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A HYDRO-ELECTRIC GENERATING STATION OF THE FUTURE

See Article, page 843

GENERATION AND TRANSMISSION

GENERAL ELECTRIC REVIEW

NOVEMBER, 1919

A Special Issue on

GENERATION AND TRANSMISSION OF ELECTRIC ENERGY

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Manager, M. P. RICE
Editor, JOHN R. HEWETT
Associate Editors, B. M. EOFF and E. C. SANDERS
In Charge of Advertising, B. M. EOFF

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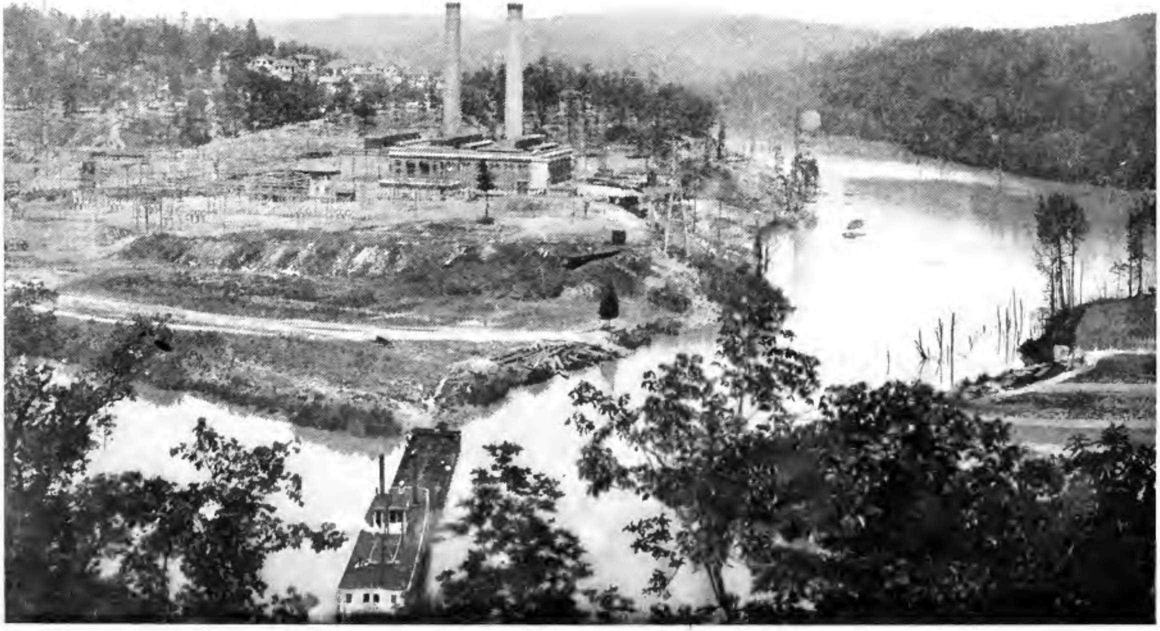


THE WARRIOR RIVER STEAM PLANT OF THE ALABAMA POWER COMPANY (See article, page 980)

GENERAL ELECTRIC REVIEW

GENERATION AND TRANSMISSION

In this issue of the REVIEW we conclude our series of articles on the War Work of the General Electric Company, which will have shown our readers how thoroughly the resources of the Company were devoted to helping the National cause. The bulk of this issue is, however, devoted to a special collection of articles on Power and Transmission which will emphasize the fact that, although the armistice was signed only a year ago, those who were so ardently working for the great cause have lost no time in turning their attention to the cause of peace.

In many respects the articles in this issue form a remarkable collection; they show the magnitude of some of the tasks that confront the engineer of today. It was only a few years ago that the engineer was puzzling over armature connections and what today would appear as simple electric circuits. At the present he is studying electric circuits which embrace a host of towns, many counties, and in some instances a number of states.

It was only a few years ago that we pointed with pride to some of our large power houses and talked of their "enormous" capacity and told of the load they were carrying, the number of lights they were supplying, the street railways they were operating, and then, later, of the power load that was being added.

A later development was tying some of these stations together in a single town, but now, as it is told in some of our articles, many towns are tied together. In building up such interconnected systems many stations can be eliminated. In Mr. Hunt's article an instance is cited where as many as 121 plants were abandoned. Now hydraulic power sources have been connected up with steam power houses and the network of transmission lines span many states. Enormous economies have been secured in this way. The movement on foot now is to tie these systems themselves together until it looks as if the future will see whole countries served by comprehensive carefully planned systems of transmission lines. The control of such large powers presents peculiarly difficult problems, many of which are dealt with in this issue.

We shall leave the reader to learn of these developments from the articles themselves as we wish to point out that there is a perfectly definite reason for these developments and that, as in previous periods of our history, it is the engineer who has realized the situation and is working to meet it.

We have heard a great deal of the conservation of fuel, and, indeed, a series of articles is still appearing in our columns on this important subject. Coal, water and oil are our chief sources of energy, and water is fast becoming of paramount importance, but we are interested only in our fuel resources as a means of getting energy, and one of the chief considerations that concerns us is how to get the energy from its source to the place where we want to use it. This is just why electric transmission lines are to play such an important part in our future welfare.

With an electric transmission line the conversion of the chemical energy in coal or oil, or the mechanical energy of falling water, can be carried out at the source and the electrical energy can be transmitted to the actual place of use. It can be taken into the factory, street or home and there converted into heat, light and mechanical energy as the case may be. What is of still greater importance is that this form of energy is under the most wonderfully perfect control. It is available day and night. The closing of one switch may start a huge motor in a steel mill, the closing of another switch may light a city street with arc lamps, and the closing of a third may heat the baby's milk in a nursery. There is no other form of energy that can be used so conveniently as electrical energy. There is no other known form of energy that can be so economically derived from so many other forms of energy, transmitted over great distances and then converted to the form of energy required at the spot where it is wanted. There is no other form of energy that can be handled with so little labor.

So the main purpose of our great transmission systems is to provide energy wherever it is needed. This has been done so successfully in the past by electricity that its use is extending all the time and we are daily becoming more dependent upon it.

If future progress can be judged by the past we shall soon be absolutely dependent upon our transmission systems for our supply of energy in the factory and in our homes. It is a recognition of this that is causing the engineer to take such pains to devise apparatus that will assure continuity of service.

With all our enthusiasm for our work and our pride in our accomplishments, we must remember that with the growth of civilization and industrialism man has made the children of his own creation the master of his destinies. Should machines of his own making suddenly fail a large percentage of the population would perish. The more civilized the area, the greater would be the percentage to die. Imagine all transportation facilities to New York, London, Paris and some small town in the West to fail suddenly. The loss in the large cities would be appalling, while the inhabitants of the smaller communities might suffer more from inconvenience than from actual lack of necessities.

The further we progress the more intensified will these conditions become and larger will be the percentage of people who will become absolutely dependent on man-made devices for the necessities of life. This is serious but inevitable. There is no chance so far as the human mind can see of altering this condition of affairs. Man must become more and more dependent for his everyday necessities on the work of man. Machines have civilized the world and on machines men must depend. Of course the seriousness of this depends on how well man-made machines are made and how well they are operated. Past experience has shown that man has made good machines and that they have been operated with an extraordinary degree of success, and both past and present conditions would indicate that the engineer is thoroughly aware of the extreme importance of making developments to keep pace with the requirements or of even setting the pace.

Every machine built requires energy to operate it. The least important may be operated by human energy or some small energy storing device such as a spring, but the more important machines must depend for their supply of energy upon some remote source—the coal mine or the waterfall.

We feel that the series of articles in this issue show how thoroughly the electrical engineer is awake to the importance of his work, and how hard he is working to perfect his part of the great plan of modern life. We sometimes wonder whether the mechanical engineer is as fully alive to the importance of making his machines as efficient as they might be made by applying the same methods of research to their production as the electrical engineer has applied in bringing electrical apparatus up to its present wonderful state of efficiency.

It is interesting to contemplate what machines are doing today and still more interesting to think of what they may be made to do in the future. The steam engine is still in its infancy—and the results that may be achieved in mechanical science are just as far reaching as those we are so constantly hearing of in the realms of physics. There is just as much need for research in mechanics as there is in other sciences and we expect to see many new developments when the same methods of research are applied. The higher cost of labor demands that more work be done by machines and also that machines be made more efficient.

If we are to rely on machines and on electrical energy more each year for the necessities of life, we must make our machines as efficient as it is possible to make them, and further, we must guard ourselves by providing assurances that they will be operated for the good of the communities they serve. Operators must be made to understand that they are public servants and that any interference with service for selfish reasons is a crime against the community. The more we do by machines the greater responsibility we are placing in the hands of those who are responsible for the operation of our transmission systems, because after all, machines are but machines, and we must still depend upon our fellow man to operate them. Kipling, in the "Secret of the Machines," tells this part of the story well—

"But remember, please, the Law by which we live,
We are not built to comprehend a lie,
We can neither love, nor pity, nor forgive,
If you make a slip in handling us you die!"

J. R. H.

F. H. Rogers

E. A. Dillard

F. L. Hunt

R. J. McClelland

B. Nikiforoff

C. B. McManus

J. M. Oliver

CONTRIBUTORS TO THIS ISSUE

W. S. Moody

C. M. Ripley

E. D Eby

J. W. Upp

T. W. Gordon

C. P. Steinmetz

O. C. Traver

A. R. Smith

M. C. Olsen

F. W. Peek, Jr.

N. L. Rea

CONTRIBUTORS TO THIS ISSUE

T. A. Worcester

E. G. Merrick

W. W. Lewis

C. M. Hackett

H. H. Dewey

D. B. Rushmore

E. A. Lof

H. R. Wilson

Robert Treat

A. G. Darling

H. Goodwin, Jr.

CONTRIBUTORS TO THIS ISSUE

Some Fundamentals of Engineering Economics

By D. B. Rushmore

Chief Engineer, Power and Mining Engineering Department, General Electric Company

For the ordinary comforts and luxuries, attainable today, many of which we have come to look upon as necessities, we are indebted, in part, to the discovery that man can enhance his own productiveness many fold by substituting mechanical power for his own labor, and in part to the wonderful discoveries and inventions which have made available nature's vast stores of energy for this purpose. The author sketches the evolution of the present industrial era, and draws attention to the dependence of our prosperity upon an ever increasing use of power as a substitute for human toil. That research and invention should be encouraged is emphasized as a condition precedent to our continued development along the lines of material betterment Mention is made of the more important problems resulting from our present use of electric energy in the industries, and a plea is entered for a greater measure of co-operation between manufacturers and users of electrical apparatus in their solution —Editor.

Every age has problems peculiar to itself, and history is a record of the continuous evolution incident to their solution. The laws of nature are immutable and we prosper as we recognize and work in accordance with them or suffer as we run counter. The method of attacking any problem is first to collect the facts and then carefully and intelligently to analyze the principles and natural laws which are involved. The deductions therefrom are applied with judgment to the modified conditions of a new problem.

What are then the important problems and difficulties of the present time? Primarily there is a demand for a life containing more happiness. The individual wants, amongst other things, more to say regarding his own destiny, more opportunity for self-expression and the satisfaction derived from useful achievements, and, incidentally, more of what we call wealth, that which contributes to the satisfaction and pleasures of mankind, and that for which man will give his work in exchange.

No political or industrial democracy can be founded with safety on anything but the intelligence and character of the people who compose it, and among these mental possessions must be included a knowledge of fundamental economics. From this standpoint, what claims have we for membership in such an organization and what in this direction are we doing to prepare ourselves or others for the responsibilities connected therewith?

We must understand, and work in accordance with, the laws of nature and of economics, or suffer accordingly. At the present time many of us are suffering; we do not want to; we do not clearly understand why we are. We are trying to strive intelligently and energetically to remove the difficulties and to find a solution to the problem.

Never before in our history have such great things been involved in world problems, and never before has there been such necessity for clear and correct thinking. On being right in our conclusions will depend the happiness of many hundreds of millions of human beings.

We can here treat of but one phase of this situation—the increased production of wealth in order that the amount per capita may be sufficient.

Wealth, the commodities which satisfy the demands of life for food, shelter, clothing, heat, light, etc., is produced in certain amounts each year and only the amount actually produced is available for distribution. What, then, are the elements involved in the production of wealth and how can these be so modified as to increase the output?

For our present purposes all wealth may be said to be created by operations comparable to those of a manufacturing company. The raw materials of nature, of the animal, vegetable, or mineral kingdoms found in the earth, water, or air are converted into finished products for ultimate consumption by various manufacturing processes which involve, among other things, power driven machinery, energy in various forms, and labor. Labor, on careful analysis, is a combination of power and intelligence—two factors which where possible should be, and often are, separated—man supplying the intelligence, nature the power. The elemental raw materials have existed in fixed quantities and locations since the coming of man. Civilization has continuously improved, and the material condition of the world has generally been one of steady advancement. In part, the explanation is found in the influence of invention and discoveries, and in part in the utilization of large sources of energy which are available as a substitute for the physical work of man.

The development of articulate speech, the discovery of fire, the invention of the bow and arrow, the domestication of animals, and the discovery of methods for preparing and working iron, all mark eras of progress in the upward march of mankind. So also are distinct advances marked by the invention of writing, of gunpowder, of the compass, of paper and the printing press. At last came the steam engine and the great era of industrial development during which man began to use the forces of nature for his own purposes. Since then inventions have become too numerous to mention. Formerly man consumed as power only the energy which he personally produced. Then the wild animals were domesticated, and, especially for transportation purposes, served as prime movers for power purposes—thermodynamically the most efficient ever developed. Energy from the earth's rotation and from the sun, the latter found in many forms and places, wood, coal, oil, gas and water power, utilized in machines of man's invention, is the basis of our present industrial activity. The material status of a civilization may, therefore, be judged by the energy consumption per capita. The whole age is denoted by, and is dependent upon the increased use of power in the various economic activities. No reiteration of such fundamental facts can properly be called trite. They constitute the basis of a policy for future plans.

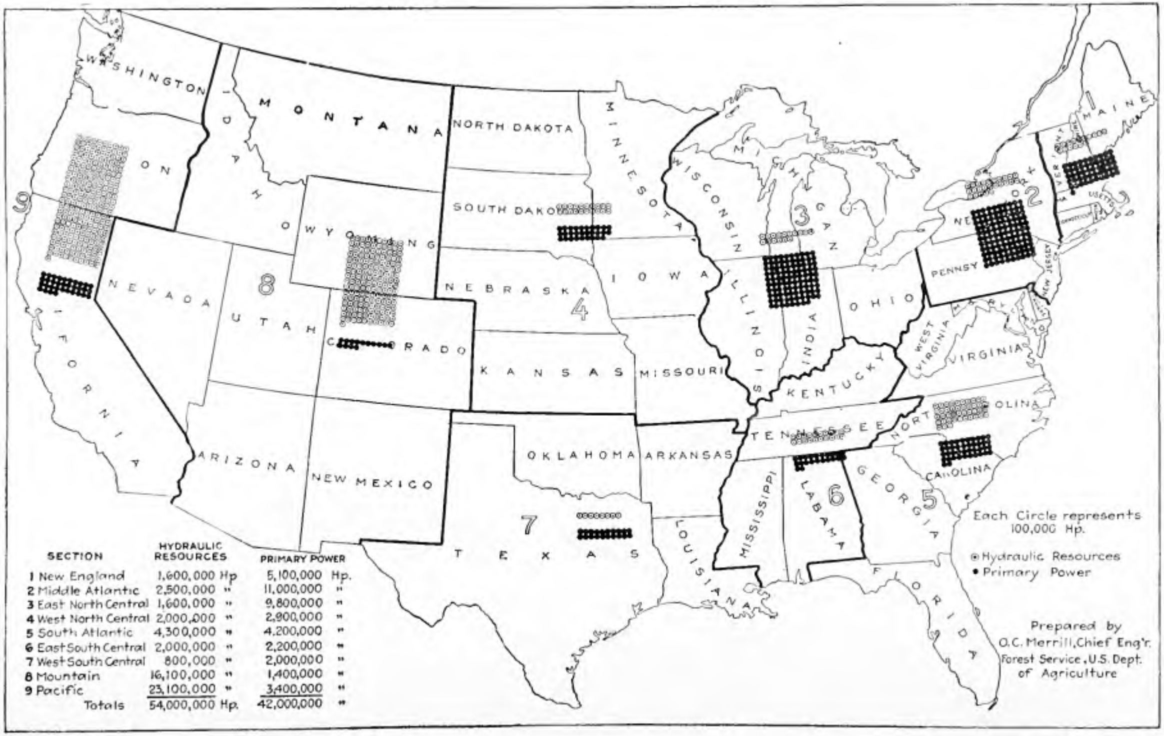
The cost of most finished products is, in a very large measure, made up of the wages paid to labor. If we take the various costs involved in making a finished razor blade from the iron ore lying in the ground we shall find that labor, directly or indirectly, has received by far the largest part of the expenditure. This being true, a change in wages or in the return paid to labor is reflected almost directly in the cost of the product, and, therefore, increasing wages mean necessarily increasing prices and the "vicious circle" is in full operation.

At the present moment the high cost of living is one of the most important problems in the world. People of all classes are beginning to understand that merely raising wages is not a solution. The world is short of commodities. What we need is increased production, increased efficiency in production, and a decreased labor cost per unit of output. This only will solve the problem. High wages and low labor cost per unit are not by any means incompatible, but all restrictions on production must be removed, all possible increases in the efficiency of production must be attained and also, at a time like this, every possible individual and collective economy in consumption should be practiced. Only along these lines of sound economics can the serious problem of high living costs be solved.

Now what is our object? In part at least, to produce in this country and in the world more wealth so that we may all have more of those things which are necessary for life. More production, that is the thing of first importance. Without greater labor and more hours it means more research, more discovery and invention, more labor saving and automatic machinery, more utilization of the materials and forces of nature for the purposes of man, in fact, more *engineering*. From the age of human labor we come, through the substitution of power driven machinery for physical effort, to the greatest of present and future economic needs, an available supply of energy in large quantities and at a minimum cost. On this our present civilization, and still more the hope of a better future, absolutely depends.

In treating the economic question from its industrial aspect, the question of power supply is of paramount importance. Power supply at present is derived from a limited number of sources of energy—coal, oil, gas, and water power. Our coal deposits are limited in quantity and when once used are not replaceable. The same holds true of oil and gas. But the wonderful source of energy known as water power is only wasted when it is not used, and is being continuously renewed. The pressing demands of the present, and ordinary precautions of preparedness for the future, urgently demand the development of all water powers up to the limit of commercial feasibility. The nation needs these as it needs no other natural asset and the public is rapidly coming to understand and appreciate the vital importance of this situation. The millions of dollars of energy which are annually wasted in this country at such places as Niagara Falls and elsewhere by the non-utilization of water power constitute an economic crime of the first magnitude. That all parties interested in the development of such water power should be properly safe-guarded and protected is admitted by all.

The development of water powers must follow all of the economic laws in which labor, capital investment, and competitive sources and methods are involved. England and other countries of Europe on which the economic pressure has been greatly increased of late are directing their attention forcibly to the importance of this subject of water power development, and from an economic stand-



SECTION	HYDRAULIC RESOURCES	PRIMARY POWER
1 New England	1,600,000 Hp	5,100,000 Hp.
2 Middle Atlantic	2,500,000 "	11,000,000 "
3 East North Central	1,600,000 "	9,800,000 "
4 West North Central	2,000,000 "	2,900,000 "
5 South Atlantic	4,300,000 "	4,200,000 "
6 East South Central	2,000,000 "	2,200,000 "
7 West South Central	800,000 "	2,000,000 "
8 Mountain	16,100,000 "	1,400,000 "
9 Pacific	23,100,000 "	3,400,000 "
Totals	54,000,000 Hp.	42,000,000 "

Fig. 1. Map of the United States, showing by Sections the Primary Power Generated and the Hydraulic Resources

point there is nothing in the whole world of greater importance to its inhabitants. Table I gives important data concerning the water power of North America and Europe, and Table II shows the horse power used by the leading manufacturing industries in the United States. These tables show very forcibly what a tremendous factor power has become in our modern civilization. Fig. 1 is of special interest as it shows the distribution of hydraulic power sources in our own country.

The location of an industry is a matter of great importance and not only present, but future conditions of labor, transportation, manufacturing facilities, and power supply must be considered. In general, the most economical site for a water power development is not always that best suited for the manufacturer who consumes the energy produced; hence power transmission is nearly always essential. The great diversity of load on modern distributing systems and the peculiar character of some manufacturing processes renders an interruption to power supply of great importance. Water power development and high voltage power transmission must necessarily compete with local steam plants utilizing fuel, not only in cost, but also in quality of service. The difficulties to be met with at each new step in the development of high voltage transmission, as regards the use of increasing pressures, the complexity of networks, the magnitude of the power generated and distributed from particular points, and the amount of power which can be concentrated at a particular fault, have made this field of engineering not only one of [illegible] importance but also one requiring [illegible] study and experience. It is a tribute to the

TABLE II

PRIMARY HORSE POWER USED BY LEADING MANUFACTURING INDUSTRIES

1914 CENSUS

Agricultural implements	121,428
Automobiles including bodies and part	173,681
Boots and shoes, including cut stock and findings	112,920
Boots and shoes, rubber	21,621
Brass, bronze and copper products	122,700
Bread and other bakery products	107,771
Brick and tile	170,758
Cars and general shop construction and repairs by steam railroad companies	133,994
Cement	490,402
Chemicals	282,385
Copper, tin and sheet-iron products	75,263
Cotton goods, including cotton small wares	1,585,953
Electrical machinery, apparatus, and supplies	227,731
Fertilizers	114,281
Flour-mill and grist-mill products	822,384
Foundry and machine shop products	1,129,768
Ice, manufactured	161,988
Iron and steel blast furnaces	1,222,273
Iron and steel, steel works and rolling mills	2,706,553
Leather, tanned, curried and finished	172,712
Lumber and timber products	2,796,902
Paper and wood pulp	1,621,154
Printing and publishing	335,210
Slaughtering and meat-packing	260,996
Smelting and refining, copper	194,980
Woolen, worsted and felt goods, and wool hats	398,367
Total all industries	22,547,574

TABLE I

WATER POWERS OF NORTH AMERICA AND EUROPE*

Country	Area Sq. Miles	Population Latest Census	H.P Available	H.P. Developed	Per Cent Utilized	H.P. Available Per Sq. Mile	H.P Developed Per Sq. Mile	H.P. per Capita	
								Available	Developed
U.S.A.	2,973,890	98,783,300	28,100,000†	7,000,000	24.9	9.4	2.35	0.28	0.071
‡Canada "A"	2,000,000	8,033,500	18,803,000	1,735,000	9.2	9.4	0.87	2.34	0.216
‡Canada "B" Populated	927,800	8,000,000	8,094,000	1,725,000	21.3	8,7	1.86	1.01	1.216
Austria-Hungary	261,260	51,173,800	6,460,000	566,000	8.8	24.8	2.17	0.13	0.011
France	207,500	39,601,500	5,587,000	1,100,000	11.6	26.8	3.14	0.14	0.016
Norway	124,130	2,391.780	5,500,000	1,120,000	20.4	44.3	9.02	2.30	0.468
Spain	190,401	19,588,700	5,000,000	440,000	8.8	26.3	2.31	0.26	0.022
Sweden	172,960	5,522,400	4,500,000	704,500	15.6	26.0	4.08	0.81	0.127
Italy	91,400	28,601,600	4,000,000	976,300	24.4	43.8	10.7	0.14	0.034
Switzerland	15,976	3,781,500	2,000,000	511,000	25.5	125.2	32.0	0.53	0.135
Germany	208,800	64,926,000	1,425,000	618,100	43.4	6.8	2.96	0.02	0.010
Great Britain	88,729	40,831,400	963,000	80,000	8.3	10.9	0.91	0.02	0.002

* From the *Electrical News* April 15, 1918.

† This represents continuous power. Compare with the value given on page 822 (54 millions), which evidently represents the maximum power available during a certain portion of the year, thus requiring considerable auxiliary reserve to make it continuous.

‡ "A" excludes Yukon and Northern Area improbable of immediate development. "B" included in "A" in area actually settled.

careful study of those engaged on this work that increasing distances and higher voltages have been attained without increasing the troubles involved, and in many cases actually reducing them.

Every man in business knows that production in general naturally overtakes demand. All business men and manufacturers of every kind are engaged in a study and effort to legitimately increase the demand for their goods. This is so well known, so entirely proper and desirable, and so generally adopted as not to need discussion. Public utility concerns devote not a little time and money to investigating new loads for their systems. Manufacturers of power machinery of all kinds are naturally interested in new fields and opportunities for the use of their products, and in many cases new apparatus and developments have been worked out with the joint co-operation of the manufacturer, the utility, and the consumer. The close relationship which has existed between these three parties to the electrical industry and the clear appreciation of the mutual difficulties and problems involved have been an important factor in the rapid development of the electrical industry.

Electrical machinery, as is well known, is so complicated in its own characteristics, and is involved in such a variety of factors in connection with its application that it cannot be sold by the same methods utilized in many industries. Sugar is a standard product and the buyer does not need expert advice or any specific tests or inspection in purchasing such a commodity. With electrical machinery, however, matters are different. The technical ability which has been developed in connection with this industry is such that in many cases the engineers of a particular establishment, or those employed by a public utility are fully competent to purchase and operate electrical apparatus without special assistance from the manufacturer. Many consulting engineers are also doing excellent work in helping to solve the problems involved in these situations, especially with regard to large developments.

The necessities of the situation, however, require, and the manufacturers of electrical apparatus recognize, that they owe to the public, to the purchaser, and to all parties involved, a duty for the successful and satisfactory performance of their products. This is met by maintaining an organization of many highly trained engineers who have devoted years of study to the peculiar requirements of the apparatus manufactured and the conditions of its application. A great many years of experience, a wide acquaintance with systems and individuals, and a continual activity in studying possible advances has developed a corps of engineers who have become experts on the work of power generation and transmission.

To sum up in a few words the essence of the present economic situation, we can say that the greater part of the wealth produced each year is the result of industrial activity. Industrial production is fundamentally dependent upon labor and power supply. The great demand of the present moment is for an increase in production in all lines of commodities necessary for life. Production necessitates the investment of capital, the contribution of real work on the part of labor, utilization of inventions and discoveries, the supply of energy available in large quantities and at low cost, and the continued development of highly trained and efficient intelligence for the utilization and harmonious operation of these factors. With these clearly understood and faithfully applied, the serious and important problems of the present and the future will be successfully solved.

Power Transmission and Industrial Development

By Ross J. McClelland

This valuable article points out forcibly how vital a factor the transmission of power is [illegible] of modern life and how our future prosperity is inseparably tied up with its development. The article [illegible] what the functions of transmission are, deals with our power sources and shows in what direction [illegible] to look for economies. He brings out the relationship between power supply and transportation, [illegible] paragraphs to the inter-connection of power systems and shows the influence that a comprehensive [illegible] power supply will have upon our industrial and economic development.—Editor.

Power transmission is still in its infancy, from the point of view of its place in our industrial organization. It is difficult for those who have seen and taken part in the advances of the last 20 years to appreciate that these advances have brought us to a merely preliminary stage and that the present transmission developments are casual and small scale in comparison with the coming system, which is to constitute the backbone of our industrial civilization.

As an industrial factor, electrical power transmission has hitherto been tentative and semi-experimental. Transmission has only recently been developed to a point where it is capable of assuming its eventual industrial responsibilities, and the industrial and economic situation has not been ripe for such comprehensive handling of the power supply problem as would afford scope for full development of electrical transmission. But the period of reorganization and readjustment following the war has, with startling suddenness, opened opportunities for large scale development, and the period of intensive industrialism into which we are about to enter will convert these opportunities to urgent necessities.

That we are on the threshold of a period of unprecedented industrial activity we must believe, if we believe in the industrial future of America, since the developments of the next five or ten years will determine whether America is to be the predominant industrial nation or primarily, in an international sense, a mere producer of raw materials and a consumer of industrial products. The United States, with half of the world's coal resources, must eventually be the pre-eminent center of industry. There are no compelling reasons why it should not so establish itself during our generation. In any event, whatever the extent or rapidity of our industrial development, power supply is destined to be one of its most important problems, and electrical transmission of energy the principle around which the solution of the power supply problem will be built.

Significance of Power Supply

The greatest step in the history of human advancement was the establishment, less than a century ago, of the so-called "Factory System" in England, and the accompanying period known as the "Industrial Revolution." This movement, the beginning of modern industrial civilization, consisted essentially of the organized and specialized production of manufactured commodities, and was based upon and particularly characterized by the extensive use of mechanical power. A second great step was the development on a comprehensive scale of transportation facilities—railroads and steamship lines—an essential condition to a large industrial system, since it freed the factories from close local limitations as to supply of raw materials, supply of fuel for power and distribution of manufactured products.

An equally important and significant step will be the establishment of a comprehensive power supply system. It likewise will enlarge the scope of industry and reduce its limitations. It will unquestionably be attended by economic, social and political effects of the same order as those resulting from the other two great movements mentioned.

Power is the basis of industrial civilization. Industrial development and standards of living are closely dependent upon the per capita use of power. The report of the British Reconstruction Committee, which attracted such wide attention last year, presents a most interesting series of statistics showing that the average net output of workers increases consistently and almost directly as the power use per capita. The report presents the following conclusion, very pertinent to any consideration of our own plans for the future:

"It is scarcely possible to exaggerate the national importance of a technically sound system of electrical supply, because it is essentially one with the problem of the industrial development of the country, which largely depends upon increasing the net output per head of workers. * * * * In the U. S. A.

the use of power, where it can be used, is nearly double what it is here. On the other hand, not only are the standard rates of wages higher in the U. S. A., but living conditions are better. There is little doubt that in the U. S. A. the average purchasing power of the individual is above what it is here, and that this is largely due to the more extensive use of power which increases the individual's earning capacity. The best cure for low wages is more motive power. Or, from the manufacturer's point of view, the only offset against the increasing cost of labor is the more extensive use of motive power. The solution of the workman's problem, and also that of his employer, is the same, viz., greatest possible use of power."

It is interesting to note in this connection that in sustaining its position, the United States, with one fifteenth of the population of the globe, burns nearly one half of the coal produced annually and is estimated to use half of the power generated.

For the future, the aspirations of the labor classes to higher living standards, involving higher wages and shorter working hours, together with the necessity for our industries meeting keener international competition, will inevitably require an increase in per capita productiveness made possible only by increasingly great use of power.

A consequent great increase in our power supply must and will be effected. Our growth as an industrial and highly productive nation will, however, be vitally influenced by the adequacy of this power supply, whether the minimum which must be provided or the maximum which can advantageously be used. The manner of obtaining it, moreover, will have far-reaching effects upon our industrial and political system. It is the purpose of this article to discuss certain phases of the problem of power supply, and in particular the vital part to be played by electrical transmission.

Functions of Electric Transmission

In a general power supply system, electrical transmission as distinct from distribution to local areas, has two primary functions:

1. To transmit power from distant energy sources to industrial areas. The energy sources may be either water powers or coal fields. The latter is the condition of particular interest, since it involves radical departure from the present general practice

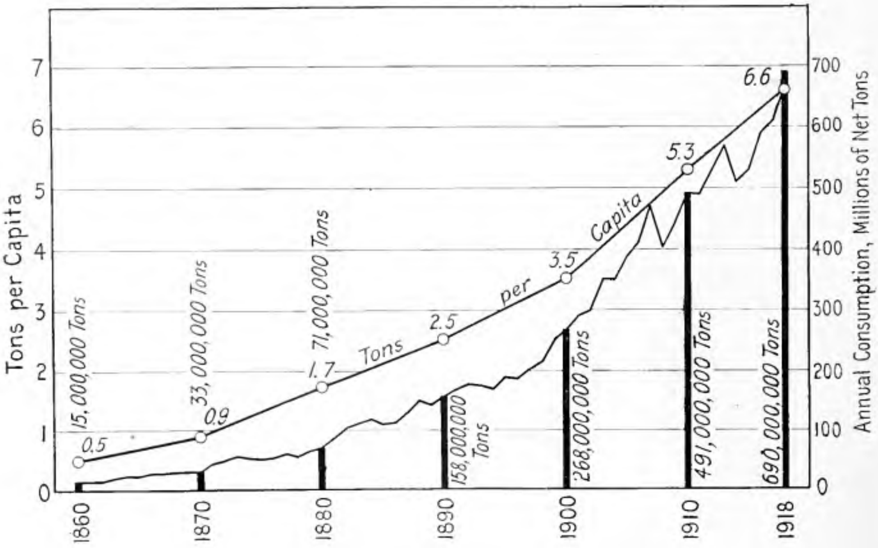


Fig. 1. Curve showing the increase in the annual consumption of coal in the United States, and the increase in consumption per capita, from 1860 to date

of hauling coal for power generation locally in the industrial areas.

2. To interconnect power systems and enable pooling and organized treatment of power requirements and resources over wide areas.

The fulfillment of these two functions enables the establishment of a comprehensive power supply system which, while presumably starting in the more distinctly industrial regions, should eventually be extended to cover the entire developed portion of the country, constituting the sole and exclusive source of power over the territory covered. The vital improvements in our industrial system resulting from such a power supply system, as will later be pointed out in some detail, may be briefly summarized as follows:

1. Maximum efficiency of power generation and economy of investment.
2. Bringing within economic range other important measures of national economy, such as extensive water power development, railroad electrification and recovery of valuable coal by-products.
3. Stimulation of industry generally and development of new specialized industries, due to assurance of adequate power supply over the entire region involved.
4. Great extension of areas suitable for industrial development and consequent checking of present tendency toward excessive localization of industry.*

Power Sources

Since the power supply problem depends directly upon power sources, the part to be played by electric transmission must be considered in the light of the conditions surrounding these sources. There are at present only two significant sources of primary power: water power and coal. The use of oil and natural gas as power sources is confined to relatively small regions and will not affect the general situation. These fuels are too limited in quantity and too valuable for other purposes to be considered in any general survey of power resources. For the greater portion of the United States, water power is an incidental rather than a determining factor in power supply. There is not enough water power, except in the Rocky Mountains and on the Pacific Coast, to supply more than a small portion of the power requirements of the immediate future. In nearly all cases water power depends directly [illegible] transmission to make it available for [illegible] use.

Our principal power source is coal. Our coal reserves, relatively to other countries, are tremendous, and they are widely regarded as so extensive that no present thought need be given to their exhaustion. It is coming to be recognized, however, that, at the rate at which coal consumption is increasing, Fig. 1, the life of the coal fields, and especially of the higher grade and more accessible deposits, is a matter of vital concern. For a long series of years our coal consumption has been doubling approximately every ten years, an annual increase of nearly 7 per cent, and during the past three years has been increasing at a much faster rate. If our coal consumption were to continue to increase at the apparently normal rate of 7 per cent per annum, the life of our known coal reserves would be as follows:

	Years
Eastern District, which includes the most accessible and best quality of our fuel . .	50
Eastern, Central and Southern Districts . .	65
Entire United States and Alaska, two thirds of this being low-grade coals and lignites . .	84

NOTE.—These figures are based upon estimates of the United States Geological Survey. They include coal in veins as shallow as 14 in., all coal up to 30 per cent ash and all known deposits within 6000 ft. of the surface. The proportion of recovery from the mines is taken as two thirds, considerably higher than has been obtained heretofore.

If figures were available as to the rate of exhaustion of coal reserves mineable and usable under present standards—a small portion of the total—they would be still more startling. Direct evidences of approaching scarcity of high grade coal and increasingly higher coal prices are already unmistakable. Floyd W. Parsons, editor of the *Coal Age*, writes as follows:

"Each year now witnesses the exhaustion of a number of high grade coal areas. Far more mines producing better grades of coal are being worked out than there are new mines commencing to produce. In many famous coal regions, such as Cambria and Clearfield counties in Pennsylvania, the original areas are practically worked out. The same story may be told of other famous districts. Coal that sold ten years ago for $50 an acre now brings $700. Seams that netted the owners royalties of six to ten cents a ton are now leased on a royalty basis of thirty cents a ton. Operating companies are now going over their acreage, taking out pillars and working low grade thin seams.

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* The problem of power supply, and this subject in particular, are admirably analyzed in a monograph published by the Smithsonian Institution: "Power, Its Significance and Needs," by Chester G. Gilbert and Joseph E. Pogue.

Some beds are being worked that wouldn't have been looked at five years ago. All this means high operating costs and a lower grade of product."

The conditions obtaining in the coal situation thus indicate clearly that the time is in sight when we must curtail our rate of increase in coal consumption, when consumption will be determined not merely by our needs, but by increasing scarcity and expense of supply. Curtailment of the growth of our fuel production will tend to carry with it a curtailment of our industrial development which can, however, to some extent at least, be offset by increasing economies in utilization. The need of such economies in power generation is emphasized by the fact that power use of coal is the use which is most wasteful of its chemical and thermal values.

