	1443	7021	51	642	—
5192	325	5192	0	347	5437	22	245	—
40861	2134	40861	0	10038	232743	7904	191882	—
52432	3851	52432	0	11828	245201	7977	192769	49

lated plants must be shut down faster than they were ever put into operation, if the present rate of growth of the central stations is to continue. With this condition confronting them, of what immense value are the data compiled by the census bureau for the Superpower Survey! How necessary is it for the central stations to study the situation most critically and formulate definite plans for procedure! And, be it remembered this is not for the benefit of the central stations only, but even more for the industries. For the central stations it means *growth*, for the industries it means *economies*, because the determinations of the Superpower Survey were predicated upon dollars and cents economies to the industries to be supplied.

Curves similar to Fig. 2 can be plotted for any states, cities or other areas throughout the country, from the final census publications, and a little further comment may therefore be useful.

Data on the power used by manufacturers were first collected by the census for 1869. Since then it has grown rapidly due to two causes, viz., growth of industry, and growth of use of power per unit of product. An appreciation of the values of these two factors is necessary to a proper understanding of the curve for a particular territory. Many old basic industries, formerly strong in the Superpower zone, most of them heavy power users, are moving west. At the same time the "finishing" trades are increasing their use of power to try to keep down costs and offset the increasing distance to the center of consumption as it moves west. These industries have the advantage of an estab-

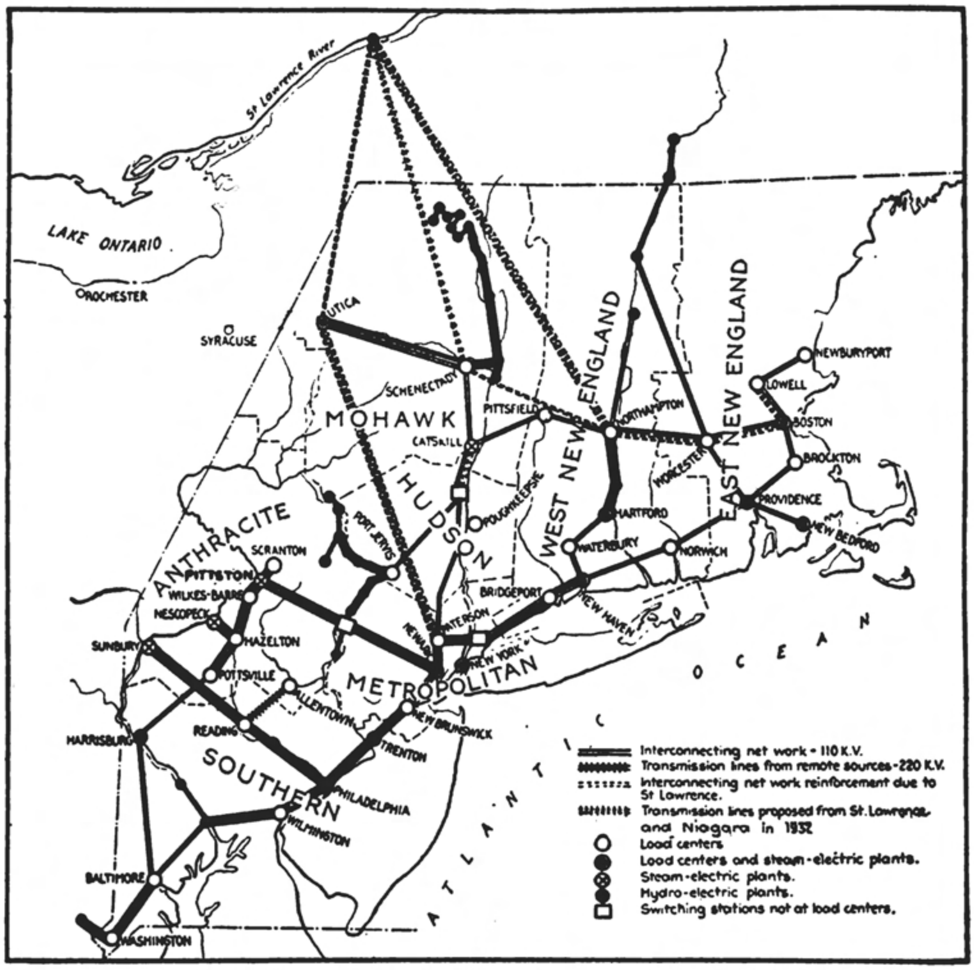

Fig. 3. Map of Proposed Superpower Transmission System for 1930

lished name and reputation, and in normal times proximity to the ports for foreign trade.

The form of the curve "Purchased H.P." is familiar to all central station men. An understanding of the logarithmic growth in the past is necessary to a prediction of its course in the future. Before the "Purchased H.P." curve started, the central stations were

nature *physical*, *commercial* and *financial*. All have a cumulative effect and account for the logarithmic shape of the curve.

The *physical* factor has been pointed out above. A 500-kw. central station could not supply a 1000-kw. industrial load; but as the size of the station grows to 3,000 kw. to 5,000 kw. or more it is physically possible to supply the 1000-kw. industrial load, and

