Progress in the Electric Power Industry

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Synopsis: The subject of this paper concerns the progress that has been made in the generation of electricity by steam and its distribution. It is significant that the two authors selected by your committee to discuss this subject are both power plant designers, and that their two working lifetimes cover the whole history of electric power generation since its beginning. That there has been progress in the electric power industry during this brief span of years is well illustrated by Figure 1, which shows that electrical residential rates on a national basis have a history of continuously lowering during the past 50 years while, at the same time, the cost index has been continuously rising. Where else than in the electric power industry can such a record of progress be shown?

A Story of Progress

Boilers

BEFORE going into a more technical analysis, let us review the physical equipment back of this concrete record of achievement to see if the road behind points out the road ahead. Figure 2 is a model of the first Edison station, the Pearl Street Station in New York. Boilers are tiny, hand-fired, and operated at about 100 pounds steam pressure. Figure 3 shows a Roney stoker under a power boiler. These boilers operated at about 200 pounds pressure and are much larger in size. Figure 4 shows an underfeed stoker-fired boiler, similar to types which were installed through the 1920's. The capacity is up to several hundred thousand pounds per hour, and pressures up to 1,200 pounds; temperatures up to 725 degrees could be obtained. Figure 5 shows a boiler fired by two underfeed stokers. Such boilers were installed in the late 1920's and early 1930's, and some were of very large capacity. Figure 6 shows a boiler, installed in the late 1920's burning pulverized coal. Notice the use of refractory walls. Such furnaces, although practical, required high maintenance and were of small size. Figure 7 shows a modern pulverized coal-fired boiler. Note that the use of refractories has almost disappeared. Such boilers can be made in extremely large sizes, and pressures up to 2,500 pounds, and temperatures up to 1,050 degrees are available today.

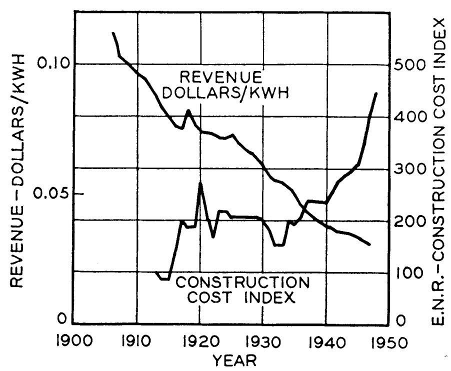

Figure 1. National average residential revenue per kilowatt-hour compared to construction cost index

In thinking over these pictures of the progress of boiler design, we should consider the principal indications or trends in their design. From the very start, continual progress is to larger and larger units. We also note a continued tendency to operate at higher pressures and temperatures. Has there been a continuous improvement in efficiency? Actually, not of any great moment. James Watt's early boilers for pumping-engine service in England had test efficiencies of 86 per cent, while the newest and best boilers today rarely exceed 90 per cent. Although not shown on these pictures, but connected with the boilers and the progress of their design, we should not forget the improvements which have been made by the use of regenerative feed water heating, as well as by the use of the reheat cycle.

Turbogenerators

Let us see what the history of prime movers and generators can show us. Figure 8 shows the first Boston station with Edison Jumbo generators. This is a d-c machine of about 120-kw capacity. Figure 9 shows the Atlantic Avenue engine room some 10 years later. Note that the generator brushes ride on the face of the commutator. Capacities up to 2,000 horsepower were not too uncommon in such large compound steam engines. Figure 10 shows a room full of vertical turbines, first installed about 1905, in operation today for peak loads. The maximum capacity of a single unit is 15,000 kw. Steam conditions are 200 pounds, 525 degrees. Figure 11 shows a turbine room of the late 1920's. The main units operate with 400 pounds, 725 degrees steam. Such 1,800-rpm machines were available up to 150,000-kw capacity. This station also contains three of the early 1,200-pounds 725-degree turbines. These machines were of a type which did not become popular for another 20 years. In other words, they were topping turbines, a small high-pressure unit taking the steam from 1,200 pounds down to approximately 400 pounds, then the steam returning to a header, and in this case, being reheated before going to the low-pressure turbine. Figure 12 shows a modern 3,600-rpm turbine.

The dominant fact brought out by this brief review has been the great extension in the available heat range which is responsible for the great progress in fuel economy. The use of condensers brought the lower level of useful heat downward to low temperatures and very low pressures while the extension to higher temperatures, pressures, and the use of reheat

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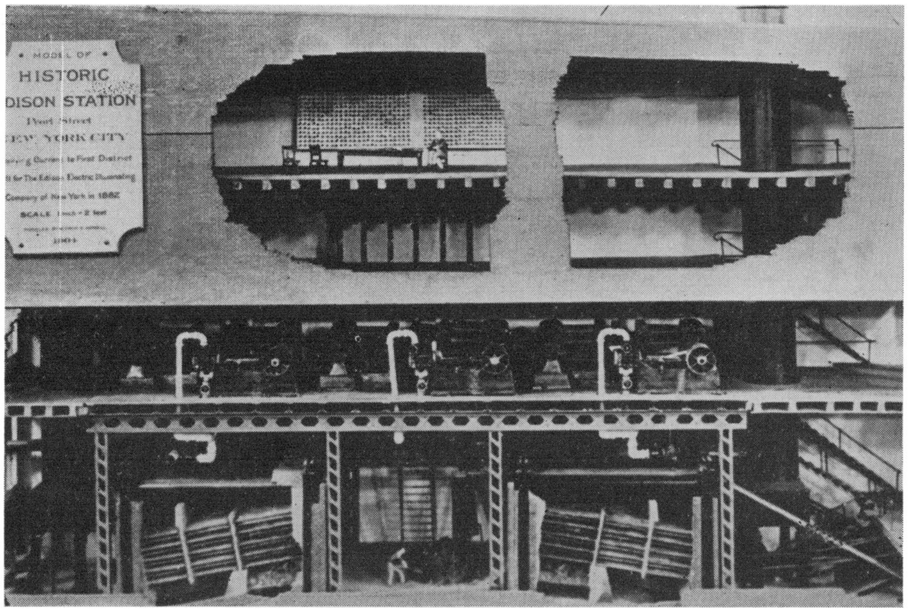


Figure 2. The first Edison station—Pearl Street model

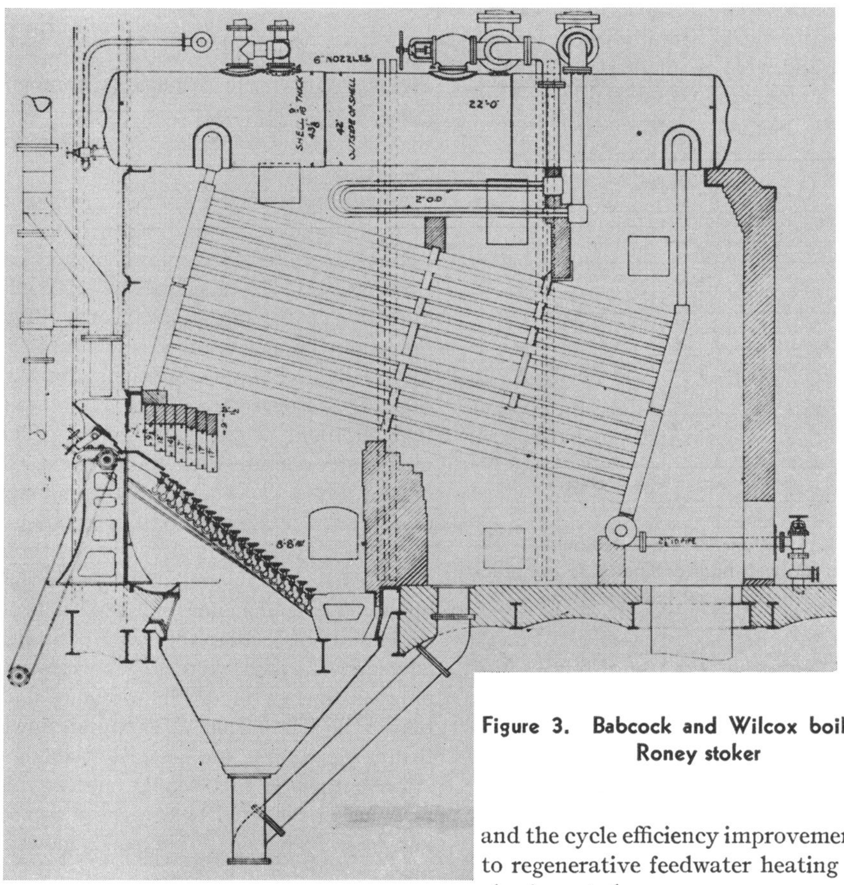


Figure 3. Babcock and Wilcox boiler with Roney stoker

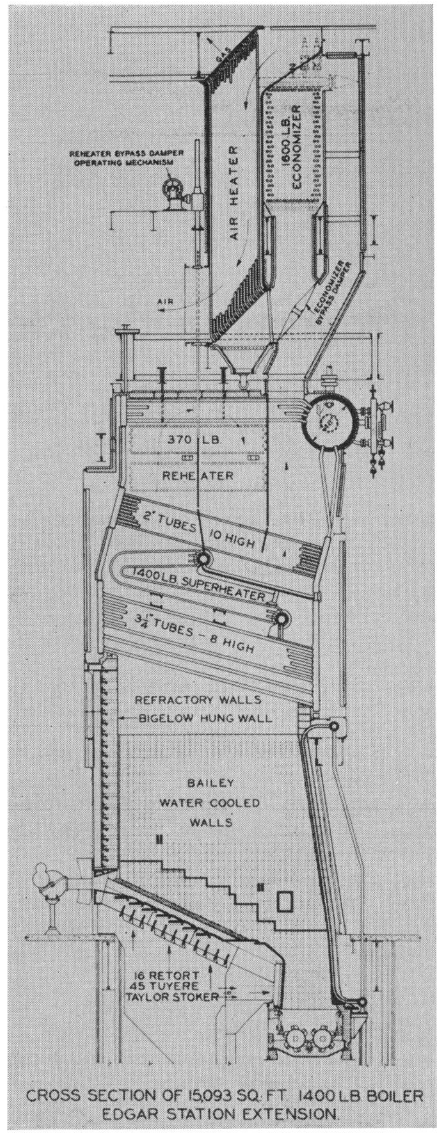


Figure 4. Underfeed stoker

raised the upper level of available heat. The efficiency of utilization of the available energy changed moderately from a figure of 70 per cent for a compound engine to perhaps 86 per cent for a modern turbine.