It is of interest to review the important relation of electrical transmission to the principal feasible measures of economy:

1. Centralization of power supply in highly efficient electric generating plants of the largest practicable size. Such plants would have a thermal efficiency of about four times that of a reasonably good isolated plant and about twice that of an ordinary large central station. This centralization will be practicable only through the establishment of a comprehensive interconnected power supply system.

2. Superseding or minimizing of railroad hauling of coal for power by generation at or near the coal mines and transmission of power electrically. At present it is estimated that every 100 tons of coal shipped involves burning 10 tons in the railroad locomotives. (Substitution of mine plants would of course be gradual. Good existing plants would be continued in service until economically obsolete, then relegated to a peak load or reserve function.)

3. Fullest possible utilization of water power within economic limits as to costs, which, as will be discussed later, is to a great extent dependent upon development of a comprehensive transmission system.

4. Electrification of steam railroads. It is estimated that the present railroad use of more than 25 per cent of our fuel output would be reduced by complete electrification to 8 per cent or less, and that in addition the efficiency and capacity of present railroad facilities would be greatly increased. Economic feasibility of railroad electrification on a large scale would be greatly expedited by, if not contingent upon, the existence of an extensive transmission system. Such a transmission system would not only reduce directly the investment required for electrification, but would enable full advantage to be taken of the great diversity between railroad and general power load.

5. Electrification of coal mining operations, particularly in case of anthracite mines, where a mine use of more than 11 per cent could be reduced to possibly 1½ per cent by electrification, representing an effective saving at present rates of production of nearly 10,000,000 tons annually. In bituminous mining, the mine use is not so great in per cent, but a similar saving could be effected, probably somewhat greater in aggregate amount. Mine electrification is not directly dependent upon electric transmission, but the full possible economies can be realized only when it is developed in connection with a general power system.

6. Improvement in our extravagantly wasteful methods of coal mining. Of deposits worked to date, it is estimated that more than half of the coal content has been irretrievably wasted.

Of these principal measures of economy, it will be noted that the first four are directly dependent upon extensive transmission, and that all except the last are dependent upon it directly or indirectly for full feasibility and efficiency.

Relation of Power Supply to Transportation

The problem of power supply is intimately associated with the transportation problem. The United States with its high industrial development and its large extent of territory is peculiarly dependent upon railroads, and this dependence involves elements of danger, both on economic grounds and for political and other more general reasons. Recent developments in the railroad situation have served to make some of these dangers clearly evident.

From the economic standpoint, as a particular instance, railroads are inflexible in times of industrial expansion. They are expensive and slow to construct, have very little efficient overload capacity and are subject to inescapable congestion at certain geographical "bottle necks." Rapid industrial expansion imposes a demand upon transportation facilities for:

1. More raw materials,
2. More finished products,
3. More coal for industrial power.

Railroad inflexibility in the face of this triple stress results in congestion and expense, with consequent checking of expansion. In slack times there follows an over-development of railroads with consequent likelihood of inefficiency creeping in, an inefficiency which it is difficult to eradicate during the next period of stress. The railroad breakdown under the industrial emergency of the war was not an abnormal phenomenon. It is something which, to some extent at least, will occur in every period of industrial expansion.

The country has thus far placed practically the entire burden of its industrial development, including the supplying of power, upon its transportation facilities. The hauling of coal for power purposes constitutes over one third of our annual freight movement. It is easy to understand the reasons both of an economic and engineering character why this has been the case. The engineering art has, however, reached a stage where this dependence is no longer physically necessary, and economic considerations point strongly to gradually relieving the transportation facilities of the burden of supplying power. A system of trunk electrical transmission lines, collecting energy from water powers and steam stations located near the mines and thence delivering it where it may be utilized most advantageously, will serve to relieve our unduly great dependence upon transportation. At the same time it will form the foundation of an efficient and economical power supply system which will open up what might almost be described as a new economic era. The relief to transportation will be effected to the greatest extent at the times and in the places where congestion is most severe.

Electrical transmission is far more flexible than railway hauling of coal. Transmission lines can be constructed much more quickly when need appears and can temporarily be heavily overloaded with no other penalty than a temporary increase in losses. It is likewise inherently more economical, on a sufficiently large scale, than railroad hauling of coal. There is accordingly no industrial justification for transporting power in the enormously bulky form of coal when it is capable of 100 per cent concentration on the spot and shipment with a maximum of efficiency and convenience over electrical transmission lines. The relative balance of costs will be a special problem in each particular project, but various studies have shown, at present high construction prices, a direct saving in energy costs for a large capacity transmission system as compared with railroad freight costs. In addition there would be the important savings resulting from diversity, flexibility as to points of delivery and the other advantages of interconnection. There will also be various incidental advantages such as civic betterment and improved living conditions for labor, resulting from removal of the industry of power generation from the immediate neighborhood of large centers of population.

Any comparison of costs under immediate conditions will not, however, present the problem in its true economic light. Freight rates are certain to increase, and the policy gaining in favor in authoritative circles of a radical lessening of the extreme differences in the present classified freight schedules would, if carried out, result in a further material increase in low commodity rates, such as those for coal. Furthermore, the coal situation will soon compel the use of relatively lower grades of fuel, with consequent higher freight costs per unit of energy. In general transmission costs are almost wholly fixed charges, while freight costs are largely for labor. The whole trend of industrial progress has been characterized by substitution of machinery and equipment for man power.

There has been extensive discussion of late as to the general feasibility, from the engineering standpoint, of long distance, high capacity electrical transmission, and it appears to be the consensus of enlightened opinion that the problems of development and operation can be approached with full confidence of prompt commercial solution.

Interconnection of Power Systems

A comprehensive system of power supply involves other features, however, than centralized production of power near its source. An element of equal importance is the interconnection of central station systems and large industrial establishments now operating independently in contiguous districts. This function of electrical transmission supplements that previously discussed in an especially fortunate manner, since the same system of electrical transmission lines, with usually relatively minor additional expense, may serve to effect interconnection.

Diversity. The primary advantage of interconnection lies in the fact that the combined load may be carried with a materially smaller amount of installed generating capacity and at the same time with higher efficiency. The saving possible as a result of diversity in maximum load between separate systems, even where the loads are of a generally similar character, is greater than is ordinarily realized. A similar saving will result from the relatively smaller amount of spare generating capacity required for reserve purposes. Studies of a number of typical projects indicate that the increased load which may thus be carried from a given amount of generating capacity as a result of interconnection will usually amount to 15 or 20 per cent. It will naturally be greater as interconnection is extended to wider limits. The saving in investment is highly important, and at the same time the higher load factor upon the generating stations will enable more efficient use of fuel.

Large Units and Plants. Interconnection over a wide area will alone make feasible the increased sizes of stations and of individual units which constitute so essential an element in working out the economies in investment and in fuel consumption toward which we are aiming. In this connection it should particularly be borne in mind, in any comparison with the present method of relatively local generation, that the comprehensive system will bring the benefits of large scale generation not merely to large cities and important industries, where to some extent they may already be realizable, but to the entire area served by the system.

Flexibility. An important industrial advantage of interconnection is the flexibility as to points of power delivery, and the readiness with which load may be shifted from one part of the district to another. New large loads may ordinarily be taken on at any point on very short notice, whereas, under present conditions, they frequently could be supplied only after long delay involved in the building of new power plants. This flexibility is of particular advantage in the case of large loads of a temporary character.

Relation to Water Power Development. Interconnection is also of peculiar and vital significance in connection with the utilization of water powers, at least in the East. Most of our more important undeveloped eastern water powers are located on relatively large streams where it is not feasible to develop seasonal storage. Accordingly if water powers of this type are to serve a relatively local market they must either be developed only for the minimum flow of the stream or must be supplemented by large steam reserve capacity, either of which is likely to put the project outside of the range of economic feasibility.

The large aggregate load which becomes available for organized treatment on an interconnected system opens an opportunity for economic development of water powers of this typical character. If operated to carry base load during periods of high stream flow and to carry peak loads only during periods of low stream flow, they may be developed for many times the minimum flow of the stream without any duplication of investment in reserve steam capacity being necessary.

Another limitation on development of large water powers is that the high investment required must practically all be made at the start, whether or not load is available for the full output of the plant. This limitation will obviously become of relatively less significance when water power projects are considered as portions of a large system.

Relation to Coal By-product Recovery. A most important measure of national economy is the development of some economically feasible system of extensive recovery of coal by-products. Each ton of bituminous coal is estimated by Mr. Floyd W. Parsons to contain useful products of a value of possibly $20 in the form first extracted. In a broad sense their value to the nation is much higher, since they open the way to a whole series of new industries. The development of the coal by-product industry will be enormously facilitated by concentrating the consumption of coal for power purposes in a relatively small number of large plants.

Influence of Comprehensive Scheme for Power Supply Upon Industrial and Economic Development

Regional industrial development depends primarily upon accessibility of raw materials and of power, chiefly upon the latter, since even the crudest raw materials are usually more readily transported than is coal. The centralization and localization of industries around power sources has been clearly marked in our industrial development thus far. Our earliest industries were in New England around the small water powers which the mechanical art at that time was able to develop. Later, with the advent of relatively large steam plants, the industrial center shifted to the vicinity of the coal regions and in the main has continued there. Even in the districts adjacent to the coal regions the larger industries show a forced concentration along the main lines of supply from the mines and near the ports where tide-water coal is available. A cumulative secondary influence of concentration is the necessary immediate proximity to large condensing water supply. This centralization in relatively small areas, if continued, will constitute an effective limitation upon both the efficiency and the magnitude of our industrial system.

This restrictive influence upon industry may be largely and effectively reduced by a comprehensive system of interconnected transmission lines. Such a system, by making adequate power readily available over the wide areas within the range of feasible electrical transmission, would greatly extend the territory suitable for general industrial development. The tendency to concentrate industries near the coal fields, while it would not be removed, would be lessened to an important degree, and the more local limitations of established coal routes and condensing water supply would cease to function. Furthermore, by rendering feasible more extensive development of water powers, the regions within economic range of power sources would be materially enlarged.

The possibilities of electric transmission as an industrial decentralizing influence have an excellent illustration in the new and important industrial development in the southeastern States, which has arisen since the advent of electric transmission. These industries are supplied mainly from water powers, but instead of being concentrated in the immediate vicinity of the water powers, are widely distributed over five states.

The effects of such a distributed development of industry, in contrast to a concentrated development, will be far-reaching. It will leave industries free to seek favorable locations with respect to markets and raw materials. It will relieve, relatively, the excessive transportation congestion in certain districts and give to transportation a better balanced and more diversified character. It will have a marked and most important effect upon labor supply and living conditions and will tend to check the concentration of population in large cities, which is recognized as a serious menace to our economic and social well being. It will tend to prevent a wide divergency of interests between different sections of the country, with consequent sectional antagonism and inability to develop national constructive economic policies.

The establishment of electricity and electrical transmission in their proper roles in our industrial life will do more than exercise an equalizing effect upon industry. It will greatly stimulate the use of electrical power and thereby increase the productivity and efficiency of our industrial system. It will relieve new industries of the necessity and the financial burden of providing their own power facilities. It will open up [illegible] extensive new uses for electrical power and for electricity in other forms than power. These new uses, particularly in the province of electro-chemistry and electro-metallurgy, will not merely constitute *per se* an advance in our industrial development, but the new products furnished will form the basis for a new chain of highly specialized and valuable industries, which will free us from dangerous dependence upon foreign supplies and will add greatly to our national wealth and prosperity.

Obstacles to be Overcome

The reasons for the present inefficient individualistic state of the power supply industry are clearly evident, and many of them will persist as obstacles to a comprehensive handling of the power supply problem. Aside from the fact that the engineering art has only recently reached the stage where it is capable of handling adequately the technical features involved, the following considerations may be noted:

1. A general power supply system necessarily involves large scale undertakings, even initially, and hence presents a tremendous financing problem. The present method of power supply shoulders a large portion of its financing upon the railroads, which, while not conducive to ultimate economy, does reduce the direct financial burden.

2. The pooling of power requirements of various industries and public utilities implies a higher degree of co-operation than has hitherto been feasible.

3. Competition has not been an effective stimulus, since the benefits to be obtained would accrue to industries generally rather than to any specific industry as an advantage over others.

4. Legislation and public sentiment, at least in pre-war times, were adverse to substitution of large, inherently monopolistic enterprises for individualistic handling of problems.

5 Public utility regulation has usually tended toward restriction of return upon investment rather than toward ultimate economy to power users and to the country.

It is evident that the obstacles are not to any material extent physical, and that they do not arise primarily from mere inertia and short sighted conservatism on the part of those directly interested. The power supply problem is one of essentially public importance, and effective progress will be very difficult without the support of enlightened public interest and a constructive policy on the part of regulatory authorities. The widespread attention which the subject is receiving and the broader viewpoint which experience is giving to our relatively new public regulatory bodies afford a basis for optimism.

Conclusions

1. Industrial development depends upon the use of power, and the per capita power use is a direct index of individual productivity and national economic well-being.

2. If our industrial position and our high standard of living are to be maintained and improved, we shall become more and more dependent upon adequate power supply.

3. Our industrial future depends primarily upon our coal resources, and our best and most accessible coal is being exhausted at a rate so rapid that every feasible economy in fuel consumption is a national necessity.

4. Our present method of individualistic local power generation tends to concentrate industrial development in a few geographically favored localities, to the detriment of industrial growth and efficiency, and of sound social and political conditions.

5. Railroad hauling of coal for power is inherently uneconomical, and it accentuates a dangerous dependence of industry upon transportation facilities.

6. A comprehensive system of power supply, based mainly upon a network of high-capacity transmission lines collecting power from large steam plants in the mining regions and from water power plants, will conserve fuel resources, increase industrial efficiency and stimulate new industries. By making power available over relatively wide areas, it will tend to distribute industrial opportunities over a greater portion of the country, with consequent incalculable advantage to our economic well-being and our national unity.

7. The development of such a power supply system requires large scale handling and presents a critical financing problem. It will require the most thorough co-operation of the numerous diverse interests involved. Progress will be greatly facilitated by the support of enlightened public interest.

Designs of Large Vertical Alternating-current Waterwheel-driven Generators

By M. C. Olson

Alternating Current Engineering Department, General Electric Company

The author calls attention to some of the special features that have to be considered in the [illegible] and electrical design of large hydro-electric generators. Such machines are being constructed in sizes up to [illegible] kv-a. capacity and there seems to be no insurmountable difficulty in building much larger units should [illegible] demand.—Editor.

The speed of waterwheel-driven generators varies over a wide range, the head of water available being the chief factor in determining the speed and consequently the diameter of a machine for a given capacity.

We are limited in peripheral speeds with our present material; so if we wish to secure a sufficient margin of safety in design at the run-away speed, machines of larger capacities and high speeds inherently become very long in the direction of the shaft. The rotor becomes much more difficult to construct than rotors of lower speeds.

The range of speeds of larger waterwheel-driven generators varies approximately from 50 to 750 r.p.m. This extreme variation in speed necessitates different designs in which the construction of the stator and rotor differ greatly, and in which special provisions for ventilation must be made for the various designs.

For slow speed machines the question of stresses, as far as the rotor is concerned, is not very difficult; but slow speed machines become very large in diameter, which requires both stator and rotor to be so designed that the parts will come within the allowable weights and dimensions that can be handled and transported.

In some cases the flywheel effect, or WR^2, demanded by the waterwheel makers, in order to obtain certain required speed regulations, compels the generator builders to go to larger diameters and more expensive machines to meet this requirement.

Fig. 1 shows a sectional view of a generator of moderate speed. It is a 14,060-kv-a., 11,250-kw., 0.8 p-f., 3-phase, 50-cycle, 6600-volt, 375-r.p.m. machine. Two such machines were built for the Ebro Irrigation Co., Spain.

The special requirement here was low temperature guarantees, such as 9000-kw., 1.0 p-f., 30-deg. rise; 9000-kw., 0.8 p-f., or 11,250-kv-a., 35-deg. rise and 11,250-kw., 0.8 p-f., 40-deg. rise, all temperature rises being measured by thermometer or by temperature coils. It is seldom that the customer's specifications request such low temperature guarantees as 30 deg. C. rise, and there seems to be no reason why such guar-

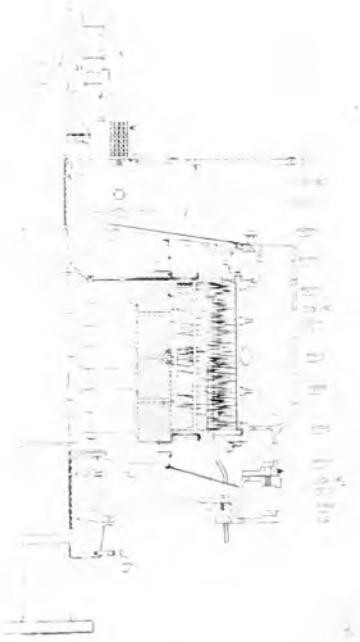


Fig. 1. Cross Section of Vertical Type Alternating-current Waterwheel-driven Generator, 16 Poles, 14,600 Kv-a., 375 R.P.M., 6600 Volts

antees, which are very difficult to meet, should be called for, as the customer is primarily interested in the safe operation of the machine at the maximum guaranteed load.

The machine is furnished with base, shaft, two guide bearings and direct connected exciter. A General Electric spring thrust bearing is located at the top for supporting the total revolving element, which amounts to 240,000 lb. Of this, 130,000 lb. is the weight of the turbine runner and water thrust.

Fig. 2. Stator of Waterwheel-driven Generator shown in Fig. 1

On account of the maximum shipping weight of 50,000 lb. and limitations as to dimensions, the stator was made in two parts, the base in two parts, and rotor field spider in four sections.

Stator

One half of the stator or armature, with its punchings and windings, is shown in Fig. 2.

The armature punchings are securely dovetailed and clamped in the stator frame, the lower clamping flange being cast as part of the stator, while the upper flange consists of a number of rigid steel castings. The air ducts for ventilation can be seen at regular intervals in the armature core.

The armature winding is of the distributed type, all the coils being alike. The distribution is such as to reduce the higher harmonic voltages to a minimum, to facilitate radiation, and to equalize the temperature in the windings resulting from the copper losses. The armature windings are equipped with imbedded temperature coils located throughout the different parts of the winding. By means of suitable instruments it is possible to determine the internal temperatures of the windings while in operation. The temperature coils located in the center of the core and in immediate contact between the coils have been found by experience to show the highest temperatures.

The projecting ends of the coils are mechanically braced by means of insulated steel ring binding bands, rigidly attached to the stator frame. The individual coils are firmly laced to these binding bands. This construction will prevent the distortion of the coils due to the heavy mechanical stresses resulting from short circuits.

Rotor

The complete rotor is shown in Fig. 3. The rotor spider consists of four solid cast steel wheels keyed to the shaft and bolted together. The pole pieces are made up of laminations riveted together and fastened to the spider by means of two "T" dovetails. The field winding consists of copper strip wound edgewise; and as the outer edge of the copper is exposed to the air, very effective cooling is obtained. The coils are clamped firmly between the pole tips and the field spider in such a way as to prevent distortion during the maximum overspeed condition.

This machine has one pole bracket between the poles for supporting the field winding. Between the sections of the field spider are openings for air and at each end of rotor is attached segmental sheet iron fans for assisting the rotor in drawing in air for ventilation. These fans are so designed as to obtain sufficient pressure to give the required amount of ventilating air.

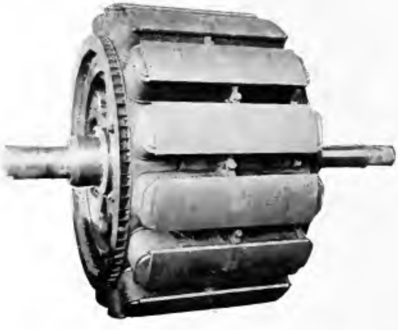


Fig. 3. Rotor of Waterwheel-driven Generator shown in Fig. 1

The lower bearing bracket is made of cast-iron in one piece. In addition to supporting the lower guide bearing it is so designed as to support the total rotating element when dismantling the thrust bearing.

The upper bearing bracket is made of cast steel in two parts. It is supported from the armature frame and carries the upper guide bearing, the General Electric spring-thrust bearing, and the direct-connected exciter.

In order to obtain the proper clearance between the waterwheel and the waterwheel casing, an adjustment between the upper bearing bracket and the stator frame is provided for by means of adjusting bolts.

To avoid the possibility of circulating currents flowing through the shaft and bearings, the upper bearing bracket is insulated from the stator frame.

Fig. 4. Equipment for High Speed Test on Generator shown in Fig. 1

The thrust bearing for supporting the total revolving element is a standard General Electric spring-thrust bearing, furnished with copper cooling coils through which water is circulated.

The amount of oil required for the step bearing with cooling coils is approximately two gallons per minute, and for the two guide bearings approximately three gallons per minute.

Ventilation

The usual method of ventilating vertical generators is to have air enter the pit beneath the generator through ducts. The openings or ducts for the admission of the air should be of such dimensions that the velocity of the air entering the pit will be approximately 1000 to 1500 ft. per minute.

The number of cubic feet of air per minute required for ventilation depends upon the losses of the machine. The poles, together with the fans at each end of the field spider rim, will draw air in through the rotor. The air is then forced over the field coils and poles through the armature ducts and windings and finally into the stator frame.

The heated air in the machine being described then passes out at the top of the generator at the outer periphery of the frame, the openings in the stator frame as shown in Fig. 1 having sheet iron covers.

In some cases the warm air passes into the room through openings in the stator frame. In other cases the warm air is led to the outside of the building through sheet iron housings.

Overspeed

All waterwheel-driven generators are required to be so constructed that they will safely withstand the maximum run-away speed which can be attained by the waterwheels, which usually is from 1.7 to 2 times the normal rated speed.

The maximum overspeed for these waterwheels is 1.8 times the normal speed. The rotors were therefore tested at a maximum speed of 675 r.p.m.

Fig. 4 shows the equipment for making this overspeed test. It consists of a pit 31 ft. in diameter and 15 ft. high. The rotor to be tested is supported by heavy girders, upon which is mounted a direct-connected induction motor for driving the rotor at the proper speed.

Fig. 5. Rotor of Waterwheel-driven Generator in Testing Pit

Fig. 5 shows the assembled rotor in the testing pit.

The external circumference of the rotor over the poles was measured by means of a steel tape as this is the dimension that would be changed most if any bulging out of the poles took place, due to the centrifugal force. A careful measurement and inspection was made after the overspeed test, and was found to be the same as the original dimension, which indicated that there was no distortion whatever.

Fig. 6 shows the external appearance of the largest capacity waterwheel-driven generator built. The armature punchings are not assembled in the stator. It is a 32,500-kv-a., 25-cycle, 150-r.p.m., 20-pole, 12,000-volt machine. It was designed with special reference to high efficiency and all round reliability.

The temperature guarantee at 26,667 kv-a., 0.9 p-f. continuously, is 45 deg. measured by a temperature coil in the armature winding, and 40 deg. on rotor by thermometer. At 32,500 kv-a., 0.8 p-f. continuously, the temperature guarantee is 55 deg. C. on the armature winding by temperature coil and 55 deg. by thermometer on the rotor.

The armature coils are insulated with class B insulation. The reactance of the generator is approximately 20 per cent. The WR^2, or flywheel effect, is approximately 12,000,000, which is normal for a machine of this size and speed.

The shaft has a forged coupling, and is arranged for one guide bearing, and a thrust bearing at the top to support a total revolving weight of 477,000 lb., of which 150,000 lb. is the weight and water thrust of the waterwheel parts. This machine is designed for a maximum runaway speed of twice normal speed.

In order to facilitate handling and shipment the stator spider is split vertically in four parts.

Fig. 7 shows the assembled stator spider on a 60-ft. boring mill, the upper flange being machined by one tool and the lower flange by another tool. The punchings and windings will be assembled up at destination.

The armature winding consists of a standard barrel type winding, with two coils per slot. The windings have imbedded temperature coils located throughout the different parts for indicating the temperatures. The external insulation of the coils and the turn insulation consists of mica tape. The projecting ends of the winding at both the top and bottom are supported by two insulated steel rings carried by brackets attached to the stator spider. The individual coils are firmly laced to the supporting bands.

The core of the armature is built up of the best grade of 0.014 silicon steel sheet, and is so treated as to keep core losses a minimum.

Rotor

The field spider is shown in Fig. 8. It consists of six cast steel wheels with spaces between for the flow of air for cooling. These wheels are rabbeted together at the hub in addition to being held together by bolts through the arms. The figure shows two milling machines cutting dovetails at diametrically opposite points.

It is very essential that reliable castings be obtained for the rotor of waterwheel-driven generators in order to withstand the stresses occasioned by the overspeed requirement.

The poles are attached to the field rim by means of two "T" dovetails. The field winding is of copper strip firmly supported between poles by means of supporting brackets.

The brakes for stopping the rotor will act against the lower section of the field spider rim and in this case will be furnished by the waterwheel builder.

The upper bearing bracket which supports the thrust bearing and carries the guide bearing is made of cast steel in halves, with eight arms.

Ventilation

The machine is arranged to take in air from the dynamo room, both at the top and from the pit underneath the generator, and to exhaust through ventilating holes in the stator spider into a sheet iron casing supplied by the customer. The casing will surround the machine and will conduct the air into an exhaust chamber under the operating gallery, then to the outer air or dynamo room as desired.

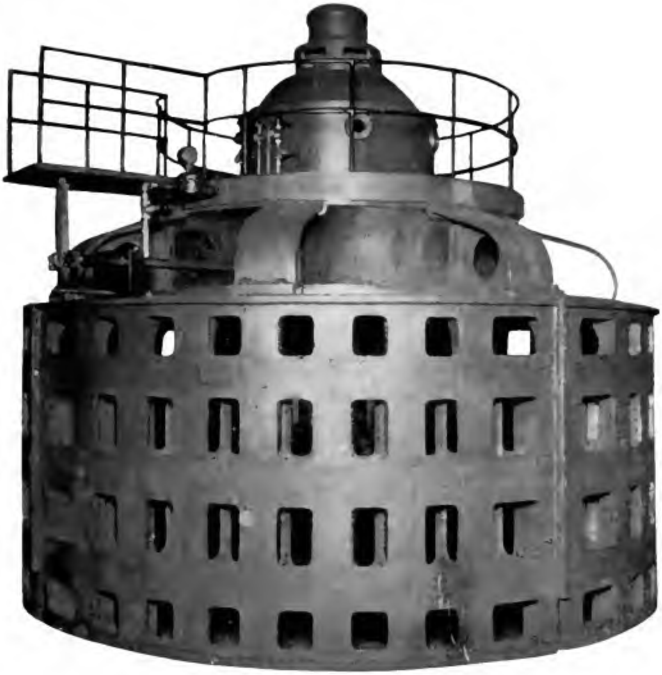


Fig. 6. Photograph of the 32,500-kv-a. Waterwheel-driven Generator for the Niagara Falls Power Company

Provision will be made in the chamber underneath the gallery for an exhaust fan, which may be required to insure a sufficient flow of air during all conditions of weather.

To the upper and lower rim of the rotor spider suitable fans are attached to assist the poles in the proper circulation of air for ventilation. The housing to serve as bafflers is arranged at the top and bottom, and is so designed as to minimize eddies and to prevent the return of the air.

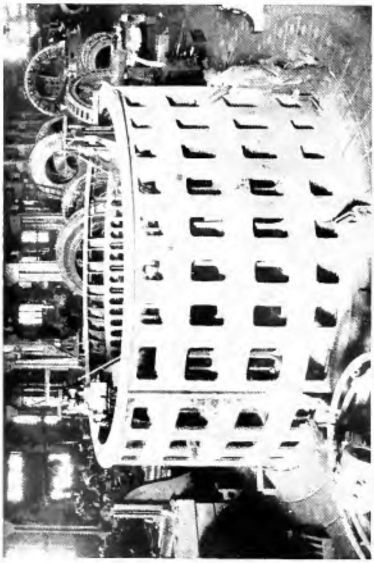


Fig 7 Stator of 3250-kv-a. Generator on 60-ft. Boring Mill, Upper Flange Being Machined by One Tool While Lower Flange is Being Machined by Another Tool

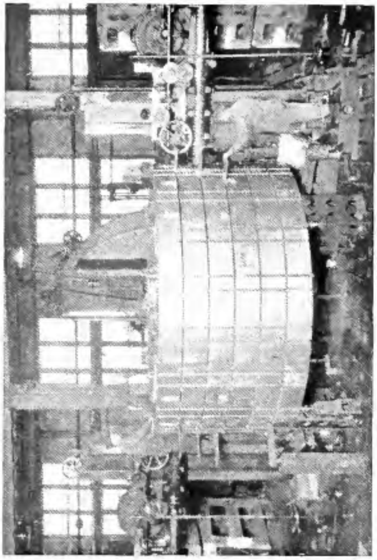
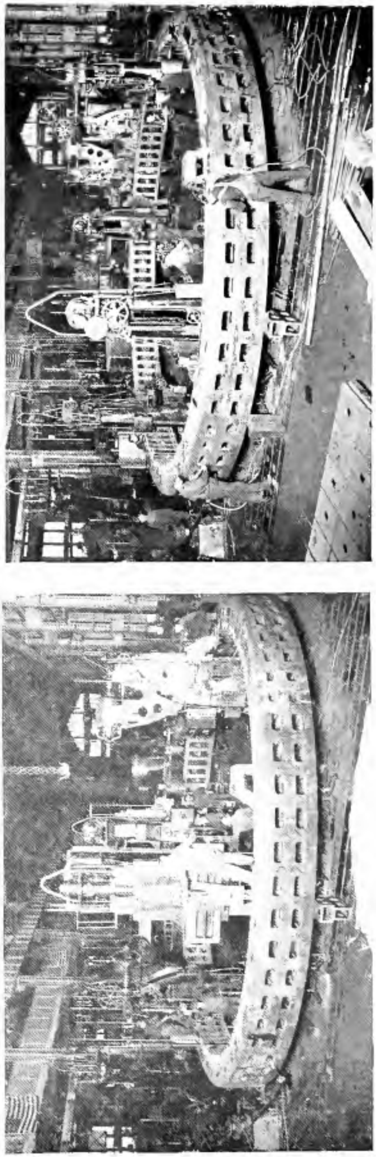


Fig. 8. Milling Machines Cutting Dovetail Slots for Poles at Diametrically Opposite Points on Rotor of 32,500-kv-a. Waterwheel-driven Generator



Figs. 9 and 10. Four Slotting Machines and Four Milling Machines at Work on Stator of 136-poles, 10,000-kv-a., 55.6 r.p.m., 6600-volt Vertical Type Waterwheel-driven Generator for Cedars Rapids Manufacturing and Power Company

Figs. 9 and 10 show the stator spider of the largest diameter and lowest speed waterwheel-driven generator ever built. It is a 10,000-kv-a., 0.75-p-f., 55.6-r.p.m., 6600-volt, 136-pole machine, with a temperature rise of 45 deg. C., and will stand a 25 per cent overload for two hours without injury. In one of our illustrations four slotting machines are at work at one time, while in the other four milling machines are operating at the same time.

The stator is cast in four parts and bolted together. The outside diameter is approximately 28 ft., while the height is about 3 ft.

Fig. 11 shows the rotor for this machine. It consists of a split cast iron center of [illegible] arms and a rim made of cast steel in four parts firmly keyed together. The poles are attached to the rim by means of bolts.

Ten of these machines were built on the original order and two on a subsequent order.

The last two machines have General Electric spring-thrust bearings for supporting the total revolving element, which amounts to 550,000 lb.

Fig. 11 Rotor Spider of 10,000-kv-a. Waterwheel-driven Generator Ready for Boring and Turning Operation

Spring Thrust Bearings and Cooling Coils on the Large Vertical Generators at Cedars Rapids Power Station

By T. W. Gordon

Alternating Current Engineering Department, General Electric Company

For many years one of the limiting features of large vertical machines was the need of a simple thrust bearing. We now have such a bearing. The author takes a specific case and describes the bearings as installed, bringing out the requirements that must be met in the design of such bearings and telling of their successful operation. The bearings described have now been in operation for a sufficient length of time to demonstrate their success. —Editor.

The combination of great weight with very low speed imposes especially severe condition on the thrust bearing supporting the rotating element on the 10,000-kv-a., 55.6-r.p.m. vertical shaft hydro-electric generating units at the Cedars Rapids Power Station of the Montreal Heat, Light & Power Co. Two critical periods occur in the operation of low speed bearings: First, in starting, as most of the oil has been squeezed out while at rest, and second, in shutting down, when, on account of the higher temperature of the oil and bearing parts, the oil film cannot be maintained for the last few revolutions. In machines of this size, on which the thrust bearing encircles the shaft, the bearing surface is a considerable distance from the center of the shaft. With this undesirable, but equally unavoidable construction, it is quite evident that a very slight departure from a perfect alignment will tend to shift most of the load to one side of the thrust bearing, and result in an extremely high local pressure.

The critical condition, due to slow starting and stopping, is made worse by increased local pressures, and a combination of low speed and very high pressure is liable to cause injury to the bearing. The last two units installed at Cedars Rapids have thrust bearings with flexible supports which eliminate the danger due to high pressure on a small part of the bearing by providing for an equal distribution of the load at all times.

Another unique feature in the installation of the last two generators in this station is the use of water cooling coils in the oil bath surrounding the thrust bearings. For the proper lubrication of a thrust bearing, the only requirement is a bath of clean oil, from which the heat is being removed as fast as it is generated in the bearing. Until recently it has been customary to continuously circulate a large quantity of oil from a central station system to the thrust bearing housing, to carry off the heat. This method requires large pipes, oil pumps, filters, and often water cooling pipes at some point in the system. The logical and most economical way to get rid of the heat is to abstract it from the oil in the thrust bearing housing. It is then only necessary to supply enough filtered oil to keep the oil bath in good condition. In the case of certain large high speed generators the quantity of oil for the thrust bearing can be reduced from around 50 gallons per minute to three gallons for each generator.

Fig. 1. Parts of Spring Thrust Bearing (in foreground) to Support Lead of 550,000 lbs. on ATB-136-pole, 10,000-kv-a., 55.6-r.p.m., 6600-volt Generator, Cedars Rapids Power Station

Fig. 1 is a photograph taken at the Cedars Rapids Power Station on the St. Lawrence river during the erection, in 1918, of the eleventh and twelfth generators, which, as stated above, were furnished with spring-thrust bearings and cooling coils. In physical dimensions these generators are the largest in service, having an outside diameter of 37 ft., 4 in. The weight of the rotating parts of the generator and the turbine, together with the downward pressure of the water on the runner, is 550,000 lb. The thrust bearing is located in the bell-shaped housing at the top of the generator according to the present practice in the design of stations having vertical shaft hydraulic turbines. In the foreground is the base ring of the thrust bearing with some springs assembled on the center-pins which hold them in place. The large tube in the center, which projects above the level of the oil bath, is fastened to the base ring, and forms the inside annular wall of the oil housing. The springs, Fig. 2, are two inches on the outside diameter by one and a half inches high, and 368 of them are used in these bearings under a load of 1500 lb. each.

Fig. 3 shows the bearing and cooling coils assembled in place on top of the generator. The distinctive feature of this type of bearing is the comparatively thin babbitted stationary bearing ring, resting on springs. This ring is a steel plate with a babbitted bearing surface, 56 inches outside diameter, 28 inches inside diameter and two inches thick. There is a saw-cut through one oil groove to prevent any tendency of the ring to dish with changes in temperature. It is held in place by two heavy dowel pins mounted in the base ring. The rotating ring is bolted to the thrust collar or driver above, which in turn is keyed to the shaft. This ring is made of a special grade of iron and the rubbing surface is ground and polished to a high degree. The rotating surface of the bearing has six large oil grooves which produce a rapid circulation of oil across the babbitt. At 55 r.p.m. every portion of the babbitted surface is washed by a stream of cool oil, flowing at high radial velocity, five and one half times per second. The bearing is immersed in a bath of filtered oil to a level about three inches above the rubbing surface.