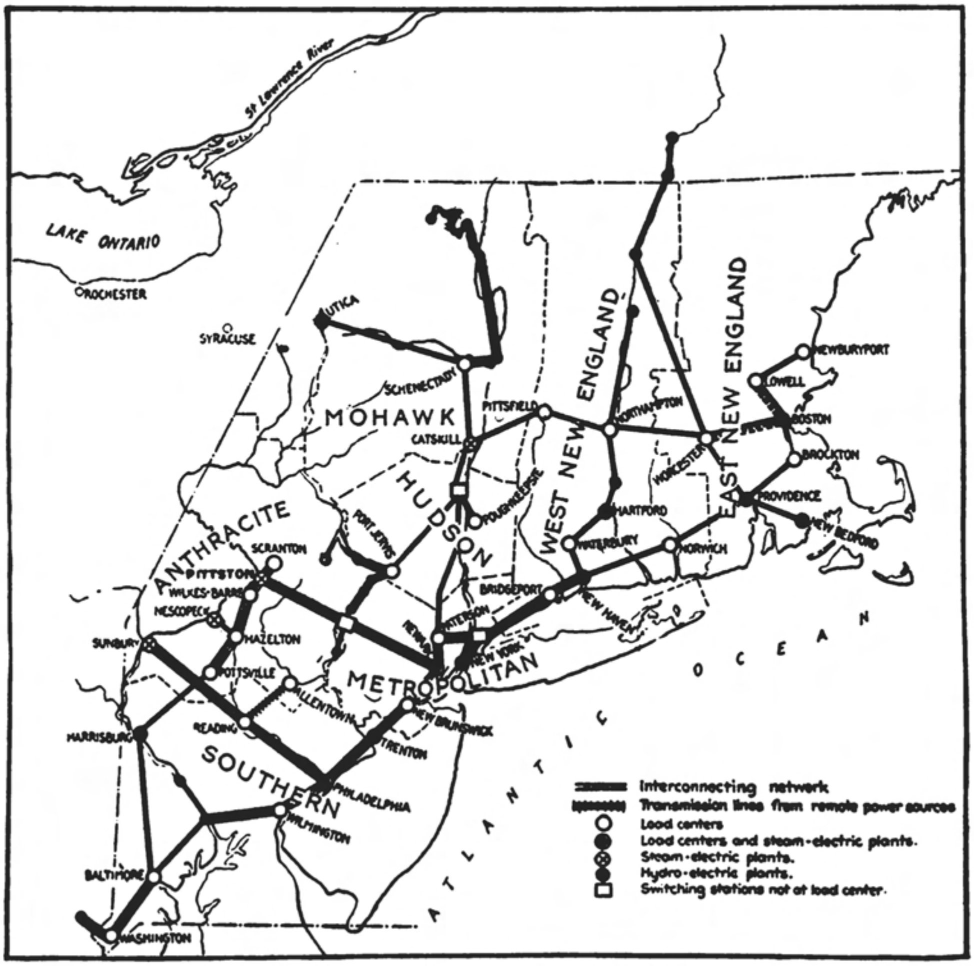

Fig. 4. Map of Proposed Superpower Transmission System for 1925

in existence supplying street and house lighting in all communities of importance. Motors then became commercially practical to replace some of the small engines in use by the industries. The size of these motors at first could only be comparable to the lighting loads, which were small. But the gradual addition of small units of load built up the central stations till they could handle larger loads. The three factors involved were in

that addition makes it enough larger to handle an even larger load.

The *commercial* factor acts in a similar way. The central station must grow to be considerably larger than an industrial load before it can generate cheaply enough to cover the distribution cost. Most larger loads have been supplied with very little profit at first, but have increased the total load so that costs have been reduced, profits increased on the smaller loads, and ultimately become profitable through the addition of larger loads.

The *financial* factor is again similar. It is hard for a new unproven enterprise to obtain capital. But when it is successfully operating and the field ahead is apparently large, it can attract new capital each year in ever increasing amounts.

New capital is necessary for the physical extensions for new loads and can be had if commercial rates are such as to insure a return. The three factors work together to produce a curve of ever increasing growth of central stations till the saturation point is reached, or those supplying the finances fear it is approaching. The curves in Fig. 2 show in what a free field the central stations have been working below "horse power that might have been purchased." But they also show that the critical or saturation point will come very speedily with similar progress in the next few years. Therefore in these curves are found justification for the optimist, reason for the conservatism of the pessimist, and a chart for the guidance of the true progressive.

In concluding this section it is interesting to note that the largest industrial establishment, measured by power used, relied entirely upon purchased power, and several others of the larger ones were also supplied very largely by central stations. Also that the industry of manufacture of electrical machinery was the most efficient in its use of fuel.

ENGINEERING PHASES

Fundamental Principle

Most fundamental engineering principles are simple and should be understood by all, but unfortunately are often clouded over by the mass of detail that enters into our large developments of the present day. The fundamental principle of design of the Superpower System is the expansion, to cover the whole zone, of that principle which has made central stations successful in their particular territories. This is the principle of unification of systems of power supply. While this has been done in some sections quite completely there are other sections where much is still to be desired. The unification of local systems combined with the general interconnection throughout a large territory would make an ideal arrangement.

The Superpower System

The idea of the survey was to determine the ultimate necessities of the zone and design a system to meet them. A ten year period was decided upon and plans prepared for 1930. To determine the development of the system the portion of it that would be needed and could be built by 1925 was also decided. Fig. 3 shows the system proposed for 1930 and Fig. 4 that for 1925.

The interconnecting network has been based on 110,000 volts. There are a few lines to be of the highest commercial voltage, and therefore figured at 220,000 volts. These latter lines are for bringing power into the load area from points of economical generation outside the load area. They are:

A line from Sunbury to Reading to Philadelphia,

A line from Pittston to a switching station for the upper Delaware water power to Newark,

Lines from the St. Lawrence, if that water power is developed some time after 1930.

Three stations are proposed in the anthracite field to use the small sizes of coal, located at Pittston, Nescopeck and Sunbury. These are not mine-mouth plants for they must be located conveniently for good condensing water, which is rather scarce in this region, and they must use the small sizes of coal from many mines. Mine-mouth plants in the bituminous field were not found practical as it would be necessary to go too far west to get condensing water.

Fig. 4 shows that by 1925 the system should be pretty well outlined but that the stations would not be developed to full size.

Studying these maps shows that New York State should continue to hold its place of industrial prominence. The water powers of the Adirondacks shown are among those most easily developed and should supply economical power to the central eastern section of that state. This same section is in the best location to receive later the power from the St. Lawrence River for further development. Industrial conditions in this section are now good, and if housing and other essentials keep up with power supply, this section should have a great future growth. Locations near the Delaware and Susquehanna water powers also offer attractions for the future, but on account of the nature of these developments they will have to be made to care for some large bulk demands rather than for the gradual development of industries near them.

Importance of Distribution

Those keenly interested in distribution have long lamented the lack of consideration that is given to its economics in practically all central stations. Generation receives close study and the last ½ of 1 per cent in efficiency is sought out like the "lost sheep." But when the current has been put on the distribution system, little more concern is shown for it. It is true that distribution is a most complicated problem, but all the more reason for giving it the required attention.

The Superpower zone was not found to be any exception as regards distribution. The records for generation were entirely satisfactory for their purpose, but it was impossible in the time assigned to secure records of the distribution of energy.

There is no question that power can be generated in large well located central stations, and even transmitted many miles to industrial centers, more cheaply than it can be generated in even the largest industrial plants. But when it is there it must be distributed. No matter whether power is generated or purchased by a central station, the distribution is there and calling urgently for attention. The Superpower Survey investigations confirmed this for the zone. So the Survey means an awakening to the value of exact studies of distribution throughout the country.

Economies in distribution extend through every detail from the consideration of the proper size secondary and transformer to use for house lighting, through the various demands of power supply, through the combinations of apparatus in substations, through main feeders to the points of bulk supply of power. Some of these points were naturally more accented by the Survey than others, but all need great study at this time.

Substation Practice

The System of the Commonwealth Edison Company, in Chicago, is acknowledged to be an example of central station practice approaching perfection in the fundamentals and has been studied by most men well advanced in the art. Yet looking at the other systems throughout the country, it would appear that the degree to which combinations have been carried in Chicago to take advantage of diversity are almost unappreciated. From one substation which is supplied by a-c. feeders the company furnishes service for light and power on a-c. circuits; and through synchronous converters working *in parallel* the same station supplies four railways with 600 volts direct current through independently metered feeder groups. The economies in investment and operation are obvious and sufficient to overcome any old prejudices against such combinations.