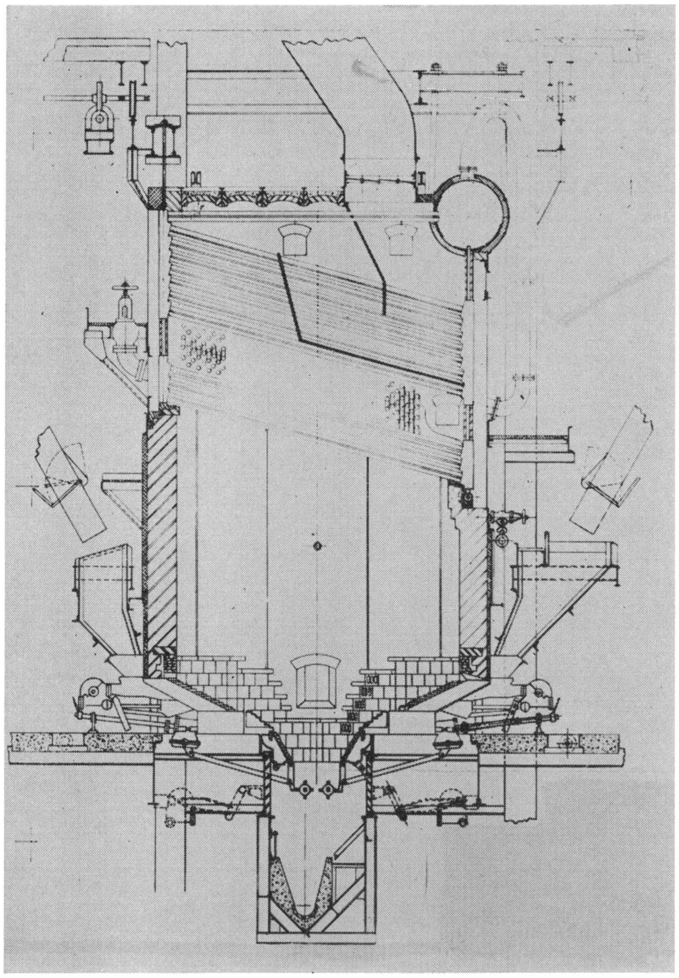
The tendency to large sizes is important and the cycle efficiency improvements due to regenerative feedwater heating should also be noted.

Switching

The electrical side of the power business also has quite a history of progress. Figure 13 shows a Pearl Street switch in 1882. This is quite a far cry from Figure 14 which shows a d-c switch in service today but which was built in the early part of the century. Figure 15 shows 6,900-volt hand-operated oil switches. These were put into service early after the transfer from direct to alternating current and are still in service. Figure 16 shows a 14,000-volt oil circuit breaker. Installed in segregated compartments and fully automatic, these were a great advance over the switches available at the time and many of those installed as early as 1904 are still in daily use. Figure 17 shows a 14,000-volt modern airblast switch at the Mystic Station. These represent the latest available development and have by no means reached the top of their possibilities for rapid operation and capacity of interruption. Figure 18 shows a 69,000-volt outdoor oil switch. These were developed in the late 1920's and are available in this country up to 300,000 volts.

BOILERS

(Continued)



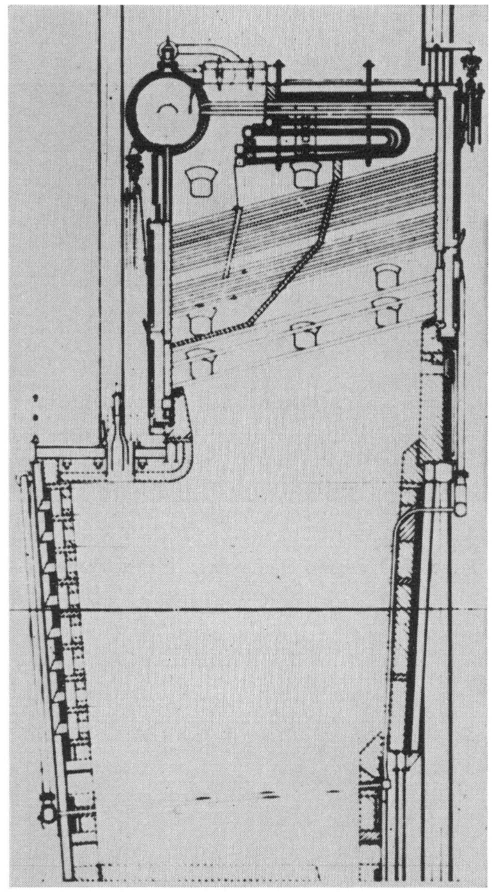


Figure 5 (upper left). Double stoker

Figure6 (upperright). Early pulverized-coal boiler

The picture that can be seen from this series of illustrations on the development of switching shows a very similar tendency to the prime mover and generator equipment; in other words, a definite tendency towards larger units and a very definite tendency for an increase in voltage. But it should be noted that the development to a maximum voltage of 250,000 came quite early and there is some indication that voltages much above this figure are far in the future. There has been a steady growth in interrupting capacity and a steady increase in speed of opening and reclosing. There is some indication that the change in types travels in cycles, from air-break switches to oil-break switches and back to air-break again.

Transmission

An important part of the electrical power business is transmission. Of course in the early stages when direct current was used, there was no transmission as we understand it today and when the transfer from direct to alternating current was