Fig. 2. Springs Used in Spring Supported Thrust Bearing. Illustration about actual size

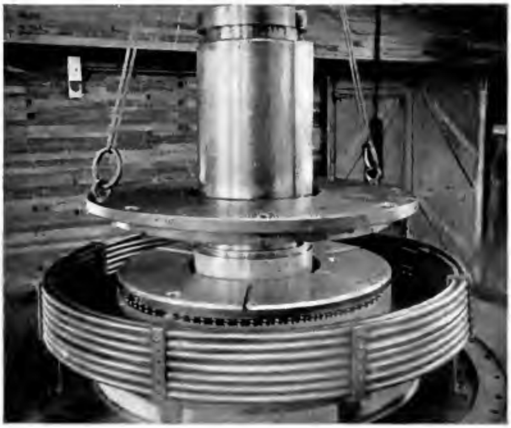


Fig. 3. Spring Thrust Bearing and Cooling Coils to Support Load of 550,000 Lbs., Cedars Rapids Power Station

The design of this spring thrust bearing is based on the idea of providing one bearing surface which is so yielding, flexible and elastic that it automatically adjusts itself, while in operation, to any tendency toward unequal distribution of the load, due to inaccuracies in workmanship or alignment. On large generators the machining cannot be as accurate as on small units, hence there is an added advantage in having a flexible support for the thrust bearing. The babbitted surface of a spring thrust bearing is given a good machine tool finish at the factory, and ordinarily does not require any "scraping" by hand, or other special attention when put in service.

Fig. 4 is a photograph of one of the babbitted surfaces at Cedars Rapids after the first run of ten hours. This surface was finished at the factory in the usual way, as just stated. The rubbing marks indicate that the load was well distributed over the entire surface. The fine radial lines are tool marks presumably due to a faulty tooth in the driving gears of the boring mill at the factory on which this part was machined. These fine ridges were too small to be noticed until after the bearing had been run, and then were discernible only by the reflections in a good light. The tops of the ridges were evidently flattened and polished while the unit was starting and stopping, when the speed of the bearing is too low to maintain a perfect oil film between the rubbing surfaces. The babbitt was not wiped at all, and the bearing was placed in commercial service without further attention.

Fig. 4. Babbitted Surface of Spring Thrust Bearing After Initial Run, Cedars Rapids Power Station

Specifications for the thrust bearings and cooling coils at Cedars Rapids contain, in part, the following requirements:

The bearing shall be capable of sustaining a maximum load of 600,000 lb. continuously without injury at a normal speed of 55.6 r.p.m.; the temperature of the oil is not to exceed 45 deg. C., when water is supplied at 25 deg. C. It shall also be capable of operating without injury at a maximum runaway speed not exceeding 111 r.p.m. for a space of one hour, and the oil temperature is not to exceed 55 deg. C. under these conditions. The bearing shall be capable of starting from rest, and stopping as often as required by service conditions, or operate at a speed of 10 r.p.m. for one hour, without injury. The bearing shall also be capable of suffering no injury from an interruption of the water circulation for half an hour while operating under otherwise normal conditions, or for the space of 20 minutes at an over-speed not exceeding 83 r.p.m.

Fig. 5. Babbitted Surface of Spring Thrust Bearing After First Ten Hours Operation, showing fine radial lines not visible before the run and presumably due to machining at the factory

Concrete Parts for Generators

By C. M. Hackett

Power and Mining Engineering Department, General Electric Company

The development of our large hydro-electric projects requires the economical use of material and manufacturing facilities in the construction of the electrical equipment. Some of the large alternating-current generators require stator frame and bearing support castings of enormous size, that tax manufacturing and shipping facilities as well as add considerable expense to the equipment. The author points out that the use of concrete may offer a solution to these problems in certain cases and calls attention to some of the possible uses of concrete in the construction of these large units, setting forth some of the special features to be looked after in the design and installation. Should we come to the use of outdoor generators in some of our large developments, such construction would show many advantages.—Editor.

The manufacture of reinforced concrete may now be regarded as having reached the scientific stage. Haphazard methods will doubtless continue to be used in the selection of materials and in the manner of mixing for many kinds of work, but it is possible with our present knowledge of aggregates, cement, water and the methods of combining them, to get not only uniform strength in all parts of a concrete structure of large size and mass, but, also, to produce duplicates of that structure in any quantity desired. This progress, combined with the great strength of the finished product, has led to the adoption of concrete for various classes of work where metal has heretofore been regarded as the only suitable material.

There are two parts of large size, low speed, vertical shaft generators usually made of steel or iron that can with advantage be made of reinforced concrete, namely, the stator frame and thrust bearing support.

The use of concrete instead of metal for these parts does not involve any problems of stability or strength that cannot be readily solved by care in design and construction; and, provided technical and practical knowledge of conditions to be met are kept in mind when carrying out the work, the chances of trouble developing are no greater than with all-metal machines.

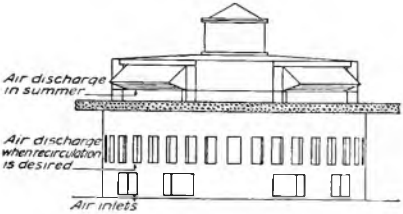


Fig. 1. Elevation of Generating Unit

The concrete stator frame will, in most cases, be combined with the power plant structure. If a house is to be built over the generators, the stator will likely be nearly, if not completely, below the floor level; but, if the machines are to be of the out-of-door type, then it will generally consist of a cylinder between the operating floor and upper deck or platform, extending somewhat above the latter, and will be an important part of the support for that deck as well as a means of carrying the load imposed by the thrust bearing.

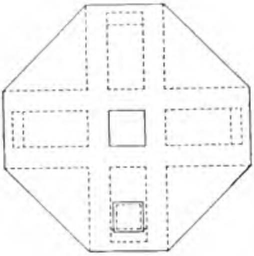


Fig. 2. Plan of Bridge

The main points to be considered in the design of the stator frame are ample cross section for carrying load, and reinforcement so placed as to distribute the stresses produced by short circuits and unbalancing.

The admission of air to the machine, as well as its discharge after having passed through the windings, will also form a feature of the design, and in case generators are of the out-of-door type, and recirculation of air is necessary during a portion of the year, outlet ports and dampers for air control will be required in the stator as well as in thrust bearing supporting structure, so that the discharge of air from the machine can be regulated according to temperature conditions.

The securing of the stator laminations and windings to the concrete can be accomplished either by anchor bolts, spaced and arranged to support and adjust the clamps which hold the laminations, or by the use of a skeleton ring, cast in sections and machined to the proper form and dimensions. If a ring is used it will rest on a shoulder formed in the concrete and will be bolted and grouted in place after the final adjustment of the rotor has been made.

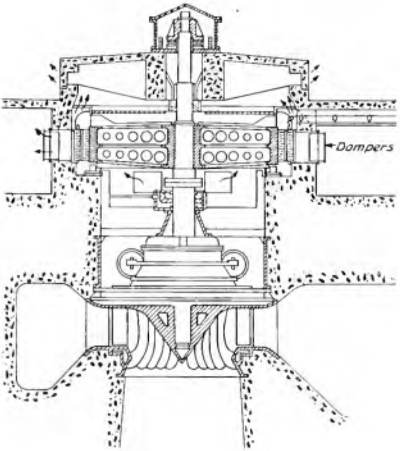


Fig. 3. General Section of Generating Unit

When the bolt type of support is adopted, the placing of the stator laminations and windings must be done at the power plant. They may be put in either at the factory or at the plant if the skeleton ring is used.

The taking off of leads, the shrouding to control the direction of air, and the placing of vanes for driving it will be approximately along the same general lines as for an "all metal" machine. Also, the arrangements for braking and lifting the rotor will contain no novel features.

The bracket or bridge for supporting the thrust bearing may consist of a heavy floor or cover with deep girders rising from it, or the girders may extend below the floor in truss form.

In designing this part, the following points should be carefully considered:

The reinforcing steel should be of a high grade, viz., equal to the best structural steel.

In placing the steel, the heavy, or primary, bars should be located so that they carry the load to the best advantage while the lighter or secondary reinforcing should be so placed that there is no portion of the concrete that is not effective, not only for supporting the load, but for distributing and absorbing vibration. To meet this latter condition, a massive structure is desirable.

To facilitate handling, eye bolts or tapped sockets, into which eye bolts can be turned, should be so placed that they are well tied into the primary reinforcing, and cause the structure to be held level when being lifted.

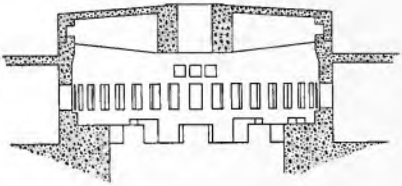


Fig. 4. Section Through Stator and Bridge

The bearing plates may be formed of steel plate if no adjusting of the position of bridge is to be made by them, but in case such adjustment is desired, then flanged castings, strongly anchored to the stator and bridge, with the necessary adjusting screws and allowance for the desired movement, will be required.

The simplest method of adjusting thrust and guide bearing housings will be by wedging and shimming, and to seam them in place after rotor is accurately centered. They should be so designed as to permit the pouring of grout into all open spaces between castings and concrete structure before anchor bolts are tightened. If desired, the guide bearing housing can easily be designed to allow for a small adjustment of that portion which holds the bearing shell and in this way make it possible to correct any inequality in the air gap.

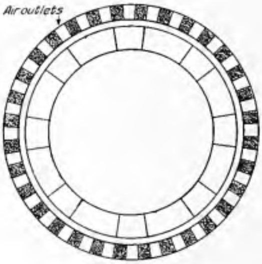


Fig. 5. Plan Section of Stator showing Openings for Air Discharge

The bolts for holding the bearing plates in position may be moulded directly into the concrete, but if anchor bolts are to be used for holding the bridge to the stator, properly located tubes of sufficient size to allow the bolts some play should be moulded into the structure. It should be possible to remove anchor bolts from both the bridge and stator when the bridge is to be lifted.

Only the vertical type of machine has been considered in the foregoing, but it is also practical to build stator frames of concrete for large size horizontal shaft machines, using either a solid or split ring as may be desired. The housing or weather protection of such machines, if of the out-of-door type, can also be conveniently made of concrete, and provisions can be made for handling the sections of the housing if at any time it is necessary to do anything in the way of repairs on the windings.

The economies to be found in the substitution of concrete for metal for parts of generators lie chiefly in the lower cost of materials and labor, reduction in shop expenses, and the saving in freight and handling charges. To these may be added a considerable saving in the cost of weather protection, if the generators are to be of the out-of-door type, since the concrete bridge structure can be waterproofed at a small cost, and its general design makes the effective protection of all joints and openings a simple matter.

A study of the advantages of the use of concrete in the construction of generators indicates that its special field lies with machines of large size. Just how far down the scale of sizes it is likely to show a gain over metal, can only be determined by time and experience. The indications are, however, that it will prove practical and economical in a fairly large field.

Automatic and Remote Control Generating Stations

By A. G. Darling

Power and Mining Engineering Department, General Electric Company

Experience has amply demonstrated the feasibility and economy of automatic substations, and though actual operating data are somewhat more meagre, the automatic generating station has proven its right to a recognized place in the industry. The author discusses various means whereby the automatic generating station may be controlled, depending upon the conditions surrounding the installation and the objects to be accomplished. It is quite probable that the next few years will see a large number of these automatic and semi-automatic generating stations in operation, and the additional energy which is thus rendered economically available should be an important factor in our industrial life.—Editor.

Rising labor costs, together with lower grades of labor available for central station service, have caused the present day demand for devices that will insure successful operation and reduced labor costs.

One phase of this demand has been met by automatic equipment successfully applied to hydro-electric generating stations. The most striking example of this application is the generating station of the Iowa Railway and Light Company at Cedar Rapids, Iowa, which has been in successful operation for over a year and a half.* The Drop plant of the Pacific Power and Light Co. in the Naches Valley is another prominent example of attendantless operation.

Full Automatic vs. Remote Control

Without regard to the size of the plant and its component parts, there are two distinct types of control to be considered as offering distinct advantages.

When the proposed plant is located so far from any attendant that it must perform its functions with its own brain power, then the full automatic control is an essential feature. But when, for example, it is convenient to run control wires for adjusting the gate openings from zero to full gate, there may be an economy in remote control of water and equipment which will not be offset by the cost of pilot wires. Other features of the full automatic plant are quite as likely to be a detriment, in such cases, as they are an advantage in other cases.

Size of Plant

Technically, there is no limit to the size of plant to which automatic control may be applied. But with increasing capacity, the labor item per kv-a. installed decreases to such a point that it will equal the fixed charges on the investment in automatic features. While plants with automatic features have operated for weeks at a time without the doors being unlocked, yet practically, the superintendent who does not periodically inspect his apparatus, of whatever character, may expect to be shut down for repairs occasionally when he finds it least convenient. It is considered good practice to have a watchman inspect apparatus of this character at least once a week, and in plants of several units where considerable sums of money are involved, a watchman of no special electrical or mechanical ability would not burden the operating charges. Automatic equipments for plants of 16,000 kw. capacity have been planned and proposed.

The Field of the Attendantless Generating Station

Many low head sites are undeveloped because the labor items added to the large initial costs make the installation uneconomical. But when automatic features can be paid for by the saving in labor in from one to four years' time, and thereafter result in clear gain, some of these sites prove to be money-making developments. It will frequently be found that such sites lie in close proximity to main generating stations where attendants are required. Therein lie fertile fields for remote control features which make it possible to utilize waste water and economize stored water.

Small power sites, which by themselves, would not be considered feasible, yield very readily to automatic apparatus when tied in with larger systems. The high head site with accompanying high speed waterwheels makes an ideal application of the induction generator with its smaller number of auxiliaries, provided there is sufficient magnetizing current in the system to excite the generator without materially decreasing the system power factor.

Stations supplying small loads, important in their own field, can be relied upon to start and stop on time, demand, or water level settings thereby relieving the usual one or two man shift.

The accuracy with which the control equipment can be set to perform its functions is equivalent to having the best technical and operating labor on hand at all times.

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* This station is described in detail in the A.I.E.E. proceedings of June 28, 1918.

Depending on the reliability of the source it is possible to secure control supply from a small transformer tapped with fuses from the main circuit into which the automatic station is feeding and outside any of its disconnecting switches.

The more important schemes of performing the general operations are shown in the tabulation below.

General Features of Control Systems

With a schedule of operations to perform, and emergency conditions to be taken into consideration, the component parts of the control apparatus take very definite form.

Minimum induction generator control has the fewest number of parts. Its speed and voltage are functions of paralleled synchronous generators. Its overload limit is the capacity of the prime mover, and so long as the induction generator is designed to carry that capacity plus a safe margin, it cannot be damaged by overload. Its mechanical speed limit is a function of waterwheel runaway speed, and so long as that is taken into consideration by the builders, it cannot do itself any harm from that standpoint.

Technically, then, a starting and stopping device which will function at the owner's predetermined idea, together with protection against external and internal accident, is all that is necessary. Practically, the owners generally desire a measure of output, both instantaneous and cumulative, and further protection from overspeed, overload, loss of one phase, loss of water head, hot bearings and internal generator accidents. Automatic paralleling features will cut down the rush of current when paralleling is done out of synchronism. Gate control will insure constant output with normal head of water.

Synchronous generators add the advantage of giving a predetermined voltage and frequency, and so they improve the power factor instead of making it worse, also they give independent instead of dependent operation. The addition of a direct current excitation source adds no unsolved problem and assists in obtaining a positive source of control supply. In stations of considerable size, it is often advisable to have an independent source of power to operate switches, gate motors, etc., etc. Small storage batteries charged from the exciter serve this purpose. In the induction generator plant the same purpose may be served by a small low voltage battery charged from a direct current generator directly or belt connected to the waterwheel.

The proper sequence of events is best fixed by a master controller, motor-driven from either an external alternating current source or a storage battery.

GENERAL METHODS OF CONTROL

Unit or Group Operation

Function	Automatically Controlled by	Remotely Controlled by
Starting Conditions:		
Load Demand	Contact Making Ammeter	Main Station Operator
Water Surplus	Pressure Gauge or Float Switch	Main Station Operator
Starting:		
From Water	Elec. Control of: (a) Hydraulically Oper. Gate (b) Electrically Oper. Gate	Remote Elec. Control of: (a) Hydraulically Oper. Gate (b) Electrically Oper. Gate
Synchronizing:	(a) Through reactance (b) Fractional Voltage Transformer Taps	Same as automatic, though function may be manually performed by attendant in main station if synchronizing switch is located therein
From External Electrical Source	Started as a Motor by: (a) Compensator (b) Fractional Voltage Transformer Taps	Same as automatic, except starting equipment may be located in main station and function performed manually
Speed Control Within Fixed Limits	(a) Electric Control with varying water pressure (b) Balanced hydraulic control	Same as automatic but may be adjusted by main station operator
Voltage Regulation	(a) Tirrill Regulator (b) Fixed Setting	Same as automatic
Shutting Down:		
Load Decrease	Contact Making Ammeter	Main Station Operator
Water Deficiency	Pressure Gauge or Float Switch	Main Station Operator

The protective and control equipments utilized in such stations are all standard apparatus which has had long usage in other types of application, so that no question of reliability of untried apparatus enters the project.

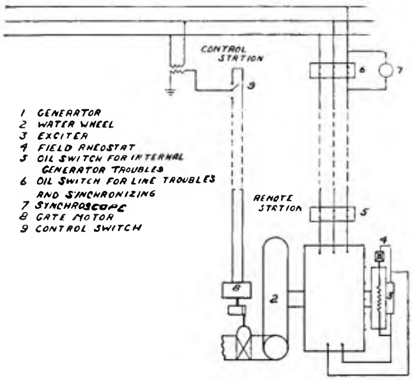

Fig. 1. Simplified Wiring Diagram of a Remotely Controlled Synchronous Generator Station

Figure 1 shows a simplified wiring and connection arrangement of a remotely controlled synchronous generator station, in which the operator at the main station has complete control of the speed, and therefore of the load that the remote station will carry. By closing the control switch in one position the gate motor opens the water gates. The operator then synchronizes at the main station. The plant is then operating on the load determined by the operator. Shutting down is performed in the reverse order.

Figure 2 illustrates an automatic station which is started and stopped by a float set in the forebay to operate at a predetermined water level. The drum controller then actuates the remaining control apparatus to perform its functions in proper sequence and time. The generators are synchronized with the line by paralleling, at approximately normal speed and voltage, through the reactor which prevents destructive rushes of current. With a time delay relay, to allow the set to come to proper speed, the reactor is paralleled by the main generator switch and then dropped out of circuit to be ready for the second generator. Interlocking devices prevent simultaneous synchronizing.

A motor driven exciter, supplied from an external source, may be used as a method of excitation and battery charging, which is particularly apt when the generator speed is low enough to cause expensive direct connected exciters, and belted exciters are deemed inadvisable.

Speed Regulation

Comparatively speaking, automatically controlled generating plants are small when compared with the systems into which they feed. (This, of course, excludes all stations which may be operated independently of other stations.) For that reason, it is not so essential to provide a means of careful speed regulation. Having once determined the gate position that will give the desired output, adjustments are made to always bring the generator to that speed. Any normal variation in water head, system frequency, etc., will not, as a rule, be great enough to cause interruption of service from the automatic plant. For these reasons, it is found possible to eliminate the waterwheel governor as being somewhat unnecessary. Considerable economy in the first cost of the governor, and the control apparatus for it, is effected thereby.

In most cases of existing stations there is just as great a field for automatic control as there is in the undeveloped plants, more so perhaps as not a few operating stations have high labor costs continually being charged to their operation.

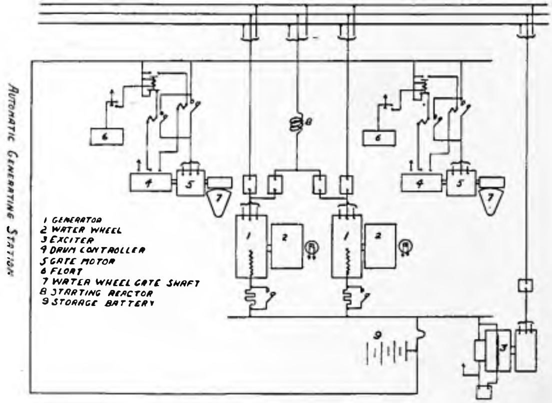

Fig. 2. Simplified Wiring Diagram of an Automatic Controlled Synchronous Generator Station

Features of Design in Large Hydraulic Turbines

By F. H. Rogers

Hydraulic Engineer, I. P. Morris Department, William Cramp and Sons Ship
and Engine Building Company

The work of producing highly efficient hydro-electric generating units devolves equally upon the hydraulic and electrical engineers. Manufacturers of hydraulic machinery have not been idle in devising means for producing the ever increasing quantities of power required by the nation's industries, and at the same time accomplishing a real conservation of natural resources by a continually more efficient use of potential water power. In view of this tendency toward units of large and larger size, a gain of even a small percentage in overall efficiency becomes of importance. In this article the author analyzes problems encountered in designing wheels of high efficiency, for both high and low-head applications. The relative importance of losses occurring in pen stock, runner and draft tube at various heads and specific speeds is discussed in detail, and attention is called to conditions under which certain of these losses become sufficiently important to warrant considerable effort to minimize them.—Editor.

The great importance of high efficiency for hydraulic turbines is now universally appreciated and in recent years extensive experiments have been made and much study given to the subject, with the object of reducing the losses in the various parts of the turbine and water passages.

Modern demand calls for large size units; and while twenty years ago a 5000-horse-power turbine was considered of exceptional size, today the building of a 30,000-horse-power wheel causes little comment. Among the most noteworthy turbines which have recently been built, or are now under construction, might be mentioned: One 22,500-horse power for the Washington Water Power Co., Spokane, Washington; three 37,500-horse power for the Niagara Falls Power Co., Niagara Falls, New York; two 52,500-horse power for the Hydro-Electric Power Commission of Ontario (Queenstown Plant). A gain in efficiency of one per cent on a 30,000-horse-power turbine means an increased output of 300 horse power continuously for the same water consumption, which is equivalent to 1,960,000 kw-hr. in a year.

Fig 1 Interior View of the Long Lake Station of the Washington Water Power Company, near Spokane, Washington, showing two 22,500-h.p. turbines designed for a head of 168 ft. at a speed of 200 r p.m. A third unit is now being installed

In considering the features of design which affect the efficiency, two classes of turbines will be studied: (1) low-head units, and (2) high-head units, as the head determines the characteristic of the runner design, or, in other words, the specific speed. Expressed as a formula:

$$N_s = \frac{\text{R.p.m.} \times \sqrt{HP}}{H^{\frac{5}{4}}}$$

which defined, means the specific speed N_s is the revolutions per minute of a unit at best efficiency if the runner were reduced in size so that it would develop one horse power under a head of one foot.

For low-head units high specific speeds are used, whereas for high heads the reverse is true. This can be more readily explained by a study of the runner. For low heads, the velocities are low and the water will follow the radical curvature of the high specific speed runner, Fig. 3; whereas for high heads, gradual curvatures must be used to suit the high velocities and so prevent corrosion, Fig. 4. Another limiting factor is the draft head, or the total vacuum at the discharge of the runner. This is made up of the vertical height from the runner to the tail-race level plus the velocity head at the runner throat D_2, minus the velocity head at the outlet of the draft tube minus the friction loss in the tube. The maximum possible draft head is about 33 feet at 70 deg. F. at sea level, but in practice it is well not to exceed 28 feet and to maintain this margin when the plant is located at higher elevations. For high heads, if a high specific speed runner were used, the velocity through the throat D_2 would be high so that the runner would have to be located close to the tail-water or it is possible that the velocity head at this point might exceed the maximum allowable draft head. Hence, to avoid danger of pitting the runner (corrosion) and to permit of a practical location of the runner above tail-water, it is necessary to use low specific speed runners for high heads. For low heads, the high specific speeds may be used with the resulting advantage of high revolutions per minute.

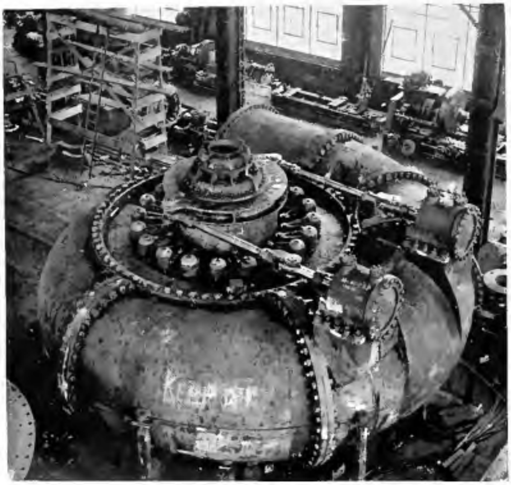

Fig. 2. 37,500-h.p. Turbine for the Hydraulic Plant of the Niagara Falls Power Company, Niagara Falls, N. Y., designed for a head of 214 ft. at a speed of 150 r.p.m. One of these units is now being installed and another is under construction

Low-head Units

In considering the various features which affect the efficiency in the design of low-head units, particular attention must be given to the draft tube. Of course the design of the runner is of primary importance, however, it is not the intention of this article to deal with this phase of the matter but rather to assume a runner of correct design and to study the relative importance of the losses which occur outside of the runner itself.

The curves shown in Fig. 5 are plotted from the average values taken from a number of typical runners. The velocities at the top of the draft tube are expressed as velocity heads and are plotted as percentages of the total heads for various specific speeds. As the water does not usually leave the runner in a direction parallel to the axis of the draft tube, there are two components of velocity to be considered: (1) the axial velocity, and (2) the tangential or velocity of whirl.

It is seen that for high specific speeds, both of these items become of great importance. Thus, for a head of 30 feet the specific speed would be about 83 and the energy to be regained in the draft tube would amount to 12.5 per cent of the total available head considering the axial velocity, and 8.25 per cent considering the whirl velocity. As velocity heads are used in plotting these curves, the total energy to be regained is represented by the sum of the values taken from curves *A* and *B* for any particular specific speed. For such runners, therefore, the draft tube design is of great importance for no matter how efficient the runner may be in itself it is possible to lose a considerable percentage of the total head (20.75 per cent in the case assumed above) with a design of draft tube which fails to regain any of the velocity.

The problem confronting the designer of high-speed turbines is, therefore, to construct economically a draft tube which will regain as much as possible of the energy at the discharge of the runner. A long straight draft tube with a small angle of diffusion is found to be the most efficient design, but for large units such construction would involve costly excavation and hence a curved tube must be used. As the losses due to change in direction of flow are usually severe this point has been given considerable study in recent years and many experiments have been carried out to determine the best design of curved tube with the result that efficiencies of 90 to 93 per cent have been obtained for high specific speeds, proving that a large part of the energy at the runner discharge is regained in the draft tube.

The principal remaining losses which occur outside of the runner itself are: (1) in the intake and penstock, (2) in the casing, (3) disc friction of the runner, and (4) leakage at the runner seals. The first two losses can be kept small if these parts are properly designed. For the penstock, the question of pressure change, speed regulation, and first cost are the determining factors. The third and fourth losses are of minor importance in high specific speed runners due to the relatively small diameter of the runner, but as will be shown are of far greater significance for low specific speeds.

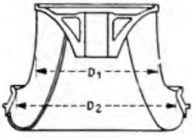

Fig. 3. Typical Runner of High Specific Speed for Low-head Wheel

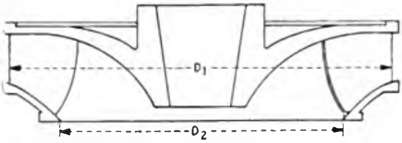

Fig. 4. Typical Runner of Low Specific Speed for High-head Wheel

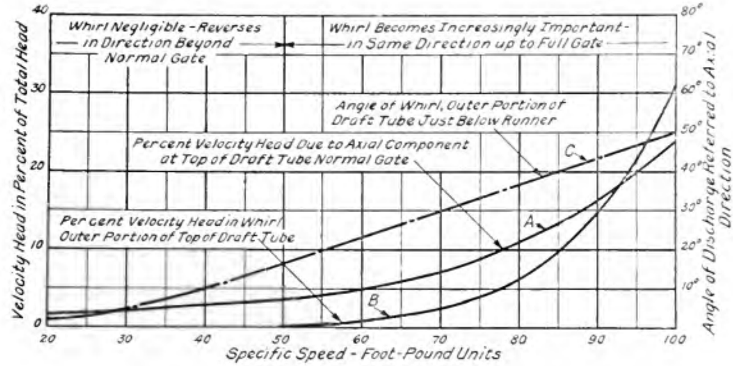

Fig. 5. Curves showing Energy to be Regained in Draft Tube for Average Wheels of Different Specific Speeds

High-head Units

For high-heads low specific speeds must be used and it will be noted from Fig. 5 that for such units the energy to be regained in the draft tube is small. Thus for a head of [illegible] feet the specific speed would be about 22 and the energy to be regained in the draft tube would amount to about 2 per cent of the head for the axial velocity, whereas the whirl velocity would be negligible. Hence, if the draft tube had an efficiency of only 50 per cent instead of 75 per cent, the efficiency of the unit would decrease but one half of one per cent. Therefore, for such heads the draft tube design is of but minor importance.

There are two losses, however, that deserve special attention: (1) the disc friction of the runner and (2) the leakage at the runner seals. The former loss is the power required to drive the runner submerged. It has been found by experiment that the water above and below the runner rotates at about one half the speed of the runner and, hence, a friction loss occurs between this water and the stationary parts (the upper and lower covers) and an additional loss occurs between this water and the runner. To keep this loss as low as possible, the inner surfaces of the head covers and the outer surfaces of the runner are made smooth and free from unnecessary projections.

The loss due to revolving a flat disc in water is given by the formula:

$$HP = KD^5N^3$$

where HP = horse power lost
D = runner diameter in feet
N = revolutions per minute
K = coefficient depending on character of surfaces

Experiments which have been made on machined brass discs give a value of $K = 0.000,000,000,413$. No tests have been made on turbine runners to determine this loss, but for comparative purposes the same coefficient may be used.

As an example, consider a 20,000-horse-power turbine designed for a head of 500 feet. For a specific speed of 22 the speed would be 368 r.p.m. and the runner diameter 6.45 feet. The disc friction loss as given by the formula is 230 horse power or 1.15 per cent of the full-load output. As this disc loss is constant for all gate openings, it would amount to 2.30 per cent of the output at half load. On the other hand, a 10,000-horse-power turbine designed for a head of 30 feet and a specific speed of 80 would run at 56 r.p.m. and have a runner about 11.8 feet in diameter. Hence, the disc friction loss is 16½ horse power which is only 0.165 per cent of the full-load output, or 0.33 per cent of the output at half load. Therefore on high-head units this loss is of considerable importance especially at part loads and must be taken into account in calculating the possible efficiencies to be expected.

The second loss mentioned—leakage at the runner seals—is also an important factor in the design of high-head units. This leakage water escapes between the periphery of the runner and the stationary parts and, hence, performs no useful work. The amount of this leakage depends on the pressure existing at the intake to the runner and on the area between the runner seals and stationary parts. For high-head turbines the pressure at this point is proportionately greater than for low-head units, and in addition the diameter of the runner is relatively greater as will be noted from the two types of runners shown in Figs. 3 and 4. Thus, with the ordinary design of runner seals the leakage at this point is an important factor for high-head units.

As a comparison of this leakage loss between high and low-head turbines consider a 20,000-horse-power unit operating under a head of 500 feet as compared to a 10,000-horse-power turbine under a head of 30 feet. If the ordinary type of seal rings are used in both cases, the leakage at the runner seals of the high-head unit will amount to approximately 10 cubic feet per second which is 2.4 per cent of the full-load quantity required by the unit; whereas for the low-head turbine, the leakage loss will amount to approximately 8 cubic feet per second or only 0.2 per cent of the full load quantity. This leakage is, therefore, of great importance on high-head units and hence special seal rings have been designed to reduce this loss to a minimum. By the use of such seals on the runner and stationary parts it has been found possible to maintain about the same per cent of leakage for high-head wheels as occurs on low-head wheels with the ordinary design of seals.

In conclusion, it should be noted that the design of each hydraulic turbine presents a different problem in which special attention must be given to the particular features of the design which are of most importance for the head under which the unit is to operate. It is safe to predict that the future development of the hydraulic turbine will be along the lines of large size reaction wheels for high heads and higher speed units for low heads, so that the particular features of design discussed will become of ever-increasing importance.

Some Recent Developments in Power Transformers

By W. S. Moody

Engineer, Transformer Engineering Department, General Electric Company

Transformers play an important part in our large transmission system and the author has shown how their design has been kept abreast of other developments to withstand the heavy service imposed by the greatly increased capacity of the individual unit and the adoption of higher voltages. The improvement in self-cooled transformers, brought about by the development of the radiator tank, have made it possible to use self-cooled units in many places where water-cooling would formerly have been considered essential. The author tells how the special problems involved in the design of transformers for electric furnaces were met successfully and he also deals with the use of conservators.—Editor.

It is, of course, generally appreciated that the possibility of transforming electric power from low potential to high potential and back again to low potential, with an almost negligible loss, by means of static transformers; i.e., transformers that have no moving parts, adds greatly to the possibilities of power transmission. Even the engineer, however, seldom stops to consider seriously what a relatively insignificant industry power transmission would be without any means of transforming electric power except rotating apparatus.

Generators with revolving armatures were not successfully made for voltages over 2500 for many years after alternating current was generally used, and those built for pressures as high as 6600 volts were never very reliable. The use of revolving field generators later made the problem somewhat simpler, but today a generator for over 25,000 volts is to be avoided, even in the very large capacities.

If limited to such a voltage and to the use of a similar high voltage machine as a motor, the writer ventures to say that not 15 per cent of the present power transmitted by electricity would be practical, commercially.

In the June, 1916, issue of the Review the writer presented, in considerable detail, some of the many electrical and mechanical features of large, high voltage transformers that must be treated with skill and care in their design

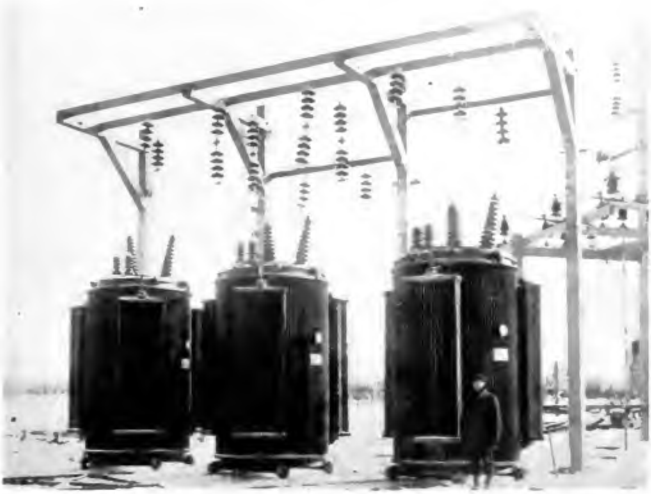

Fig. 1. Outdoor Substation of the Great Northern Power Company. Radiator-type Self-cooled Transformer. Recent developments in transformer design have made possible the installation of large high-voltage transformers out doors. The use of this type of station has been accelerated by recent power demands with corresponding shortage in material, labor, and time necessary for building stations to house transformers.

and manufacture if they are to give reliable service and transmit power for many years. In the years intervening engineering and industrial activities have been so largely devoted to the demands of war that the usual growth of power transmission has not been possible; but there has been a splendid opportunity to test transformers already in service and to demonstrate that such of them as are in conformity with the best practice are thoroughly reliable even when conditions necessitate heavy overloads and continuous service.

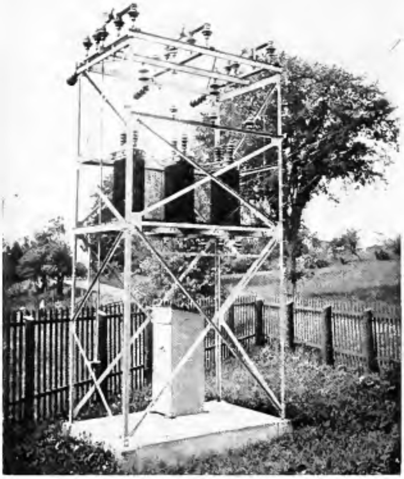

Fig. 2. 33,000-volt, 150-kv-a Outdoor Substation. Typical of small transforming stations which have been coming into favor for a number of years with consequent saving in building expense.

Perhaps the most noteworthy feature of recent development that has thus been thoroughly tested during this period is the installation of large and high voltage units in outdoor stations. At first it was only the more adventurous of operating engineers who were willing to trust the designing engineer to furnish them with transformers that should stand up when so installed, and then it was considered only in the less important and smaller substations. So well were the designs worked out, however, in all the many details, that even from the first little additional trouble was experienced. When the war-time shortage of structural steel, labor and the urgency of demand combined to make station building almost out of the question, practically no operating engineer hesitated to install even the largest and highest voltage units out-of-doors in both water-cooled and self-cooled types. Fig. 1 shows an outdoor installation of three self-cooled, 60,000-volt transformers, while Fig. 2 is representative of a modern pole-type substation of small capacity.