The transmission line of the Chicago, Milwaukee & St. Paul Railroad is owned by the railroad. But in the light of experience the electrical engineer for the road, Mr. R. Beeuwkes, said at the Pasadena Convention of the National Electric Light Association a year ago that he considered it would be better for the central station to own and maintain the transmission line. This is an example of thought and experience from the other side. If there are fundamental economies of considerable amount to be effected by the central station supplying current at trolley voltage—and it is done in many cases—surely that principle should become one of usual practice instead of the exception.

In the station of the Commonwealth Edison Company, referred to above, advantage is obtained not only from the diversity of the loads but also from the improved power-factor due to the operation of the converters. If motor-generator sets were necessary on account of the trolley current characteristics, further economy would be possible by the proper design of the motors. The motors could be designed for a certain amount of leading current, so that they could be used for correction of the substation power-factor, maintaining it at unity. The fields could then be controlled by automatic regulators set to hold the voltage constant on the a-c. bus for distributing circuits practically regardless of changes in any of the loads. This is not an expensive scheme for there are certain compensating economies in the construction of the machines.

Automatic Substation Voltage Control

To show by a specific example that such a system can supply good a-c. service with properly designed motors and regulating apparatus, calculations have been made on a transmission line that is considered as going beyond the extreme requirements for the Superpower territory, or in fact for any territory. The assumed line is 50 miles long and is to carry 30,000 kw. at 60 cycles, with 66,000 volts at the generating station. The potential at the receiving end is fixed at 60,000 volts. The size of the conductors has been taken at 500,000 cir. mils. At full load and unity power-factor the voltage drop would be 8 per cent in the line, leaving a small margin for transformer regulation. But the great point is that the drop can be kept constant at all loads and the automatic regulators will hold the voltage constant through all fluctuations of load. As the load drops the regulators would drop the power-factor, thereby increasing the proportionate line drop to hold the voltage constant. As the load swung on again the regulators would increase the fields and the power-factor, thereby decreasing the line drop and holding the voltage constant. In the extreme case of no load, the motors would carry 10,500 kv-a. with zero power-factor lagging. This does not take into account the regulation of the transformers at no load, which would aid in holding the voltage down to a great extent, with much less lagging current. Fig. 5 gives vector diagrams for full load, part load, and no load, showing how the automatic regulators will keep the voltage constant at the receiving substation by changing the fields of the motors, and so varying the power-factor.

This study is of great interest, but there is not space here to go into it further than to say that all calculations seem to indicate the necessity of operating a general system for power interchange at very close to unity power-factor during full load conditions. Therefore every piece of synchronous apparatus that can be taken over by the operating company and operated for the good of the system as a whole is a direct saving in other such apparatus. Further, operation at unity power-factor means that high reactance transformers can be used without fear of poor regulation, and may be used to the fullest extent for the reduction of short circuit intensities, with a consequent reduction in cost of the switching apparatus required.

In closing this particular item of discussion it should be noted that these developments are not purely engineering but have important commercial features.

Distribution Voltages

The careful study of moderate voltage is advocated, although it is appreciated that extra high voltages have a natural fascination. Doubtless the calculations and construction of extra high voltage lines are very interesting but both are simple compared to the complications of calculations and construction for a comprehensive distribution system.

Some very interesting developments have been going on in the last few years in connection with distribution. Since the distribution of power in the zone is going to be a critical point, as has been pointed out above, it is in place here to set forth a few simple points for consideration.

The "Standards of the A.I.E.E." give a series of standard voltages. This standardization is very good and has helped immeasurably in the production of apparatus, etc. But as systems have increased and been compelled to go up in voltage, it has been found in many cases that the steps taken have been too conservative. For certain reasons some of the voltages now in use will probably become more common and standard for particular sections. It is particularly important that such standardization be carried out in the zone.

There is little question that 2,300 volts will always have a place. With its fullest development it has a capacity of from 1,000 kw. to 2,000 kw. per circuit either in three phase or quarter phase. This means that it is available for supplying all but the largest loads.

Above this there is a whole string of voltages from 6,600 volts to 16,000 volts, which were considered for many years the highest voltage safe for cables. It is in the use of

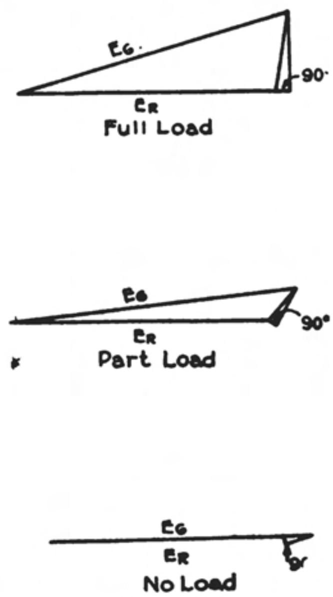

Fig. 5. Vector Diagram of Automatically Regulated Transmission Line

these that many are now finding that they have been too conservative.

Then there comes a group from 22,000 volts to 35,000 volts. These are the highest for which standard three-conductor cable has been manufactured. On account of physical limitations it is not likely that much higher voltages than this will be used generally in three-conductor cable. On account of the same limitations there is also little advantage in the higher voltages of this group; in fact, the lower ones allow a little more flexibility of design. All voltages of cables of this group have a capacity of about 10,000 kv-a., though the lower voltages may be built for a lower capacity while the higher ones may not.

It appears then that there is little necessity for any potential between 2,300 volts and 22,000 volts, and any systems with intermediate potentials should investigate carefully before going on with extensions.

The next voltage that stands out is 66,000 volts. It has several distinguishing features. It is high enough to have a very considerable carrying capacity, as was shown in the calculation in connection with automatic substation voltage control. It is the highest voltage for which transformers and switches are built with solid bushings. (The filled bushings for higher voltages increase the cost of switches and transformers tremendously.) Single conductor cable is now available for this voltage so that transmission lines may be run underground through the heart of city districts at this voltage. Otherwise it is necessary to have a transformer substation on the edge of the city and use lower voltage cables for the underground section. This not only involves the cost of the transformer station, but puts definite limits on the operating characteristics which are not present when there are no transformers.

Lines operated at 66,000 volts are usually constructed with suspension type insulators, but there are many pin type installations from the early days, and some more recent ones with enviable records. With the greater knowledge now had on the subject of design, many engineers feel that the possibility of using pin type insulators is a most important point, and that it should receive the closest attention. Some of the particular advantages are: Rigidity, and therefore greater variety of construction arrangements; narrower right of way; better possibility of combination with towers for holding trolley wires for railroads, so that the railroad distribution system may be made the same voltage as other parts of the general distribution system without a serious compromise or erection of independent towers on the railroad right of way; and as a result of all these, a much lower total annual cost.