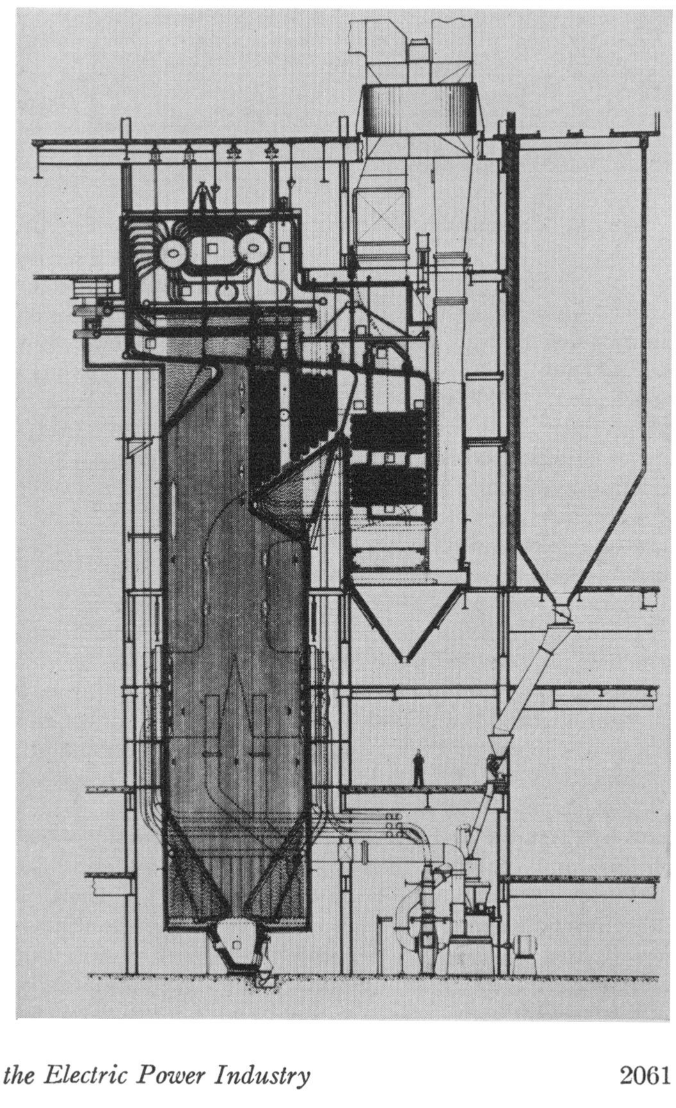


Figure 7 (right). Modern pulverized-coal boiler

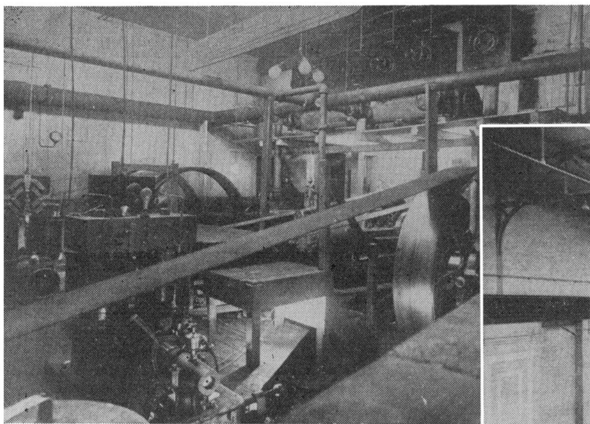


Figure 8. Jumbo generator, Head Place Station

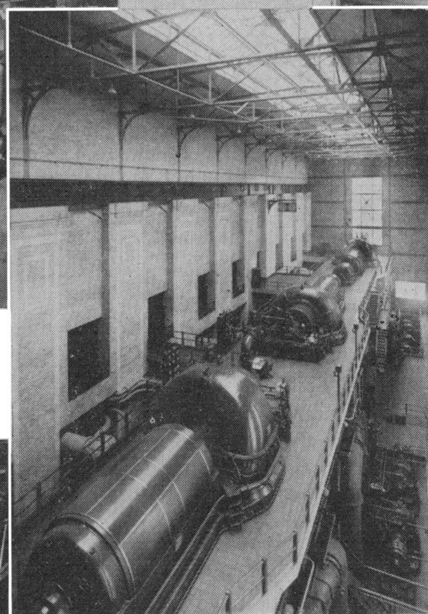


Figure 11. Horizontal turbines—1,800 rpm

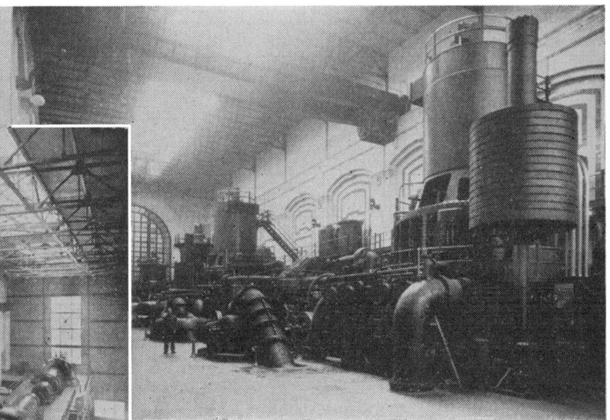


Figure 10. Vertical turbines

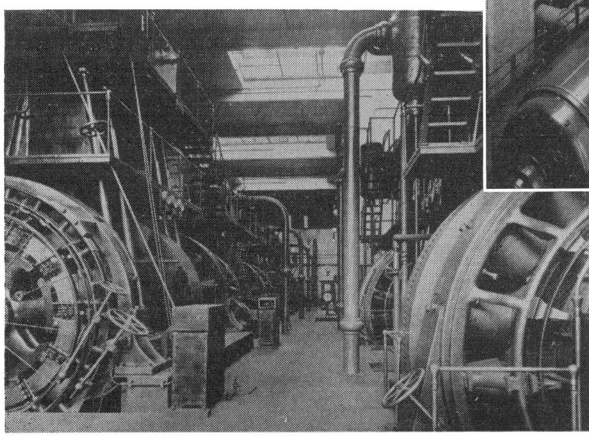


Figure 9. Compound engine generators

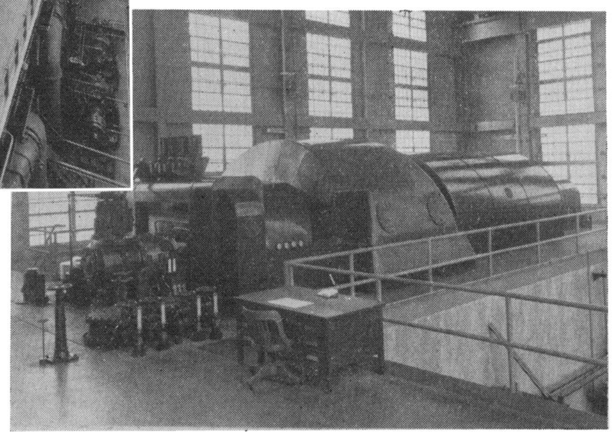


Figure 12. Modern turbines—3,600 rpm

reached, it was clear from the start that transmission at high voltage was desirable. Figure 19 shows an early transmission line at 110,000 volts. This type of construction is in marked contrast to Figure 20, which shows a modern high-tension transmission line for 110,000 volts but of wood pole construction. The change from the steel towers to wood has been made with an improvement in resistance to lightning and with a substantial decrease in cost. The progress in cable construction is likewise significant. The sample of early transmission cable, as shown in Figure 21, was installed in 1911 and is still in use at 14,000 volts with a solid oil-impregnated insulation. Modern transmission cable, as shown in the cross section in Figure 22, is filled with oil under pressure and has little more insulation thickness for operation at 110,000 volts. Other insulating mediums such as inert gas are used in modern cable. The pictures suggest that the rise in voltage to approximately a maximum of 350,000 volts, a-c overhead occurred quite early and that there has been little tendency to exceed this voltage in present-day practice. Underground cables were somewhat slower, but the maximum voltage of 110,000 volts was reached fairly early with solid cable, modern practice going to cheaper and better construction involving oil and gas-filled cables and the pipe-type construction involving high-pressure gas or oil.

Transformation

Along with high-voltage transmission, apparatus for transformation of voltages had to be developed at the start. Figure 23 shows the Pearl Street regulators. These, of course, are not transformers as we understand them in modern a-c practice. They are, in fact, carbon-packed rheostats. The purpose, however, is for the control of the voltage in the individual d-c feeders. The construction is shown for the Pearl Street Station in 1882. With the conversion to alternating current, modern transformers appear. Figure 24 shows an early air-blast transformer of approximately 5,000-kva capacity. Some transformers of this type are still in service. Figure 25 shows a much later, standard oil-filled transformer and Figure 26 shows a modern oil-filled transformer.

A review of the progress of transformer development shows a rapid increase in size and voltage to match transmission requirements. There was a definite change from single-phase to the 3-phase units. From the very start, as indicated by the Pearl Street regulators, there were many special types. From the standpoint of efficiency no piece of apparatus was ever as satisfactory as the transformer. The fundamental principles were early developed and applied to produce practically perfect machines.

The final phase of the electric power business concerns distribution.

Distribution

Figure 27 shows Pearl Street connections in 1882. These were the principal d-c feeders leaving Pearl Street Station. D-c distribution, which was in the form of