An article in the August, 1918, issue of the REVIEW described "Radiator Tank Transformers," a good example of which is shown in Fig. 3. By the use of these radiators we are able to build self-cooled transformers in any desired capacity. It is of particular advantage for out-door installation in that the transformers require the minimum amount of attention. Furthermore, in large self-

Fig. 3. 50,000-volt Moderate Capacity Power Transformer. Use of the all-welded steel radiators on transformer tanks has made practical the building of self-cooled units in any desired capacity. The installation of such transformers out of doors has eliminated the difficulty often experienced with large self-cooled units when installed indoors, of keeping the ambient temperature at a conservative value.

cooled units the problem of properly ventilating the room in which they are installed so as to keep the ambient temperature at a conservative value, is of no small importance on account of the large amount of heat liberated into the room. The installation of such units outdoors, therefore, is an ideal solution of this problem. It will be noted that radiators are used on the transformers shown in Fig. 1.

In the early history of transformer design, the importance of building transformers to meet short-circuit conditions was of minor importance, because the systems back of the transformers were small and the maximum possible short-circuit current could be only a few times that of normal. Some of these transformers, however, did not stand up when placed on large systems, having practically unlimited amount of power compared to the size of the transformer. In the article in the July, 1916, issue of the REVIEW previously mentioned, the writer called attention to various methods of designing transformers to withstand electro-magnetic forces generated in them under short-circuit conditions. It is gratifying to note that failures due to short circuit on transformers designed to meet this condition have been eliminated, notwithstanding the fact that systems have been continually growing in size.

Fig. 4. Water-cooled Furnace Transformer. Due to recent largely augmented demand, the design of such transformers has been given special consideration. The transformer must deliver very heavy currents without excessive stay loss and be reliable in a class of service where short-circuits are common.

The enormous increase in the electro-metallurgical industry in the last few years, with the consequent increase in electrical apparatus for this industry, has made it necessary to design transformers with special reference to such use. These transformers are commonly classed as "furnace transformers." Fig. 4 shows a complete furnace transformer of which a large number were supplied for one of the government nitrate plants during the war.

Fig. 5. Low Voltage Bars of a Furnace Transformer Showing Dust-proof Outlets. The large number of secondary voltages often required, and protection from the dust and dirt inseparable from such service, add other problems to the design.

The special problem in such transformers is that of producing a design capable of delivering the very heavy current usually required for these processes, without excessive stray losses and with requisite reliability in a class of service where short circuits are common.

In general, the secondary or low voltage windings of these transformers must be divided into a number of circuits or coils, connected in parallel, to obtain the necessary current carrying capacity. It is essential that the current in these various parallel circuits be properly divided, otherwise there will result high excess losses due to the currents in the individual circuits being out of phase with one another.

The difficulty of this problem is frequently accentuated by the fact that a considerable range in secondary voltage is required, which is generally obtained by taps in the primary winding, changing the ratio to give this required range in the secondary voltage with a fixed primary voltage impressed. The windings must, therefore, be so arranged that not only is the resistance of each secondary circuit approximately the same, but the reactance, with respect to the primary windings, must also be the same.

The duty on such transformers is usually very severe, especially in arc furnaces, due to the variation of the resistance of the material in the furnaces, variations of the length of the arc, breaking electrodes, etc., which cause a great variation in the current flowing. From these causes sudden current rushes, reaching values a number of times normal, are quite frequent. This, therefore, necessitates a very rugged design to withstand the constant subjection of mechanical forces in the windings due to current surges. The structure must be such that vibration incident to these forces cannot loosen the means of supporting the coils and cause failure in this manner.

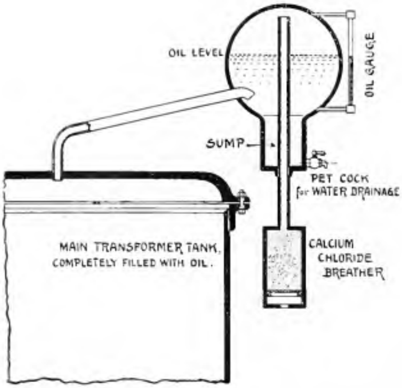

Fig. 6. Essential Features of the Transformer Oil Conservator. The features include: Transformer tank completely filled with oil under slight pressure, Cool oil only in contact with air; Breathing through Calcium Chloride; and Provision for preventing moisture which may enter through breather from getting in the main Transformer Tank

In some types of furnaces, particularly those of the arc type, the character of the arc itself causes oscillations of current and voltage at high frequency which are impressed on the secondary winding and may be reproduced by induction in the primary winding. It is necessary to insulate for these conditions. Therefore, it has been found advisable to insulate such transformers more highly than those of a similar rating employed for ordinary distribution power.

Most electric furnace operations are very dirty. The atmosphere is frequently filled with dust which may be of a conducting nature. Therefore, it is essential that oil-immersed transformers be made thoroughly dust proof and that the leakage distance between terminals of opposite polarity outside the transformer be made especially liberal, so that no trouble will be experienced even with considerable accumulation of dust on these terminals. It has frequently been thought desirable to use regular outdoor style bushings for high voltage terminals on account of dust accumulation.

Some details of construction are shown in Fig. 5, of a dust proof outlet for a low voltage bar terminal for a very complex three-phase design.

A device which is gaining in popularity among users of high voltage power transformers is the oil conservator, brief mention of which was made in the January, 1919, issue of the Review. As was there stated, the conservator eliminates contact between the warm oil and the air, thereby preventing the oxidization of the oil, and the consequent

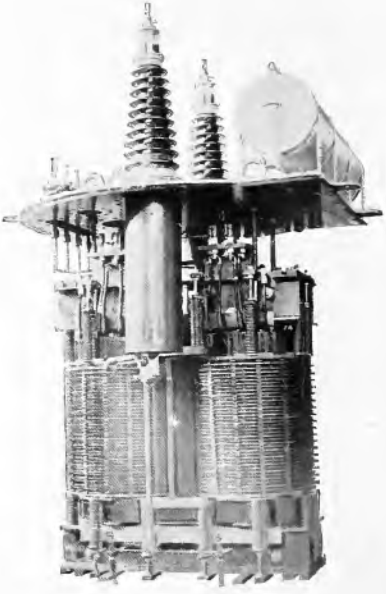

Fig. 7. Interior of a 10,000-kv-a. 120,000-volt Transformer with Oil Conservator shown Mounted on Transformer Cover. Auxiliary tank must be slightly higher than the highest point of the main tank.

formation of sludge; eliminates all possibility of moisture in the main transformer tank, thereby preventing breakdown due to a lowered dielectric strength of the oil, and also eliminates the air space above the oil in the main transformer tank, thus preventing explosions due to a mixture of air and gas being ignited by a spark or static discharge.

Fig. 6 shows clearly the principal features of the conservator. This consists of an auxiliary tank, connected to the main transformer tank, in which the oil expansion due to changes of temperature in the transformer, can take place. The auxiliary tank is placed a little higher than the main tank in such a way that the latter is always filled with oil. The pipe connecting the two tanks is large enough for free flow of oil, but too small to allow of free circulation. This results in practically ambient temperature in the auxiliary tank where the oil is in contact with the air, a feature which is essential for the prevention of sludging, and yet there is sufficient temperature rise to avoid any condensation.

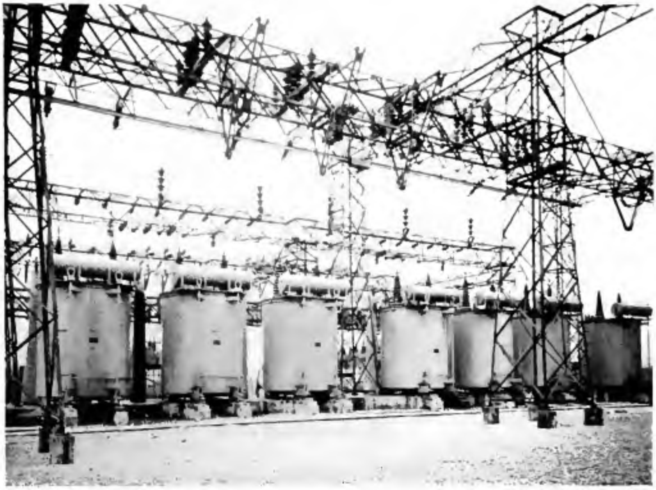

Fig. 8. Outdoor Station of the American Gas and Electric Co., at Canton, Ohio, showing an Installation of Conservator Type Water-cooled Transformers. The outdoor installation combined with the use of the Oil Conservator makes this typical of up-to-date transformer practice.

Since the expansion and contraction of oil due to changing temperature affects the oil level in the conservator tank only, the breathing takes place at this point. As a consequence, even should the chloride breather become ineffective, and the temperature drop below ambient, and moisture be drawn into the conservator, the moisture will fall into the sump when condensed.

Several methods of mounting the conservator have been used, but the essential point is that the auxiliary tank be slightly above the highest point of the main tank. While the conservator may be mounted on the transformer cover, or on a wall or trestle, the preferred method of mounting is to place the conservator on the side of the transformer tank or support it on suitable brackets from the transformer truck or base.

A large number of the conservator type transformers, covering a range in size from 1000 to 10,000 kv-a., have been in operation two or three years and have everywhere given satisfactory service. Fig. 7 shows an interior view of a 10,000-kv-a., 120,000-volt transformer with conservator, while Fig. 8 gives some idea of the appearance of an installation of these transformers. This last view is also representative of a thoroughly modern high voltage outdoor station using water-cooled transformers.

Recent Developments in Oil Circuit Breakers

By J. W. Upp

Manager, Switchboard Department, General Electric Company

The transmission of large powers at high voltage is one of our great engineering problems. The concentration of power in large interconnected stations is a modern economic necessity, and an increase in voltage means more economy. This constant increase in power and voltage demands that everything that enters into the transmission system must keep pace with the development. Those that are to lead must keep ahead of the present requirements and make future advancements possible. Mr. Upp, in this connection, shows how oil circuit breakers have been kept "ahead of the game" in interrupting capacity and in increasing voltage requirements with the necessary reliability of operation. The importance of safety devices has not been overlooked as is shown by the author's description of the removable truck type of oil circuit breaker.—Editor.

The interconnected power system with its modern generating stations of increased capacity has been made possible through the development of apparatus and devices of various kinds, but no single device entering into this development has received more engineering consideration than the design of oil circuit breakers of adequate capacity for known and contemplated requirements.

On these systems one oil circuit breaker may be required to control a small alternating current motor; another oil circuit breaker on the same system may be required to interrupt a short circuit in one or more generators or even the entire output of the station.

Fig. 1. Small Capacity Oil Circuit Breaker

Oil circuit breakers may be required for circuits of 600 volts or less; they may also be required for 155,000 volts or more; and they are used on circuits of 30 amperes and on circuits of 10,000 amperes. Oil circuit breakers may use but one quart of oil and weigh less than 20 pounds, or they may use 5000 gallons of oil and weigh many tons. They may be manually or electrically operated, be installed indoors or out-of-doors and be arranged to open or close automatically—each type having its own special use and particular field of application.

The lines of oil circuit breakers which are hereinafter described and illustrated are of two general types.

1. The *FK* type or those with a double or quadruple break per pole, comprising vertical downward moving conducting members and carrying, except in a few cases, the entire current load in a common oil tank.

   This family of breakers varies in structural details, but have the common characteristics of stationary contact members passing through insulators substantially mounted on a frame forming the top of the oil tank, and projecting beneath the oil surface in the tank. The moving contact member is carried by a vertical rod which passes through the top framework and then makes attachment with the operating mechanism.

   The oil tanks are made of sheet steel with welded seams, the shape is circular or elliptical in section in those breakers constructed to withstand high pressures, rectangular with rounded ends for medium capacity breakers, and rectangular for breakers of small capacity.
2. The *FH* type, or those with a double or quadruple break per pole, comprising vertical upward moving conducting members, each main contact rod breaking the arc in a separate oil vessel, while in breakers of all but the smallest capacities nearly all the current is carried by parts external to the oil vessel.

Fig. 2. Small Capacity Breakers of the FK Type

Fig. 3. Moderate Capacity Oil Circuit Breaker of the FK Type

Fig. 4. 73,000-volt High Capacity Oil Circuit Breaker of the FK Type, Mounted on Angle Iron Framework

Fig. 5. 15,000-volt High Capacity Oil Circuit Breaker of the FK Type Mounted on Pipe Framework

The moving contact member is carried by a vertical rod which passes upward through the top of the cell in which the breakers are installed and then makes attachment with a motor operated mechanism. The oil tanks are of one piece cylindrical drawn steel without seams, which construction enables the tanks to withstand the heavy pressures encountered in the interruption of large currents.

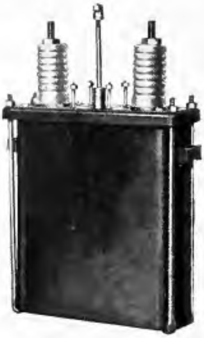

Fig. 6. Standard Pole Unit for Fig. 3

Each of these types of breakers have been in general use for many years and during that time have been constantly improved. This improvement still continues and the engineers engaged on this class of work supplement practical application of existing designs with equal energy devoted to the development of designs for the future.

The more recent advances in oil circuit breaker developments have been along the following general lines:

1. Standard unit method of construction.
2. Increase in interrupting capacities.
3. Increased safety; easy inspection and adjustment, and quick replacement.

Standard unit construction is of value to the manufacturer, but the principal reason for its adoption is the opportunity it affords to give the best possible service to a purchaser.

In breakers that are made in large quantities the standard unit types are always cheaper than other breakers of equal quality made for similar service, and the time to manufacture and deliver are lessened considerably.

In types of breakers where the line is limited, or the sales are comparatively small, the actual cost of standard unit construction may be, and often is, greater than a special breaker built for a specific application; but the ultimate cost is less, because of the saving in cost of maintenance. Repairs are easier to make, the price and time of obtaining parts are less, and the liability of extended shutdowns is decreased materially.

The plan followed on the types of oil circuit breakers hereinafter described is to stock the unit components, this being of advantage to any purchaser, but especially to large companies which have on their systems breakers of various types and sizes. The user can obtain complete breakers, or replacement parts more readily, and he can also carry in stock a sufficient number and variety of standard units to meet any ordinary emergency.

Fig. 3 illustrates the standard unit parts of a small oil circuit breaker. The triple-pole breaker shown consists of five standard units, that is, the mechanism unit, the frame unit, and the three single-pole units.

Fig. 7. Moderately High Capacity Oil Circuit Breaker of the FK Type, with Four Contacts in Each Oil Tank

The mechanism unit with the addition or omission of the tripping coils is the same for all capacities of the breaker; the frame unit is the same for all breakers of the same number of poles; and the pole units are the same for all breakers of the same voltage and ampere rating. This principle applies in general to all new developments in oil circuit breakers. The details vary, however, to suit the particular type of construction involved.

The interrupting capacity of any oil circuit breaker depends, among other things, upon the ability of the breaker to resist the pressure produced by the gases generated in the tank, and the secondary explosion of these gases when mixed with air above the oil level within the oil tank; and if the other determining factors are within safe limits, the breaker which has the strongest oil tank will have the greatest interrupting capacity.

In the Type *FK* oil circuit breakers, except those of considerable size, the arcs are drawn openly in the oil, and are free to move to any position in the tank as may

Fig. 8. 115,000-volt High Capacity Oil Circuit Breaker of the FK Type Mounted on Floor

Fig. 9. 115,000-volt High Capacity Oil Circuit Breaker of the FK Type, Mounted on Structural Steel Girders which Rest on Concrete Foundation Pillars between which a Pit is Built to Allow Removal of the Oil Tanks

Fig. 10. Single Pole of High Capacity Oil Circuit Breaker of the FK Type, showing Insulating Shield and Explosion Chamber

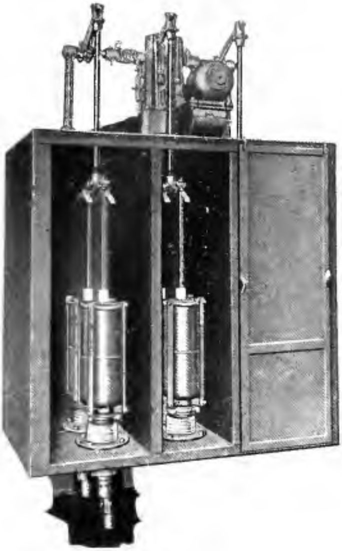

Fig. 11. High Capacity Oil Circuit Breaker of the FH Type

Fig. 12. High Capacity Oil Circuit Breaker of the FH Type with Single Pole Units, Mounted on Removable Trucks

Fig. 13. High Capacity Oil Circuit Breaker of the FH Type with Semi-portable Steel Cell

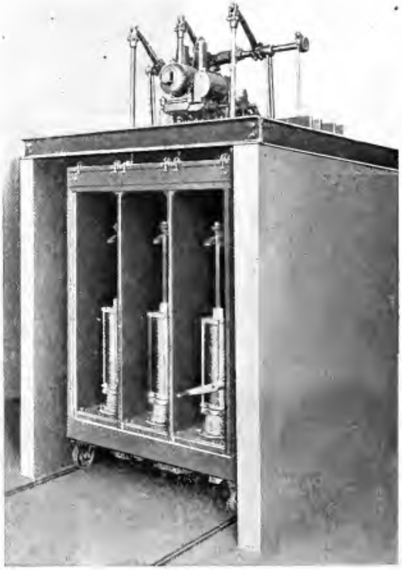

Fig. 14. High Capacity Oil Circuit Breaker of the FH Type, Mounted on Removable Truck

be determined by the magnetic repulsion of the arc and the size and shape of the gas volume. In the largest capacity breakers of this type advantage is taken of this known action in a very novel and efficient manner; and a brief description of the construction readily shows the very high factor of safety obtainable with a minimum use of material. In these circuit breakers, which have to interrupt circuits carrying very large amounts of power, the quantity of gas generated and the danger of the arc stabilizing are so great that it becomes desirable to use some limiting means to reduce the gas volume, the arc spread, and the accompanying gas explosive pressures. This is accomplished by the use of a strong metal vessel attached to the lower end of the insulating bushing as shown in Fig. 10. By means of these chambers the time required to rupture the arc resulting from a given load and load condition is greatly reduced. Also the volume of gas generated within the oil tank is reduced. Moreover, this gas is directed downward into the oil and cooled, which reduces its volume and also makes impossible its igniting any explosive charge of gas which may be above the oil level in the tank. In addition, the oil which is ejected from the chamber when the breaker opens under load is projected at high velocity upon the incandescent end of the electrode, cooling it and making reionization much more difficult.

The explosion chamber of Type *FK* oil circuit breakers is of small cubical capacity, but is constructed to withstand pressures of many hundred pounds per square inch, thus relieving the large outer oil tank from pressures which might be destructive if the arc had been drawn directly in the outer tank.

In the Type *FH* breakers the relative interrupting capacities depend also upon the strength of the oil tank, and upon the physical dimensions of the tank combined with break distance, speed of operation, and other variable quantities. In this breaker there are two or more breaks per pole, and each break is made in a seamless drawn steel oil vessel of great strength and small oil capacity, which assures the minimum fire hazard. The vertically moving contact rods pass through openings in insulating baffle plates which are supported so as to withstand high pressure. When the contacts part, a high pressure is generated in the oil space below the lower baffle, and this high pressure ejects the oil at high speed into the path of the arc and instantly extinguishes it.

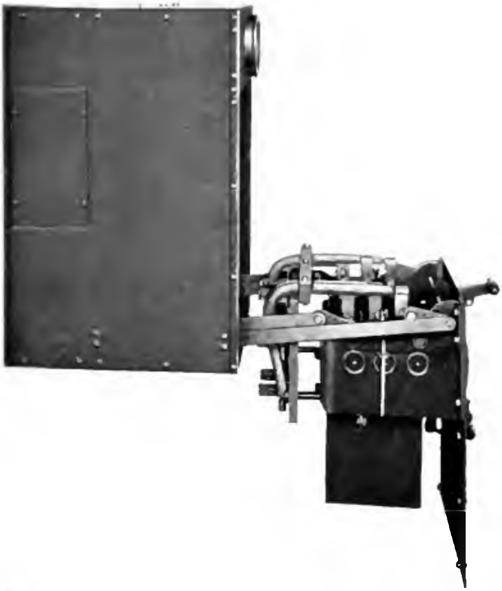

Fig. 15. Safety Enclosed Swing-out Panel, with Type FK-20 Oil Circuit Breaker. Unit for Mounting on Vertical Flat Surface

Marked progress has been made in developing means which will prevent accidental contact with oil circuit breakers while alive, and this development has also increased the efficiency of operation by giving greater ease of inspection, adjustment, and replacement. The method is to enclose and interlock the oil circuit breakers, with their necessary auxiliary apparatus, in a housing so that:

1. Access cannot be had to them while alive.
2. They can be swung out or drawn out from the housing when dead.

Figs. 12, 14, 15, 16 show this construction. With the Type *FK* breakers the current and potential transformers are housed in the same enclosure.

Fig. 15 shows an industrial type of oil circuit breaker totally enclosed in a steel housing and consequently free from the hazard of live current carrying parts. The breaker as shown is in the swing-out position, and it is so interlocked with the housing that the panel can be swung out only when the breaker is in the *off* position and the disconnecting device is therefore carrying no current. The interlock also prevents the panel from being swung back into operating position when the breaker is in the *on* position.

Type *FK* breakers may be operated on the removable truck plan if desired and when used in a switchboard of truck construction not only afford the highest possible degree of protection against accident to the operator, but reduce very materially the duration of a possible interruption. And it is the consensus of opinion of those who have given such matters consideration that this particular kind of panel will be applied more and more as time goes on and eventually will supersede the stationary type of slate or marble switchboard now in general use.

Type *FH* breakers are also made in removable truck form, Fig. 12 and Fig. 13, so that the entire breaker or any pole may be removed for inspection or adjustment and a spare breaker placed in service within a short time. With breakers of this construction, an interlocking arrangement is used which possesses several safety features that are worthy of mention.

The disconnecting switches on all phases are opened simultaneously.

The disconnecting switch cannot be opened until the circuit has been opened by opening the contacts of the oil circuit breaker.

As soon as the disconnecting switches are opened, no matter to how small an extent, the oil circuit breaker is locked so that it cannot be operated until the disconnecting switches are entirely open. Then the breaker mechanism can be operated for inspection or repair.

It is impossible to close the disconnecting switches except when the oil circuit breaker is open, and the truck and breaker are open, and the truck and breaker are in position and the cell doors closed.

The cell doors can be opened and removed only when the disconnecting switches are fully open.

While a cell door is open, it is impossible to close the disconnecting switches irrespective of the position of the operating mechanism.

The truck cannot be removed until the cell doors are open, and the oil circuit breaker is in the open position.

When the truck is removed the disconnecting switches are locked in the open position.

The description of the oil circuit breakers of the types illustrated would not be complete if emphasis were not laid again upon the primary importance of having safety in installation and in operation, and the consensus of opinion among operating and designing engineers is not too strongly stated when it is said that circuits of every description should be fully protected against accidental contact and that in modern installations of electrical apparatus every precaution must be taken to avoid the possibility of any accidental contact with live parts. The manager of a power plant or of an industrial installation who permits the use of apparatus without adequate safety protection is not conserving his resources in a proper manner.

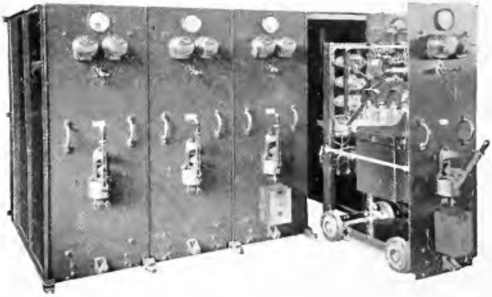

Fig. 16. Safety Enclosed Unit Panel Switchboard Removable Truck Type, Front View, One Truck Removed

Interchangeable Bushings for High Voltage Apparatus

By Eugene D. Eby

Engineer, High Voltage Bushing Engineering Department, General Electric Company

High voltage bushings were for a long time one of the limiting features of high tension transmission. The author shows that the difficulties have been overcome and that a successful line of bushings have been standardized. There now seems no limit to the size for which these bushings can be made. This article contains much valuable data which should be known by those interested in the technical side of transmission line developments.—Editor.

With the increase in voltage and size of power transmission systems, the interconnection of such systems, and the demand for greater reliability and absence of service interruption, there has arisen a need for greater attention to the high voltage bushings or terminals of the various classes of apparatus connected to these high voltage circuits. The General Electric Company has recognized this need of the operating companies by the establishment of a High Voltage Bushing Engineering Department, which is devoted to the peculiar problems of the design and manufacture of bushings for high voltage apparatus.

Fig. 1. Filled Type Flange Clamped Porcelain High Voltage Bushings for Transformers, Oil Circuit Breakers and Lightning Arresters. Range of Operating Voltages, 73,000 to 177,000 volts

The General Electric Company's standard types of bushings are divided into two groups: those for operating voltages not exceeding 73,000 volts, which are of the "solid" type, and those for voltages above 73,000, which are of the "filled" type. Some of the more important features of design and performance of the "filled type" bushings are dealt with in this article.

A line of filled type bushings, which is partly illustrated in Figs. 1 and 2, has been standardized for operating voltages between 73,000 and 250,000 volts. The keynote in the design of these bushings, both electrical and mechanical, has been *reliability;* in their application, it has been *interchangeability.*

Fig. 2. Filled Type, Flange Clamped Porcelain High Voltage Bushing for Transformers, Oil Circuit Breakers and Lightning Arresters. Maximum Operating Voltage 250,000 Volts

As illustrated in Fig. 3, these bushings are interchangeable between all the standard classes of high voltage apparatus, so that a given bushing, when equipped with the proper detachable terminal accessories, may be assembled with a power transformer, an oil circuit breaker, a lightning arrester, a potential metering transformer or a current metering transformer, or may be transferred from one to the other. They are supplied in designs adapted to high and low altitude installations, as shown in Fig. 4, according to the location of the system, and are uniformly suitable for outdoor service.

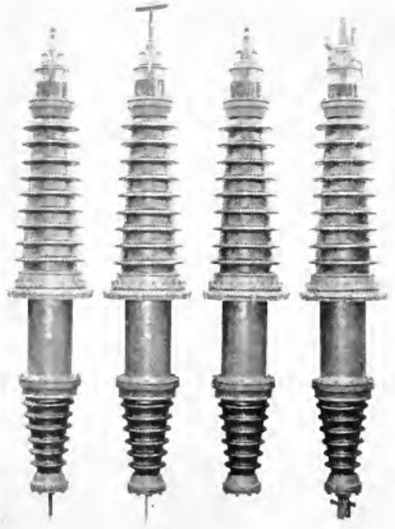

Fig. 3. Filled Type High Voltage Bushings Class F2 400 A. Equipped with Terminal Accessories (Detachable) for the Class of Service Indicated. Left to Right: Constant Potential Transformer, Lightning Arrester, Oil Circuit Breaker and Metering Current Transformer

Rating

The voltage rating of a bushing is related to, and should not be less than, the highest normal operating voltage of the circuit to which it is connected. As far as the bushings are concerned, this normal rating should apply to all parts of the circuit, including both the generating and receiving ends of the line. This is desirable because the over-voltage stresses to which the bushings, as well as other insulation, are subjected, may be as great at the receiving end of the line as at the generating end, although, under normal operating conditions, the voltage at the receiving end is usually lower.

As a general rule, no distinction is made between systems which are Y-connected, and those which are delta-connected, in so far as the choice of bushings is concerned. This is the regular practice also in the case of high voltage lightning arresters. No system may be considered grounded, from the standpoint of the bushings, unless dead grounded at both ends of the line, at present a rather unusual condition. Even such grounds may be disconnected from the system by opening the high voltage oil circuit breakers, which would leave the line bushings on the circuit breakers connected to ungrounded lines. Until experience has shown conclusively that so-called grounded systems present less severe operating conditions for

Fig. 4. Filled Type High Voltage Bushings for High and Low Altitude Service. Transformer Contacts on Bushings, Lightning Arrester Transformer Contact in Center and Oil Circuit Breaker at Right

the bushings, it appears to be good engineering practice to treat all systems alike, disregarding their connections.

The coefficient of safety is based on the A. I. E. E. specifications for the test voltage of high voltage apparatus. Taking as a basis of reference the highest test specifications, namely, two and one quarter times the normal line voltage, plus 2000 volts, as in the case of oil circuit breakers, it has been found by careful review of past experience that a factor of safety in the bushings represented by a ratio of 7:10 to 9:10 of this test specification, has resulted in occasional flashover of the bushings in service. Ratios greater than 1 have always given successful operation. The test specification of the A. I. E. E., therefore, is considered safe and sufficient for the bushings, as well as for the completed apparatus. These "filled type" bushings are designed to withstand a test, with or apart from the apparatus with which they are operated, equal to the test specified in the Standardization Rules of the Institute.

The effect of altitude on the flashover voltage of bushings is similar to its effect on other types of gaps, such as lightning arrester gaps and line insulators. Fig. 5 shows a curve representing the relation of flashover voltage at different altitudes for bushings of the type shown in Fig. 1. On this curve it will be noticed that a reduction in the flashover voltage of about 12½ per cent is the result of an increase in altitude from sea level to 4000 feet. Likewise, an altitude of 10,000 feet corresponds to a reduction of 27 per cent in the flashover voltage. Thus a bushing which has a flashover voltage of 375,000 volts at sea level, would flashover at about 330,000 volts at 4000 feet altitude, and at about 275,000 volts at 10,000 feet. This illustrates the necessity for taking into account the altitude of the installation. Since the maximum one-minute test voltage of the bushing is definitely related to the flashover voltage, it follows that the normal operating voltage is also definitely related to the flashover voltage, and consequently is affected by the altitude of the installation. For instance, a bushing having a normal operating voltage rating of 154,000 volts at sea level, would be reduced in rating to 135,000 volts at 4000 feet, and to 112,000 volts at 10,000 feet.

This great effect of the altitude upon the rating of the bushing involves only the upper end of the bushing, whose insulating surface

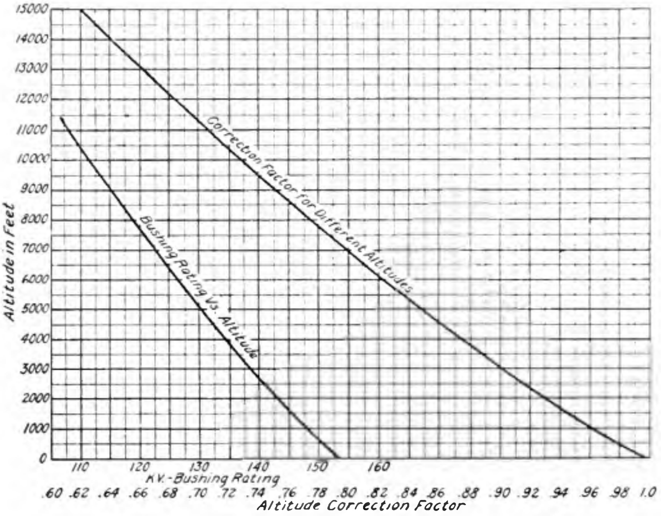

Fig. 5. Curves showing Variation in Flashover Point with Change in Altitude and Correction Factor for Different Altitudes

is exposed to the atmosphere. The puncture strength of the bushing is not affected by the altitude, nor the strength of the insulating surface of the lower end of the bushing, which is entirely submerged in the oil of the apparatus in which it is assembled. For this reason, installations at high altitudes, particularly those exceeding 4000 feet, are supplied with "high altitude" bushings, whose upper section has been lengthened to increase the striking distance, corresponding to the decrease in the dielectric strength of air at the high altitude. As illustrated in Fig. 4, the high altitude and low altitude bushings are exactly alike below the supporting flange.

Temperature also affects the relative air density, and consequently the arc-over voltage of the bushings. A difference of 1 deg. C. in temperature has the same effect on the relative air density, and therefore on the arc-over voltage, as a difference in altitude of 100 feet. Thus a difference of 40 deg. C. in temperature corresponds to a difference of 4000 feet in the altitude of installation. Such temperature conditions, however, exist at all altitudes and have to be considered in the factors of safety which apply to all installations. Other conditions also affect the flashover voltage, such as the condition of the surface of the bushing, whether clean or dirty, different degrees of humidity and especially rainfall. All of these conditions, likewise, are present to a greater or less degree at all altitudes, and at all places of installation. Experience has shown that these conditions, inclusive of temperatures, are properly provided for by the factor of safety represented in the A. I. E. E. test.

Fig. 6. Dry Flashover of Filled Type Flange Clamped Porcelain Bushing at 395,000 Volts

Fig. 7. Wet Flashover of F3 Bushing at 305,000 Volts

There should be some definite relation between the insulation strength of the bushing and that of the line to which it is connected. There exists, however, such a wide variation in the actual value of line insulation, not only on different systems, but at different points on the same system and at different periods of time after the erection of the line, that it is quite out of the question to establish any very definite relation between the bushing and the line insulation. Protective devices such as lightning arresters, on the other hand, offer a basis of comparison which can be utilized in the rating of the bushing.

Tests have shown that these standard bushings are very "slow" under high frequency impulses, which feature is highly desirable in order that high frequency disturbances shall be discharged over the protective gap, rather than over the bushings. On the other hand, in order to safeguard against low frequency disturbances, it is well to have the 60-cycle arc-over voltage of the bushing equal to at least twice the arc-over voltage of the protective spark gaps. This relation results from the theoretical value of the reflected wave. Considering a wave of potential just below the breakdown voltage of the protective spark gap, such a disturbance would not be discharged upon approaching the apparatus protected by the spark gap, and the wave would pass on to the transformer or end of the line, there to be reflected at theoretically double its initial value. Under such circumstances, the bushing should not flashover, but should withstand the double value of the wave, which would then be discharged by the spark gap.

All of these considerations have led to the assignment of an arbitrarily chosen symbol to each bushing in the standard line such as F1, F2, F3, etc., to the "low altitude" bushings, and F1A, F2A, F3A, etc., to the "high altitude" designs. These symbols serve to distinguish the different sizes of bushings in all particulars except current carrying capacity. The "flat" voltage rating has been superseded by the "voltage-altitude" rating, so that a given bushing may operate on systems of different voltage at different altitudes with the same factors of safety. This classification symbol also allows the bushing to be assigned to a system according to its operating conditions without violating any arbitrarily established voltage rating.

Performance

With bushings, as with other apparatus, and all the more so because upon the bushing depends the serviceability of the apparatus, reliability is the one characteristic which stands out above all others in the requirements of design. The successful bushing must be able to withstand all of the normal and abnormal conditions against which ingenuity can fortify it. Among the most important of these conditions is the ability of the bushing to protect itself against destruction from voltages in excess of its breakdown strength. Not only must the bushing be able to operate under all normal voltages, and such abnormal voltages as are within the range of its design, but it should be provided with a safety valve against higher voltages which would endanger its puncture strength, and consequently its further usefulness. In other words, the bushing should have a puncture strength greater than its flashover strength, or conversely it should have a flashover voltage lower than its puncture voltage. That is, it should be able to withstand flashover without puncture so that upon application of a voltage exceeding its flashover voltage, a flashover of the bushing will result, which will protect it against puncture. This is one of the characteristics embodied in the line of filled bushings here described. Figs. 6 and 7 illustrate this characteristic of flashover without puncture, both dry and wet. The bushing should be able to withstand such an experience an indefinite number of times.

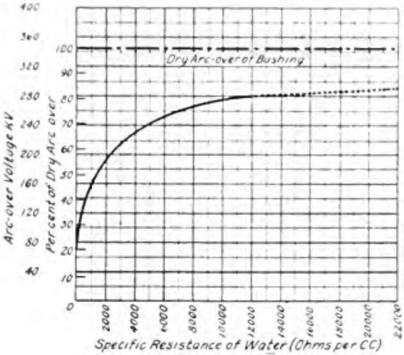

Fig. 8. Curve showing the Wet Arc-over Voltage of Bushings for Various Specific Resistances of Water and the Percentage of This Voltage to Dry Arc-over Voltage

The "speed" of the flashover of a bushing is also of special importance, just as is true of protective spark gaps, except that the bushing should have the opposite characteristic from the spark gap. It is essential that the spark gap, installed to protect the other apparatus, should discharge over-voltages promptly, with as little delay or "time-lag" as possible. Spark gaps differ greatly in this respect. Those which develop corona before flashover are subject to a comparatively long time element, and are termed "slow." Those which do not develop corona before flashover are fast. Examples of these two types are the needle gap and the sphere gap, respectively. The bushing, which is not a protective gap, should be so designed that it will have a considerable time lag, that is, it will be slow to flashover. This characteristic has been included in the design of the filled type bushings.