It may not be out of order then to consider why suspension type insulators have been so generally used on 66,000-volt lines. There were undoubtedly physical reasons in many cases. An example of this is the Pittsburgh case where the whole system has been designed to change to double voltage. But often it would appear that the psychological cause has been greater than the physical. Some one says: "While we are building let's have a real line." If the "real line" includes suspension insulators in their minds, there is no argument of economy that can persuade the use of the lowly pin type insulator. Finally, precedent points toward the suspension insulator as standard practice, and the advocate of the pin type has to face criticism as a reactionary. But in the face of this criticism it is here advocated that a detailed study be made of the pin type insulator for 66,000-volt lines.

Sixty-six thousand volts is a very worthy potential, and particularly in the Superpower zone deserves the closest study by operating men because of the short runs and frequent substations usually involved.

The Superpower report deals with major transmissions and therefore cannot go into the details of economical secondary distribution—it is too local a matter—but if local distribution is studied in the light of the information in the report it should be possible to show savings comparable with those to be made in generation.

CONCLUSION

The conclusions in the Superpower report have, of course, been worked out for the Boston-Washington region. While these are of great interest, those outside the zone should read for the fundamental truths expressed in terms of the particular region as an example.

The studies of load possibilities in each central station field are most important so that physical, commercial and financial growth may be full and logical.

Distribution is a problem neglected by most central stations, yet with tremendous possibilities for economy. It cannot be avoided, but is brought more to the fore by a superpower system for the bulk supply of energy.

The electrical industry has made tremendous progress and at an increasing rate; let all interested get behind the movement for logical, complete economical development as exemplified by the Superpower Survey.

Abstract of "Appendix C" of Superpower Report on the Electrification of Railroads*

By W. D. Bearce

Railway and Traction Engineering Department, General Electric Company

The most valuable feature of the Superpower scheme as it affects the railroads is not so much the saving in the cost of operation, great as this is, but the increased capacity that will be the result of electrification of existing tracks and yards. Steam operation cannot avoid frightful congestion at the principal railway terminals included in the Superpower zone, as was sadly demonstrated during the war; electric operation can easily do it. The economic feature of railroad electrification in the zone, while secondary, is a considerable item, representing the tidy annual sum of $81,000,000, or 14.2 per cent of the cost of electrification. Other advantages that will result from the development of the Superpower system are discussed in the articles in this issue by Mr. W. S. Murray and Mr. H. Goodwin, Jr.—Editor.

On account of the several railroad electrification projects which are being seriously considered both in this country and abroad, Appendix C of the Superpower Report of the U. S. Geological Survey is of particular interest. This section of the report was prepared under the direction of Cary T. Hutchinson and N. C. McPherson and is subjected "Proposed Electrification of Heavy, Traction Railroads in the Superpower Zone."

* A synopsis of this feature of the Superpower Scheme was supplied by W. B. Potter, General Electric Review, April, 1920.

Out of a total of 36,000 miles of railroads which have been studied in the territory embraced by the superpower zone, 19,000 miles could be profitably electrified, netting an annual saving of from 11 per cent to 19 per cent on the investment necessary. Based on the traffic handled in 1919, the amount of fuel which would have been saved if trains had been electrically operated is calculated at 8,890,000 tons of coal.

The estimated saving in the cost of operation includes a reduction in certain items of

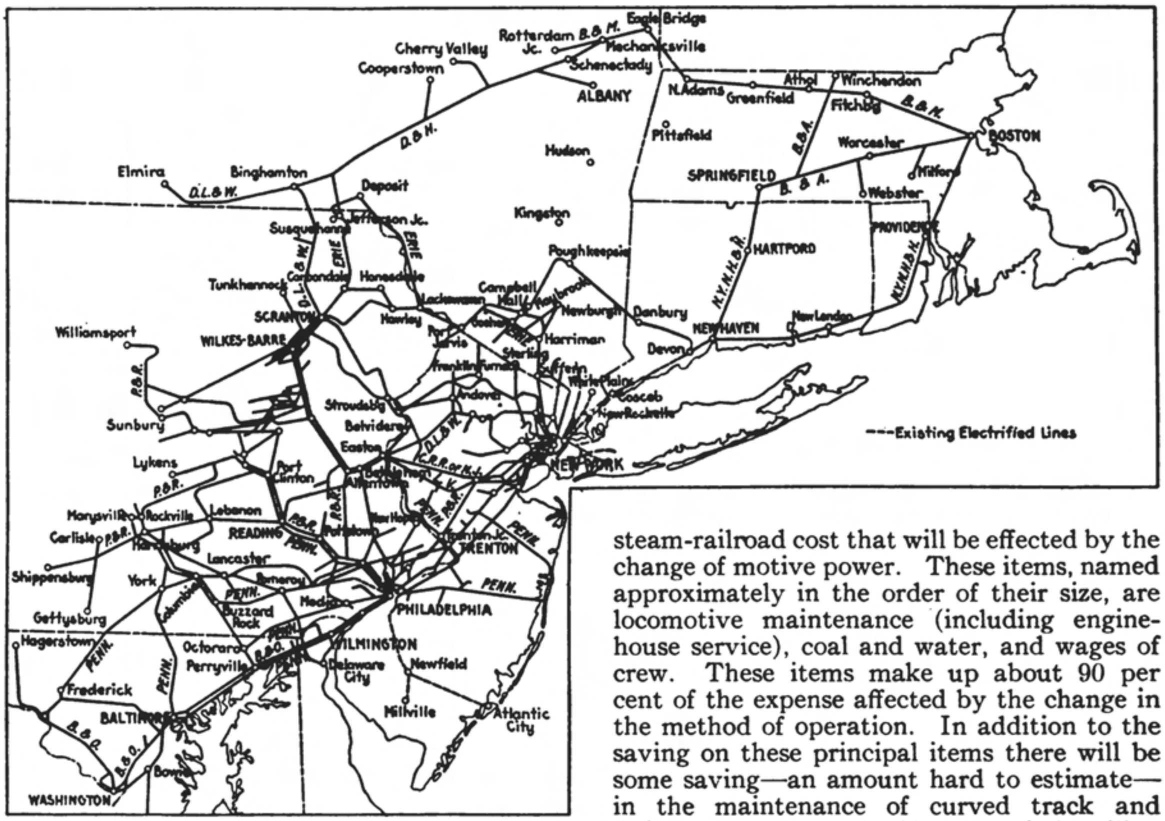

Fig. 1. Map Showing Class 1 Railroads Within the Superpower Zone for Which Electrification Is Recommended

steam-railroad cost that will be effected by the change of motive power. These items, named approximately in the order of their size, are locomotive maintenance (including engine-house service), coal and water, and wages of crew. These items make up about 90 per cent of the expense affected by the change in the method of operation. In addition to the saving on these principal items there will be some saving—an amount hard to estimate—in the maintenance of curved track and freight cars, as a result of better train handling and in certain minor items.

The energy for train operation is assumed to be delivered to the railroad company's substation, thereby relieving the railroad company from any investment or responsibility for the operation of an independent generating plant for railway power.