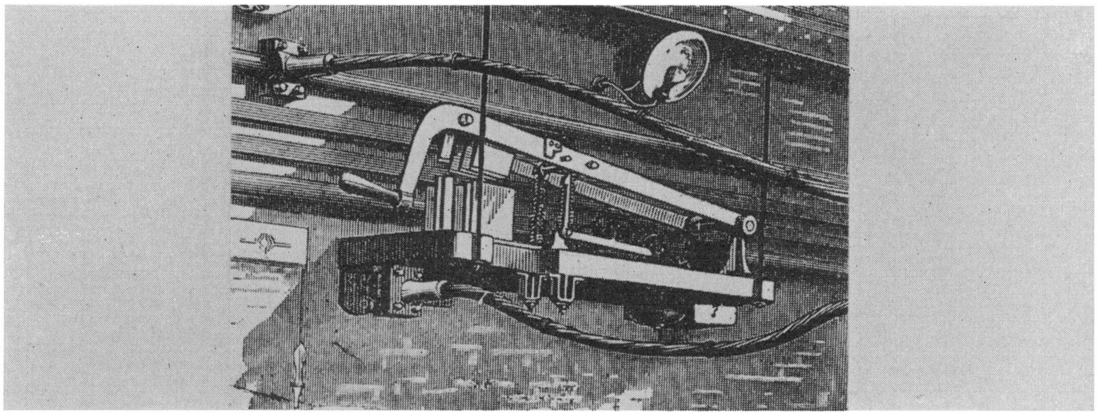


Figure 13. Pearl Street switching

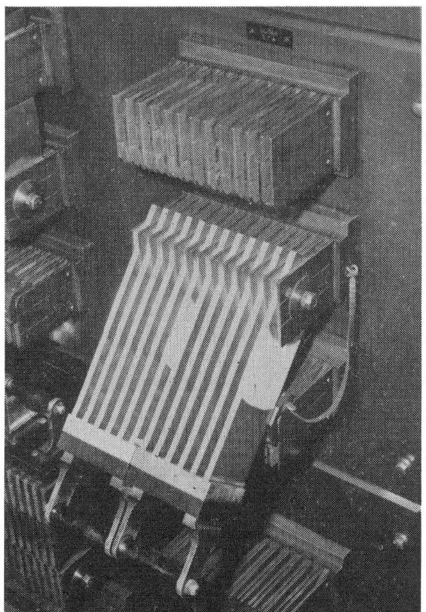


Figure 14 (left). D-c switch

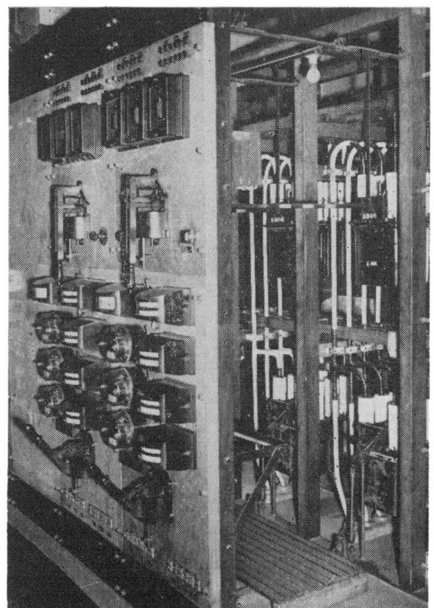


Figure 15 (right). Hand-operated oil switch

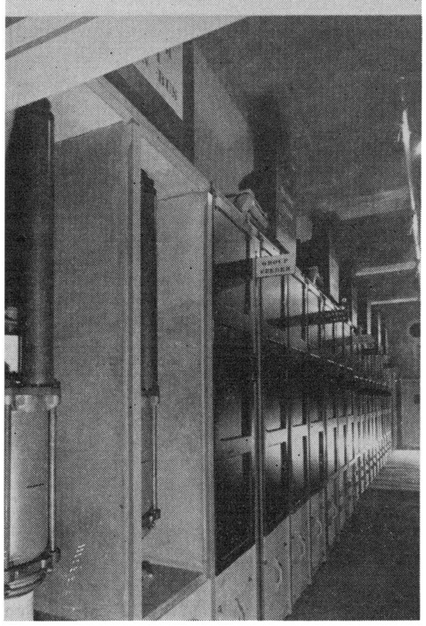


Figure 16 (left). 14,000-volt automatic oil circuit breaker

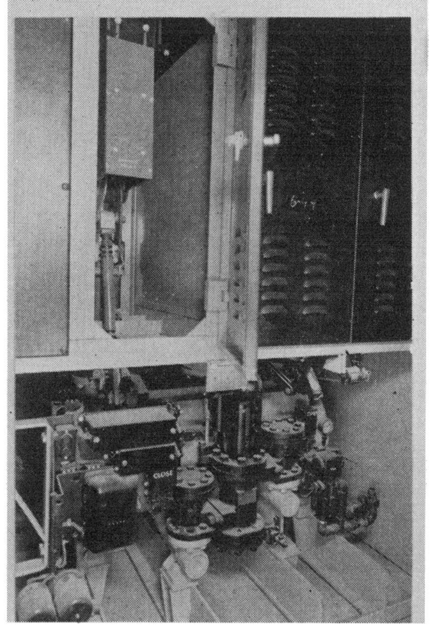


Figure 17 (right). 14,000-volt automatic air-blast circuit breaker

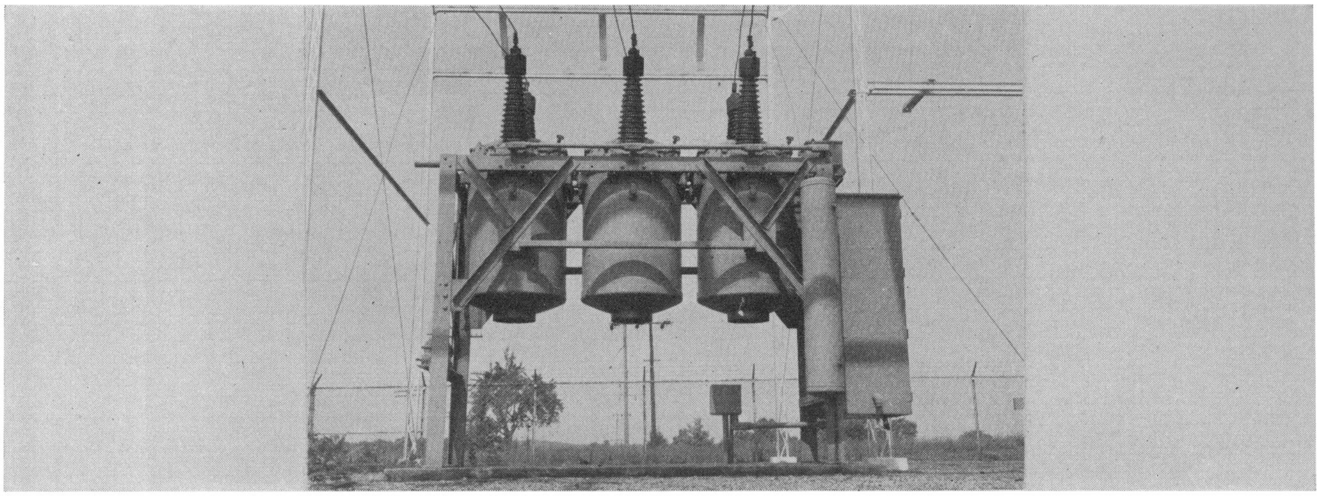


Figure 18. 66,000-volt outdoor oil circuit breaker

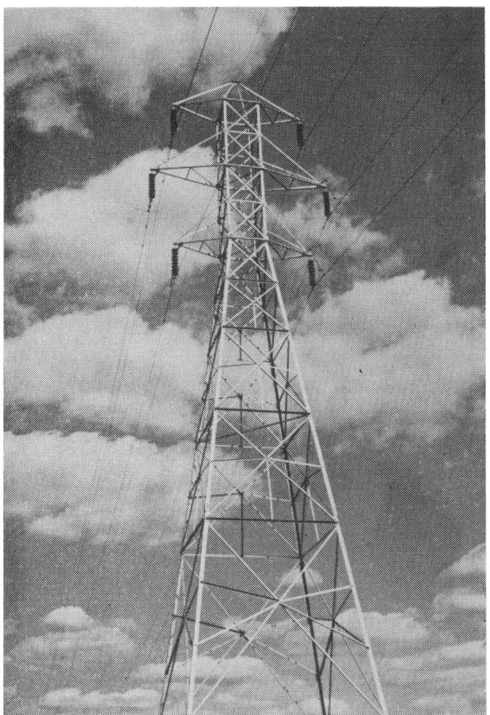


Figure 19 (left). Early 110,000-volt transmission line

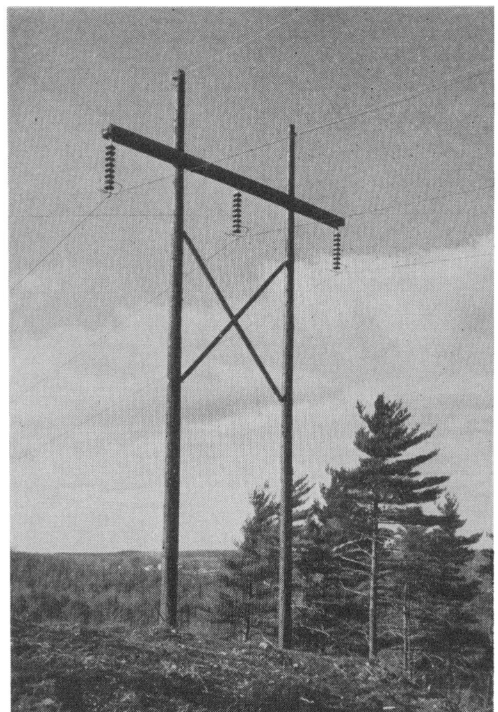


Figure 20 (right). Modern wood pole, 110,000-volt transmission line

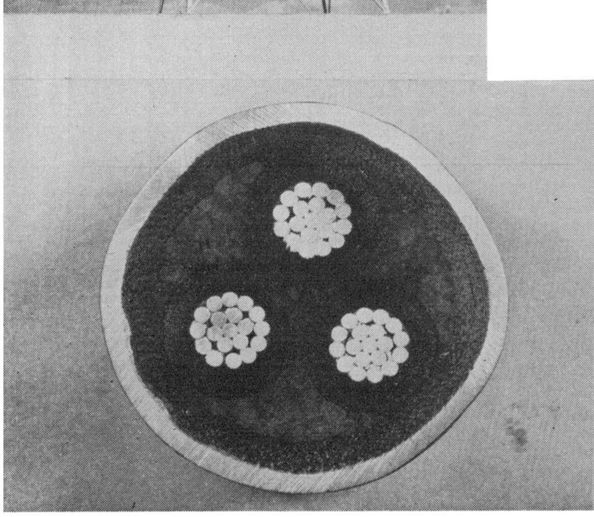


Figure 21. Early solid cable, 14,000-volt service

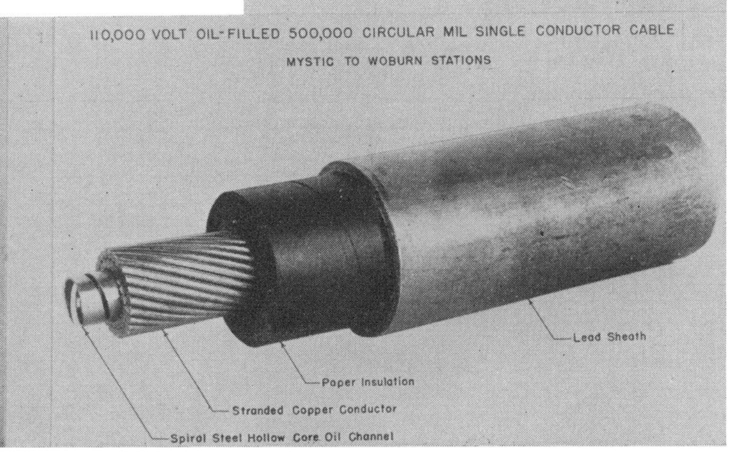


Figure 22. Modern oil-filled cable 110,000-volt service

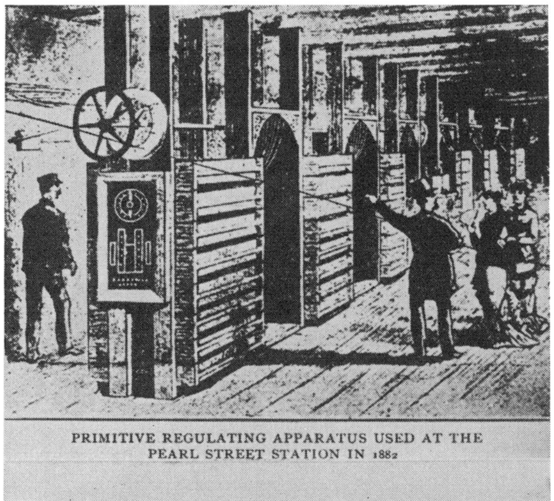


Figure 23 (left). Pearl Street regulators

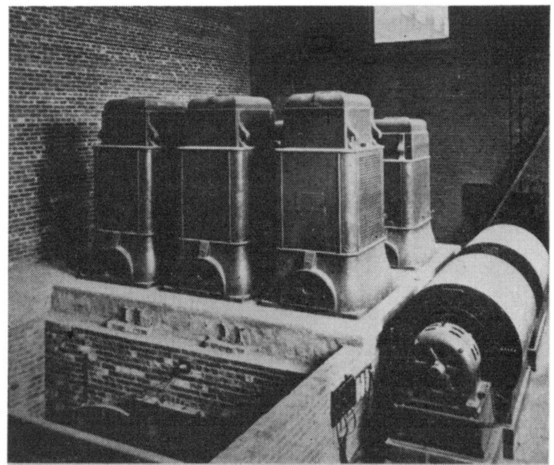


Figure 24 (right). Early air-blast transformers

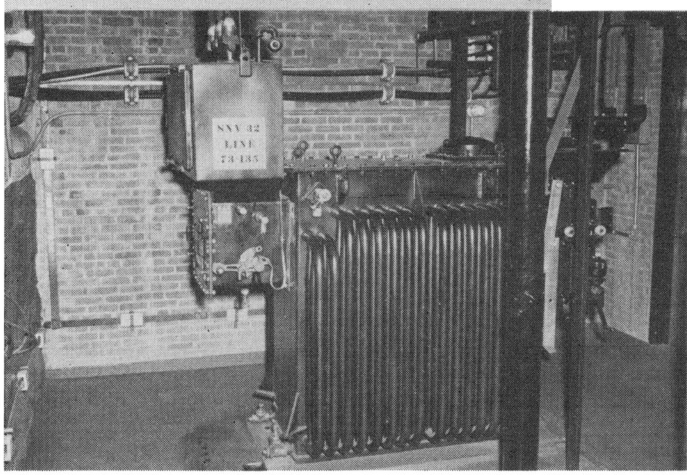


Figure 25. Oil-filled self-cooled transformer

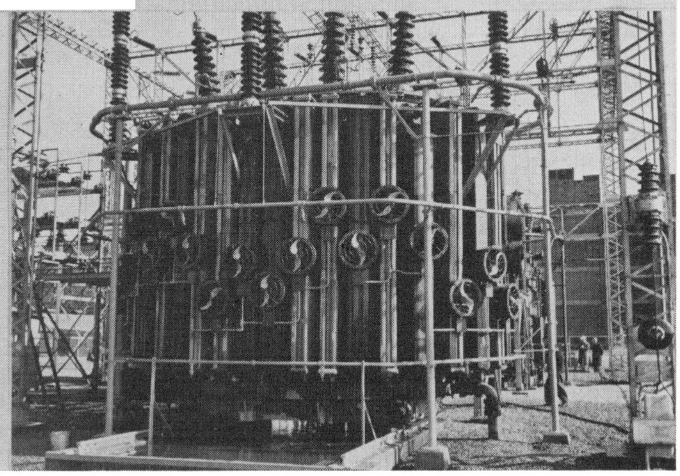


Figure 26. Large modern oil-filled transformer

a network, was early supported by large storage-battery installations as shown in Figure 28. This is still in operation. As the distances increased and the advantages of a-c distribution became apparent, the departure was to a-c, radial overhead distribution, as shown in Figure 29. The problems of overhead distribution in congested city districts led to the radial underground distribution with transformers set in manholes and with underground ducts. The problem of radial, a-c distribution was met in the early 1920's, as shown in Figure 30, by typical nonattended automatic substations.

The problem is solved today very differently, as shown in Figure 31, by change from radial distribution to the secondary a-c network. Instead of the large substations, the substations consist of entirely automatic underground vaults tied into a network system. Here again, the philosophy of design has turned the full circle back to the substantial networks which were common in the d-c days. Another method of solving the problem is illustrated in Figure 32 which shows an entirely automatic factory-built primary-network substation. Here the network is on the 4,000-volt side. The economies in attendance and care and first cost are apparent from the illustrations. Finally, Figure 33 shows the typical unit-type substation again, factory-built and unattended and fully automatic, which serves radial primaries in the same way that the typical automatic substation of Figure 30 used to do. What can be seen from these few brief illustrations of the progress of distribution?

We see the progress from the early d-c network going to the a-c radial system and back again today to the a-c networks, both on the primary and secondary ends. We see today factory-built unit substations taking the place of the large buildings of the early days. If we wished to take the time, we could have shown you many of the modern tricks of distribution, such as, the banking of transformer secondaries, the improvement in capacity of distribution systems by the addition of capacitors and the widespread use of pole-type voltage regulators.

The Technical Side