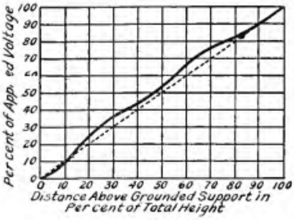

Fig. 9. Curve showing How Uniform Surface Distribution is Accomplished by Increasing Distance Above Grounded Support in Proportion to Voltage Applied

Reference has already been made to the A. I. E. E. test specifications of $2\frac{1}{4}$ times the normal line voltage plus 2000 volts. In order to apply this test for a period of one minute it is necessary to provide an instantaneous flashover value of about 10 per cent greater, or about $2\frac{1}{2}$ times the normal line voltage. In the design of General Electric bushings, a flashover voltage equal to at least three times the normal line voltage is provided, and in the case of the lower voltage ratings, a still higher factor is used.

The wet flashover voltage under a rainfall of 0.2 in. per min., at an angle of 45 deg., varies from 70 per cent to 90 per cent of the dry value, depending on the size of the bushing, those of lower rating having the higher ratio. The value of the wet flashover voltage is affected greatly by the specific resistance of the water used in making the wet test. It was found in tests on a sample bushing, that a ratio of wet-to-dry flashover voltage of 80 per cent with water of 10,000 ohms per cubic cm., was reduced to a ratio of 55 per cent with water of 2000 ohms resistance. Fig. 8 illustrates the variation in wet arc over of a bushing due to change in the specific resistance in the test water. As a rule rain water is higher in resistance than any tap water available for such tests. Distilled water represents an artificial condition which should not be employed in making wet tests on bushings and insulators. Naturally distilled water gives a higher wet test than tap water or even rain water, because of its higher resistance.

In order that the bushings shall not deteriorate under the voltage stress of normal service, the insulating surfaces should be entirely free from corona at all normal voltages, and preferably also of double normal voltage or those voltages which may appear repeatedly on the line. To accomplish this efficiently, a potential distribution is necessary which is uniform along the external insulating surface of the bushing. This is accomplished in the filled type bushings by features of design which give an essentially uniform surface distribution, such as is illustrated in Fig. 9. This uniform surface distribution means a uniform surface efficiency, so that the flashover voltage is proportional to the striking distance through the air from the top terminal to the grounded support. *The ratings of the bushings are therefore directly proportional to their linear dimensions.* The absence of corona on the insulating surface, even up to voltages approaching flashover, constitutes a protection of the surface from heating, which is always dangerous to the insulation. Corona is not suppressed, however, on the metal terminal parts at points not adjacent to the insulating surfaces, because the presence of corona previous to arc-over represents the dissipation of energy, and this in turn requires a time element which increases the time lag of the bushing.

Corona within the tank is entirely suppressed by the use of a grounded metal sleeve, which forms the central portion of the external shell of the bushing. The upper end of the sleeve is flanged to form a support upon the cover of the tank; the lower end extends below the surface of the oil. Thus all of the exposed surface of the bushing within the tank is at ground potential, and there can be no difference of potential along this surface, and

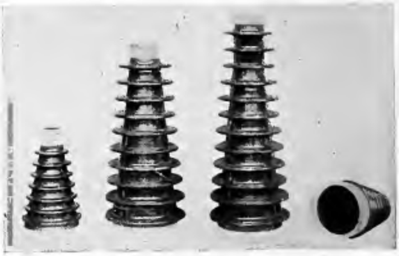

Fig. 10. Porcelain Parts for Bushings

consequently no corona or static discharge on the bushing in the air space above the oil. This is essential in order to prevent danger from the explosion of the gases which may collect in the air space between the oil and the cover.

These bushings are all designed to carry the rated current of the circuit at temperature rises which shall not injure the insulation nor exceed any established specifications. In the following paragraphs attention is called to the current carrying circuit through these bushings, which is different in the case of transformers and oil circuit breakers.

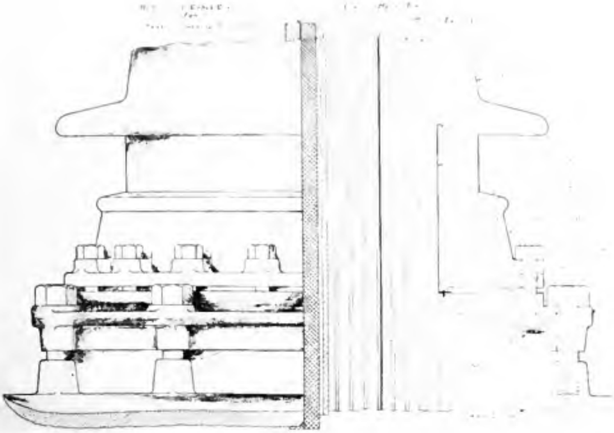

Fig. 11. Details of Flange Clamped Joint of Filled Type High Voltage Bushings

Construction

General Electric standard filled type bushings as illustrated in Fig. 1, consist of an external shell of porcelain and iron, through which there passes, from end to end, a metal tube surrounded by insulating barriers, spaced concentrically to form ducts filled with the oil, or insulating compound. The porcelain shells, one above the grounded metal sleeve, and the other below, are each in one piece as illustrated in Fig. 10, which shows a low altitude top, a high altitude top, and two duplicate bottom sections. The development and utilization of large single-piece porcelains for bushings represents a decided advance in the mechanical construction. It has eliminated the numerous joints between the narrow sections of earlier types of bushings, has permitted the flange clamping of the few remaining joints, and has effectively removed the danger of oil leakage.

The value of oil as an insulating medium is everywhere recognized. This applies to bushings as well as other types of high voltage apparatus. Its high insulating strength, reaching extremely high values under impulse voltages, its ability to circulate freely, and thus serve as a heat dissipating medium, and its fluid character which eliminates air pockets or voids in the insulation, all combine to make mineral oil the best possible insulation for high voltage bushings.

The method of attaching the porcelain shells to the adjacent metal fixtures is illustrated in Fig. 11. Around the grooved tapered end of each porcelain is a flanged metal clamping ring, secured to the porcelain with steam cured Portland cement. The end of the clamping ring is located flush with the carefully ground end of the porcelain which rests upon a varnish treated, composition cork gasket, between the porcelain and the machined surface of the adjacent metal part. By means of the many bolts through the flanged clamping ring, the gasket is tightly compressed between the porcelain and the adjacent metal. Thus a joint is made which is independent of any clamping pressure derived from the center tube through the bushing, and which depends for its tightness upon the local bolting of each clamping ring. The universal satisfaction which this construction has given is ample testimony to its reliability.

The center metal tube, extending lengthwise through the bushing from end to end, serves in the case of constant potential transformers and lightning arresters, as a conduit for the detachable cable conductor which connects the transformer winding or lightning arrester cone stack to the top terminal of the bushing. In the case of oil circuit breakers, this center tube itself serves as the conductor, connections being made at the ends by means of suitable detachable contact parts. When used on a current metering transformer, the center tube of the bushing serves as one side of the double-conductor circuit, the second or return conductor being a concentric rod assembled inside, and insulated from the center tube.

The oil space inside of the bushing between the center tube and the external metal sleeve is divided into concentric ducts by means of insulating cylinders, which serve to direct the circulation of the oil lengthwise of the bushing and to increase the puncture strength between the center tube and sleeve. The top of the bushing is fitted with a glass gauge, through which the level of the filler may be observed, and which acts as an expansion chamber to allow for the change in volume of the filler with change of temperature. In the bottom casting there is a drain plug for drawing off the oil when necessary.

Each bushing is provided with a name plate, on which there are indicated the nomenclature, classification, current capacity, serial number and specification number. A caution plate mounted beside the name plate indicates the kind of filler used with the bushing, i.e., whether oil or compound, and warns against an admixture of the two. The oil supplied with oil-filled bushings is generally of the same quality as that supplied with the apparatus with which the bushings are to be used. The compound in compound-filled bushings is the General Electric Company's standard No. 239 which is a heavy rosin oil mixture, having the consistency of thick molasses.

Fig. 12. 110,000-volt Outdoor Transformer Equipped with Class F2 High Voltage Bushings

Fig. 14. Assembled Tank Unit of 115,000-135,000-volt Aluminum Lightning Arrester Equipped with Class F3 Line Bushing and Class F1 Neutral Bushing

Fig. 15

Caution plates on high altitude bushings state that they should be used only at altitudes above 4000 feet. This restriction is imposed to safeguard the puncture structure of the bushing against the increased arc-over voltage which would result from the use of a high altitude bushing at low altitudes. With the accessories assembled on these bushings for current metering transformers, there is provided an additional name plate, indicating the combined current rating of bushing and accessories, which, because of the double-conductor feature, may differ from the main name plate rating of the bushing for other uses.

Interchangeability

A bushing of this type may be used on a power transformer, a potential metering transformer, a current metering transformer, an oil circuit breaker, or a lightning arrester. Detachable terminal accessories are used to adapt the bushing to any one of these classes of apparatus. The bushing may be interchanged among the different classes of apparatus by exchanging the terminal accessories. The name plate rating of course must be observed in considering interchangeability. Fig. 3 illustrates the four classes of service to which these bushings are adaptable.

The left-hand bushing in this figure is equipped with terminals for a constant potential transformer. The conductor is a detachable flexible cable, whose lower end extends to the terminal board or winding of the transformer, while the upper end terminates in a threaded stud, secured in the lifting hook casting at the top of the bushing. By loosening this connection at the top, the bushing may be removed from the transformer without effecting an entrance through the cover. It may be installed likewise by drawing the cable up through the center tube while the bushing is being lowered onto the cover. This eliminates the necessity of removing or lowering the oil in the transformer, which is usually required by an internal connection to the bushing.

The second bushing in Fig. 3 is equipped with terminal parts for a high voltage lightning arrester. The contact shoe above the top terminal is a part of the transfer device, used for charging the third and fourth tanks of a four-tank arrester. In this case also, a flexible detachable conductor is used, passing from the connection on the cone stack up through the center tube to the top terminal. The neutral side of the arrester is usually fitted with a lower voltage bushing, which is

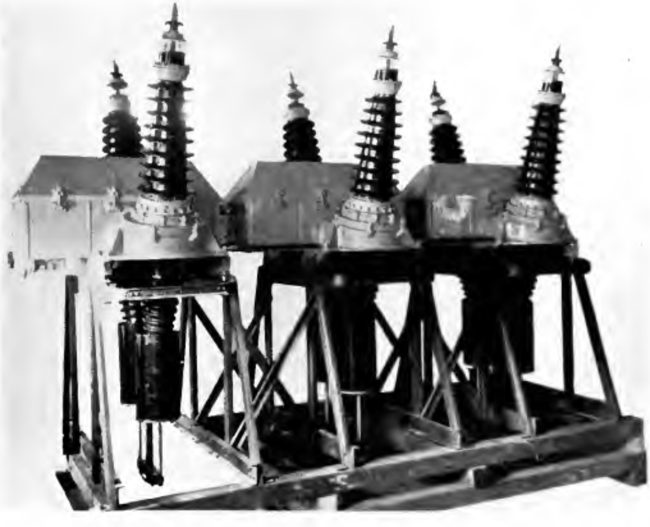

Fig. 13. Triple pole, Single-throw, Solenoid Operated Oil Circuit Breaker Equipped with Class F2 High Voltage Bushings

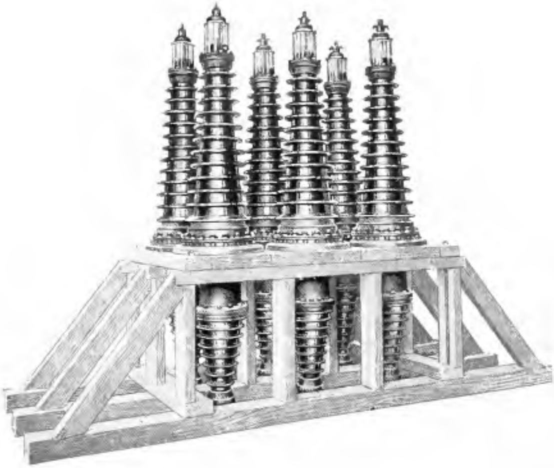

Fig. 16. Method of Packing Filled Type Bushings for Domestic Shipment, Upright in Crates

Fig. 17. Horizontal Packing of Single Bushings for Domestic Shipment

Fig. 18. Roof Entrance Bushing

Fig. 19. Another Type of Wall Entrance Bushing

not interchangeable with the line bushing, but usually of similar construction.

The third bushing in Fig. 3 shows the top terminal used with oil circuit breakers. This terminal makes connection directly to the center tube, which in this class of service is utilized as the conductor. The lower terminal or contact head which connects to the lower end of the center tube, is not shown in this illustration. This part varies with the design of the oil circuit breaker, and is different for breakers having different rupturing capacities.

The fourth bushing shows the terminal accessories for use with a current metering transformer. In this case, the center tube serves as one conductor, and a concentric rod within the tube and insulated from it provides a return circuit. The two connections at each end of the bushing are clearly distinguished in the illustration. Only one bushing is used on a single transformer, and two such bushings on a metering outfit, containing two transformers.

These four classes of apparatus to which these bushings are applied interchangeably are illustrated in Fig. 12, Fig. 13, Fig. 14 and Fig. 15, showing a power transformer, an oil circuit breaker, a lightning arrester and a current metering transformer, respectively.

Packing and Shipping

For domestic shipment, these bushings are usually packed upright in crates as illustrated in Fig. 16. Compound-filled bushings are shipped filled: Oil-filled bushings are usually shipped empty with the oil in separate containers, although they can be shipped filled when desirable.

When horizontal shipment to domestic customers is necessary or desirable, the bushings are packed singly in a double excelsior lined box as shown in Fig. 17. For foreign shipment, a similar form of horizontal packing is employed, except that a heavier construction is used to meet the more severe requirements of foreign shipment. This is shown in Fig. 20.

Entrance Bushings

Bushings of the same general construction as described for the interchangeable type have been developed with the modifications required for roof and wall entrance service. Fig. 18 shows a high altitude roof entrance bushing of the compound-filled type, and Fig. 19 shows a low altitude oil-filled wall bushing. These bushings are made as far as practicable from parts of the interchangeable standard bushings. Thus an additional top porcelain with clamping rings attached, such as used on the standard apparatus bushing, will serve as a spare part not only for the apparatus bushing but for either end of the roof and wall bushings.

The center tube of the roof and wall bushings is utilized as the conductor with a terminal coupling at either end. The outside end of the wall bushing is closed with a metal expansion member, to allow for the different expansion of the metal tube and the porcelain shells. A connection is provided on the wall bushing from the grounded metal sleeve to an external oil reservoir, with a sight gauge in the pipe for observing the oil level.

Roof or wall thimbles are supplied when desired. In the case of the roof thimble, the opening is made large enough to pass the supporting flange of the bushing, and an intermediate adapter is provided between the bushing and the thimble. This allows the bushing to be hoisted through the roof thimble from within the building, which is frequently more convenient than raising it to the roof from the outside. Both the bushing adapter and the roof and wall thimbles are laid out to receive standard blank pipe flanges for closing the openings during construction or previous to installation of the bushings.

Acknowledgment

In the designs which have been described and illustrated there is provided for the operating and transmission companies a line of high voltage bushings whose reliability has been thoroughly demonstrated, and whose complete interchangeability has been the hope and desire of construction engineers. A large and valuable contribution to these results has been made by many engineers, both within the General Electric Company and among the operating companies, whose friendly co-operation and constructive criticism have been both welcomed and utilized in the development of these bushings. The author desires to acknowledge his indebtedness to those who have so generously assisted with their engineering skill and operating experience in the solution of this important problem.

Fig. 20. Horizontal Packing of Filled Bushings for Shipment to Foreign Countries

Power and Transmission

By H. H. Dewey

Power and Mining Engineering Department, General Electric Company

The stimulus of feeding our gigantic war machine affected the power supply companies in a peculiar manner. While the demand for power increased enormously, the normal supply of generating equipment to meet that need was not immediately forthcoming, due in part to the urgency with which the necessary raw materials were required for the production of munitions, and in part to the long time essential for manufacture. To supply this deficiency the tendency, already in evidence, toward interconnection of power systems was greatly enhanced. The author graphically sketches the most striking features of this tendency, and calls attention to many of the problems which must be anticipated and solved if it is to continue at the present rate. The experience of over a decade in the design and operation of large power systems has convinced him of the necessity for co-operation between manufacturers of electrical apparatus and the operators who use them, if serious difficulties in the handling of future power networks are to be avoided.—Editor.

During the past few years the development of large hydro-electric power projects has been practically at a standstill owing to the war and general economic conditions. The end of the war saw a great shortage of power in practically all civilized countries, even though extensive steps had been taken to increase the efficiency with which the sources of power, coal, oil, gas and water were used. The demand for power increased enormously during the war due to the necessary substitution of electrically driven machinery for labor in many industries and the development of new manufacturing processes requiring electric power in large quantities.

In the face of these conditions the large power companies arose to the occasion as best they could and squeezed the last kilowatt from their power supply, pooling their interests with rival companies to take advantage of the last gallon of water in their hydro-electric developments and to burn every pound of coal at its maximum efficiency. Electrical machinery, cables and transmission lines were called upon for heavy continuous overloads, considered far from safe in normal times, but the exigencies of the occasion demanded the heroic measures that were taken with surprisingly few disastrous results.

Toward the end of the war there were strong indications that new developments must be undertaken, even under the conditions of labor and high prices of material existing, and many projects were being investigated and a few even started during the latter months of the war. Some of these developments were financed by the Government and others encouraged in every way possible. Notable among these was the decision of the Cliff Electrical Distributing Company to extend their hydro-electric development at Niagara Falls. Three 32,500-kv-a. generators were purchased and are well under way at this time. This decision was reached at a time when there was a crying need for power at Niagara Falls for war purposes, and had the war continued great use would have been made of the output of these large machines.

Other developments under way were the large steam plant at Sheffield for interconnection with the Alabama Power Company for the purpose of furnishing power for the Air Nitrates Company at Sheffield. Work has been going on by the Government engineers at Muscle Shoals, making preliminary plans for the development of a large hydro-electric project on the Tennessee river, which is expected to take over the load of the nitrates plant and supplement other hydro-electric power in this section.

For the most part, however, few new projects have been undertaken, with the result that practically all of the power companies have little power to sell, and it would seem that extensive developments in the next few years along the lines of large power systems, both hydro-electric and steam, with long distance transmission in many cases, can be expected. There is no immediate prospect of a great reduction in the cost of either material or labor, and such projects will be handicapped by these conditions, but demands for power indicate that many of these developments must be put through even under existing conditions.

The European countries are seriously handicapped by a fuel shortage, and are making an extensive survey of their hydro-electric possibilities in a manner never before attempted. Many projects are being investigated involving hundreds of thousands of kilowatts, with long distance transmission that must be accomplished at voltages in excess of any hitherto employed in these countries. Conditions are somewhat different from those in the United States, but there is a tendency to take advantage of the experience in high voltage transmission that we have gained, and many of the projects are being layed out in a preliminary way along the lines of American practice.

Many projects are being studied in South American countries for the development of large blocks of power and for long distance transmission, some of which involve longer distances of transmission than have been previously used, at altitudes which are in excess of any now in existence; and many new problems are being presented for the high tension engineer to solve.

In our own country the demands during the period of the war have caused the concentration of larger amounts of power, due to the interconnections of existing systems, than were previously employed and the problems of operation have become proportionately more complicated. Until the past few years few systems exceeded a connected generating capacity, in any one system, of 150,000 kw. and even those were in many cases, either split into blocks of 50,000 to 75,000 kw. with an emergency tie, or these blocks were connected together with comparatively light circuits which could be automatically disconnected under conditions of short circuit or other trouble. There are now several systems solidly connected together with a generating capacity exceeding 200,000 kw., which, under short circuit conditions, will concentrate in excess of 1,000,000 kv-a. in the fault, where previously few systems would give in excess of one half of this amount. The tendency toward the increase in size of power stations and the interconnection of systems, presents a very real problem to the designing and operating engineer, in so designing his system that the concentration of energy, during trouble in a short circuit, can be safely handled by oil circuit breakers and other protective devices. Mr. Merrick's paper in this issue calls attention to some of the problems that are apt to be met in systems of this kind.

The use of outdoor apparatus for high voltage work, both in the sub-station and generating station equipment, is being more and more extended. Only slightly more than five years ago the station designer very gingerly considered the possibility of placing transformers and oil circuit breakers out of doors, and went to considerable expense to provide for all possible contingencies. Such projects were only considered where the climate was especially favorable, and even then much criticism was heard of this radical step. Experience has proved, however, that practically all high tension equipment can be safely installed out of doors, even in very severe climates, and our most conservative engineers are laying out their sub-stations, and in many cases their power stations, with all high tension equipment out of doors. The space factor that can be used in many cases renders the equipment even safer than it would be if installed indoors in an expensive building. Great economies have been effected along these lines.

There is a tendency, in addition to placing the high tension transformers and oil circuit breakers out of doors, to go still further and make an attempt to save the large investment in a power house by building generators that can be safely operated out of doors. In some of the extremely large developments many hundreds of thousands of dollars can be saved by building generating equipment for out of doors use, and with the present high cost of material and labor, and the necessity for as economical a development as possible, there seems to be no inherent reason why the complete equipment for a large hydro-electric development should not be placed out of doors.

The cover illustration was sketched by Mr. C. M. Hackett after an extensive study of the possibilities of different designs for a large development, involving the use of fifteen 25,000-kv-a. generators. The sketch illustrates one of several proposals for this development, and it will be noted that the generators are built into and are integral with the downstream face of the concrete dam, which is built up as a two-deck structure. The generator proper is located between decks, with only the waterproof cover and the thrust bearing housing showing above the upper deck to indicate the presence of a 300,000-kw. generating station. A gantry crane will be used to handle the generators and waterwheels during installation and for repairs. The ventilation is arranged so that air may be taken in from the outside and, after passing through the generators, discharged to the outside through the louvres showing above the deck; or, in cool weather, all or part of the heated air may be discharged between decks and recirculated. It is proposed to house the auxiliary equipment, consisting of exciters, pumps, pumping, signal equipment, etc., in the space between decks, but all switching equipment, possibly including even the low tension switches, will be of the outdoor type and located on the shore as shown in the right-hand background. Connections from the generators to the switchgear are carried in the concrete tunnel shown on the apron of the dam above and back of the generators. Operation is to be from the control house on the shore adjacent to the switch yard.

The saving that could be realized with an installation of this kind will be appreciated when it is considered that the generators and waterwheels must be installed on approximately 60-foot centers, which would require a power house about 1000 ft. long

Another source of economy in the development of hydro-electric stations, especially those of small capacity, may be the employment of automatic or remote controlled generating stations. Automatic railway substations have been in operation for a sufficient length of time to illustrate their economy, and it is not unreasonable to expect similar economies with small hydro-electric generating stations. The saving in labor effected would be no small item in the operating expense of such stations. Mr. A. G. Darling's article in this issue describes some of the features that should be taken into account in the design of such stations.

It has been the dream of many engineers and some captains of finance to extend transmission systems until practically the whole country is connected together into one vast transmission system. The advantages of diversity of load because of differences in standard time, differences in the run-off from the various watersheds, the types of industry to be served, the natural location of water and fuel for auxiliary steam plants, etc., are features that without doubt would be of tremendous advantage from an economic point of view if such an arrangement could be brought out. A comprehensive scheme for putting through such a project on a large scale has not as yet been satisfactorily worked out. In certain parts of the country, such as the New England States, in certain sections of the Southern States and in California and some other sections of the country a great deal has been done along these lines and very considerable economy effected. This has been accomplished, however, only where existing systems came within easy striking distance of each other and tie lines could be constructed with comparatively little expense, to effect an exchange of power between the systems. Where long distances have to be traversed carrying large blocks of power, the investment would be considerable and it will probably be difficult for some time to sufficiently interest enough captial to put through an extensive trunk line system for the economical transfer of power from one section of the country to another.

Much interest is being developed in the electrification of trunk line railroads, especially where heavy traffic is involved. Should we greatly increase the electrification of our main line railroads an extensive system of transmission lines would be necessary for the supply of power. Such a system would cross the territory now covered by transmission systems and these transmission lines would undoubtedly be used, not only for carrying the necessary power for the electrification of the railroads, but for the transfer of energy between existing systems and would allow the strategic location of large and economical steam turbine plants, where cooling water and transportation facilities would present the maximum advantages.

From time to time the question of the relative economy of transporting fuel by rail from its source to power plants located at the center of the load versus the project of building large steam plants at coal mines and transmitting power, has been discussed. A difference of opinion as to the relative advantages has been apparent, this difference of opinion probably being due to particular projects that have come under consideration. The initial investment in transmission lines with a more or less fixed capacity for a given distance makes a project of this kind difficult to handle. The location of coal mines is generally at a considerable distance from points where extremely large blocks of power can be utilized and at the same time there is usually a dearth of cooling water at the mines. Such projects as the Windsor Development of the American Gas & Electric Company, the West Pennsylvania Traction Company, the Lehigh Power and Navigation Development at Hauto and a few others have illustrated the economy of large steam plants near the mines. Their range is more or less limited, however, and we have yet to see a development of very large proportion reaching out with large blocks of power for great distances from the mines. The longest transmission line at the present time is that of the Southern California Edison Company, which transmits approximately 60,000 kw. for a distance of 240 miles. It would take a large number of such transmission lines to serve New York and New England, from the mines of Pennsylvania, for instance. Higher voltages are in sight for such projects, and it is possible that we shall see in the near future some developments of this kind that will prove to be economical. Mr. R. J. McClelland's article in this issue discusses a project of this kind and his arguments in favor of the economical side of such a development are very convincing.

The operation of transmission systems made up of thousands of miles of high tension lines will undoubtedly present many problems but as yet none have come up that cannot be solved. The natural growth of such systems will in most cases permit picking up many loads in various sections if care is taken in the original layout. Very long high voltage lines are difficult to handle when unloaded on account of the charging current, and they may be a source of high voltage trouble if the load is tripped off accidentally leaving a long section of unloaded line on a comparatively small generating station. Mr. T. A. Worcester's paper in this issue discusses this point in the case of very high voltage lines. Several systems are now operating having in excess of 1000 miles of single circuit, 110,000-volt lines connected together, with comparatively little difficulty from this source.

Another source of anticipated difficulty in the extensive interconnection of systems is the probability of trouble in one section affecting service disastrously on all other parts. The greater the number of circuits there are extending over wide areas, the greater the total number of line short circuits there must be and if, as some engineers anticipated, the whole system were affected seriously each time, it would be out of the question to operate such a network. Experience has shown, however, that with long lines of high reactance connecting together distant parts of the system, short circuits have a comparatively local effect only and if the system is well laid out, and proper attention is given to relaying so as to cut out quickly the part in trouble, no disastrous effects are met with. See Mr. R. Treat's article in this issue for a discussion of the relay problem.

One of the most important features in the operation of such a system or interconnection of systems will be the question of load despatching or power despatching. For such a system to be an economical success not only must all water be used at all times but steam stations and the transmission system as well must be operated in the most economical manner. Stream flow at the dam sites must be anticipated and steam plants brought into service or shut down at the [illegible] with due respect to the system demand for power and the use of water and fuel.

All large power companies place [illegible] importance on their load despatching [illegible] and have an efficient organization [illegible] the load and water and steam conditions constantly, keeping accurate records of changing conditions. Where large amounts of territory are covered local load despatchers are employed, reporting to the main office. Should our networks grow to the proportions suggested, the local sections would be despatched as now, but an elaborate system of records and co-operating load despatchers would have to report regularly to central offices where constant studies were being made to utilize the resources most efficiently.

Such a vast system as we have visualized would undoubtedly be under the control of many individual interests and many difficulties would be encountered in working out proper rates for exchange of power, co-operation between operating forces, local managers, etc., and an efficient and powerful organization directing matters would be necessary.

It is becoming more and more apparent that we are at an important point in the development of Power and Transmission, and some systematic study of the conditions to be met should be made.

Developments in this field up to the present time have been made with no comprehensive plan in mind, and we find ourselves confronted with problems and limitations that were not altogether anticipated. The rapid growth in the electrical industry in the past few years makes it very evident that a great amount of power must be developed and transmitted economically and efficiently with great attention given to reliability of service. To best meet this situation, future plans must utilize all of the experience obtained from our past developments and proper weight must be given to the requirements to be met and the facilities at hand for meeting them.

A considerable amount of study has been given various phases of the situation by many engineers working more or less independently, and many valuable suggestions have been made for taking care of the future needs of the country with respect to the proper development and transmission of power. Many problems remain yet to be solved, however, and some means should be devised for coordinating the work of the various engineers to obtain the best results. A close co-operation between the engineering societies, consulting and operating engineers, as well as manufacturing companies, is necessary in order that the economic demands of the country may be served.

The limitations in concentration of power, and in voltage of transmission, require special consideration, and while many opinions have been expressed as to what the limitations are, if any, the subject is far from being exhausted. The construction and insulation of high voltage transmission lines has passed through various evolutions during the past few years and there is still a considerable difference of opinion as to the factors of safety necessary. With increasing length of lines and higher voltages in sight, the cost of the transmission line becomes of maximum importance, and a survey of our present practice with its influence on future developments would seem wise. The problems of protection of high voltage lines, use of lightning arresters, effect of high current short circuits as well as many other similar problems should have their share of consideration.

The power handled in transmission systems with voltages of 66,000 and above is slightly in excess of two million kilowatts. Developments are now under consideration which if put through, will more than double this amount of transmitted power. Systems will be built that will dwarf any now existing. The success of these developments will have an important bearing on all future projects and every effort should be made to look beyond immediate requirements so far as possible.

The world looks to us to set the pace in the field of development and transmission of power, and we do not want to make any mistakes that can possibly be avoided.

The Limitations of High-voltage Transmission

By T. A. Worcester

Power and Mining Engineering Department, General Electric Company

Within the recollection of many who are still taking active part in the world's affairs, the transmission of energy at 10,000 volts was an achievement, and a proposal to make use of 50,000 volts would have been considered madness. Transmission of power at 150,000 volts is now an accomplished fact, and the inadequacy of this potential for our present needs is attested by the very serious and general consideration which is being given to the use of 220,000 as the next step. The author, who has been closely identified with the development of high-tension transmission for a number of years as engineer, speaks with the highest authority on this subject. The present discussion is timely and the conclusions drawn will be of great interest to all connected with the industry.—Editor.

The subject of this article has received considerable thought and attention by engineers since the very inception of transmission, and with the growth of systems and increase in voltages the ideas which have been expressed have been undergoing constant change and revision. The electrical transmission of energy is really not a very old industry and, indeed, might be said to be in its infancy even today. The first 1000-volt transformer was made only thirty years ago and had a capacity of only 9 kv-a., or 9000 watts as it was spoken of in those days. Lighting circuits were run from it for a distance of one half mile or so. In 1890 a company attempted the transmission of a few kilowatts for several miles. In 1892 the largest transformer which had been built was 30 kv-a., 5000 volts; and since that date both the kv-a. capacity and voltages have been increasing at a rapid rate. The growth in voltages is shown in Table I.

TABLE I

INCREASE IN TRANSMISSION VOLTAGES

Year	Maximum Voltage	Year	Maximum Voltage
1894	11,400	1907	104,000
1896	22,000	1909	140 000
1900	54,000	1912	150,000
1901	80,000		

The capacities have increased at a like rate to the extreme size, in 1916, of 25,000 kv-a. With this increase in voltage and capacity there has been a corresponding increase in distance of transmission until today we have power carried 240 miles at 150,000 volts. It is an interesting feature also that high-voltage transmission is not rare now, but that there are some fifty companies operating lines at voltages of 70,000 and above, and that their systems aggregate some 14,000 miles of single-circuit line on which over 2,000,000 suspension insulator discs are used and to which over 2,000,000 kw. in generating capacity is connected.

These figures indicate the importance of this subject; and it is proper that we should be thoughtful in determining what the tendencies and necessities of the future will be and what the limitations are in the various elements entering into the design, construction, and operation of systems.

That the voltages in use at present will be inadequate for future developments is already evident from a study of the characteristics of systems which have been in contemplation during the past few years. A number of very large projects have been studied and these might be divided into two distinct classes: (a) those which involve the transmission of a relatively large amount of power over comparatively long distances, one to two hundred thousand kilowatts, two to six hundred miles; and (b) those in which there is an even greater amount of power to be carried for shorter distances. For each of these classes of system the present maximum of 150,000 volts is not sufficiently high and as the increase in the amounts of power and distances of transmission are so much in excess of past practice a voltage commensurate with this increase must be chosen.

In attempting to determine a suitable voltage for systems of the classes indicated, one is confronted with the problem of striking a balance between opposing factors; one the desire for economy and the other the difficulties incident to the use of the higher voltages. If there were no limitations to permissible voltages, a value would be selected in the same manner as is now done on lower voltage systems by balancing between cost of lost energy and fixed charges on the installation. There are, however, limitations in the permissible voltage and these must be taken into account as well. The various elements which enter into the problem of high-voltage transmission are: the transformers, oil circuit breakers, disconnecting switches, lightning arresters, bus and line insulators, transmission conductor, and transmission towers; and the design of these elements for voltages much in excess of 150,000 involves many complicated and difficult problems which increase almost in proportion to the increase in voltage. In the preliminary studies which have been made on the proposed systems, a maximum limit of 220,000 has been set on the voltage and while it is appreciated that this is not the maximum practical voltage for transmission, it is a value so much above what has been used in the past that it is considered a conservative top limit with present types of designs of the various elements of the system. A discussion of some of the problems encountered in the study of 220,000-volt equipment will be useful in determining the limitations of high-voltage transmission.

In the design of any transmission system the engineer usually has a given set of conditions from which to work; he has a fixed amount of power at a waterfall to be taken a certain distance and delivered at a certain voltage and frequency, and the first problem is to select the voltage and frequency of transmission. In the majority of large industrial centers throughout this country 60 cycles is used, although there are some important districts using 25, 30, 40, and 50 cycles. Sixty cycles has so many advantages in cost and size of equipment that it bids fair always to hold the preference. Most high-voltage systems will have to supply power at this frequency and it will be advisable in most cases to build the lines for this frequency. For lines up to 200 or 250 miles the matter of frequency is not a very serious item. Both the reactance and the capacity of the line are directly proportional to the frequency so that when the higher frequencies are used the reactive drop at times of heavy load, and the capacity rise and the charging current at times of light load become relatively large, and these are vital problems for consideration.

The drop in voltage between the generating and receiving ends of a 200-mile line operating at 220,000 volts, three-phase, 60 cycles and carrying 100,000 kw., 0.8 p-f. load could be approximately 75,000 volts and the rise in voltage from the generator to the receiver end at no load would be 18,000 volts, making the variation between no load and full load at the receiver end of the line about 93,000 volts—a really excessive amount. These values can be improved by the use of synchronous condensers at the substation; in fact, if sufficient condenser capacity is used the voltage at the receiver station can be held at an almost constant value. The charging kv-a. of a 200-mile 60-cycle line operating with 220,000 volts at the generating end would be approximately 50,000 kv-a.—an amount which would be difficult to handle.

It is always desirable to be able to charge a transmission line with one generator, the reason for this being that when charging a line without load the fields of the generators are very much over-excited due to the large leading current being supplied by the armature to the line and the exciter voltage must be reduced to practically zero in order that the armature voltage will not rise to an excessive amount. With such low exciter voltage it is difficult to hold two or more generators in synchronism. It would mean then that on the system in question the generators should each be capable of charging the line with 50,000 kv-a. leading current and zero field excitation without the armature voltage exceeding normal value. Obviously, it might not be feasible or desirable from other standpoints to have the generating units of such large kilovolt-amperes capacity; assume for instance that the waterwheel design works out most economically for a 25,000-kv-a. generator and that it is desired to keep the charging kilovolt-amperes within that value. This can be done by resorting to a special design of generator with low armature reaction so that with zero voltage field excitation when carrying 25,000 kv-a., leading the armature voltage will not exceed 70 per cent of normal. With this reduction in voltage the charging kilovolt-amperes of the line, which is proportionate to the square of the line voltage, would be reduced one half, or to 25,000 kv-a. If a still smaller capacity generator is desired, a different design could be made to hold the voltage to a lower percentage of normal when carrying full kilovolt-amperes leading current. This would of course lower the line voltage and, consequently, the charging kilovolt-amperes.