The comparison of costs of investment and operation need take no account of the system of electric traction to be used except in so far as the use of different systems might entail different costs of operation and construction. The only two systems that are applicable to general traction within the superpower zone are the 3000-volt direct-current system and the 11,000-volt (or higher) alternating-current system, both with overhead distribution circuits and rail return.

The alternating-current system generally involves a lower investment cost than the direct-current system, as at low frequencies of supply, substations with rotating machinery are replaced by transformers erected along the right of way; but this saving will not be effected under the superpower system, for

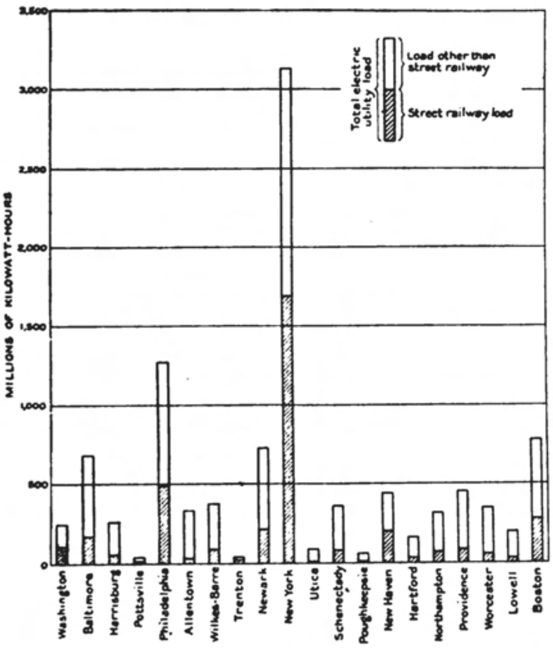

Fig. 2. Distribution of Electric-utility Load Among Load Centers of Superpower Zone in 1919

the frequency adopted for generation and transmission, 60 cycles, requires substations with rotating machinery for the alternating-current as well as for the direct-current system, and the capital costs of the two are nearly equal.

In order, then, to avoid some uncertain elements in the estimates of the cost of the alternating-current system it has been decided to base all estimates, both of operation and of construction, on the 3000-volt direct-current overhead system. Substantially the same results in money could, however, be obtained with the alternating-current system, certain gains being offset by certain losses.

The procedure of the railway division of the Superpower Survey in studying the proposed electrification comprised the collection of a large amount of physical data which were tabulated and analyzed in order to formulate conclusions. Physical and operating data were obtained directly from the officers of the roads involved, covering the year 1919. Costs of substation equipment, electric locomotives, catenary line material and other electric facilities were obtained from the large manufacturing companies and advice of competent operating engineers was sought and their criticisms were considered in making up the final estimates of costs of construction and operation. A tabulation of available operating figures shows a range of power consumption from 29 to 57 kw-hr. per thousand ton-miles of trailing train.

Test data show that in similar service one kw-hr. input to the motors in switching service is the equivalent of 29 pounds of coal used on a steam switcher. A similar figure also from various recent tests of locomotives in road service is 7.5 lb. of coal per kilowatt-hour at the locomotive. This figure is identical with that deduced by the American Electric Railway Association for a modern Mallet locomotive with superheater. Comparative figures furnished by the electrical engineer of the Chicago, Milwaukee & St. Paul Railway are 8.4 lb. per kw-hr. Confirmation of these figures is obtained from data on the several roads operating electric service in the zone affected. These data show that the coal saved in freight service is from 50 to 70 per cent, passenger service 70 to 75 per cent and switching service 70 to 85 per cent.

Maintenance of Steam Locomotives

From 50 to 100 per cent of the net saving effected by electric traction is obtained from the reduction of cost of locomotive maintenance. Statistics for steam and electric locomotives compiled from the records of the Interstate Commerce Commission are given, indicating an average cost of nearly 50 cents per locomotive mile per 100 tons weight on

COST OF MAINTENANCE OF STEAM LOCOMOTIVES FOR 1919

From Report of the *Superpower Survey*

System	Average Weight on Drivers (Tons)	Distance Traveled (Thousands of Locomotive Miles)	INTERSTATE COMMERCE COMMISSION ACCOUNTS							
			Repairs (No. 308)		Engine-House Expense (Nos. 388 and 400)		Total Cost			
							Actual		Prorated to 100 Tons on Drivers	
			Per Locomotive Mile (Cents)	Per Locomotive Year	Per Locomotive Mile (Cents)	Per Locomotive Year	Per Locomotive Mile (Cents)	Per Locomotive Year	Per Locomotive Mile (Cents)	Per Locomotive Year
Boston & Maine	80.9	24,592	25.33	$5,562	8.66	$1,904	33.99	$7,466	55.63	$12,263
New York, New Haven & Hartford	63.9	23,071	29.9	6,110	11.02	2,253	40.92	8,363	64.05	13,210
Central New England	68.6	1,844	31.23	7,578	10.37	2,540	41.60	10,118	60.65	14,755
New York Central	86.5	91,313	21.15	5,302	8.55	2,103	29.70	7,306	34.28	8,433
Delaware & Hudson	89.2	11,015	32.6	7,319	12.22	1,832	44.82	9,151	50.20	10,269
Lehigh & New England	74.2	1,212	27.8	5,521	7.82	1,554	35.62	7,075	48.05	9,545
Lehigh & Hudson River	76.3	767	27.8	4,267	8.77	1,345	36.57	5,612	47.94	7,362
Erie	90.4	26,078	45.6	9,790	9.65	2,070	55.25	11,860	61.19	13,126
Delaware, Lackawanna & Western	77.9	19,263	26.9	6,836	9.45	2,401	46.35	9,327	46.62	11,855
Lehigh Valley	85.6	17,883	40.6	7,126	8.75	1,537	49.35	8,663	57.62	10,115
Central of New Jersey	72.9	12,289	29.2	6,210	6.24	1,328	41.60	7,538	48.55	10,339
Pennsylvania	83.53	112,595	38.6	9,216	6.85	1,634	45.45	10,850	54.60	12,983
Philadelphia & Reading	78.3	22,164	32.6	6,853	8.93	1,879	31.53	8,372	53.00	11,152
Totals	80.76	364,086	31.8	$7,246	8.39	$1,911	40.19	$9,157	49.80	$11,310

COST OF MAINTENANCE OF DIRECT-CURRENT ELECTRIC LOCOMOTIVES, 1919

System	Number of Locomotives	Average Weight on Drivers (Tons)	Distance Traveled (Locomotive Miles)	Total Maintenance	COST			
					Actual		Prorated to 100 Tons on Drivers	
					Per Locomotive Mile (Cents)	Per Locomotive Year	Per Locomotive Mile (Cents)	Per Locomotive Year
Baltimore & Ohio	8	88	214,400	$24,600	11.47	$3,076	13.02	$3,491
Butte, Anaconda & Pacific	28	81	565,600	36.700	6.49	1,312	8.01	1,619
Chicago, Milwaukee & St. P.	46	225	2,181,200	340,200	15.59	7,394	6.93	3,286
Michigan Central	10	108	245,500	34,600	14.10	3,462	13.05	3,205
New York Central	73	92	1,940,900	124,400	6.41	1,704	7.00	1,862
Pennsylvania Terminal	31	103	1,348,000	225,300	16.71	7,266	16.30	7,088