We have reviewed the past progress of the electric power industry and commented on certain trends which can be read into the data presented. Let us now see what some of these generalizations mean in their technical aspect.

Large Size

A review of the past has stressed the tendency toward large size. Generally speaking, it is easier to build good and efficient equipment in the larger sizes than it is in small sizes. Many of the friction and loss quantities are fixed by the existence of the machine itself and large size reduces them in proportion to the total output. In addition, large size permits introducing refinements in design

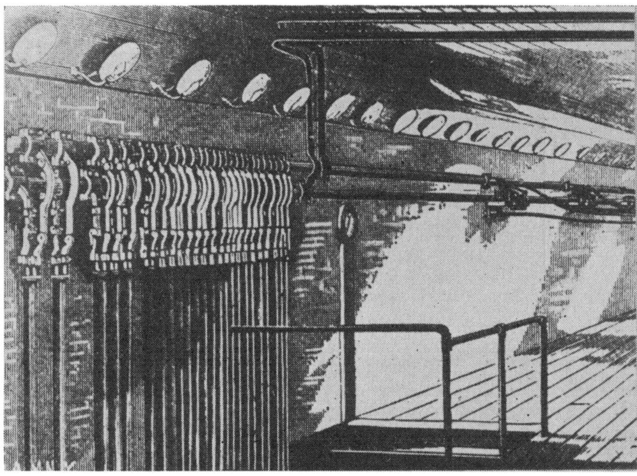


Figure 27. Pearl Street connections

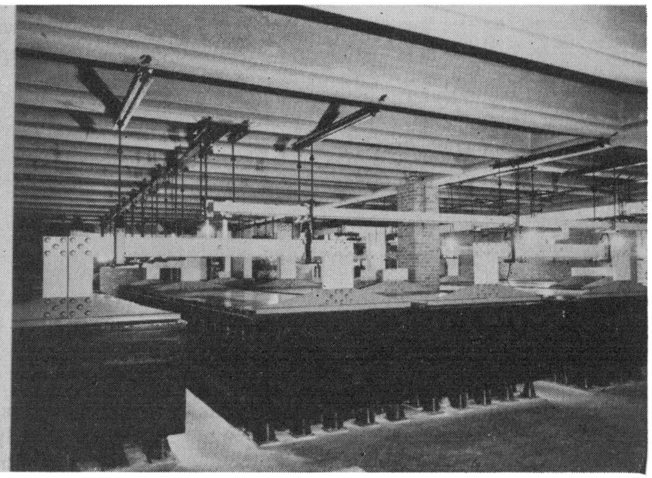


Figure 28. Battery room

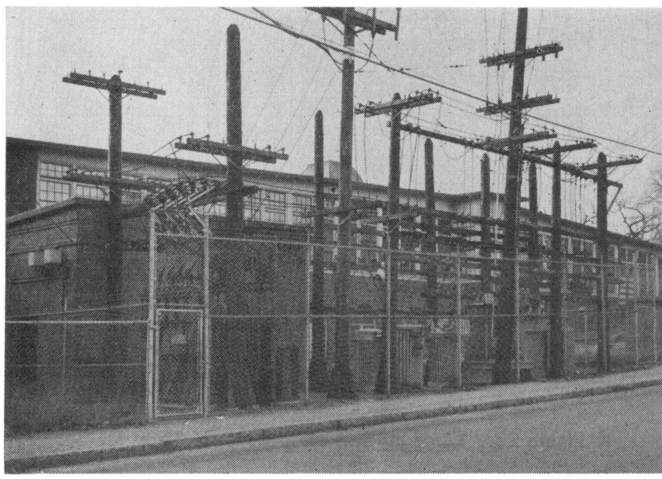


Figure 29. Early a-c radial overhead construction

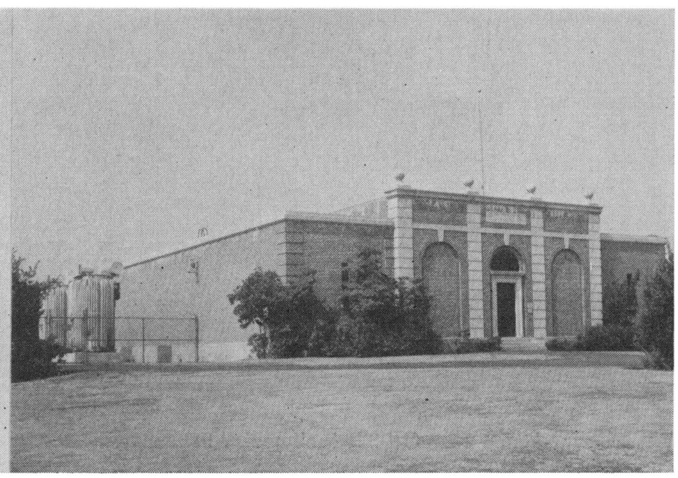


Figure 30. Radial, manual, and automatic substation

which would be of so small total effect in smaller equipment that they could not be afforded. This is plain on the mechanical side of the problem with the old 120-kw jumbo generator; it would have been difficult to justify five stages of feedwater heating, even if this concept had been fully appreciated at the time. However, in a modern large-sized turbogenerator of 100,000 or 150,000 kw, it is very simple to go to seven or even nine stages of feed water heating. Similarly, in the use of reheat, certain fixed losses are introduced into the cycle which could not be tolerated in a small unit. In large units these fixed losses are not too much greater, and the possibilities of obtaining the true theoretical gain from reheat can be realized. In such a simple matter as the use of modern feedwater treatment, which is essential to the use of large-capacity, high-tension, high-pressure units, large-scale operation makes possible the employment of suitable personnel and suitable equipment for the complicated feedwater treatment, which could not possibly have been afforded by the small-scale operations 50 years ago.

The Cycle

A review of the progress of the past has shown an increasing use of higher temperatures and pressures. Figure 34 shows the effect of modern pressures and temperatures on the cycle efficiency. The use of this figure, with the engine efficiency ratio shown in Table I, permits the calculating of the performance of any particular cycle which you may desire. The ideal cycle efficiencies are drawn without regenerative feedwater heating and the effect of this is taken care of in the efficiency ratio. The choices between getting better cycle efficiency from increased pressure or increased temperature are clearly indicated. Both are effective if operations are conducted on a large enough scale. One of the early troubles with high pressure was concerned with the leakage losses in the small-capacity machines considered at that time. These are not such important factors in the large-scale machines that are being built today. Suffice it to say that substantial gains in cycle efficiency can be obtained with more certainty by the increase of temperature rather than by pressure.

Prime Mover and Generator

Throughout our review of the past, there has been a continuous increase in prime mover speed and size. With our choice of the 60-cycle frequency for a-c use, we have run into a natural limit on speed of 3,600 revolutions a minute with the 2-pole generator. On the other hand, it is not apparent that we have exploited anywhere near to the limit the size of machines that can be built for this speed.