From the foregoing it is evident that for lines up to 200 or 250 miles, 60 cycles is feasible. For longer lines, however, conditions are such as to make a lower frequency worth considering. At 220,000 volts, 60 cycles, the charging kilovolt-amperes of a 300-mile line would be 75,000 and the rise in voltage from generating to receiving station on an unloaded line would be about 50,000 volts. The drop in voltage at full load 0.8 power-factor would be over 100,000 volts and the range from full load to no load would be too large for practical operation. Even with synchronous condensers of such capacity to correct the full load power-factor to unity, the drop in voltage over the line would be 45,000 volts, although at no load if the condensers are operated lagging the receiver station voltage could be kept from rising more than 10 per cent above the generating station voltage. From this standpoint of regulation a 300-mile line could be handled at 60 cycles, but a more serious feature would be the charging kilovolt-amperes to be handled at no load. The value of 75,000 charging kv-a. can be reduced by reducing the generator voltage if a special design of generator is used, as previously described, but it would be necessary to hold so low a voltage to prevent the charging current rising to an excessive amount that the design would be considered impracticable and should be avoided if desirable results can be secured by other means.

At 25 cycles, the characteristics of the system would be very much better. The charging kilovolt-amperes at normal voltage would be only approximately 30,000. The drop in the line at full load 100,000 kw., 0.8 p-f. would be 62,000 volts as compared with over 100,000 volts for the 60-cycle line, and this value could be reduced to a reasonable amount by the use of about one half the condenser capacity required for a 60-cycle line. Furthermore, at no load without condenser capacity the voltage rise from the generator end to the receiver end of the line would be only 16,000 volts, or by operating the condensers 20,000 kv-a. lagging, the voltage at the receiving station could be held down to a value approximately equal to the generator station voltage.

For lines of much greater length than 300 miles it may be necessary to consider the use of frequencies below 25 cycles. For lines of double this length even with 25 cycles the charging current and increase in voltage at no load are quite large and frequencies of 10 to 15 cycles offer certain advantages. The possibilities of such frequencies will not be discussed at the present time, however.

Although a transmission system 600 miles in length might be a theoretical possibility, a question might be raised as to whether lines of this length can be considered practical from an economic point of view. A 600-mile 220,000-volt line would cost between $25,000 and $30,000 per mile erected, or a total of fifteen to eighteen million dollars. The generating station and step-up and step-down stations would cost another twenty million per 100,000 kw., making a total investment for a 100,000-kw. system of 48 million dollars. This capitalized at 15 per cent would mean a required income of seven million dollars, or $140 per kw-yr. on a 50 per cent load-factor basis. This is excessively high and coal would have to be very expensive to make such a project pay. However, it is not beyond the range of possibilities, and a consideration of lines of this length should not be considered as purely theoretical.

In the foregoing, mention has been made in several instances of 100,000 kw. per circuit, and at first thought this value might seem excessive. However, when discussing these long high-voltage transmission lines one must necessarily figure on dealing with large amounts of energy per circuit—otherwise the projects could not be considered economically feasible. For instance, it would be almost absurd to consider transmitting 10,000 kw., 200 to 250 miles. Theoretically, this could be done with reasonable energy loss and voltage drop at say 110,000 volts, but the amount of money required to build such a system would be so great as to make the price of power prohibitive. For a line of this length, an initially large investment is required in right of way, towers, insulators, minimum size of conductors, and erection to make the line suitable for transmitting even a small amount of energy and its capacity can be increased in large proportion with a much less proportionate increase in cost. To illustrate the point: a 250-mile 110,000-volt 10,000-kw. line might cost $2,500,000, whereas a line of the same length operating at 220,000 volts with 100,000 kw. capacity would cost $7,500,000, an increase in output of 10 to 1, with an increase in cost of 3 to 1. In the one case the line investment is $250 per kw. and in the other case $75 per kw.

One might argue that by this same line of reasoning higher voltages and greater amounts of power might be used, but it is doubtful if with the present state of development of line equipment and apparatus this would be economical or desirable. Even at 220,000 volts the cost curve is going up rather steeply. High-voltage station apparatus, transformers, oil circuit breakers, lightning arresters, etc., would cost from 40 to 50 per cent more than for 154,000 volts and the transmission line 25 to 30 per cent more, and there are line problems which would be difficult to handle. In a 220,000-volt line, in order to avoid corona and secure necessary clearance between conductors and towers, it would be necessary to space the conductors on from 20 to 25-ft. centers, depending on the altitude. For any higher voltages even greater clearances would be required, the length of insulator strings would be greater, and the conductor spacing, weight, and cost of tower increased proportionately.

For 220,000 volts at 4000-ft. altitude with 20-ft. spacing it would be necessary to use a conductor having a diameter of one inch in order to prevent corona loss. Obviously it would not be economical to use an all copper conductor of this diameter for a high-voltage line, and a composite conductor of the same diameter having a steel core with either copper or aluminum wrapping could be used. Any desired proportion of steel to conducting material can be used to secure the necessary diameter and conductivity. In a long, high-voltage line carrying a large amount of power it would be permissible to allow some corona loss during storms, if in doing this a material saving could be made in the conductor by reducing the diameter. Storms would not be apt to occur over any great length of a line at one time and a reasonable loss could be taken when they do occur. In fact, there are cases where proposed lines would traverse mountainous districts at very high altitudes—10,000 to 15,000 feet—and it would be more economical to design the line to have some corona loss under normal conditions rather than to use a conductor of such diameter and with such spacing as to entirely eliminate corona. This would not be an entirely new departure in transmission practice as there are a number of high-voltage lines which have been in operation for some years and on which there is considerable corona. The experience with these lines seems to indicate that there is no serious deteriorating effect from the corona as has been suspected and feared.

Up to the present time the only insulators which have been seriously considered for use on 220,000-volt lines are the standard types of 10-inch suspension discs; and if the customary practice prevailing in lower voltage systems is extended to this supervoltage work, it will necessitate using strings up to twelve or fourteen discs. As is well known, the voltage distribution along a string of insulators is not uniform; and when voltages of the order of 200,000 are being considered, the voltage applied across the disc next to the line is quite large in comparison with its flashover voltage and should be reduced by special means. Various schemes of grading have been suggested and the prospects are good that some practical arrangement of this sort will be worked out in a short time. It has become customary on lower voltage lines to use a larger number of discs than would be required to give a certain flashover and puncture strength in order to provide against possible reduction in factors of safety due to deterioration of the insulators. With the re-introduction of the Hewlett link type of insulator which is free from deterioration troubles, it is hoped that practice will soon again dictate the use of a more moderated number of discs per string. Such a change, together with suitable grading, will bring about some reduction in the length of insulators for 220,000-volt service, which will be very much appreciated in the design of towers for this voltage.

For anchor or dead end points a modified type of the 10-inch link type disc has been developed which has a very high mechanical strength and will eliminate the necessity of using multiple strings for this work. This will be a considerable help in the construction of lines using high strength steel reinforced aluminum or copper cable which would otherwise require four to six strings in multiple at all anchor points.

The high-voltage station apparatus to be used on a 220,000-volt system would be in most respects very similar to the apparatus for lower voltages. All apparatus, of course, assumes very large dimensions in order to provide necessary clearances for insulation and for this reason it is more difficult to make and more costly than similarly rated lower voltage apparatus. The transformers would demand unusual construction owing to the large kilovolt-amperes capacities which would be required, resulting in large cores and the wide spacing of windings to care for the high voltages. In the step-down transformers in which there is likely to be a high secondary voltage for distribution, the size of coils and spacing are especially large.

The oil circuit breakers would be of the same type as used on lower voltages. Greater rupturing capacities would doubtless be required, however, due to the large concentration of power likely to be installed in individual stations as well as the systems as a whole. For this reason it may be necessary to use two breakers in series, interlinked to operate simultaneously. Such breakers could be built to have quite a high rupturing capacity, but every effort should be made in the layout of high-voltage high-power systems to see that the short-circuit currents will be reduced to a minimum. In a recent article,* oil circuit breakers to rupture 3,000,000 to 4,000,000 kv-a. are spoken of. While it is the opinion of designers that such breakers can be built, it is questionable if any power company would care to have a short circuit of such magnitude occur on its system as the results of such a short circuit in its immediate neighborhood, even though interrupted very promptly by an oil circuit breaker, would very probably be disastrous. It is not necessary even on a very large system to have such heavy short-circuit currents, as they can very readily be reduced to more moderate values by the judicious use of the natural reactance of the transformers and lines and the use of artificial reactance where necessary without appreciably reducing the flexibility and efficient operation of the system.

It is recognized that transient disturbances on a high-voltage system are likely to be severe, but the theory has often been advanced that the higher the voltage the greater the insulation and, consequently, the less the danger of breakdown of apparatus from high-voltage transients. While this theory may be true to some extent it is the writer's opinion that potentials, either direct or induced, will at times be applied to the circuits in excess of the insulation strength of a 220,000-volt system and that it is not entirely safe to omit the use of lightning protective equipment on systems of this voltage. Lightning arresters for 220,000 volts, although large and costly, would add only a small percentage to the cost of an installation and should more than pay for themselves in preventing damage to more expensive and important apparatus, such as transformers, oil circuit breakers, etc.

While the foregoing does not fully cover the subject of limitations of high-voltage transmission, it is hoped that sufficient suggestions have been made to illustrate what some of the problems are and to indicate that these are capable of solution at least up to 220,000 volts. There is no immediate demand for voltages above this value and later experience only can show whether still higher voltages will be practicable.

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* "Problems of 220,000-volt Power Transmission," by A. E. Silver, A.I.E.E., June, 1919.

Relay Protection for Large Power Stations

By O. C. Traver

Switchboard Engineering Department, General Electric Company

In a number of articles in this issue mention is made of the large size and extreme [illegible] power systems. With the increasing dependence which industry places on a continuous [illegible] interruptions to service are tolerated to a less and less extent. In complicated networks [illegible] be met only by comprehensive systems of selective relaying, and these are possible only with [illegible] superiority over those available but a few years ago. The author describes recent developments [illegible] ments in the design and construction of relays and indicates the variety of results which can [illegible] by their proper combinations.—Editor.

With the large and more or less intricate networks which are being built today, and with the rapidly increasing practice of interconnecting existing systems, the time has come when much more attention must be given to relay protection; because the only possible way of obtaining service which can be classed as satisfactory is by the aid of relays, which working in conjunction with the other protective apparatus will guard the system against numerous unhealthy conditions which at various times are set up during normal operation.

This article will not cover the history of the relay art, nor attempt to consider all the schemes that have been proposed or are in operation. It will concern itself merely with a discussion of several points in connection with the application of relays which should prove helpful to the man whose problem it is to protect the electrical system; for after all it is he who applies the relay who counts much more than the relay itself. The relay has possibilities which can only be obtained by some one who understands the nature and characteristics of his entire system. Only by harmonizing all the characteristics of each item entering in the system can the real value of the relay be obtained. Much detailed study of the subject is needed, and it is hoped that the following information which refers particularly to some of the newer schemes and describes briefly some of the later types of relays and their application will be of some value.

A separate article in this issue deals more in detail with the method of the procedure in handling the broader aspects of the problem.

Balanced Schemes for Parallel Transmission Lines

One of the most promising methods used in the protection of networks is the balancing of separate parallel circuits which normally carry approximately equal currents. If the currents maintain their equality in spite of high values, it is a good indication that no fault exists in that particular group. On the other hand, a certain degree of unbalance would be a safe indication of trouble. The problem, therefore, is in general to separate a current which is representative of the actual unbalancing, and pass it through proper relays to cause the faulty feeder to be disconnected.

It is impractical to describe here the various modifications of these schemes in detail. However, the basic principles involved are discussed below and these are sufficiently flexible to permit application in various ways to the problem which may be in hand.

In the diagrams accompanying the description of these balanced schemes, arrows are used to indicate the relative direction of current and of power. These arrows show power normally flowing from station "A" to station "B." In each case, however, the equipment is suitable for power flowing in either direction.

In general, the over-load relays used are adjusted to operate instantaneously or nearly so. Some operating companies report that the opening of the breaker is so rapid that there have been cases where a cable has healed immediately, due to the hot insulating material flowing into the opening made by the fault. Usually the point of breakdown has been located by subsequent inspection.

Balanced Protection of Two Parallel Lines Not Discriminating

An exceedingly simple scheme of balanced protection is illustrated in Fig. 1-A. This has given good results on a system which is so arranged that the lack of discrimination on the part of the relays, between the sound and the injured line of a pair, is not vital. On the system referred to the substations are in ring formation with two lines for each connecting link and consequently each station is provided with power over at least two different groups of lines, and from two different busses. The complete, though temporary, interruption of one of these sources does not, therefore, kill the bus and no hardship is imposed greater than the inconvenience of determining the good line preparatory to replacing it in service without its mate. This inconvenience is to a considerable extent compensated for by the freedom of the equipment from all alternating current potential connections. While these potential connections, in present day relays, do not occasion the misgivings they were responsible for in older types, their elimination is desirable.

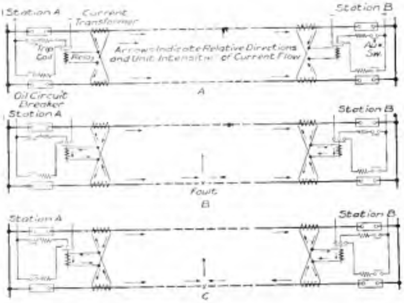

Fig. 1. Balanced Current Protection for Two Parallel Lines (not discriminating)

The balanced equipment as shown in Fig. 1-A consists of "cross-connected" current tranformers in the similar phases of the two lines, to the equi-potential points of the secondaries of which an over-load relay is connected. Reference to the arrows will show an assumed normal current flow. So long as the currents are equal and in the same direction in the two lines there will be no current to flow through the relay coil as demonstrated by the arrows on the secondary circuits. A short circuit will not, therefore, improperly open these circuit breakers providing, of course, line characteristics are such that a suitable balance is maintained.

Assume now a restricted fault in one of these lines, as in Fig. 1-B, such that the power direction remains throughout as formerly, although the intensities have changed. It will be noted that the resulting difference in the currents in the two lines is reflected in the secondaries, appearing as a current through the relay coils, causing the contacts to close, and tripping both circuit breakers at each end of the two lines.

Following such an operation, it is necessary to find the healthy line and replace it in service with time over-load protection (not illustrated in the diagrams).

If the fault should be more severe so that there is a relative reversal of current at one end of one line the results will be as indicated in Fig. 1-C. Here again the differential current passes through the relay coils. It should be noted that at the end where the reversal occurred the vectorial difference appears as an arithmetic sum.

If, at any time, the fault should occur so near station "B" that the currents at Station "A" remained balanced, then the station "A" relay would not operate immediately, but at "B" the differential current would be very great due to the reversal in the relative directions of the currents. Station "B" would, therefore, clear quickly after which there would be established a large differential at "A." An open circuit in either of the lines will likewise unbalance the pair and result in their isolation in case of sufficient current flow.

Balanced Protection for Two Parallel Lines (Discriminating)

In order to obtain discriminating action in the relay for short circuits in either of two parallel lines, reverse power relays may be included in the schemes shown in Fig. 1. With this modification the arrangement is as illustrated in Fig. 2. It should be noted that in case of an open circuit in one of these lines the resulting unbalance would cause the opening of the sound feeder at one end, in case of sufficient current flow.

As in the indiscriminating case, so long as a balanced condition is maintained between the corresponding phases in the two lines, there will be no current in the differential or relay circuit. When a fault occurs, however, the vectorial unbalancing in the main circuits will be indicated in the relay coils as illustrated in Figs. 2-B and 2-C. In these figures the arrows may also be considered as indicating direction of power flow. The moving contact of the reverse power relay will travel in the direction of the arrow.

Looking at the matter from another viewpoint, if we assume for the moment that only one line is in service, then the current and potential connections to the reverse power relay should be so made that for power flowing from the bus to the line the contacts would close on the side to trip the breaker of the line in service. When both lines are working, the circuit having the greater flow of power from the bus to the line will control the operation of the reverse power relay and, therefore, trip the breaker of the line in trouble, which will always carry the greater power from the bus to the line. It should be borne in mind that power flowing from the line to the bus is of negative value, therefore, for cases as shown in Fig. 2-B where power flows from the line to station "B" bus over both circuits, the circuit having the greater flow from bus to line is the one having the least flow from line to bus.

In the event of one line being in service alone, it is the general practice by means of auxiliary switches on the circuit breakers to automatically introduce time overload relays in the protective equipment, which will operate in conjunction with the reverse power relays in a manner similar to that described in connection with Fig. 13 or Fig. 16. This time delay also serves to prevent the opening of the sound line immediately following the tripping of the faulty one.

In place of the single reverse power relay with double throw contacts, it is also possible to obtain substantially the same results with two sets of relays each equipped with single throw contacts arranged in a manner similar to that described for the protection of three or more parallel lines as shown in Fig. 6.

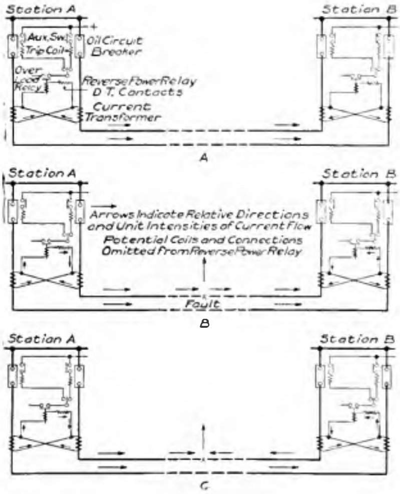

Fig. 2. Balanced Power Protection for Two Parallel Lines (discriminating)

Figs. 3, 4 and 5 illustrate in greater detail some of the methods by which this scheme using reverse power relays with double throw contacts is applied. One line diagrams are used for greater clearness.

Fig. 3 shows the connections and [illegible] ment required to protect either [illegible] of outgoing lines. Instantaneous action [illegible] tained if both lines are in service the trip circuit being established from the negative through the overload relay contact [illegible]

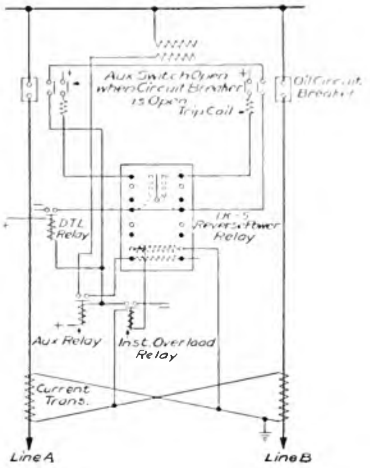

Fig. 3. Instantaneous Balanced Power Protection for Two Parallel Lines, with Provision for Definite Time Action with One Line in Service

auxiliary switch on each circuit breaker, and finally through the proper set of reverse power relay contacts to the trip coil of the line at fault.

When one circuit breaker is open, the balancing effect of the two lines no longer exists, therefore, it is sometimes necessary to introduce a time delay for further selective operation. The opening of the circuit breaker automatically opens its auxiliary switch; therefore, in case of a fault with only one line in service the trip circuit is established from the negative through the overload relay contacts to the coil of the definite time limit relay and after the desired delay a new circuit is made through the definite time relay contacts to the reverse power relay contacts. Only in case the power direction is from the bus to the line will the reverse power relay contacts be closed on the side to trip the remaining breaker. In place of the definite time relay with the d-c. potential coil illustrated, there may be substituted a-c. time overload relays, the operating coils of which are connected one in each differential circuit. The contacts may be connected similarly to those of the definite time relay shown. For a three-phase grounded neutral system, three time overload relays must be used in place of the one definite time relay with the d-c. coil, thereby resulting in slightly greater expense. Otherwise the use of the extra overload relays is preferable.

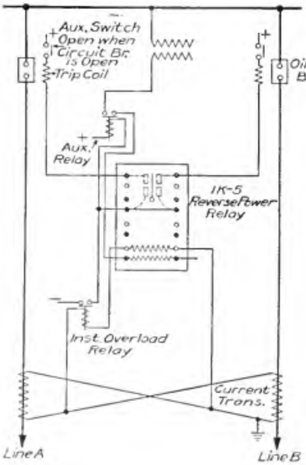

Fig. 4. Instantaneous Balanced Power Protection for Two Parallel Incoming Lines

Another alternative, particularly for outgoing lines, is to insert time overload relays in each current transformer secondary circuit and connect the contacts to trip the corresponding breaker directly. The extra auxiliary switches would then be arranged simply to disconnect the differential relay group in case one line is out of service. This last arrangement has the advantage or disadvantage as the case may be of tripping both breakers in the event of a sustained balanced fault.

As an exact balance of currents in the two lines is very improbable the sensitive reverse power relay is likely to have its contacts closed on one side or the other, if the lines are at all loaded, even though both lines are in service, unless some means are provided to prevent it. In such cases it is possible that the instantaneous overload relay would close its contacts before the reverse power relay contacts would open, if closed on the wrong side, and trip the wrong breaker. On this account the auxiliary relays are introduced in this equipment to disconnect the a-c. potential circuits of the reverse power relays until after the instantaneous overload relay has operated, thereby insuring that the reverse power relay contacts will be normally in a neutral position, and, therefore, unprejudiced in the event of a fault. If a time overload relay is substituted for the instantaneous overload relay in the differential circuit the resulting delay would make these auxiliary relays unnecessary.

Fig. 4 shows a simple arrangement which may be used for incoming lines only. This is like that explained in connection with Fig. 3 except that all special provision for single line operation is omitted. This is possible on account of the fact that the line will be non-automatic for power flowing from the line into the bus, and being incoming lines only, no considerable power will flow out.

The third scheme is shown in Fig. 5. In this case the circuits are still balanced, but instead of instantaneous action with both lines in service the same time delay is introduced as for single line operation. In order to prevent the second line from tripping in case of a fault in one, the two relays—the instantaneous opening relay and the time delay reclosing relays are installed. The tripping current for the circuit breakers is carried through the coils and contacts of these relays

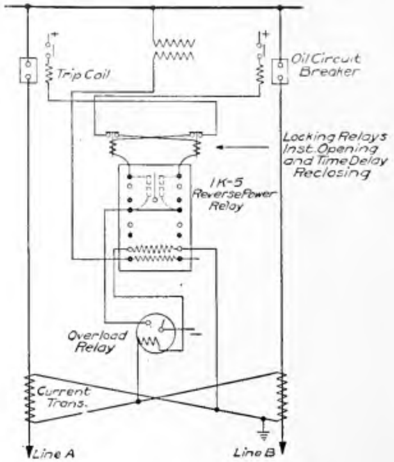

Fig. 5. Time Limit Balanced Power Protection for Two Parallel Lines

in such a way that when one breaker is being automatically tripped, the relay trip circuit of the other breaker is opened and does not reclose for a time long enough to permit conditions on the system to become normal, after which the second line can be tripped in case of an overload which remains on a sufficient time, and providing the power flow is from the bus to the line.

This equipment is somewhat simpler than those previously described. No additional auxiliary switches and no auxiliary relays to open the potential circuit of the reverse power relays are needed.

Balanced Protection for Three or More Parallel Lines

Where a number of parallel lines are involved the underlying feature is the same as described in connection with Fig. 2, although the treatment of the matter is necessarily different. Here, as shown in Fig. 6, the current transformer secondaries are connected all in series in a loop circuit, so that when the primary currents are all equal the secondary currents will also be equal, and will circulate through the loop as one current of the magnitude of each, and practically none will pass through the coils of the overload and reverse power relays which are connected across each current transformer secondary.

Fig. 6-B illustrates a fault in one line, such that power is reversed at Station "B" in this line from the direction taken by the remaining sound lines. It will be observed that only in the case of the injured line is the power direction through the reverse power relays (as indicated by the arrows) such that the contacts will close—at Station "A" this is because there is a preponderance of positive power flowing from the bus into this particular line—at Station "B" the injured line is the only one having positive outward flowing power.

Inasmuch as the success of the scheme depends upon the relatively low impedance of the loop circuit as compared to the impedance of the coils, it will be apparent that some method should be provided to eliminate the useless impedance injected in the loop circuit by the relays of a dead feeder. This is usually done automatically by short circuiting, by means of auxiliary switches on the circuit breakers or by auxiliary relays controlled by such auxiliary switches, the relay equipment of the line whose circuit breaker is open.

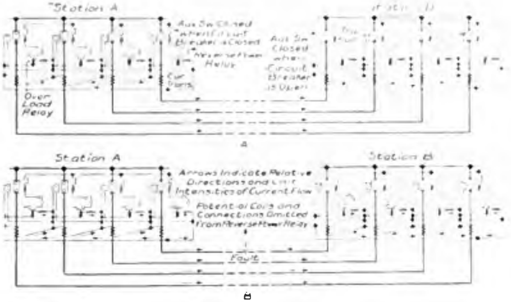

Fig. 6. Balanced Power Protection for Three or More Parallel Lines

It will be noted that when all but one line is out of service, the relay equipment of the last line will be short circuited by the auxiliary switches or relays referred to in the preceding paragraph and accordingly the last line will be non-automatic unless some means is provided to open the loop circuit. This opening of the loop may be accomplished manually or it may be done automatically with considerable complication of auxiliary switches, etc., which complication is usually considered inadvisable. When the loop has been opened, each feeder will be left with overload and reverse power protection, at values determined by the settings of the overload relays. Various other means also somewhat complicated, may be used for inserting additional relays for the protection of this last line. But these schemes on account of their variety, will not be described here.

If an open circuit should occur in one of the conductors or if, when putting another line into service only the breaker at one end is closed, an unbalanced condition will result which may tend to open the good lines in use if the current flowing at the time is sufficiently great. This danger becomes relatively smaller as the number of lines involved is increased, because the secondary unbalancing will be inversely proportional to the number of lines in service. For instance, if the overload relays are set to operate at the normal load of each feeder and if four lines are in, three continuous and one broken, an overload of three times normal on each feeder would be required before any trouble could be encountered. The break would usually be detected before this excessive current would occur.

Protection by Mechanically Balanced Differential Relays

This relay is illustrated in Figs. 7 and 8 and may be used for the protection of parallel transmission lines against unbalanced current in the similar phases, such as would be occasioned by a fault in one of the lines. As the current increases in the lines, the difference in current in the two lines must also increase before the relay will operate. This compensates for a normal inherent difference in impedance in the two lines. The characteristic curve, Fig. 9, shows the results to be obtained on outgoing lines.

The relay operates to trip the line carrying the greater current. It may be used, therefore, for outgoing lines or, providing there is some source of power to insure that the injured lines will carry the greater current, for incoming lines. The simplicity of this relay strongly recommends it for the use referred to. The freedom from a-c. potential connections is a noteworthy advantage.

Fig. 7. Mechanically Balanced Differential Relay for Protection of Parallel Lines

Fig. 8. Interior of Relay Shown in Fig, 7

Diagram, Fig. 10, illustrates one method of making the connections. The relay consists of three solenoids, the two smaller outside solenoids tending to hold the moving mechanism down, while a differential current passing through the larger center solenoid will tend to raise the mechanism upward. When the difference becomes sufficiently great to overcome the weaker of the two small solenoids, the contact mechanism will be operated on the side to trip the breaker carrying the heavier current. So long as a balanced condition exists within the operating values, the relay will not trip either breaker no mater how high the current may be in the two.

Protection for Three or More Parallel Incoming, Outgoing or Tie Lines—Current Relays Only

Fig. 11 shows the one-line connections for a balanced scheme for three or more parallel lines in which no a-c. potential connections are involved.

Saturating transformers are connected to the secondaries of the instrument transformers. They are used for two reasons, namely: to limit the amount of current which any individual line can furnish to the loop and also to permit grounding each instrument transformer's secondary circuit close to the winding. The resistance connected in the secondary of the saturating transformer also assists in limiting the amount of current furnished to the loop. The secondaries of all saturating transformers are connected in series through the respective resistors. An induction overload relay is then connected directly across each saturating transformer and its resistor. The auxiliary relay contacts or the auxiliary switch is connected across the protective relay circuit and is intended to short circuit the relay and other equipment whenever the oil circuit breaker of that circuit is open.

So long as there is a balanced condition with respect to currents on all lines, there can be no action of any relay connected in this manner.

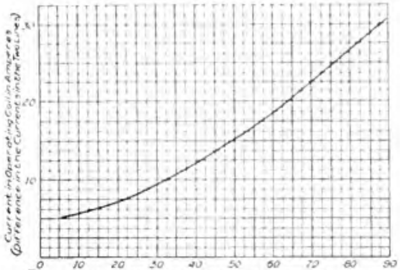

Fig 9. Characteristic Curve for Mechanically Balanced Differential Relay

Consequently all breakers will remain in for all through short circuits.

If an unbalanced condition occurs, the majority of the circuits will control the minority irrespective of whether the minority carries more or less current than the majority.

In case of a fault in one of these lines, it will be disconnected nearly instantaneously regardless of whether it carries more current or less current than the two good lines.

If a balanced fault should occur on two or three feeders at one time, faulty operation might result. However, the chances for such a possibility are remote and do not outweigh the advantages to be had under the more usual faulty conditions. If five lines should be operating in parallel and two should simultaneously develop balanced faults, the faulty lines would both be cleared properly. If four lines are in and two lines develop faults, it is possible that under some extreme and improbable conditions all four lines would be tripped due to the fact that the equipment cannot decide which set is in the majority. In case two faults involve different phases, they are not to be considered as balanced faults.

It will be observed that the more feeders there are in circuit at any given time the more certain the operation of the equipment will be.

The overload relays may be set so that for short circuits of sufficient severity to disturb the system, the faulty line can be cleared in from one quarter to one half second no matter how near to the source of power the fault may be

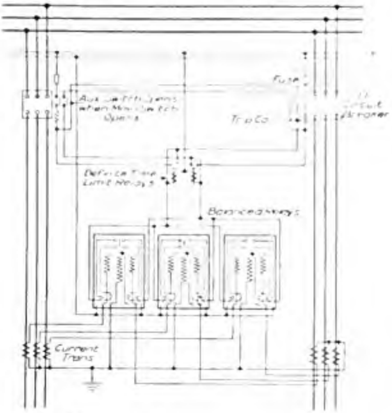

Fig. 10. Connections for Mechanically Balanced Differential Relay

located. Higher time settings are, of course, permissible if they should be considered desirable.

At least three lines must be in service to give selective action. Should only two be left, both would open for trouble in either. When only one line remains in operation its relay equipment is short circuited by the auxiliary switches of the circuit breakers in the other lines which are out of service. Such single lines would, therefore, have no protection unless the loop circuit is opened by means of a lever switch which may be inserted for that purpose.

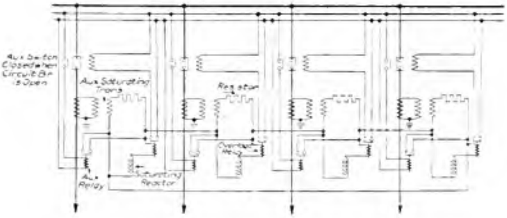

Fig. 11. Balanced Current Protection for Three or More Parallel Lines

INVERSE TIME VERSUS DEFINITE TIME RELAYS

Quite often the question arises as to the advisability of using the definite time or the inverse time relay for selective action, and in numerous cases the decision has been in favor of the definite time relay because of the more or less general understanding that the shape of the inverse time limit curve was limited. That is true so far as relays are usually constructed, but a relay can be provided so designed as to give the curve desired.

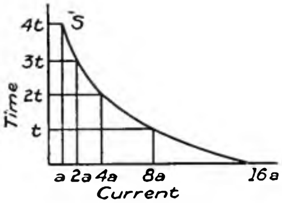

Fig. 12. Theoretical Inverse Time-Current Curve

The inverse time relay is often of greater value than the definite time relay, and one case of this character is as follows: If for example two links of one circuit are in series, and the relay furthest from the generating station is equipped with a current transformer, whose ratio is one half the ratio of the current transformer connected to the relay near the station, or, if the current setting of the relay furthest from the station is one half that of the relay near by—it is obvious (with suitable current transformers) that in the event of a short circuit beyond the relay furthest from the station, that the current in this relay will be proportionately twice as great as the current in the relay nearer the station.

Fig. 12 will illustrate the action of the relays under these conditions. In the curve it is assumed that doubling the current in the relay reduces the time of operation by a time in seconds "t" which is the time required to give selective action between the circuit breakers controlled by the relays.

Since the relay nearest the fault receives the equivalent of twice the current in the relay next closer to the source, the difference in time between the operation of the relay contacts in the two relays will always be "t," or the time required to give the proper selective action.

Of course to obtain the results as just described it is necessary that the relays should be so set that the time of action is never less than "t" except for trouble in the immediate section. If the current set up in the system because of a fault were so great as to be of serious danger to the system, the time of operation of the relay would be so rapid that much damage might be avoided and synchronous apparatus would be less likely to fall out of step.

Use of Overload and Reverse Power Relays

Fig. 13 shows a method of applying the overload and reverse power relays to parallel incoming lines. It also illustrates the use of simple overload relays at the outgoing ends of the same lines. Their contacts are connected in series so that both must operate before the breaker will be tripped.

Although overload and reverse power relays have long been used for the protection of incoming parallel feeders, the degree of protection afforded has been advancing rapidly during the past few years, due principally to the greater reliability and sensitiveness of the later types of reverse-power relays. The polyphase reverse power relay has been particularly successful. When properly applied and in good mechanical condition, its action approaches perfection. Of course, we must be careful when using the polyphase relay on a system with the neutral grounded through a resistance; that is, because of a tendency in the case of a ground to cause power to flow in one direction over one wire and in the opposite direction over the other two wires.

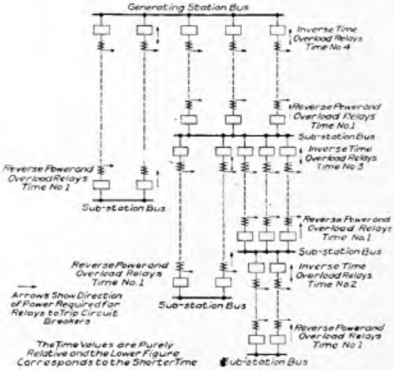

Fig. 13. Overload and Reverse Power Relays Protecting Parallel Lines

This difficulty can usually be overcome by proper interconnection of the relays. By such interconnection, the power current which would cause the trouble is balanced out so that simply the fault current is left to work in the relays. The fact that its use is limited on systems where the neutral is grounded through a high impedance does not materially affect the situation because the number of such systems is far under one per cent of the total of the country.

One reason for the success of the polyphase relay will be made clear by some detailed reference to Figs. 14 and 15, which illustrate the quadrature connection used.

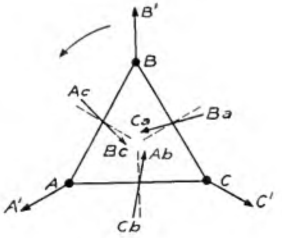

Fig. 14. Vector Diagram of Quadruture Connection for Reverse Power Relay (Normal)

In Fig. 14 "A," "B" and "C" represent the voltage triangle of a three-phase circuit. At unity power factor

$A-A'$ is the current in phase A
$B-B'$ is the current in phase B
$C-C'$ is the current in phase C

In most wattmeters and in the type of polyphase relay now under consideration maximum torque is obtained when the current in the current coil and potential across the potential coil are in phase.

In the diagram $A-A=A'$ and $B-C$ are 90 deg. out of phase. Thus if we displace the potential of phase $B-C$ 90 deg. it will be in phase with $A-A=A'$ and the use of this displacement would provide maximum torque at unity power factor on the circuit protected.

But serious faults result almost invariably in lagging currents. So instead of displacing $B-C$ by 90 deg. to obtain maximum torque at unity power factor, we can displace it as shown by B_a-C_a and then obtain maximum torque with a power factor lagging say 40 degrees. On the polyphase relay then there is made use of B_a-C_a the displaced potential B_a-C_a which is used in connection with the current $A-A'$. C_b-A_b is the displaced potential $C-A$ which is used in connection with the current $B-B=B'$. A_c-B_c is the displaced potential $A-B$ which is used in connection with the current $C-C=C'$. This relationship of current and potential for proper results should remain reasonably fixed even under the most severe distortion of the voltage triangle which may be caused by a single-phase short circuit.

Let us consider the conditions which, with such connections, would arise in the event of a single-phase short circuit. Again assuming unity power factor, the vector relations and the various potentials and currents would be as shown in Fig. 15.

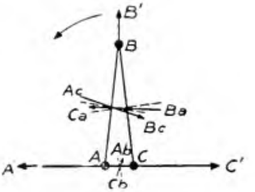

Fig. 15. Vector Diagram of Quadruture Connection for Reverse Power Relay (Single Phase Short Circuit

It will be observed that the displaced potential B_a-C_a again properly lags behind the current $A-A'$. Not only is the vector relation good but the potential is nearly at full value, a very valuable combination. The same is also true concerning the short-circuit current $C-C'$ and its companion potential A_c-B_c.

Even in the case of the third phase which is not greatly affected by the fault, the relation of potential and current is still correct.