COST OF MAINTENANCE OF DIRECT-CURRENT ELECTRIC LOCOMOTIVES, 1913–1919

Year	Total Distance Traveled (Locomotive Miles)	Cost per Locomotive Mile per 100 Tons on Drivers (Cents)
1913	2,422,800	5.83
1914	3,678,200	5.42
1915	3,808,800	5.44
1916	5,662,600	4.50
1917	6,797,000	5.89
1918	6,431,600	7.66
1919	6,495,700	9.77

COST OF MAINTENANCE OF STEAM LOCOMOTIVES FOR 1911–1919

From Report of the *Superpower Survey*

System	Average Weight on Drivers (Tons)	Distance Traveled (Thousands of Locomotive Miles)	INTERSTATE COMMERCE COMMISSION ACCOUNTS: Repairs (No. 308)		Engine-House Expense (Nos. 388 and 400)		Total Cost: Actual		Total Cost: Prorated to 100 Tons on Drivers[1]	
			Per Locomotive Mile (Cents)	Per Locomotive Year	Per Locomotive Mile (Cents)	Per Locomotive Year	Per Locomotive Mile (Cents)	Per Locomotive Year	Per Locomotive Mile (Cents)	Per Locomotive Year
New York Central:										
1911–1915	75.36	66,356	9.04	$2,460	3.1	$ 849	12.14	$3,309	16.11	$4,391
1916	82.24	108,626	7.6	2,421	3.06	972	10.66	3,393	12.96	4,126
1917	83.60	106,403	10.0	3,051	4.07	1,241	14.07	4,292	16.83	5,134
1918	85.60	100,576	17.59	4,689	7.30	1,947	24.89	6,636	29.08	7,752
1919	86.50	91,313	21.15	5,195	8.54	2,100	29.69	7,295	34.32	8,434
Pennsylvania:										
1911–1915	75.85	94,142	12.7	3,221	2.8	710	15.50	3,931	20.44	5,183
1916	83.4	105,522	13.1	3,478	2.6	687	15.70	4,165	18.82	4,994
1917	87.6	108,638	17.5	4,620	3.4	899	20.90	5,519	23.86	6,300
1918	90.4	122,965	32.88	8,960	3.7	1,784	36.58	10,744	40.46	11,885
1919	91.0	112,595	38.62	9,175	6.8	1,627	45.42	10,802	49.91	11,870
Philadelphia & Reading:										
1911–1915	62.92	24,631	11.69	2,886	3.04	750	14.73	3,636	23.41	5,779
1916	70.83	27,422	12.28	3,397	3.19	883	15.47	4,280	21.84	6,043
1917	73.20	28,126	17.85	4,993	4.14	1,156	21.99	6,149	30.04	8,400
1918	75.4	27,080	28.17	7,423	7.50	1,975	35.67	9,398	47.31	12,464
1919	78.3	22,164	32.6	6,853	8.93	1,879	41.53	8,732	53.04	11,152
New York, New Haven & Hartford:										
1911–1915	50.7	27,027	9.6	2,171	3.00	681	12.60	2,853	24.85	5,625
1916	55.6	27,495	9.98	2,272	3.61	822	13.59	3,094	24.44	5,565
1917	57.5	26,099	14.0	3,160	4.77	1,078	18.77	4,238	32.64	7,370
1918	61.4	24,784	30.85	6,400	8.99	1,861	39.84	8,261	64.88	13,454
1919	63.9	23,071	29.9	6,110	11.04	2,253	40.94	8,363	64.07	13,088
Erie:										
1911–1915	74.1	28,768	11.21	2,430	3.45	749	14.66	3,179	19.78	4,290
1916	82.3	31,621	15.65	3,765	3.90	936	19.55	4,701	23.75	5,712
1917	87.6	29,903	24.20	5,400	6.11	1,360	30.31	6,760	34.60	7,717
1918	90.0	29.316	45.3	9,950	11.75	2,582	57.05	12,532	63.39	13,924
1919	90.2	26,078	45.6	9,790	9.65	2,070	55.25	11,860	61.25	31,481

ANALYSIS OF CREW WAGES FOR FREIGHT AND SWITCHER SERVICE, 1919

System	FREIGHT SERVICE: Wages per Thousand Ton-miles	FREIGHT SERVICE: Train Movement (Millions of Ton-miles)	FREIGHT SERVICE: Savings in Wages Under Electric Operation 25 Per Cent	SWITCHER SERVICE: Wages per Switcher Mile	SWITCHER SERVICE: Train Movement Thousands of Switcher Miles	SWITCHER SERVICE: Savings in Wages Under Electric Operation 25 Per Cent
Boston & Maine	$0.40	6,600	$660,000			
Boston & Albany	.42	3,266	343,000			
New York, New Haven & Hartford and Central New England	.55	8,183	1,130,000	$0.60	4,900	$980,000
New York Central	.27	10,914	738,000	.45	5,086	760,000
Delaware & Hudson	.35	5,650	495,000	.69	1,143	265,000
Lehigh & Hudson River	....	....	....	....	....	....
Erie	.29	5,707	415,000	....	....	....
Delaware, Lackawanna & Western	.31	6,200	481,000	.58	3,200	620,000
Lehigh Valley	.50	5,093	635,000	.57	3,480	660,000
Central of New Jersey	.50	4,400	550,000	.57	3,000	570,000
Pennsylvania	.38	22,545	2,140,000	.61	14,024	2,850,000
Philadelphia & Reading	.49	10,900	1,330,000	.58	7,763	1,760,000
Baltimore & Ohio	.42	3,380	355,000	....	....	....
Totals	....	92,838	$9,272,000	....	42,596	$8,465,000

Average wage saving per thousand ton-miles, 10 cents; per switcher mile, 20 cents.

drivers as compared to less than 10 cents for heavy direct-current electric locomotives reduced to a similar basis.

Maintenance of Distribution and Substations

Careful provision is made in the analysis of operating costs and calculated savings for maintenance of the low tension distribution system. This is taken at $600 per mile for main track and $400 per mile for yard track. These figures are based on actual operating costs of existing roads and other general considerations.

The cost of operation and maintenance of substations is based on $1.50 per kilowatt per year, giving 0.7 mill per kilowatt-hour for a capacity factor of 25 per cent.