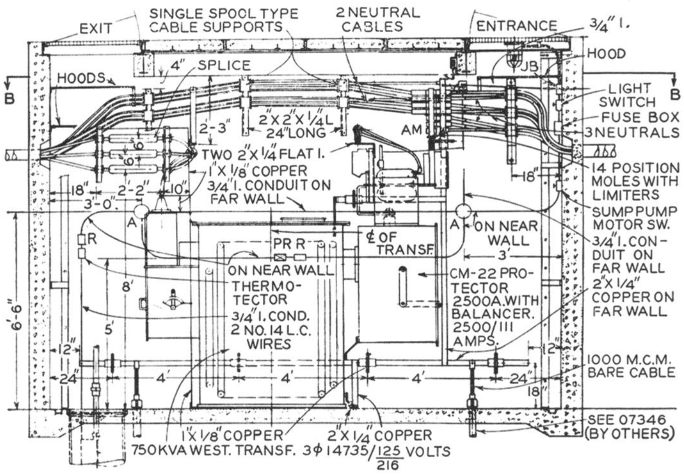


Figure 31. Secondary network vault

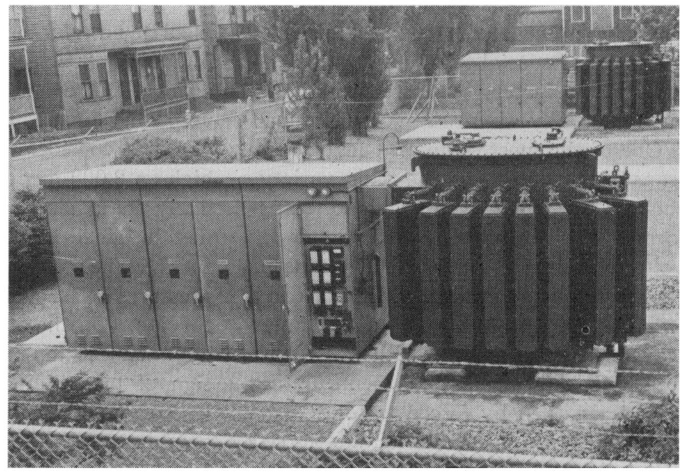


Figure 32. Primary network unit

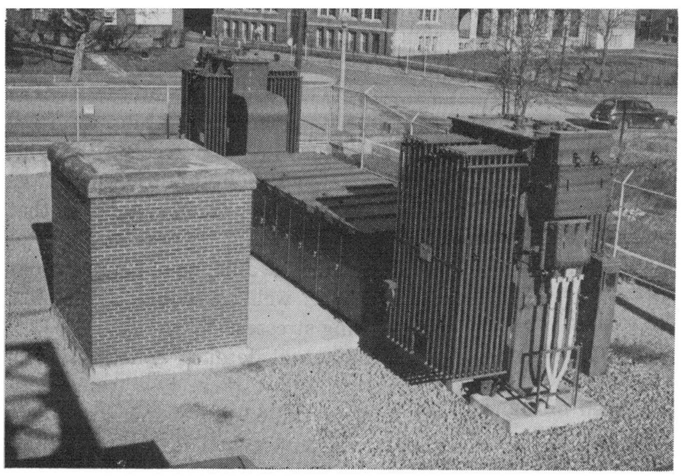


Figure 33. Unit substation

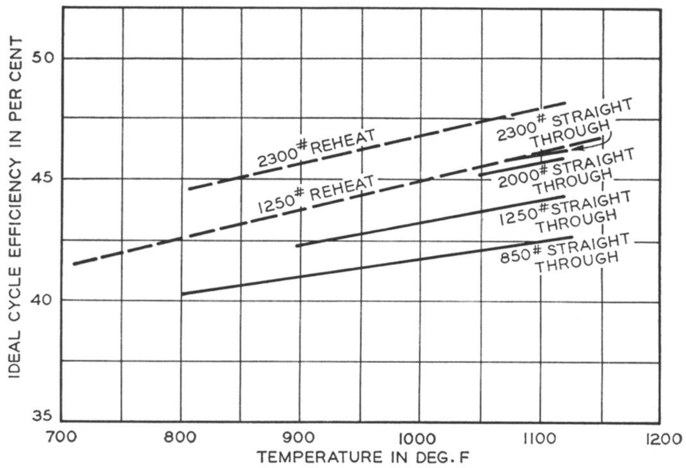


Figure 34. Ideal cycle efficiencies versus temperature for reheat cycles and straight through cycles at various pressures

Under this heading should be discussed the important advantages which have occurred to 3,600-rpm prime movers and generators by the use of hydrogen cooling. This has permitted a marked reduction in physical size or, on the other hand, a marked increase in capacity, and suggests many possibilities for future developments.

ELECTRICAL

In electric equipment, the tendency to larger sizes and capacities has come to match the growth of prime movers. They have had their own advantages in simplicity, in lowered costs of switching and transformation. The efficiency of transmission and distribution after the abandonment of the d-c system was good. There has been no great improvement in this today. As we have indicated in our survey of the past, the rise in voltage occurred quite early in the development of the power industry and presents many technical aspects. The use of higher voltage makes the problems of insulation and of corona discharge much more critical. Higher voltage, of course, permits the use of the same copper to distribute more power with satisfactory losses. There is considerable question as to the future field for use of voltages beyond the 350,000-volt level. It may well be, however, that for local transmission and distribution considerably higher voltages than those now used may prove desirable.

Table I. Annual Plant Net Heat Rates

	Pounds-Degrees		Efficiencies % Cycle	Ratio	Plant	Annual Heat Rate Net Btu/-Kwhr
Mystic*	1,250	900	42.3	0.714	30.2	11,300
Port Washington**	1,250	815	42.9	0.757	32.5	10,500
Twin Branch**	2,300	940	45.8	0.738	33.8	10,100
Proposed *	2,300	1,100	46.0	0.715	32.9	10,350
Proposed *	2,000	1,050	45.0	0.715	32.2	10,600
Proposed *	1,600	1,000	43.5	0.715	31.1	10,950
Proposed **	2,300	1,050	47.2	0.725	34.2	9,950
Proposed **	2,300	1,000	46.5	0.725	33.7	10,100
Proposed **	2,300	900	45.4	0.725	32.9	10,350
Proposed **	1,450	1,000	45.3	0.725	32.9	10,380
Proposed **	1,250	900	43.7	0.725	31.7	10,750

* Straight through. ** Reheat.

From our review, the trend to factory-built substations, prefabricated and prewired, is overwhelming. This trend offers no fundamental electrical problem and its extension is expected. At the same time, the trend to special types and special designs makes factory standardization difficult, especially where the volume is low.

One of the most significant features in transformer design, is the wide variety, such as tap changing under load, transformers for phase-angle shift, and for voltage control. The various means of cooling also are interesting. Many early transformers used forced air. Later transformers were filled with oil, cooled first by natural circulation, then by using forced air, then by forced water. Nowadays we are using forced oil and forced air, and instead of oil, we are using the fireproof Askarels and are even reverting to the straight air-cooled transformers. We have touched briefly on the progress of distribution system design. The possibilities are endless in the development from radial to network systems, and it is possible that the standardization which this large-volume field has brought about has hindered progress rather than encouraged it.

Lessons for the Future

This brief review of the technical and physical aspects of the progress in the past in the electric power industry may well point out certain important lessons for the future.

Large Size

The lessons of the past undoubtedly suggest that the units of the future will show a continued growth to larger sizes. This, of course, is the present handicap of gas turbines today. Their use for large power systems is largely circumscribed by their small size. Large electric power generating systems today have a peak load of as much as 2,000,000 kw and it would be ridiculous to add units to such a system having much less than 200,000-kw capacity. It will be many a day before gas turbines of 200,000-kw capacity are available, but every effort should be made to develop ordinary steam units for this size and larger.

Better Cycle Efficiency

A very fundamental part of the progress of the electric power industry in the past has been due to continuous improvements in cycle efficiency. It is believed, in the future as in the past, that the major forward steps will come by extending the available heat range upward by increased pressure and particularly increased temperatures. Today, the top temperature that is used for power generation is 1,050 degrees Fahrenheit. There is an immediate need for metallurgy in piping and in equipment which will withstand 1,200 degrees Fahrenheit and it seems, in the very near future, that we must be prepared to consider temperatures up to as high as 2,000 degrees Fahrenheit. Very likely the answer to this problem is not metallurgical. Perhaps such temperatures can be contained only by using lower pressures in the cycle as is done for the gas turbine. On the other hand, it may well be that a solution may be reached by a design of piping and equipment with refractory and insulating linings inside the pressure-resistant shell and provided with local cooling.

In any case, the tendency in the past for higher and higher temperatures is a lesson for those who are planning the use of atomic energy for power purposes. Atomic energy must be used at a high heat level to be justified by the results. Such an expensive fuel cannot be wasted as a substitute for oil and coal. Atomic scientists should bend their efforts toward the conversion of high potential energy to power, rather than considering means to degrade energy to the point where it can be contained in conventional equipment.

A similar lesson might well have been learned years ago by the proponents of the binary vapor cycles, such as the use of mercury in turbines. Between ordinary temperature limits the steam cycle can do quite well with the energy available. The excellent thermodynamic characteristics of mercury should have been utilized at much higher temperature levels.

The hopes for improvements in the steam cycle itself must be placed in the future not only in utilizing higher temperatures and pressures but also in reducing the percentage of heat rejected in the condenser by by-product use and by recirculating heat. By recirculating heat is meant all the varieties of heat traps, such as air heaters, economizers, and boiler feed heaters. It might be well to insert a word of caution that in considering heat traps it is not desirable to push recirculation to the point that the cycle reaches the dilemma which held the gas turbine for so many years. In other words, no net output. The principle of the gas turbine has been well recognized and understood for more than 100 years. During that time, many models were built. The only difficulty was that more power was used in recirculating energy, in the air compressor, than was delivered by the turbine.