If we consider a dead single-phase short circuit between A and C, then potential $A-B$ will be superimposed on potential $B-C$. The phase relationship of the connections to the relay coils is still correct and operation thereby safeguarded even with zero potential across the short-circuited phase.

For a single-phase load and no distortion of the voltage triangle, a maximum relative variation of 30 deg. between the current and potential is possible, a harmless amount. Some of the older connections result in relative variations of three times this value.

In the polyphase relay as it is now being manufactured, three elements are used; three elements separate and individual except that they are all working together on one common shaft. The relay consists then of three single-phase relays working on the same shaft. Current and potential are connected in quadrature as described above. From these diagrams it is seen that each individual phase of that relay will operate properly so that there is no particular tendency—there seems to be no tendency whatever—for any of the three phases to work incorrectly. In the case of a single-phase short circuit we have, in two elements, large currents working in good phase relationship with large potentials. These two elements provide many times more power than is needed, so that there seems no chance for the relay to go wrong in such a case.

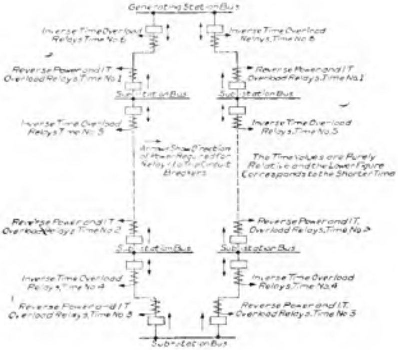

Fig. 16. Overload and Reverse Power Relays Protecting a Ring System

SUBSTATIONS IN RING OR LOOP FORMATION

The comparatively simple method of protecting substations in ring or loop formation, illustrated in Fig. 16, though far from being new, is worthy of repetition on account of its value in such cases. Each line at each station is provided with overload relays. Where these overload relays are given the lower time settings, reverse power relays are also used with the contacts of the two types so connected that both relays must operate before the circuit breaker will be tripped.

Reference to the time settings given on the diagram (these are purely relative and in no way represent absolute time value) will show that they are graded on the same basis as a single series of tamdem connected substations, assuming that one end of the loop is open at the generating station bus, and neglecting those breakers which would then be "incoming" at the various substations. It should be noted that when the other end of the loop is considered open the substation breakers which in the first case were "incoming" will now be "outgoing" and vice versa. The reverse power relays are also installed if the time of an "incoming" line is lower than any "outgoing" line farther from the source. This must be checked separately for each end, in turn considered open, at the generating station.

DIFFERENTIAL PROTECTION FOR ALTERNATORS

Where differential or reverse power protection is used for alternators, each circuit should be equipped with a device for opening automatically the field circuit of the alternator after the oil circuit breaker connecting this alternator to the busses has been opened. This requirement demands either solenoid operation for the field switch, or a manually operated field switch equipped with a shunt trip coil. A circuit closing auxiliary switch should be provided on the oil circuit breaker to insure that the breaker opens before the field switch. With the breaker open there will be less liability of damage to the field circuit, due to the high voltage which would be induced if it were opened when heavy currents were passing through the armature. Opening the field last also reduces the possibility of the alternator falling out of step with the remainder of the system, thereby increasing the disturbance on the system. It is of course evident that under none of the above mentioned conditions is the difficulty entirely overcome by the opening of the oil circuit breaker first. The trouble is, however, sufficiently reduced to consider it the preferable method.

Relays with hand reset contacts are used to insure tripping the circuit of the field switch, after the main circuit breaker is opened. By resetting the relay contacts, the field switch may be reclosed with the main circuit breaker still open. One wiring for the equipment is shown in Fig. 17 and is for use with "Y" connected armatures. The relay is shown in Figs. 18 and 19.

CIRCUIT BREAKER TRIP COIL CONTROL

Circuit closing relays are recommended for best results. Direct current is preferred for the source; and a storage battery is the most reliable means of supplying this on account of its greater freedom from effects of system disturbances. Low voltage storage batteries such as are used in automobiles have been very successful. The cost is low and charging by a Tungar Rectifier is exceedingly simple; 12-volt batteries in general have given satisfactory results, though as a greater safeguard 24-volt batteries are recommended.

Tripping reactors, a simple illustration of which is shown in Fig. 20, may sometimes be used to supply the needed constant source of tripping potential. The reactor being connected directly in the secondary circuit of the current transformer will have a potential built up across its terminals by the passage of the current. If the current is sufficiently high to operate the relay it will be high enough to provide the necessary potential for the trip coil.

It is preferable to limit the use of circuit opening relays, even where available, to positions where the maximum secondary current which the contacts must rupture will not exceed 50 amperes. If we consider only the very sensitive trip mechanism, requiring the low value of 35 volt-amperes to operate, the contacts of the circuit opening relay would be required at 50 amperes secondary to rupture 3.5 k-va., which is an appreciable amount of power.

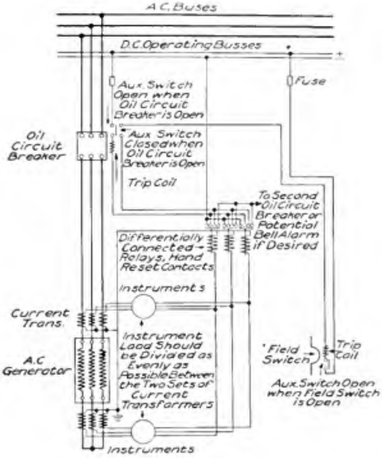

Fig. 17. Connections for Differential Protection of Alternators

METHODS OF SIMULTANEOUSLY TRIPPING TWO CIRCUITS BY MEANS OF ONE OVERLOAD RELAY

For this purpose either the time limit induction or the plunger type relays may be used. If manually operated circuit breakers are involved they may have the two d-c. trip coils connected together in multiple to be operated simultaneously by one two-contact (one circuit) circuit closing overload relay. This multiple connection is feasible due to the fact that either circuit breaker can be opened independently by means of its operating lever without disturbing the other breaker. The need for auxiliary switches to open a tripping circuit will be determined simply by the ability of the relay contact to rupture the circuit.

Fig. 18. Relay Used for Differential Protection of Alternators

Fig. 19. Relay Used for Differential Protection of Alternators (Cover Removed)

Electrically operated circuit breakers ordinarily cannot have their trip coils wired in multiple, because if so connected it would be impossible to trip one circuit breaker manually from a control switch without tripping the other circuit breaker also. In this case, the closing of the contact of the overload relay should control an auxiliary relay or relays, which will in turn control the two tripping circuits.

The diagrams illustrate the methods by which this may be accomplished. Fig. 21 shows a scheme particularly applicable to induction overload and reverse power relays. Fig. 22 shows two auxiliary relays used with plunger type overload relays. In this case, the extra auxiliary switches are not needed because the plunger relay is capable of rupturing the current taken by the operating coils of the auxiliary relay.

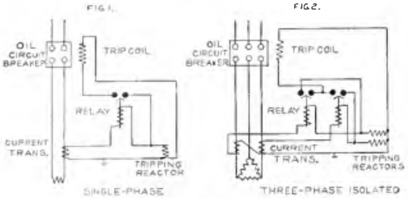

Fig. 20. Simple Connection for Tripping Reactor

For electrically operated circuit breakers, instantaneous overload relays of the plunger type may be properly provided with three contacts (two circuits).

BUSHING TRANSFORMERS

Bushing transformers on account of their lower cost, are being used to a considerable extent for protective purposes. On account of the necessarily great length of the magnetic circuit and the fact that only one primary turn can be provided, the magnetizing current must be high and accordingly the transformers are rather inaccurate for the lower ratios. However, as most operating companies now relay for short circuit protection, there is seldom any need for using these low ratios. A bushing transformer of a ratio 150/5 amperes will give good results when used with relays. As the ratio increases the errors decrease, and by the time a ratio of 300/5 amperes is reached the bushing transformer is equal in most, and superior in some, respects to the standard instrument type of current transformer for protective relay purposes. Ratios of less than 150/5 amperes are not recommended for the various balanced schemes, and even at this value it is preferable to connect the secondaries of two transformers in series. Ratios of 200/5 amperes usually give satisfactory results with a single transformer for balanced work.

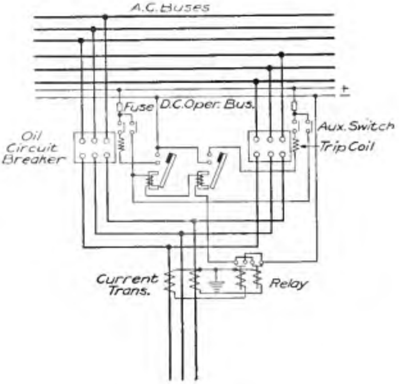

Fig. 21. Connections of Induction Overload Relays for Tripping Two Oil Circuit Breakers

TEMPERATURE RELAY FOR MACHINE BEARINGS

Figs. 23 and 24 show two views of this relay, one with the cover removed, and the other with the relay completely assembled.

This relay is used as a protective device to function in case the bearing of the machine to which it is connected becomes overheated to a dangerous extent. The contacts of the relay can be either circuit opening or circuit closing.

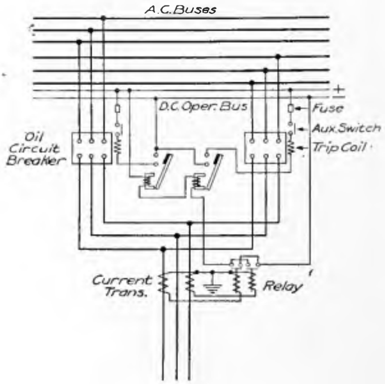

Fig. 22. Connections of Time Limit Plunger Overload Relays for Tripping Two Oil Circuit Breakers

When the relay operates, the circuit breakers controlling the circuits to which the machine is connected will be opened and the machine stopped.

The essential features of the relay consist of a "syphon," the bulb of which is embedded in the bearing to be protected. The syphon is filled with a volatile liquid which vaporizes in the bulb at the temperature at which the relay is to operate and the pressure produced expands the metal bellows or "syphon" and through it controls the contacts.

After operating, the relay is ordinarily reset by hand thereby definitely bringing the matter to the attention of the attendant.

Fig. 23. Temperature Relay for Protection of Bearings

Fig. 24. Temperature Relay for Protection of Bearings (Cover Removed)

D-C. REVERSE POWER RELAY

This new d-c. reverse power relay shown in Fig. 25 is sufficiently sensitive to operate on the "running light" current of a synchronous converter, that is, at 1½ per cent of its continuous rating. The current coil is connected to a shunt of the proper ampere capacity in the direct current circuit.

Extreme sensitiveness is obtained by the powerful excitation of the potential element acting with a well excited current element. Both current and potential windings are stationary but within the current coil there is a pivoted iron armature which is rotatable about a vertical axis and which carries the contact button shown in the illustration.

When operation takes place the action is quick and positive. Contact pressure is unusually good for so sensitive a device. The relay is regularly insulated for 1500 volt service.

HESITATING CONTROL RELAY

Hesitating control relays have been in use for a long time where the electrically operated circuit breakers controlled are equipped with an auxiliary switch to automatically break the coil circuit of the control relay. The relay closes instantaneously but "hesitates" about one second after deenergized before the contacts open again. By this time the breaker will have been positively latched closed. An earlier type of hesitating control relay made use of an oil dash pot to produce the desired delay, but it has been superseded by the type shown in Fig. 26. In the new design the time delay is obtained by means of a heavy copper tube surrounding the relay plunger and inside the operating coil. When the coil is energized the plunger is raised and the contacts closed. When the operating coil circuit is broken the usual "inductive kick" starts up a heavy current in the copper tube which in turn tends to maintain the flux. As a result the flux dies away slowly, and in approximately one second the plunger falls again and opens the contacts.

LOCKING RELAYS

Locking relays are usually provided with circuit opening contacts which are connected in series with the tripping circuit of an oil circuit breaker. They are ordinarily used to prevent the tripping of the breaker in case the current flowing at the time is above the interrupting rating of the breaker.

Locking relays are usually provided with a very high secondary current setting. For this reason care must be exercised to see that the current transformers intended for this purpose maintain their approximate ratio at the high current at which relays are desired to operate and with the full volt-ampere load of the locking relay and other equipment which may be connected to the secondary circuit.

Fig. 25. Sensitive D-C. Reverse Power Relay

NOTCHING RELAYS

Fig. 27 shows a relay designed to open its contacts after its coil has been energized a predetermined number of times, providing there is less than a predetermined time interval between these impulses. The contacts are reset by hand. This relay is used in connection with an oil circuit breaker reclosing scheme. Fig. 28 shows the wiring connections, the sequence of operation of the equipment being as follows: The overload relay trips the oil circuit breaker. The circuit closing auxiliary switch on the oil circuit breaker is closed. The notching relay makes one stop instantly.

The reclosing relay operates in a definite time, thereby operating the hesitating control relay and closing the oil circuit breaker. (A hesitating control relay is used in order to permit the oil circuit breaker to be positively locked in before the control contacts part.) The closing of the oil circuit breaker opens the auxiliary switch again.

The reclosing relay then opens immediately and is followed by the hesitating control relay in approximately one second.

The notching relay starts to reset and will do so if the circuit breaker does not open again in a pre-determined time. If it should reset, the first step made as referred to above will be lost and all further action will be as if the breaker had not opened at all.

If the circuit breaker opens within this predetermined time before the notching relay resets, the complete cycle will repeat itself excepting that the notching relay in this case will make the second step.

If the circuit breaker opens the third time before the notching relay is reset, this notching relay will make the third and final step and will lock everything open until the equipment is reset by hand by the operator.

The present interrupting capacity ratings of oil circuit breakers are based upon the breaker opening twice with an interval of two minutes between operations. Usually in reclosing schemes the breaker recloses twice and in considerably less than two minute intervals.

Fig. 26. Hesitating Control Relay

Therefore, the interrupting capacity listed generally cannot be used, but lower figures must be obtained both on account of the fact that the breaker may be required to open more than twice at short intervals, and on account of the fact that the intervals between openings are usually smaller than that upon which the standard interrupting capacities are based.

REDUCING THE ERROR OF OLD STYLE PLUNGER RELAYS

In the older types of plunger-bellows overload relays (used previous to the standard unit type) a quick return valve "F," see Fig. 29, was provided to permit the relay to reset quickly. This valve to accomplish its purpose necessarily had a section area much larger than that of the opening at "E" through which the air should be forced when the bellows is collapsed. Accordingly any leakage around "G" and then through "H" is apt to be a considerable percentage of the total expelling air, and an error is caused. Cases are on record where errors as high as 25 per cent in successive tests have been reduced to practically zero by simply eliminating this variable. To do this it is only necessary to drop away from its support the large metal body forming the upper part of the bellows, and drive a wire plug in the hole "H."

The newer standard unit relay is regularly furnished without this quick return valve.

Fig 27. Notching Relay (Cover Removed)

OIL DASHPOTS FOR RELAYS AND TRIP COILS

On account of the change in viscosity of oil, due to varying temperature, oil dashpots should not be used on relays or trip coils where selective action is required in respect to other circuit breakers in the system.

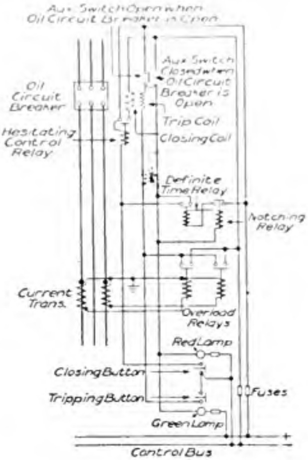

Fig. 28. Notching Relay as Applied to Automatic Reclosing of Oil Circuit Breakers

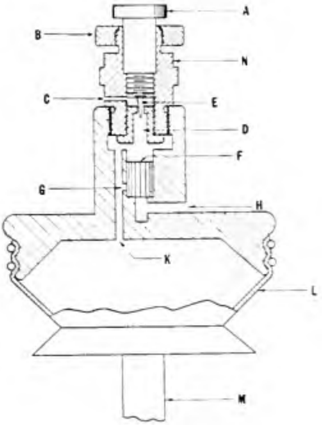

Fig. 29. Sectional View of Old Style Time Limit Bellows

Lightning II

THE EFFECT OF LIGHTNING VOLTAGES ON ARRESTER GAPS, INSULATORS AND BUSHINGS ON TRANSMISSION LINES

By F. W. Peek, Jr.

Consulting Engineer Transformer Department, General Electric Company

Probably the most fruitful sources of interruptions to service are line insulator failures and insulator flashovers due to lightning. Without doubt, some of the former are also directly chargeable to lightning disturbances. The author calls attention to the necessity of producing lightning arresters of very high speed, if steep wave front impulses are to be removed before damage is done to apparatus, bushings, and other equipment. He then proceeds with an analysis of the relative speeds of different forms of gaps, and shows the variation in the discharge value for any gaps under 60-cycle and lightning voltages, and under wet and dry conditions. A discussion is also given of the types of disturbances which damage apparatus and the protection afforded from each by different forms of lightning arrester gaps.—Editor.

The object of a lightning arrester is to provide a short circuit path to ground for transient voltages and a means of dissipating the transient energy. The ideal arrester would be one connected to the line without a gap and which sifted out all transient voltages and transformed the energy into heat without in any way disturbing the normal voltage. In practice it has been found necessary to use a gap. Between the gap and ground is usually connected an energy absorbing and arc suppressing device. The dynamic or power current always follows the discharge. Without a current limiting and arc suppressing device serious voltage and current disturbances would result. The ideal energy absorbing resistance would be one with high values for the dynamic, but with low values for lightning or over-voltages. This is approached to a high degree by the aluminum cell and the oxide film cell.

Unfortunately, no practicable energy absorbing and arc suppressing device has yet been developed which can be used without a gap on alternating current circuits. The setting of the gap is determined by its arc-over curve at normal frequency voltage. It must be set at such a spacing that under the conditions to which it is subjected by ordinary operation such as rain, harmless surges, dust, adjustment of parts, etc., it must not discharge the power voltage and thus create disturbances and destroy its energy absorbing device.

The effect of the various operating factors is not the same on all gaps. Rain, for instance, greatly lowers the 60-cycle spark-over voltage of many gaps and makes it necessary to greatly increase the setting of uncovered gaps. The setting factor, which will be called α, is important when gaps are compared. This is especially so since, while rain lowers the 60-cycle spark-over voltage and makes an increased setting necessary, it does not lower the lightning spark-over voltage.

Gaps with different electrodes set at equal 60-cycle spark-over voltages may have entirely different lightning spark-over voltages. We found, as discussed in former papers, that for the sphere gap, for instance, the lightning spark-over voltage and the 60-cycle spark-over voltage are equal, while for the needle gap the lightning spark-over voltage is very high.[1] It is obviously desirable to design a lightning arrester with low lightning spark-over voltage and insulators and bushings with high lightning spark-over voltages. It is practicable to do this. The ratio β between the lightning spark-over voltage and the 60-cycle spark-over voltage is called the impulse ratio.

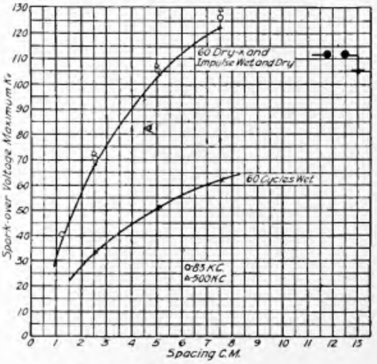

Fig. 1. Sphere Wet and Dry Spark-over Voltages, 6.25 cm. Spheres 60 Cycles and Impulses 0.2 in. Rain One Sphere Grounded

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[1] F. W. Peek, Jr., "Lightning," G-E Review, July, 1916. F. W. Peek, Jr., "The Effect of Transient Voltages on Dielectrics," A.I.E.E., Sept., 1915.

The reason for the high lightning spark-over voltages of some gaps is the time lag or the time required for the gap to discharge after the 60-cycle spark-over voltage is reached.

When a 60-cycle voltage is slowly applied to a gap and gradually increased, spark-over will occur at some definite voltage. This is the minimum voltage that will cause sufficient ionization for the gap to discharge and it requires a relatively long time.

Lightning voltages, or voltages of relatively steep wave front start at zero or line voltage and increase at the very rapid rate of millions or billions of volts per second. When such voltages are applied across a gap or insulator, spark-over does not occur at the instant the minimum or 60-cycle voltage is reached, as considerable time is required at this voltage. When this voltage is reached the spark begins to form, but is only completed after the rapidly rising voltage has reached some higher value. The "slower" the gap the higher the voltage will rise. In a uniform field, breakdown takes place over a relatively short path, everywhere at the same time. In the case of a non-uniform field represented, for instance, by the needle gap, corona forms around the electrodes before spark-over. A vast amount of air must be ionized. The condition is equivalent to putting the corona or arc resistance in series with an ever increasing capacity represented by the unbroken dielectric. Time is thus required to bring all of the space between the electrodes up to the breakdown gradient and during this time the lightning voltage rises higher and higher.

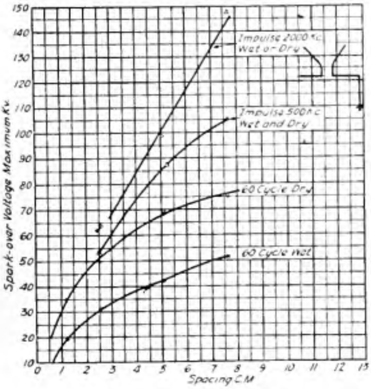

Fig. 2. Horns Wet and Dry Spark-over Voltages 60 Cycles and Impulse, Wet and Dry

In comparing the relative protective value of two gaps it is necessary to consider both the setting factor α, and the lightning spark-over factor, or impulse ratio β. This is obvious, since there can be no gain in using a gap with low lightning spark-over voltage if it is necessary to set it at large spacings to prevent the operating voltage from continually discharging over the gap.

One of the greatest factors affecting the setting is rain. Rain reduces the 60-cycle voltage without changing the lightning spark-over voltage. The effect of rain, etc., on the sphere gap is shown in the table below:

THE APPROXIMATE EFFECT OF RAIN, ICE, DUST, ETC., ON THE 60-CYCLE SPARK-OVER VOLTAGE OF THE SPHERE GAP

	Percentage of Normal Voltage to Spark-over
Thin coating of dust	98
Coating of oil	100
Heavy coating of oil and sand	75– 90
Thin coating of ice	75– 90
Thick coating of ice	75– 80
Surface oxidized	100
Ordinary pitting	90–100
Rain 0.2 inch precipitation per min. Polished spheres	40– 50
Rain 0.2 inch precipitation per min. Pitted spheres	40– 50

It is seen that the setting must be at least doubled to prevent line voltages from discharging during rain. This practically doubles the lightning voltage.

The characteristics of the various gaps will be briefly discussed.

The Sphere-gap, Sphere-horn

The sphere-gap has an impulse ratio β, of unity or very low lightning spark-over voltages. It thus offers equal protection for all sorts of transient voltages. When exposed to the weather, however, the setting factor α must be increased so that the line voltage will not spark-over during rain. The wet and dry characteristics are shown in Fig. 1.

The factor α is lower for the horn, but the lightning factor β is variable and high for very steep wave fronts. The point has the lowest α, but β is variable and extremely high for steep wave fronts. The characteristics of the horn are shown in Fig. 2.

In the practical gap the sphere and horn were combined, the horn being used to assist in breaking the dynamic arc and for the gain in discharging low frequency surges due to the smaller difference between the wet and dry spark-over voltages. A point is sometimes added to further increase the protection at low frequency surges. This gap has proved very successful in its several years of practical use, greatly increasing the protective value of arresters. See Fig. 3. Take for comparison equal wet 60-cycle settings of 50 k-v. At 2000 k-c. the spark-over voltage of the horn is 135, the sphere 100. For impulses below 500 k-c. the spark-over voltage of the horn is lower than that of the sphere. Thus, when as phere horn is used the discharge takes place across the sphere for steep wave fronts and across the horn for low frequency surges. The gain due to the sphere is greater at higher voltages and steeper wave fronts. The covered gap shown by the dotted line is superior at all wave fronts. Such references on the curves as 2000 k-c., 100 k-c., etc., mean, unless otherwise stated, an impulse equivalent to a single half cycle of a sine wave at the frequency (in kilo-cycles) indicated.

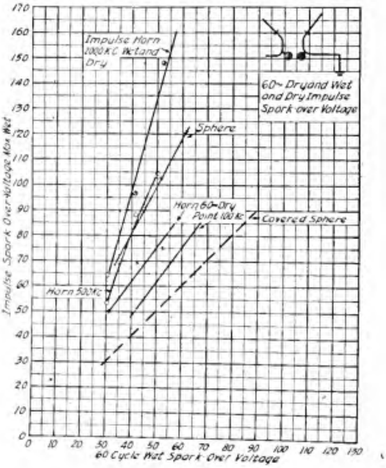

Fig. 3. Sphere Horn. Relative Protective Values of the Component Parts

The Covered Sphere

If a sphere gap is covered and shielded from the weather its protective value is greatly increased since the setting imposed by the condition that the normal line voltage must not discharge over the gap is cut in half. Such a gap, therefore, discharges lightning voltages at half the value of the uncovered sphere. See Fig. 4. This gap gives the highest degree of protection. It is not possible to use it on all types of arresters, since a horn is often necessary to assist in breaking the dynamic arc.

A gap not appreciably affected by the weather and still providing an arc breaking horn may be built as in Fig. 5. The two gaps are balanced so that the voltage divides across them in proportion to their relative settings. This causes simultaneous break down and prevents lag. The rain affects only the outside gap. For example, if the outside gap is set at 10 kv. and the inside gap at 50 kv. the outside gap would be reduced to 5 kv. by rain. If balanced wet, the total wet spark-over voltage is 55 kv. while the dry spark-over voltage is 60 kv. The only object of the outside gap is, of course, to transfer the dynamic arc to the horn when it rises and breaks. See Fig. 6.

Selective Gaps

Various forms of selective gaps have been proposed from time to time. Probably the most interesting and important one is that investigated by Mr. Allcutt.[2]

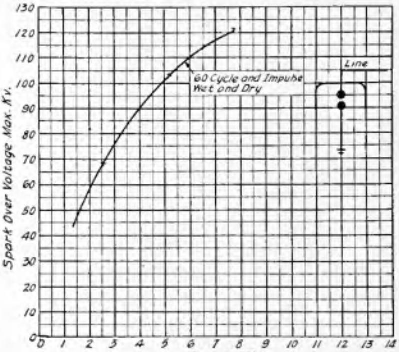

Fig. 4. Spheres Wet and Dry Spark-over Voltages 6.25 cm. Spheres-covered Gap, 60-cycle and Impulse, Wet and Dry, One Sphere Grounded

In this gap, shown in Fig. 7, the division of voltage is not greatly affected at 60 cycles if the auxiliary electrode is kept at the midpoint. This electrode is held at mid-potential by the two condensers. The capacity current at 60 cycles is too small to cause any appre-

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[2] C. T. Allcutt, Lightning Arrester Spark Gap, A.I.E.E. May, 1918. Discussion by F. W. Peek, Jr., A.I.E.E., Atlantic City, June, 1918.

ciable drop across the resistance. If the condenser current were opened on one side, the gap on that side would break down at about half voltage.

For steep wave fronts the resistance has the effect of opening the circuit on that side. See

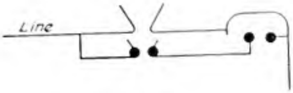

Fig. 5

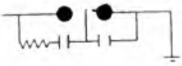

Fig. 7

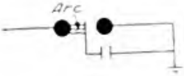

Fig 8

Fig. 8. The gap on that side breaks down. The voltage does not immediately disappear across the arc. The gap has lag because the arc over half the gap has the effect of putting resistance in series with the other half. Whether the spark-over voltage is above or below the 60-cycle setting depends upon the steepness of the impulse. The effect is similar to that which would result from a needle gap which could be set at, for instance, 100 kv. for 60-cycle operation and instantly and automatically reduced to a 50-kv., 60-cycle setting whenever an impulse came on the line. For moderately steep wave fronts the spark-over voltage would be greater than 50 and less than 100 kv., but for very steep wave fronts the impulse ratio of the 50 kv. gap would be greater than (2), or the spark-over voltage would be greater than 100 kv. The impulse ratio of the selective gap is always greater than unity; the "apparent" impulse ratio is greater or less depending upon the steepness of the wave front. The reason this distinction is made is discussed elsewhere. The apparent impulse ratio should be used in comparing protective values. This characteristic for the selective gap is shown in Fig. 9 and compared with a sphere gap for the same dry 60-cycle settings. The sphere gap spark-over voltage is practically constant for all wave fronts. The spark-over voltages are the same for 60 cycles. At moderate wave fronts the selective gap has about 5 to 20 per cent lower spark-over voltage than for spheres, while for steeper wave fronts the voltage is higher on the selective gap. The protective value of a gap, as already pointed out, depends not only on its lightning discharge voltage for a given 60-cycle setting, but also upon the setting which is imposed upon it by operating conditions. Fig. 9 shows the relative protective values of spheres and selective spheres, assuming that equal dry 60-cycle settings are possible. The settings must be such that the line voltage does not frequently spark-over and cause the destruction of the energy absorbing device under certain operating conditions. The effect of rain makes it necessary to set a non-shielded selective gap at about double the voltage that would be necessary in the protected gap. See Fig. 10.

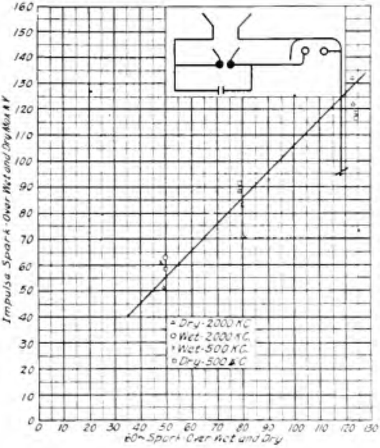

Fig. 6. Wet and Dry Spark-over Covered, Double Gap Balanced

Other forms of selective gaps have been devised and it is possible to extend the selective principle to a number of gaps in series, theoretically (neglecting lag) making it possible to discharge an impulse at a small fraction of line voltage. Such a gap would of course necessitate high initial setting and give very little protection against lightning impulses.

The selective principle may also be readily applied to covered gaps if it is deemed advisable.

Types of Disturbances Causing Failures in Practice and Relative Protective Value of the Horn, Sphere-horn, Selective Sphere Gap and Covered Gap for the Various Conditions

The over-voltages that cause insulation failures in practice may be divided into three classes:

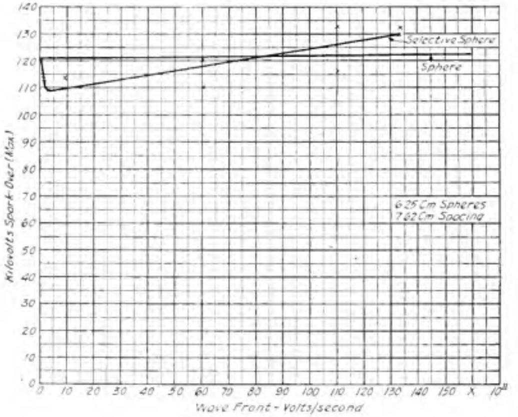

Fig. 9. Variation of Spark-ovor Voltage with Wave Front Sphere and Selective Sphere

1. Gradual increase of voltage on the line due to static or low frequency surges.
2. Very high frequency oscillations of voltages generally too low for any gap arrester to discharge, but which may cause very high internal voltages in apparatus.
3. The form of voltage with which we are principally concerned—lightning voltages of very steep wave fronts where the voltage across the apparatus increases from normal to a very high value in perhaps a millionth of a second.

Condition 1 is readily taken care of by any gap and need not be further discussed. Condition 2 is of some interest, but is a condition generally not taken care of by a gap arrester. Some results of tests will be given, however. Condition 3 is the steep wave front condition that represents lightning proper and with which we are mostly concerned.

Impulse Voltages of Steep Wave Front

The spark-over voltages of various types of gaps are plotted with equal wet 60-cycle settings in Fig. 11. Values are plotted for both wet and dry electrodes. The wave applied was a single half-cycle of a 2000-k-c. wave with a 340-kv. maximum; that is, at super-voltage. The application of a super-voltage in effect increases the steepness of the wave front. The rate of application of voltage or the wave front was thus about 70 x 10^{11} volts per second. Waves steeper than this occur on lines in practice. In fact, it was first noted that there was a difference between the 60-cycle and lightning spark-over voltages of various electrodes by the existence of such waves on an operating line. The bushings on the line always protected the lightning arrester horns although the horns had a lower 60-cycle spark-over voltage. By measuring the impulse spark-over voltages of the bushing and the arrester gap in the laboratory it was found that the bushing protected the horn for a wave front at which the impulse ratio of the horn was over (2); this corresponds to a steeper wave than the one under immediate discussion. See Fig. 11.

It will be noted that the covered gaps give by far the best protection under this condition. For example, when all the gaps are set on the line at 100 kv., lightning voltage discharges respectively at 100 kv. on the covered gap, 115 kv. on the balanced covered gap, 225 kv. on the sphere of the sphere-horn, 225 kv. on the selective sphere, and 320 kv. on a horn.

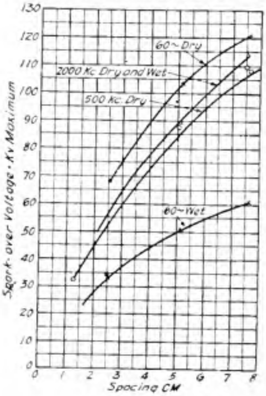

Fig. 10. Selective Sphere 60-cycle and Impulse, Wet and Dry

Moderate Wave Fronts

A similar comparison is given in Fig. 12 for moderate wave fronts. The impulses being single half cycles of 100 k-c. waves, the average fronts ranging from 0.5 to 1×10^{11} volts per second.

It will be noted that here, also, the covered spheres give the best protection. For example, at 100-kv. line setting the impulse spark-over voltages are respectively 100 kv. for the covered sphere, 110 kv. for the balanced covered sphere, 170 kv. for the selective sphere, 178 kv. for a horn or the horn of the sphere horn, 130 kv. for points of the sphere-horn and 222 kv. for the sphere. If this data is compared with that in Fig. 11 the value of the sphere-horn combination is well illustrated. For the steep wave fronts the sphere affords the better protection, while for the moderate waves the horn affords the better protection and a still greater gain is made by adding points. This comes about, of course, due to the difference between the wet and dry setting.

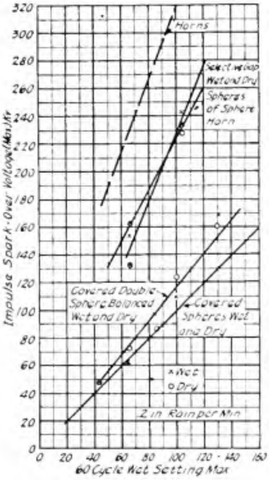

Fig. 11. Relative Protective Values of Horns, Sphere-horns, Selective Spheres, Covered Spheres, Steep Wave Fronts. 2000 Kilocycles, 340 Kv., Impulse

Ratio for Comparing the Relative Protective Value of Various Gaps

From the above discussion it is readily seen that in order to compare the relative protective value of various gaps two factors must be considered.

1. The increased 60-cycle setting imposed by operating conditions to prevent the gap from continuously discharging due to rain or harmless surges. Let the ratio of the actual operating setting to the normal setting be called α, where the normal setting is that which just prevents the line voltage from arcing over under ideal conditions.

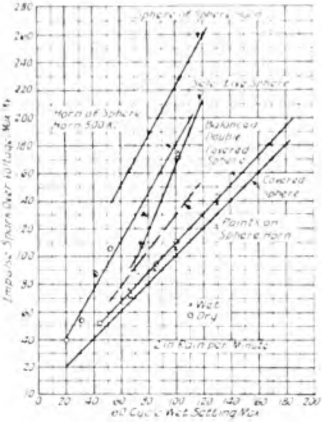

Fig. 12. Relative Protective Values of Sphere-horn, Selective Spheres, Covered-sphere, Moderate Wave Fronts. Impulse, Single, Half-cycle 100 Kilocycles, Non-grounded

2. The impulse ratio (or apparent impulse ratio for the selective gap) for the wave under consideration. Let the impulse ratio be called β. The relative protective value of two gaps is then $\frac{\alpha_1 \beta_1}{\alpha_2 \beta_2}$

For example:—a gap must be set at 50 kv. (max.) to prevent the 60-cycle line voltage from causing it to spark-over under ideal conditions. The relative protective values of a horn and a covered sphere for the 2000 k-c wave are obtained as follows from Figs. 2 and 4:

Horn	Covered Sphere
$\alpha_1 = 75/50 = 1.50$	$\alpha_2 = 50/50 = 1$
$\beta_1 = 133/75 = 1.77$	$\beta_2 = 50/50 = 1$
$\alpha_1\beta_1 = 1.50 \times 1.77 = 2.65$	$\alpha_2\beta_2 = 1$

$\alpha_1\beta_1 / \alpha_2\beta_2 = 2.65$

The horn permits the lightning voltage to rise to 2.65 times the value of the voltages permitted by the covered sphere.