Savings in Wages

One of the most notable advantages of electrification is the saving in wages of train crews. This report gives a detailed analysis of crew wages of roads within the zone for freight and switching service per 1000 ton-miles and savings obtainable at 25 per cent and 33 per cent respectively. No savings are claimed for passenger service.

The report then details unit costs of construction of 3000-volt overhead catenary, substations and electric locomotives. An analysis of the number of locomotives required is included, based on the traffic.

The summary then made estimates the net cost of electrification for the 11 selected systems with net reduction in the annual cost of operation. The results are shown graphically in the chart (Fig. 4).

The following conclusions are reached by the author of the report:

"The study described above has been made for all

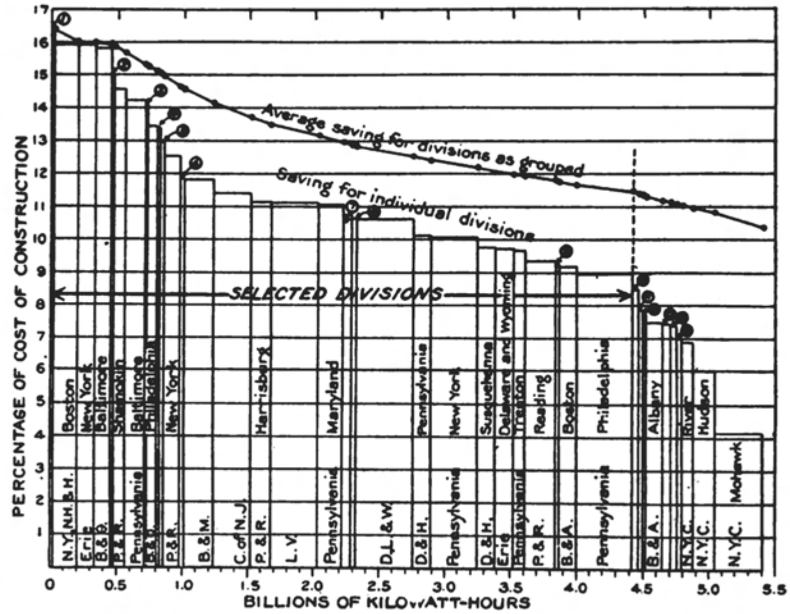

Fig. 3. Saving Effected by Electrification of Heavy-traction Railroads in Percentage of Constuction Cost, not Including Saving in Wages. Each column rep esents a railroad division or route. 1, New York and New Jersey Division, Erie; 2, Northern Division, Erie; 3, Greenwood Lake Division, Erie; 4, Jefferson Division, Erie; 5, Schuylkill Division, Pennsylvania; 6, Springfield Division, N. Y., N. H. & H.; 7, Maybrook Division, N. Y., N. H. & H.; 8, Philadelphia Division, P. & R.; 9, New York, Susquehanna, and Western Division, Erie; 10, Cumberland Valley Division, Pennsylvania; 11, Atlantic City Division, P. & R.; 12, Wilmington and Columbia Division, P. & R.; 13, Sunbury Division, Pennsylvania; 14, New Jersey and Seashore Division, Pennsylvania; 15, Lehigh & Hudson River R. R. Other divisions are indicated on the diagram

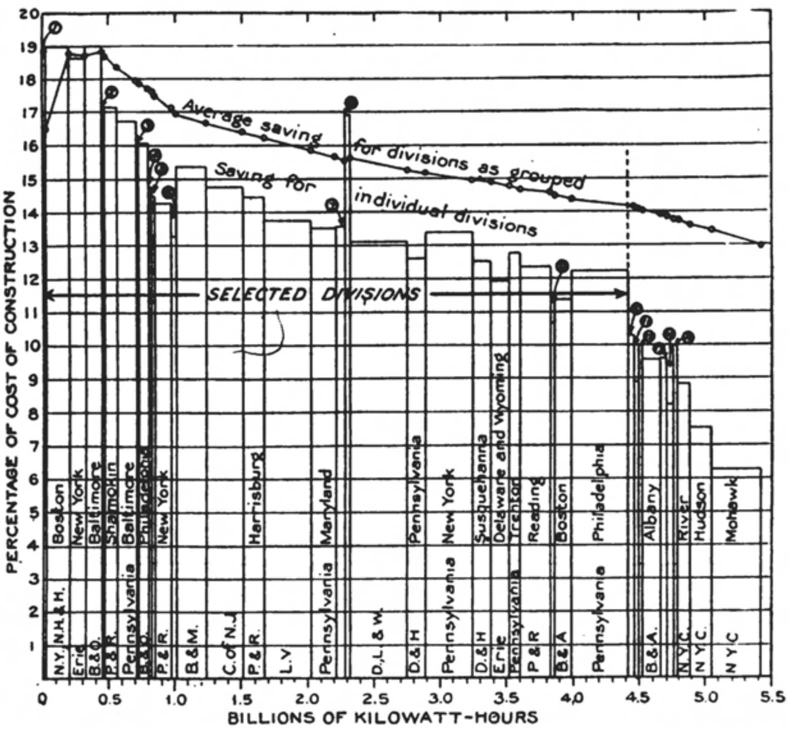

Fig. 4. Saving Effected by Electrification of Heavy-traction Railroads in Percentage of Construction Cost, Including Saving in Wages. Each column represents a railroad division or route. For explanation of numbers see Fig. 3

Class 1 railroad systems within the superpower zone except the Ulster & Delaware, the New York, Ontario & Western and the Western Maryland. The first two were omitted, after a preliminary examination, because their traffic was too light to warrant electrification. The Western Maryland was omitted because only a small part of its trackage is within the zone; the preliminary examination, however, indicates that the Western Maryland traffic would justify electrification. There remained then, 13 railroad systems* in the zone that were studied. In this study it was not possible to adhere strictly to the limits of every operating division reported by the railroads, and some divisions were therefore consolidated into routes. The number of divisions or routes ranged from one on the Boston & Main to nine on the Pennsylvania and aggregated 40 for the 13 roads."