Prime Mover and Generator

As the preceding sections have discussed, the first efforts of our manufacturers should be concentrated on extending the range of heat available to the prime mover by the use of higher temperatures, pressures, and better cycles. The development of large 3,600-rpm turbines and generators way beyond the capacities now available is also urgently needed. One step in this direction was the widespread development and use of hydrogen cooling. The design today represents a triumph of detailed, careful design. The advantages that were obtained by hydrogen cooling in the reduction of physical size and increased capacity and efficiency have rarely been excelled. It should not be forgotten, however, in this success that there are other approaches, and other means of generator cooling may well yield equally startling progress.

The progress in generator voltage design has been nowhere near as satisfactory. At a very early stage in their development, 14,000 volts were used in American generators and, while admitting that there may be many technical reasons why extremely high-voltage generators are not practical, it would seem to us that doubling or tripling of present voltages would reduce the amount of copper in our machines, as well as reduce mechanical and cooling stresses.

In the actual detailed construction of generators today, there is a tremendous amount of skilled handwork and techniques which were well developed in 1882. This is typified by the widespread use of hand-split mica. It would seem that modern manufacturing methods and design aimed at improved insulation, improved cooling, and the suppressing of corona could achieve important progress in electric machine design today. There is recent evidence of progress in this direction.

A similar field for modern manufacturing methods lies in the manufacture of laminated cores. The insulation of laminations, their punching and burring and assembly, are awaiting improvements which would lower costs and eliminate vibration and the resulting noise.

The comments so far under this heading have been largely electrical in nature and this proceeds from the idea that turbines can be built much larger in capacity than the generators which are now available. At the same time, we have full realization that the mechanical detailed design of turbines today with the large amount of skilled hand work and fitting could be very largely improved. Careful functional design in such simple matters as blade roots, nozzle block caulking, and sealing strip caulking could easily be transferred from the realm of skilled artistry to mass production.

Switching

The tendency towards larger capacity and faster switching has been clearly brought out by our review. There may be some question as to the ultimate desirable size and interrupting capacity of switching, but there can be no doubt of the desirability of minimizing by faster action and better relaying the burning of cables, windings, and cores that occur in short circuits.

Considering the present rate of load growth, the ultimate size of the electric load cannot be predicted. It may be that, rather than the design of apparatus with larger interrupting capacity, what is needed is a design of transmission and distribution systems which will limit the interrupting capacity thrown on the switching. This is obtained at present by sectionalizing, by limiters, by splitting networks into smaller parts. The opportunity exists for system design of a fundamental nature to anticipate and provide for the growths that the future will bring us.

Mention should be made of porcelain, so widely used as an insulator on our electric systems. It is indeed a difficult engineering material, subject to cracks, absorption, and brittleness and there are few ways to measure its satisfactoriness for service. With the higher voltages, higher speeds, and higher mechanical stresses that are coming in the growth of our electrical industry, some better material is badly needed.

Another bugaboo of the electric system are the moving contacts such as are found in regulators and tap changers and in the switches themselves. The problem of the moving contact has never been solved properly.

Silver plating, wiping contacts, are all improvements, but perhaps the solution is not a matter of detail but of a complete new approach. It may be that the power switching of the future will be done electronically in tubes.

Transmission

The needs for the future in the field of transmission are clearer. Lower-cost cables which can be installed more economically than present practice are necessary. If lower-cost methods of installation could be combined with some method of assuring that the cable is installed without damage from pulling, it would be extremely desirable.

It seems there is a field for standardization in transmission design similar to the unit designs of the distribution substations. On the overhead transmission lines, the control of lightning and of sleet are still none-too-well worked out and could benefit from further effort. The very real limitations on the long distance transmission of large amounts of power suggest an opportunity for fundamental research. It may well be that a continuation of the work on high voltage d-c transmission would prove fruitful.

Distribution

Returning once more to the distribution system of the electrical power industry, this is a mass production item, and because it deals in the lower voltages and with repetitive installations, it is not so glamourous as some of the other fields of endeavor. It should be borne in mind, however, that the extremely large investments which power companies make in their distribution system warrant the most intensive engineering studies. The extremely long life of distribution systems, as in all the equipment of the power industry, is also important. The first installation should provide for future growth without frequent rebuilding.

Perhaps two phases of the distribution system design call for the most immediate attention. One is the great need for lower-cost underground construction. Modern cities' civic pride and indeed the high-density power requirements of a modern city force conversion to underground distribution. If new techniques, new approach, or new modern machinery could develop a lower-cost underground distribution system, it could be put in originally and the high cost of later conversion could be avoided. The second urgent need is for improved reliability in the overhead distribution system. Aerial cable may be one of the answers to this problem. The situation is just the reverse of the underground problem. Modern overhead construction is relatively economical. Furthermore, repairs to the overhead system are quickly and economically made. It is perhaps for this reason that no great improvement in the reliability of the overhead distribution system has been made.

Transformation

The future of transformer design would appear a simple problem and will undoubtedly be a continuation in the development of larger and larger 3-phase units. The problem of the tap changer and of the moving contacts has been discussed. It is certainly desirable that there be an immediate solution to the noise problem. There seems no reason why a piece of nonrotating equipment should present a problem to the acoustical engineers every time it is installed in a residential area.

Conclusions

In summing up this review of the progress of the electric power industry, it seems clear that continued progress to low-cost power as shown on Figure 1 requires a reversal in the upward trend of the cost index. The industry will continue its present rapid growth. Cycle efficiencies are going to increase as will the temperatures utilized. New economies from large-scale operations will be realized as the sizes of equipment increase.

Many of the annoying details that seem important to us today will vanish due to the progress of the arts. Nevertheless there will be, for many and many a year, plenty of work for the designers of the electrical power industry.

Discussion

John M. Drabelle (Iowa Electric Light & Power Company, Cedar Rapids, Ia.): The authors, I. E. Moultrop and G. A. Orrok, have contributed a valuable review to the literature of the electric power industry.

To look backward is to really look forward and see the progress which has been made in the generation, transmission and distribution of electrical energy to the public and to better see what lies ahead. This progress is that of the public utility industry of the country, together with the manufacturers.

The heat cycle in the power station is the real challenge, and as long as we use water and steam, the lower end of the steam cycle does not present any such opportunity of improvement, so we naturally turn to higher temperatures and higher pressures with the regenerative and reheat cycles, together with the various heat traps on the boiler, such as the economizer and the air preheater.

With the standardization program as carried out jointly by the AIEE and The American Society of Mechanical Engineers, the time and effort of the manufacturer's engineers can be devoted to mechanical and internal refinements of the steam turbine and its accompanying generator, rather than devoting all their time to recalculating standard machines for nonstandard conditions and various nonstandard arrangements of extractions for feed water heating that contribute little or nothing in the over-all heat cycle.

As has been pointed out by the authors, the distribution system, both overhead and underground, challenges as yet the ingenuity of the engineering fraternity.

Herbert B. Reynolds (J. G. White Engineering Corporation, New York, N. Y.): The authors have presented a splendid review of the power industry and have pointed the way for further development. However, I would like to mention a few additional milestones in the progress of the art.

First there is the last stand of reciprocating steam engines for central station use in the form of the 7,500-kw units in the 74th Street and 59th Street Power Plants of the Interborough Rapid Transit Company, now part of the New York City Transit System. These engines are the largest ever built for central station use, the diameters of the high and low pressure cylinders being 44 inches and 88 inches respectively, with a common stroke of 60 inches. The diameter of the revolving field is 32 feet. Some of these units are still in use for peak load and standby service.

Another milestone was the addition of 7,500-kw low-pressure turbines to some of these engines so that the exhaust steam from the engines could be used in the turbines, thus doubling the capacity of the units and greatly improving the efficiency, making them the most efficient prime movers at the time. This improvement was conceived by the late Henry G. Stott, a past president of the Institute and one of the pioneers in large power plant work. The installation of Roney stokers under the rear of the existing Roney fired boilers in the 59th Street Power Plant by Mr. Stott was probably the first major step taken in order to increase the capacity of boiler heating surface.

Another great improvement in the power field has been the use of the fully automatic ignitrons in place of the manually operated rotary converters for the conversion of alternating current to direct current.

F. M. Gunby (Chas. T. Main, Inc., Boston, Mass.): We are indebted to the authors for recording so much so well, and also for their disclosure of trends. The picturing of some of the early works and practices is valuable and gives us good back sights.

The growth of loads has made the great increase in the size of generating units feasible.

Standardization within the electric industry is one of the fundamentals upon which the rapid development of this huge industry rests. The authors skillfully give us the shadows from some of the early days before standards emerged.

The team work which met and solved these problems is a memorial to the early figures in the electrical industry. This team work developed largely around the National Engineering Societies and AIEE can be proud of its major share in that team work.

The authors have prepared a comprehensive history or critique of the progress in steam electric power plant development. Since improvements in cycle efficiencies by means of higher temperatures must await the development of new materials, it becomes increasingly important to expand the installation of by-product plants. In large cities there appears to be an important opportunity for utilizing the heat in the steam ordinarily rejected to the condenser as a means of supplying the office-district load which is concentrated in a relatively small area for distribution. Industry has long made use of this cycle and there are examples of its use by utilities.

The authors state that they have confined their work primarily to the generation of electricity by steam. The title, however, is broad enough to warrant a reference to generation of hydroelectric power and some of the transmission problems which have resulted. The following discussion touches on that source of energy which in 1950 accounted for nearly 30 per cent of the total kilowatt-hours.

Progress in hydroelectric development parallels the great advance in thermal station design. The use of horizontal multi-runner turbines of low capacity operating in cylindrical plate steel casings and other early designs are still within the memory of many present-day engineers. Large modern installations use vertical shaft units. Probably no other factor contributed so materially to the advance leading to the modern large size vertical turbine as the advent of the Kingsbury thrust bearing.

The present top of individual unit size is in the 120,000-kva range. Prediction of output limits would be essentially based on improvement in turbine practice resulting in higher speeds. This would increase generator outputs without exceeding present rotor weights, which are fast approaching economic limits of structures and handling methods.