The results of the study are given in Figs. 3 and 4, which show for each of the 40 divisions the annual saving, in percentage of the net cost of electrification, plotted

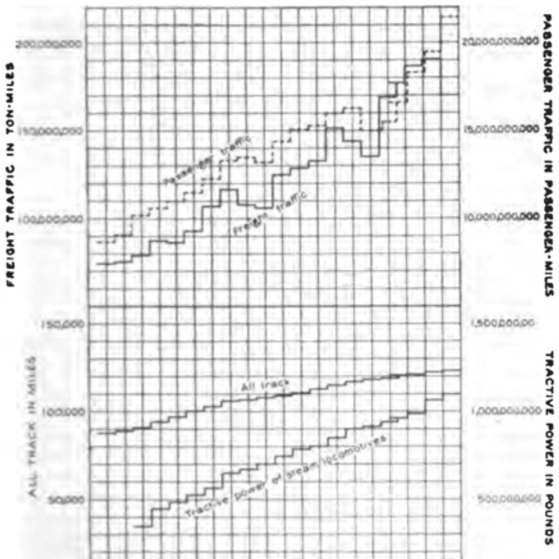

Fig. 5. Growth of Steam Railroads in the Superpower Zone in 1900–1919. Annual rate of growth compounded, 1900–1918: Passenger-miles, 5.3 per cent; ton-miles, 4.5 per cent; all track, 0.75 per cent; tractive power, 6.6 per cent

against the energy required, in kilowatt-hours per year, together with the accumulated average percentage of saving for the divisions as grouped. Fig. 3 shows the saving exclusive of the saving in crew wages, and the divisions are arranged in the order of percentages. With these results as the criterion of economical electrification the "selected divisions" are assumed to be all that show a saving of 9 per cent or more. The group of

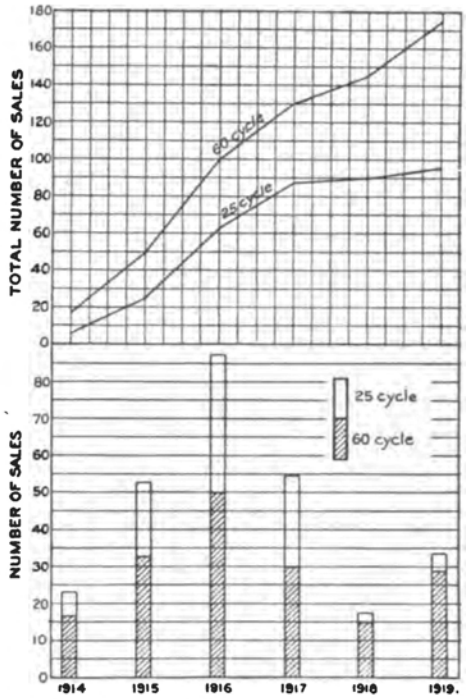

Fig. 6. Sales of 25-cycle and 60-cycle Generators in the Superpower Zone, 1914–1919

divisions thus selected shows an average saving of 11.4 per cent. It includes 30 of the 40 divisions examined. Fig. 4 shows the saving including the wage saving for the 40 divisions arranged in the same order as in Fig. 3. For the "selected divisions" these savings range from 10.6 to 19 per cent and average 14.2 per cent. The total energy required annually for these 30 divisions will be 4400 million kilowatt-hours, and the maximum demand approximately 850,000 kilowatts.

The low percentage of saving shown by the divisions not included in the selected group, except those of the New York Central, is due to light traffic. On the New York Central the train cost of transportation, the cost of maintaining steam locomotives, and the cost of coal per mile are lower than on any other system, owing in part to the fact that this is a water-level road with a large amount of through traffic; these are favorable conditions for economical steam operation and

* The Boston & Albany was included with the New York Central, and the Long Island with the Pennsylvania.

therefore afford less opportunity for saving by electrification.

Table 35 of the report summarizes for the 11 systems that include the 30 selected divisions, the net estimated cost of construction and electric equipment and the net savings from opera-

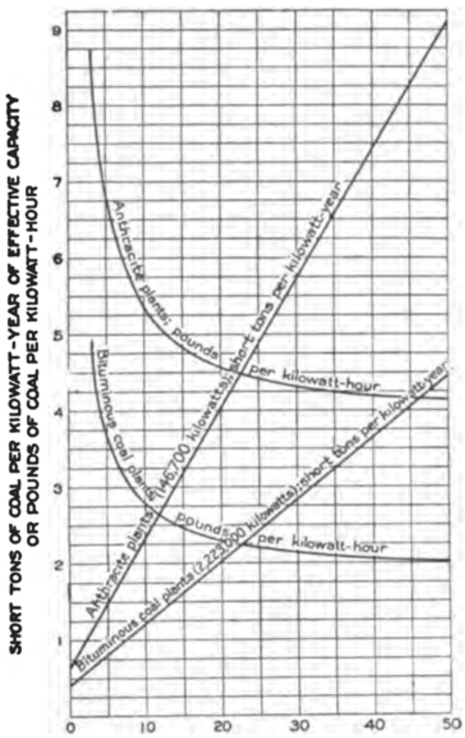

Fig. 7. Output of Electric Utilities in the Superpower Zone, 1910–1919

tion, both including and excluding saving in wages. The net cost of electrification of all the selected divisions is $570,000,000, and the annual net saving in operation, including the saving in wages, is $81,000,000, equal to an average of 14.2 per cent for the entire group, ranging from 10.6 per cent for the New York, Susquehanna & Western division of the Erie to 19 per cent for the New Haven-Boston route of the New Haven.

Fig. 5 shows the growth of traffic (both freight and passenger) of track, and of tractive power for the Class 1 railroads in the superpower zone from 1900 to 1919. The annual rate of growth has been 5.3 per cent in passenger-miles, 4.5 per cent in ton-miles, 0.75 per cent in all track, and 6.6 per cent in tractive power of locomotives.

The amount of money required for electrification is calculated to be $570,000,000. This figure is based on costs prevailing in 1919, but at present costs (June, 1921) it would be reduced by 18 per cent, to approximately $467,000,000, and before this construction can be undertaken there will be further material reductions. Probably five years from now the entire work outlined could be done for not more than $400,000,000. This is comparatively a moderate sum. Good railroad authorities have stated repeatedly that more than $1,000,000,000 a year is needed by the railroads of the United States for extensions and betterments. The part of this total to be allocated to the superpower zone, as determined by the number of locomotives, would be $150,000,000. The amount required for normal extensions and betterments for three years would therefore be sufficient to electrify the 30 selected divisions of the railroads in this territory, with an annual saving of more than 14 per cent. The most valuable feature of the change, however, is not the amount saved but the great increase in maximum capacity of existing trackage and the general advantages of electric operation.

These figures indicate that with a return of normal financial conditions all these lines should be electrified before further great expenditures have been incurred to increase

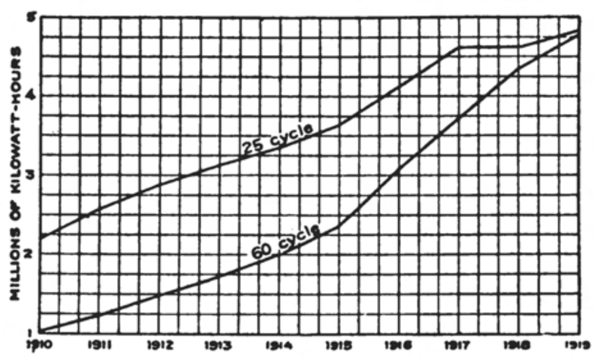

Fig. 8. Average Performance of Existing Steam-electric Plants to be Retained in the Superpower System

in a minor degree the capacity of the existing tracks and yards. Steam operation can not satisfactorily meet the conditions of the crowded terminal herein described as the superpower zone; electric operation can easily do it.