The larger units usually have direct connected stabilized exciters and a closed ventilating system consisting of an air housing and surface air coolers. There have been a few outdoor installations but no distinct trend in that direction.

Most large hydroelectric stations are now of the so-called unit design in which each unit is actually a complete independent installation having its own turbine, governor, generator, exciter, auxiliaries, and step-up transformers. Some are having the metal-clad switchgear connected to the generator air housing.

Progress in hydraulic prime movers has been notable in the trend to large size units. The limitation on the size of Francis type turbines has been fixed principally by the maximum diameter of the runner that can be shipped in a single piece. Larger diameters have been built with split runners but these have been limited to moderate heads.

The development of the propeller-type turbine has increased the speed at which units can operate under moderate heads with resulting economy. The development of the adjustable blade Kaplan unit has made possible the adaptation of the propeller unit to wide variations in flow and head conditions. Recent trends in installation of Kaplan units at heads above 100 feet have increased the adaptability of this type of unit.

Efficiencies of hydraulic turbines have not improved greatly in recent years. The maximum reported efficiency of $94^1/_2$ per cent was obtained by the installation of the 100,000-horsepower units in Canada.

Improvements in the setting of turbines, increased knowledge from cavitation research, and the development of stainless steel protection against cavitation has resulted in increased speeds for both Francis and propeller-type turbines with consequent economy in both turbine and generator.

Increased capacity of impulse units has resulted from development of multinozzle vertical shaft installations.

Since sites of important hydroelectric developments are usually far from large cities with their large loads, and generally concentrated steam generating facilities, this condition early brought long distance transmission prominently into the picture.

The trend is toward the use of large systems consisting of several stations or group of stations interconnected by heavy transmission lines. Often several such systems, including both steam-electric and hydroelectric generation, are linked up and operated as a single system. The control can be by a system dispatcher using modern aids such as carrier current telephoning and telemetering, supervisory control, automatic load frequency control, proportionate load control, or tie line control.

The protective relaying of these large systems is well understood. Great advances are being made in the field of power dispatching. The simple system of yesterday, where the regulation of the system output was concentrated in an individual, appears doomed for the larger systems. Accelerated by our post-war needs, this country is fast becoming an integrated network of power transmissions of such complexity that automatic equipment is even now assuming the task of coordinating the generation of many far-flung plants.

Where hydroelectric generation with ample pondage is available, it is often economical to increase the installed capacity and operate the hydroelectric plants for peak loads and as reserves. The increased installed capacity at such points can frequently be obtained at additional costs, which are relatively small.

E. G. Bailey (New York, N. Y.): The authors have presented a very pertinent review of progress in an outstanding industry, where engineering, invention, and development, together with progressive management, have resulted in continually lowering the cost of equipment while increasing its output in spite of advances in wage rates and the influence of inflation. The future will require the best of engineering and management to maintain the standards already recorded.

The statement in the paper that boiler efficiencies were 86 per cent in the days of Watt and only 90 per cent now may be misleading to some, because there is more to the story than just these two figures. The average boiler efficiency was probably below 70 per cent throughout all steam generating history until 1900. It is usually in the high 80's today. The over-all thermal efficiency of Watt's pumping unit was about 4 per cent as against 8 per cent for the average in 1920; 20 per cent in 1949, and 37 per cent for the best operating plants last year.

The great reduction in cost of generating steam has been due to the very high output per pound of boiler steel and the reduction in manpower per unit output. The credit for all of this is shared by the manufacturers of all kinds of equipment, as well as by the consulting engineers, management, and operators.

The future improvements likewise will be shared by all in their continuation of interest and contribution of engineering abilities.

The plant operators have striven for a high reliability of equipment, and it has been improved, thereby necessitating only a narrow margin of spare capacity.

As a user who has experienced 40-odd hours outage in supply twice in the past three years, there is still a problem of winning the battle of reliable distribution to the ultimate user against the elements.

N. E. Funk (Philadelphia, Pa.): The authors have presented a very excellent picture of the progress in the electric power industry over the years, for which they should be complimented.

There are several items, however, to which I wish to refer:

(1). In the abstract, the impression is definitely given that the improvement in the efficiency of generating electrical energy has been primarily responsible for the great reduction in the cost to the customer. This is not true. The vast improvement in efficiency has been practically wiped out by the increased price of coal, labor and power plant equipment. Thus, today the bus bar cost, including both operating and annual capital costs, is little different than it was 30 years ago, even with a great improvement in load factor.

As a matter of fact, the reduction in cost has been attained through greater customer density, greater individual customer use, greater individual customer load factor, better diversity factor, and a tremendous increase in total load.

(2). I do not feel that we will move too rapidly into units of 200,000-kw capacity.

The capital cost per kilowatt does not decrease very greatly for unit sizes over 150,000 kw, neither does the operating cost. Thus, the larger size units may require the installation of more capacity to safeguard the system, which at $150 per kilowatt overcomes the small saving from the larger size.

(3). I would not cast the gas turbine aside too lightly because of its size. There may be locations in any large system remote from circulating water where small gas turbines can be placed at a great saving in local transmission and with improvement in service reliability.

(4). Admitted there is an optimum voltage which permits a winding of the best electrical and mechanical characteristics, but it is somewhere between 14,000 and 20,000 volts, and not two or three times the present voltage.

I would assume without having made any calculations that the weight of copper depended upon the speed of the machine and its capacity, and that voltages of 28,000 or 42,000 would increase the copper weight rather than reduce it, because of increased insulation thickness. This would tend to increase the differential expansion of iron and copper; thus accentuating some of our present troubles.

William F. Ryan (Stone & Webster Engineering Corporation, Boston, Mass.): At this moment in history when every engineer in the power industry is overloaded with immediate and pressing problems it is fortunate that somebody has taken the time to review our progress to date and give some thought to long range future developments. We are indebted to Messrs. Moultrop and Orrock, not only for their own thoughtful and factual presentation, but for the stimulus their paper has given all of us who have read it to crystallize our own thoughts regarding future progress. I am sure we all agree that progress will continue at an unslackened pace, but each of us may place more emphasis on particular objectives.

It is possible, for example, that we should place more emphasis on reducing capital costs than on larger capacities or higher efficiency of generating units. The Engineering-News Record Cost Index, shown in Figure 1, has relatively little significance in the power industry. On the one hand it does not reflect the progressive inefficiency of construction labor, which makes actual costs even higher than the index would indicate, and on the other hand it does not allow for the technological advances which have enabled the designers of power plants and power systems to offset, in large part, the rising costs of material and labor. According to our own index of power equipment costs, the boilers which Mr. Moultrop installed at L Street, 50 years ago, would now cost 18.8 times as much as they did in 1901, if anyone should care to install boilers of that size and design. However, the same heating surface would now generate about seven times as much steam, and the latter amount of steam would generate nearly 30 times as much power per square foot of boiler heating surface. Actually, steam generating equipment costs less now, per unit of electrical output, than it did at any time prior to about 1939. The outstanding challenge to designers today is to hold capital costs in line.

Another item which deserves more present thinking for future progress is the cost of maintenance. Our boasts regarding decreased costs of labor and fuel are not matched by decreases in maintenance expense. It is open to question whether the cost of maintenance, per kilowatt year, is any less in our largest and most modern plants than it was in the first plants that Mr. Moultrop, or Mr. Orrock's distinguished father ever designed.

It would appear also that radical advances must be made in the art of local distribution. The traffic on our local distribution systems is increasing faster than it is on the highways, but the systems themselves have more in common with the streets of downtown Boston than they have with the freeways of Los Angeles. Radical developments are required, not only to reduce costs, but because we shall soon be unable to get enough conductors of the present type into our city streets.

As mentioned in the beginning, it is good to find someone who will take the time to look forward. Mr. Moultrop has been doing that for 60 years, and Mr. Orrock will still be doing it 60 years from now if progress in longevity parallels progress in the power industry.

I. E. Moultrop and **G. A. Orrok**: The authors feel very complimented at the caliber and quantity of the discussions presented and wish to thank the discussers.

John M. Drabelle

Mr. Drabelle emphasizes the importance of standardization. We agree with this and his other suggestions.

Herbert B. Reynolds

This discussion makes a very good addition to the paper, amplifying the section on the early reciprocating steam engines and boilers. The engineering work of Mr. H. G. Stott is outstanding in our field.

F. M. Gunby

Mr. Gunby makes a very valuable addition to the paper in discussing the developments in the hydroelectric generation of power.

E. G. Bailey

We can only agree with Mr. Bailey's careful analysis of boiler efficiencies. His discussion adds value to the paper.

N. E. Funk

This valuable discussion brings up several of the debatable points in the paper and we must agree that the efficiency of electrical generation is not the whole story on low cost. Nevertheless, had the generating efficiency not improved, costs would be much higher than they are today. The increase in total load and in load density have been tremendous factors in holding the cost of electricity down. The point we wish to make is that similar growth and increase of load density have been common to other types of industry and other types of product where the same reduction in price of the commodity to the consumer has not ensued. As to the economic size of units this, of course, is a question which can be solved only for each specific unit as it comes up. We must agree that it is very easy to purchase too large a unit for a given installation. On the other hand, for many installations reliable units of a large-enough size have not been available. This discussion sheds more light on the question of gas turbines and on the optimum generator voltage.

William F. Ryan

Mr. Ryan throws additional light on two important problems of electric power station design: the first on capital cost, and the second on the cost of maintenance. The authors have not stressed in the paper the importance of the progress in the design of power plants toward reduced maintenance expense. Actually, a comparison of the operating figures will indicate that the cost of maintenance has varied more in proportion to the capital cost of the equipment installed than with the cost of kilowatthours. This fact is only what might be expected, but the desirability of directing design toward reduced maintenance costs can not be emphasized too strongly.

Many of the discussions emphasize the point with which we would like to close. The development of the power industry has been the result of the collaboration of many individual engineers, of the power companies, of the manufacturers of equipment, the National Engineering Societies, and many others. We can all take pride in our share in this great development.