Combination of Lightning and 60-cycle Voltages

The lightning spark-over voltage varies with the point on the 60-cycle wave at which the discharge takes place; it is a minimum when it occurs at the maximum of the 60-cycle wave and in an additive direction. The lightning spark-over voltage is a maximum when it occurs at the maximum of the 60-cycle wave, but in the opposite direction. *The relative effects, however, are approximately the same for all of the types of gaps discussed.*

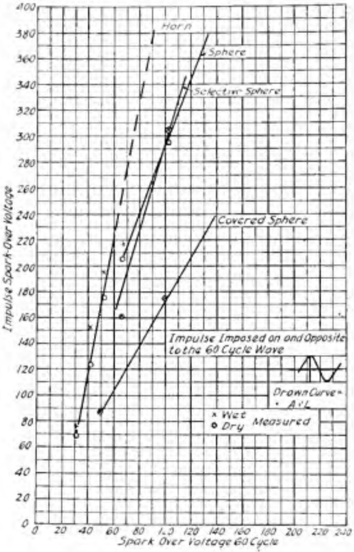

Fig. 13. Relative Protective Values of Various Gaps. Impulses Imposed on and Opposite to the Maximum of the 60-cycle Wave

Relative data for the condition when the discharge occurs at the maximum of the 60-cycle wave, but in the opposite direction, is given in Fig. 13.

High Frequency Oscillations

The effect of sustained high frequency oscillations not very highly dampened is shown in Fig. 14. It is probably very rarely that oscillations with such a low damping factor occur on a transmission line. The arcing ground condition is more nearly approximated by a series of the impulses discussed above. Note that the horn and points give good protection for sustained oscillations.

Line Insulators, Bushings and Insulation Generally

Line insulators and bushings should have a high impulse ratio or lightning arc-over voltage. The bushing mentioned above as protecting the horn had a low impulse ratio. The 60-cycle and lightning spark-over voltages were nearly equal. The horn would have given protection in this case if the impulse ratio had been higher or the wave had not been so steep. Bushings are now designed with a high impulse ratio.

SPARK-OVER VOLTAGES DISC INSULATORS
(One Side Grounded)

No. of Units	60-cycle Spark-over	Impulse Spark-over	Impulse Ratio	String Efficiency 60-cycle	String Efficiency Impulse
1	80	85	1.06	....	....
2	142	167	1.18	0.87	0.98
3	204	262	1.28	0.85	0.99
4	261	345	1.36	0.81	1.01
5	317	410	1.30	0.79	0.97
6	368	...	...	0.77	....

The 60-cycle spark-over voltage of a bushing or insulator is often very appreciably lowered by rain. It is fortunate, however, that the lightning spark-over voltage is not appreciably changed by rain.

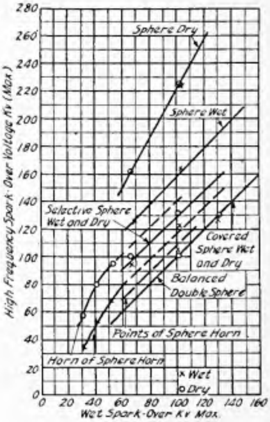

Fig. 14. Relative Discharge Values of Spheres, Selective Spheres, Covered Spheres, 50,000-cycle Sustained Oscillation

The data above were taken on different lengths of strings of Hewlett disk insulators. The impulse was a single half-cycle of a 200-k-c. wave, or of very moderate wave front.

The wet impulse spark-over voltage is approximately the same as the dry.

Impulse ratios of (3) or more have been obtained on bushings. More complete data on line insulators have been published elsewhere.[3]

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[3] Factors Determining the Safe Spark-over Voltage of Insulator and Bushings for High Voltage Transmission Line.—F. W. Peek, Jr., G.E. REVIEW, June, 1916.

Features of the New Steam Power Plant at the Erie Works of the General Electric Company

By A. R. Smith

Construction Engineering Department, General Electric Company

In describing this new steam power plant, the author successively considers the coal and [illegible] facilities, lighting and ventilation, the steam distribution, cable distribution and power distribution. He then deals with the turbine and condenser equipment. Many of the special features in this modern steam power plant will undoubtedly be of interest to our readers.

Mr. A. H. Kruesi has written an introduction to Mr. Smith's article which appears as the first paragraph.—Editor.

Introduction

The Erie Works is situated on a rectangular tract, the Central Avenue of which is about 4500 feet distant from the shore of Lake Erie and the yard level of which is about 95 feet above lake level. Early studies of the design and location of the power plant for this works indicated that there should be a central plant on the works tract of a size just sufficient to generate the steam required for heating the plant and to distribute power, compressed air, live steam, etc. For the economical generation of the bulk of the power, a plant at the lake side of about 20,000-kw. capacity was proposed. Later it was concluded to build a central station which should be capable of expansion to provide for the ultimate works development, but which may never reach assumed capacity. The present plant represents, therefore, about one quarter of what may eventually be a plant capable of supplying 250,000 pounds of exhaust steam per hour and a power output of 25,000 kw. Such a plant is to be regarded as a utility plant rather than as a power plant for the reason that it must deliver many services, such as low pressure steam, high pressure steam, compressed air, water for fire protection, etc. These services impose certain limitations. For example, the boilers must be built for moderate pressure and superheat so as to make them available for the supply of manufacturing steam as well as turbo-generators. In most other respects the requirements are expansive rather than restrictive. Such a plant cannot be built complete and regarded as finished within a few years. It must grow slowly and continuously with the factory it serves over a period of many years. Throughout this period it must

accommodate changes in kind, type and size in every part of its equipment as it grows. It must be adapted for apparatus far heavier and of different proportions than that originally planned for. This applies particularly to ample head room, both in the basement and above. The economy of design of such a plant cannot be judged by the usual standards. Adequate space and flexibility to accommodate changes have been the leading considerations in the design of this station.

Coal Handling Facilities

Coal is received by rail and the standard coal cars are run in the boiler room basement, as illustrated in Fig. 1. Two of these three tracks are primarily intended for handling ashes, but all of the tracks may be filled with cars to permit thawing out the coal in winter, and the coal can be dumped from the cars on all the tracks. A crane is provided for reclaiming the coal from the low storage or for removing coal from flat bottom cars. This crane will also serve to rehandle the coal in case of fire.

Normally, the cars are emptied into the track hopper, shown in Fig. 1, this hopper having a capacity of approximately 50 tons. The coal flows from the track hopper through a crusher to a belt conveyor and thence to a bucket elevator where it is lifted to the distributing belt conveyor above the bunker. If the upper bunker is full and cars are waiting to be unloaded, they may be dumped into the low storage, thus avoiding demurrage charges. If the coal bunker is empty and an expected shipment of coal is delayed, the coal can be reclaimed from the low storage.

The low storage has a capacity for two days' supply, or of 21 fifty-ton cars for half the ultimate station capacity. The overhead bunker has a capacity for two and one half days' supply, or equivalent to 26 cars of fifty-ton capacity.

Method of Handling Ashes

The ash hoppers are sufficient in size to hold a normal 24-hour run of ashes; thus they need only be emptied once a day. The ashes are dumped directly into standard gauge cars, similar to those employed for the transportation of coal. These cars are emptied in the yard, where the ashes are used for fill.

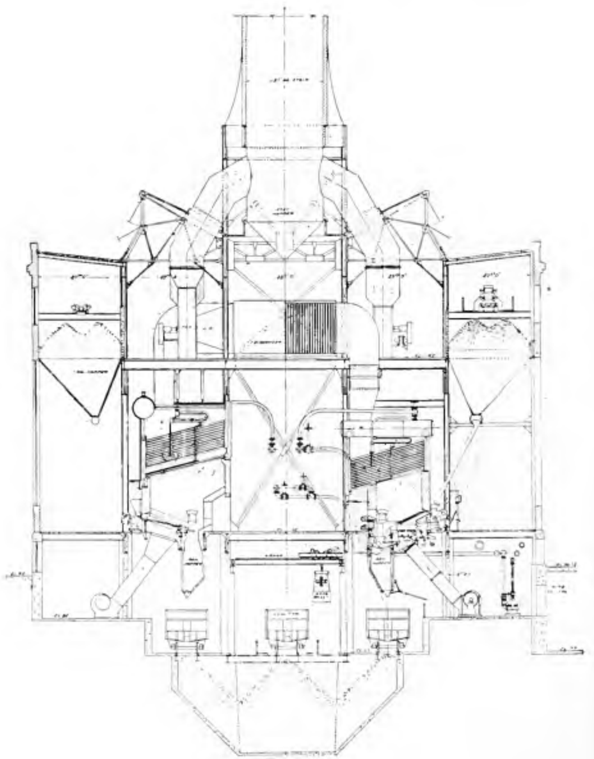

Fig. 1. Traverse Section at Stacks in Boiler Room, Central Power House, Erie Works

Lighting and Ventilation

Particular attention has been given to the natural illumination and ventilation of both the boiler room and turbine room. The coal and ash handling room in the basement consists of a large chamber 74 ft. wide and 28 ft.

high, exclusive of the coal pit. The space may be kept free from combustible gases by means of any of the forced draft blowers supplying the stokers. The basement under the firing aisle is provided with outside windows. The firing aisles are liberally supplied with windows and are also ventilated by means of the monitor roof. The economizer room and the header aisle between the boilers are lighted and ventilated by means of the monitor roof. The distributing conveyor room above the bunker is completely isolated from the rest of the building and separately ventilated and lighted by outside windows.

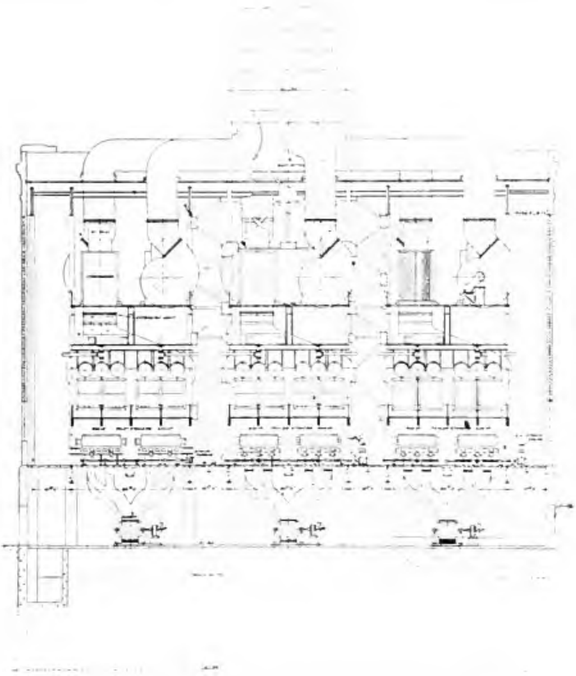

Fig. 2. Longitudinal Elevation Boiler Room, Central Power House, Erie Works

The steam subway is lighted and ventilated by means of a monitor, shown in Fig. 3, and may also be ventilated by the forced draft stoker blowers. The turbine room is provided with windows on both sides. The basement of the turbine room is lighted and ventilated by means of large well openings in the main floor. The [illegible] of switches and the [illegible] ment and the sub[illegible] are lighted and [illegible] windows.

Distribution of Steam

The steam tunnel [illegible] room and the boiler room [illegible] 26 [illegible] ft. high. This tunnel carries [illegible] exhaust mains for heating, the high [illegible] steam mains for testing and manufacturing purposes, the compressed air mains, and the return mains bringing back drips from the manufacturing and heating steam. This subway leads to the Central Avenue of the Works; between the power house and the Central Avenue subway it will be in the form of a twin subway, each about 11 ft. square. The exhaust steam for heating purposes is extracted from the three 2500-kw. turbines, which will supply some 250,000 lb. of steam per hour. This is sufficient exhaust steam for the contemplated ultimate works development, but only represents about one half of the heating steam which will then be required. The maximum heating steam in winter is required for such a short period that the economy of by-product heating does not warrant the increased investment charges consequent to enlarging the exhaust steam mains and tunnels. During extremely cold periods high pressure steam is fed into the heating mains at the various buildings.

Cable Distribution

In order to provide for the maximum flexibility for the distribution of cables, all of which will later be underground, a separate room has been allotted to the cable ducts for outgoing cables. This room is directly below the 11,000-volt switching equipment; and also below the 600-volt switching room, as shown in Fig. 3. There is one bank of ducts for 500-volt direct current cables, two banks for 600-volt a-c. cables, and two banks for 11,000-volt

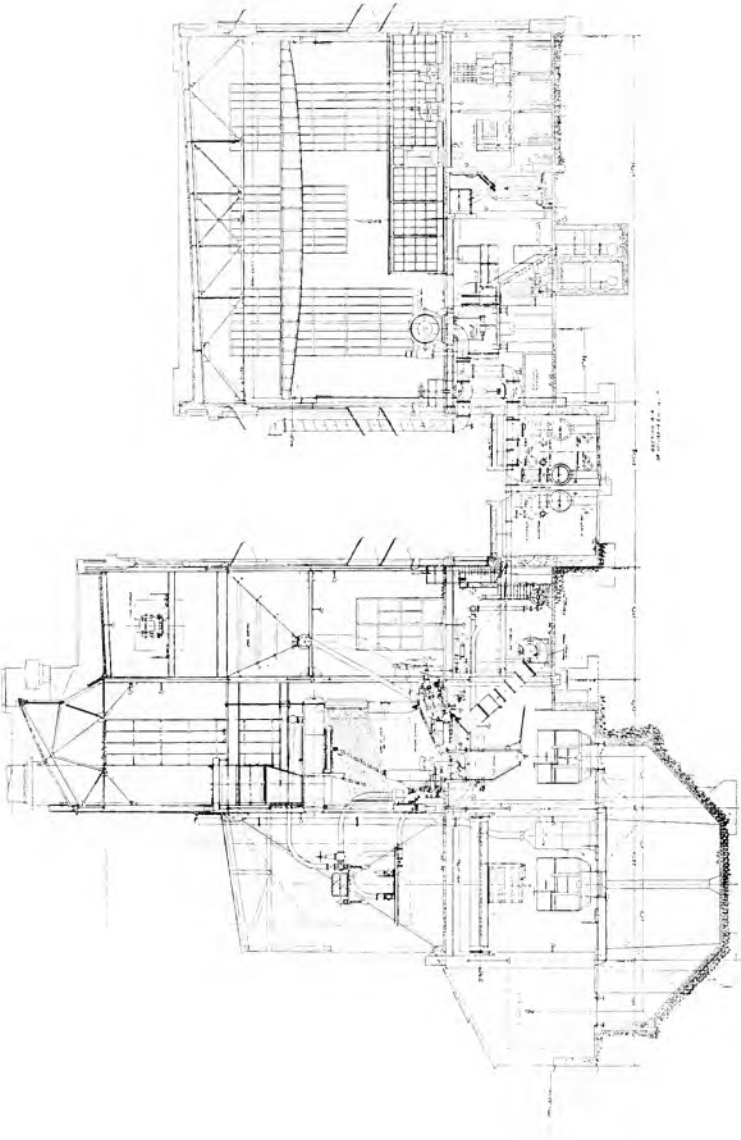

Fig. 3. Erie Works Central Power Plant Section, showing Taylor Stoker

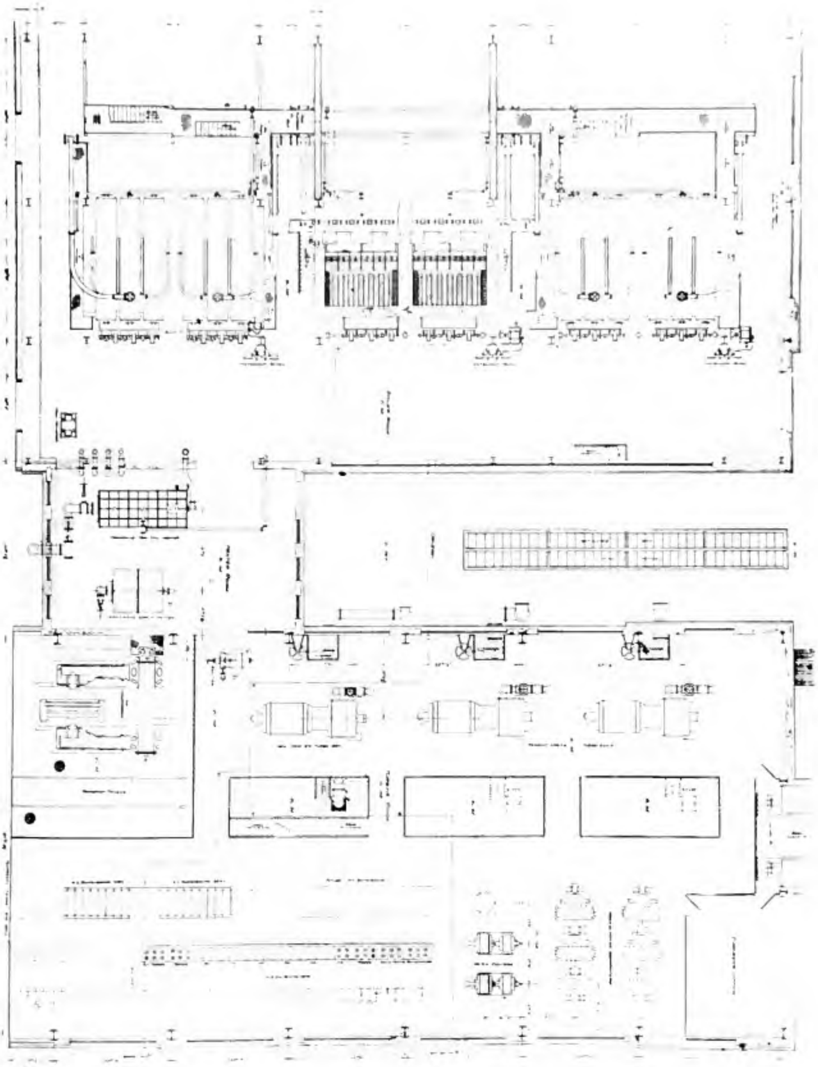

Fig. 4. Erie Works Central Power Plant Main Floor Plan

a-c. cables. Each bank of ducts is arranged so there are only two ducts side by side, and a space for air circulation is provided on either side of the bank. With this arrangement, cables can be taken out from the north or south end of the building and the ducts can be constructed to meet future requirements as regards the position of the switches.

Power Distribution

The major part of the power supplied to the manufacturing buildings is alternating current. The demand for direct current for variable speed tools was reduced to a minimum and the bulk of this is consumed in the large machine shops. On account of the large amount of alternating current which had to be distributed to individual motors, the voltage adopted was 600. For direct current service a 500/250-volt, 3-wire, grounded neutral system is employed. A separate system of 230/115-volt alternating current is used for lighting.

The works is divided into districts. Each district is some 800 or 1000 feet square, and is provided with a substation containing both power and lighting transformers. A separate 11,000-volt underground line will feed each substation and a ring feeder tapping into each substation will be used as an emergency in the event of failure of any main feeder.

For supplying the 500/250-volt direct current, a motor-generator set, designed for power factor correction, will be installed in each of the large machine shops. Other motor-generator sets located in the power house will serve smaller buildings and will act as a reserve through a ring feeder system in the event of failure of any of the distributed motor-generator sets.

An 11,000-volt distribution was found to be no more costly than 6600 volts, although the distances are rather short. In view of the fact that a lake-side power plant may possibly be installed and all of the power transmitted from the lake to the works, 11,000-volt distribution was considered better.

Turbine and Condenser Equipment

The turbine generators are 2500-kw., 600-volt, 3-phase, 3600-r.p.m. Two turbines will carry the existing load, while the third unit is used for a spare. Eventually all three turbines will be equipped with stage valves and will be operated condensing. In winter the necessary heating steam will be extracted from the second stage, the second stage valve serving to regulate the pressure on the heating steam, thus controlling the amount of steam passing into the condenser.

The extracted heating steam pressure will vary from atmospheric to 5-lb. gauge, depending on the weather conditions. Steam is conveyed through check valves to the common 36-in. headers in the subway leading to the manufacturing buildings.

The third unit is now equipped with the necessary condensing apparatus. The condenser, which contains 6000 sq. ft. of surface, is rather unusual in that the tubes are $\frac{5}{8}$-in. diameter and only 9 ft. long. This makes a very short but large diameter condenser shell which gives a direct flow of steam and minimizes the amount of ineffective cooling surface. The results so far obtained are very gratifying and, apparently, justify the design.

Considerable study was given to the question of obtaining condensing water. Lake Erie is about one mile from the works and the elevation of the works is 95 ft. above the lake level. To pump the circulating water against such a head was found uneconomical. The other alternative was to construct a power plant at the lake side. This meant carrying all of the industrial and heating steam a long distance, which entailed a large investment and considerable loss in radiation.

The natural location for a power plant, which primarily must supply industrial and heating steam, was at the center of the works, in practically the location selected. This necessitated the employment of a spray pond for condensing purposes.

The spray pond design represents a new departure, in that the water is sprayed by separate pumps and the circulating pumps take their supply from the cold water tunnel and force it through the condenser. The reliability and simplicity of a spray pond does not justify a spare equipment. We will, therefore, provide only two spray ponds, each good for 2500 kw. With the flexibility of pumping arrangement, as provided, three turbines can be operated from the two ponds with a slight sacrifice in the vacuum, or three turbines may be operated from one spray pond in case of an emergency. On the other hand, two ponds may be used for one turbine with a resulting improvement in the vacuum.

The piping to and from the spray pond is so designed that in winter the water may be circulated across the pond for surface cooling and the sprays shut down. Thus, it will be seen that any combination of cooling may be accomplished from no spraying to full spraying to meet the weather conditions without regard to the power demand.

When the load requirements exceed 5000 kw., a large power turbine of some 6000 kw. can be installed and the power house can continue in growth by addin[illegible] unit. The three 2500-k[illegible] tained for by-product heat[illegible] a spare to the larger unit [illegible] larger turbines will be wound for [illegible] so as to avoid transformation lo[illegible]

Some Sidelights on Construction Work

By N. L. Rea

Construction Department, General Electric Company

Much time and money could be saved if the good advice given in this article were followed. Each case of the transportation and installation of machinery presents its own problems, but the accumulated experience set forth in this contribution will certainly meet some phases of every case.—Editor.

One of the first considerations in undertaking a water power installation is "transportation" and its effect on machine design and shipment. "Transportation" covers all "handling" from the time the parts are placed on the cars until they are under the power house crane. The various parts of this transportation varies, of course, with every installation and deserves careful study for each case.

Railroad clearances are, of course, fixed for the various roads, but vary somewhat for different routes. We have in mind one case where it was possible to get a large piece through by special routing, turning the car several times on turntables, and taking down a couple of cattle loading chutes. The saving in assembly amply warranted the extra expense involved. The "handling" from the time the cars reach the nearest railway siding presents ever varying problems.

Sometimes it is a case of lighterage, again hauling over poor roads with the question of bridges to be considered. Speaking of bridges reminds the writer that it is not always advisable to cross the bridges when you come to them.

A certain power house is reached by a highway bridge about two hundred feet long and twenty feet above the bottom of a shallow stream. For years this bridge has been strengthened by temporary wooden posts whenever new machines were delivered to the power house.

This extra work usually caused cartage to cost from $15 to $20 per ton. On a recent installation a rigger surprised us with a bid of $8.50 per ton. Furthermore, he got away with it at a good profit to himself. He assembled the heavy pieces along the river bank near the bridge approach, waited a couple of days till the river dropped after a rain and crossed above the bridge on a skidway supported on the rocks and temporary cribs made of railway ties.

The delivery from the railway to the power house is sometimes affected greatly by the various seasons. In some cases the material must be delivered by lighterage before the close of navigation. In tropical climates it may be necessary to haul during the dry season as the roads are impassable in the rains. Again, in some places heavy pieces can only be handled over the ice of frozen streams and marshes.

All of these factors as well as the limiting size of pieces deserve careful consideration early in the game as they may warrant radical changes in the design and methods of shipment.

The question of deliveries during certain seasons may, in turn, bring up the question of storage until such time as the power house is ready to receive the equipment. If temporary buildings are necessary, they should be covered by the estimates and made a part of the contract. Armature windings should be protected from freezing by some safe and reliable heating system. An electric heater with thermostatic control is the best solution of the problem, providing of course, that sufficient current is available.

One of the most important considerations and one that deserves more thought than it usually gets, is the living conditions for the men. The large power plants are usually far from the cities, and the large gangs of men quickly swamp all the local facilities. The electrical erectors are the last to arrive and find poor picking in most cases.

The larger jobs last anywhere from six months to a year or more, and it is impossible to get good service from men living in the average construction camp bunk house.

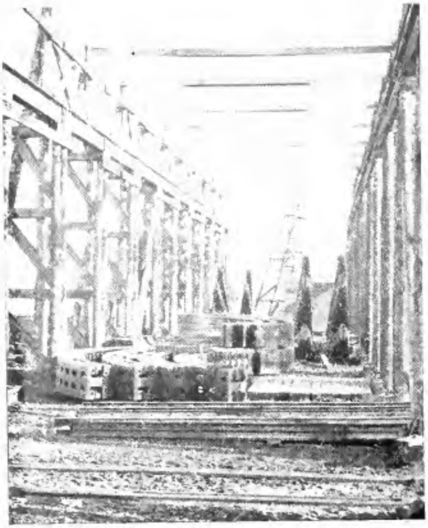

Fig. 5. Outdoor Storage Yard for Large Generator Parts

Fig. 6. Tanking Transformer Core with Special Lifting Device

Fig. 7. Special Eye Bolt for Lifting Complete Rotor

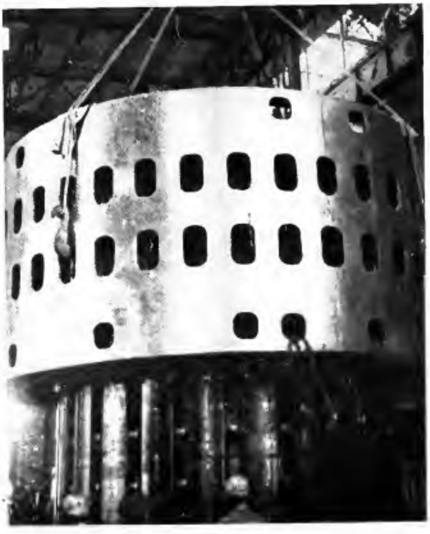

Fig. 8. Handling Armature with Cables and Special Hooks

This question should be studied carefully as early as possible and plans completed before it is time to send men. The earlier the better. In fact, some of the waterwheel manufacturers are thoughtful enough to have living quarters for their erectors covered by their contract.

The power company usually build cottages for the operating crew and one of these may be obtained if the request is filed early. Failing this, a temporary shelter of some sort may be the solution of the problem. In some cases we have used a board floor, and three-foot side walls, topped by a heavy waterproof tent and fly. The ridge pole was carried by 2-by-4 uprights which were a part of the side walls. The tents had a three-foot side wall which gave nearly six foot head room at the eaves. The space between the board side walls and the tent roof was screened and the end provided with a screen door. The side walls can be furled in warm weather. A small joker stove for damp, cold days is a great advantage.

With this arrangement a 12 by 14 tent should be used for every pair of men and a large tent supplied for a dining room and kitchen. This outfit is satisfactory in the southern states all the year round, but, of course, cannot be used in our northern winters. For the northern states or Canada, a board structure should be used.

In one instance we built a two-story house 30 ft. by 90 ft. of matched lumber on a 2-by-4 frame. This was covered outside by two thicknesses of building paper and lined with beaver board on the studding. The lower floor was equipped with a kitchen, dining room, dark room, wash room and three shower baths, and one tub with a hot water tank and heater. The balance of the space was used as storage for tools, supplies, etc. The second floor was divided into sleeping rooms and several sitting rooms, the sitting rooms being equipped with coal stoves. This club house has been used through several winters with great satisfaction. In fact, our men were rather proud about their quarters when compared to the other gangs, with a corresponding increase in their morale.

The next questions are those of assembly and erection which are, of course, in turn influenced by local conditions.

Crane data should be obtained from the customer as follows:

Number and capacity of cranes.

How operated, i.e., hand or electric.

Number of hooks per crane and capacity of each hook.

Dimensioned sketches of crane hooks.

Maximum height of hook [illegible] at the generator foundation.

Distance from the outside of the crane wheels to the center line of crane.

With the above information at hand proper slings can be ordered and a lifting device designed, if necessary. In a few cases the large size of the generators or lack of head room has made advisable a structural steel lifting device for use with two cranes.

An eye bolt is usually necessary for handling the field and shaft on vertical generators. It is our opinion that this bolt should be strong enough to lift the total revolving weight, including the wheel shaft and runner. Sooner or later some power house employee will use the eye bolt for this purpose when changing bearings or working on the wheel and the additional cost of the heavier bolt is cheaper insurance. If the machine has a solid rotor hub, some jacking equipment will be necessary and in many cases we have designed the eye bolt to serve as a strong back as well.

The jacks must, of course, be ordered or obtained locally. This point should be determined in advance of starting the erection.

The question of aligning and leveling the generators must also be carefully planned and any special equipment ordered.

Small machines are comparatively easy to erect and a thickness gauge, plumb bob, straight edge and a good spirit level are about all the special equipment necessary. The larger machines are often beyond the range of any practicable straight edge. These may necessitate a special tram swung on the turbine shaft for centering and leveling. This leveling is, of course, checked with a special Y level and target which will give results inside ten mils on diameters up to 40 feet.

It is advisable to have this work checked by the resident engineer, the waterwheel erector and the generator erector before grouting, and to have all three sign a statement of the facts in triplicate, each retaining a copy for record. Something like the following will serve: "We, the undersigned, have this...... day of...... 19.. checked the setting of Unit No......in the Power House of......Company, at......with the following results:

This unit is on the center line of the generators within......thousandths of an inch.

On its own center line within......thousandths.

Is at the proper elevation within...... thousands.

Is level within......thousandths.

Is central with the waterwheel within...... thousandths.

These three independent checks not only prove the alignment before the base is grouted, but prevent any future discussion in case of trouble developing during operation. It is very important that the wheel erector, generator erector and resident engineer cooperate to the fullest extent. The station cranes are usually the limiting feature in the erection and work should be scheduled so that there will be as little conflict as possible. Each party should know just when he will have the crane and plan his work accordingly. It is sometimes necessary for someone in authority to take a decided stand and force a showdown on the crane service. Far too often one erector will deliberately tie up a crane for hours to delay the other work. Sometimes this is to cover up his shortcomings when his end of the work is behind, or it may be just general cussedness.

The actual details of the erection must, of course, be decided to suit local conditions and the particular design of the wheels and generators. If the machines are shipped without punchings, core assembly tools will be necessary. If without windings an oven for heating coils must be built.

If the armature is shipped wound, but in sections, direct current must be provided for warming the joint coils when making up the split. Sometimes it is necessary to heat the individual coils with current before placing in the slot. This current requirement sometimes runs up to fifteen hundred or two thousand amperes which usually means an electrolytic generator and a motor or engine to drive it. In some cases the exciter sets will be of sufficient size and arrangements can usually be made for using one of them.

The switchboard, exciter and transformer work can usually be easily handled in the time required for the main generator erection. This work should be planned with this end in view and also to take advantage of any holdups on the generator erection by transferring men.

There are always delays on parts of the work caused by belated building construction, the erection of the waterwheels, building of switch cells, bus compartments, delays in shipment, or in transit, etc. Turning these to advantage by the proper shifting of men is one of the best ways of cutting erection costs. Each part of the work should be completed, if possible, and left ready to put in service. Far too many erectors leave a lot of minor adjustments to the last minute only to find that the men have forgotten just where they left off and that the resulting confusion increases cost, delays the starting and creates a very bad impression with the customer.

Fig. 9. Rapid Transit in Manchuria

The best erectors have the loose ends tied up at all times and keep ahead of the other contractors.

The oiling system for the generators should be installed very carefully. Every length of pipe should be reamed at the ends and blown out with compressed air or steam before being connected up. It is advisable to rap the pipe smartly with a rawhide or wooden mallet while blowing out to dislodge any scale or chips.

Oil proof paint or pipe compound should be used on all joints and the complete piping flushed with oil or kerosene before it is ready for service. If the station has a circulating oil system the oil should be pumped through the piping and back through the filter several times as a further safeguard against abrasives getting in the bearings.

Too much care cannot be used during erecting and starting to prevent accidental or malicious damage to the apparatus. The machines should be examined very carefully just before starting until they are turned over to the regular operating force and all general construction work is finished. There is always the chance of bolts, nuts or small tools being left where the vibration, windage or magnetic pull will draw them into the air gap. Malicious mischief is all too common and some warped mentalities take delight in causing damage. In times past we have found railroad spikes, or pieces of scrap iron placed on the air baffle plates between the poles of vertical generators. Machine screws or spikes have been driven into the air ducts so as to ground the winding to the core. Large tacks have been placed in the bottom of a slot while the winders were at lunch. In fact, nearly every kind of scheme that would cause delay or damage has been tried sometime or other. It is, therefore, advisable to quietly, but firmly discourage close inspection by all persons not directly connected with the work. The storage of lunch baskets, coats, hats, etc., on top of oil switch pots or in the bus structure, by laborers, during erection, should be discouraged as it is liable to be continued after the plant is started with surprising, if not disastrous, results.

The amount of drying required will vary inversely with the protection given the apparatus during erection. The expense of temporary shelters over the generators and exciters will often be saved several times over when drying and starting and time is very valuable when starting up.

The subject of drying is too broad for treatment in a short article; however, it may be noted that local facilities will determine the best scheme and it is always wise to play safe. It is better to dry a day or two longer rather than take a chance and burn out an armature. Of course, the operating department will usually bring all sorts of pressure to bear as long as they get the credit for an early start and someone else will be the "goat" if there is trouble.

Perhaps we are over cautious, but that is a good fault, in insisting that the resistance of an alternator shall be higher than the limit given by the following empirical formula:

$$\text{Resistance in megohms} = \frac{3 \times \text{rated voltage}}{\text{Kw. rating.}}$$

This is somewhat higher than the value given by the A. I. E. E. rules, but the formula is an easy one to remember and we have never had any trouble from using it.

After the drying out is completed, the machines should be phased out, the synchronizer and meter connections checked and any necessary changes or adjustments made before the equipment is turned over to the operating force. This transfer should be carried out with enough formality that there can be no question as to the time of transfer or of the operating condition of the equipment as turned over. We have known of bearing failures due to failure of the oil supply, when there were several men who were all supposed to be watching the unit, everyone of them assuming that some of the others were looking after things.

Personal responsibility is a great incentive to good, careful work in operating, as everywhere else, and all chance of starting the old game of "passing the buck" should be avoided.

The last act of a successful installation is the disposal of scrap, excess material and the odds and ends that always accumulate.

Of course, excelsior, packing cases and skids should be looked after as fast as they are emptied to keep down the fire risk.

It is usually advisable to burn the excelsior promptly, as this has little value and is very inflammable. Small boxes can usually be sold for packing or firewood. Large skids can be dismantled for the blocking that is always at a premium during erection or sold to local contractors for blocking or as firewood. The parts of very large machines may be shipped on special cars which are returned to the factory for further shipments. In this case the skids should, if possible, be returned. It is always advisable to ask advice of the factory before disposing of any of the large skids as they are expensive and often can be used to advantage.

During erection all scrap should be saved for disposal at the completion of the work. The value of the odds and ends of scrap cable and wire may run into several hundreds of dollars and will all disappear unless a careful watch is kept.

Short lengths of cable, spare armature coils, insulation, tape, insulators and floor tubes can usually be sold advantageously to the customer for his stock room. The office will always co-operate in this by granting an attractive price.

Any tests necessary for acceptance will, of course, be covered by the contract and all details determined by a conference with the customer's engineers.

These may vary all the way from taking a saturation curve to complete efficiency tests and oscillograph records under short circuit conditions.

On completion of the tests the equipment should be turned over to the customer and a "Construction Foreman's Release" presented for signature to the proper individual in the organization.

The Electrical Layout of Large Power Systems

By Robert Treat

Power and Mining Engineering Department, General Electric Company

The use of power is becoming an increasingly important factor in our daily lives. Many industries are totally dependent for their very existence upon a supply of energy. Electric energy has proved to be superior to any other form of energy as a means of transmitting power from the point of generation to the place of use. Our whole social and industrial existence is vitally concerned in the power supply being continuous, a characteristic which has not heretofore been realized with a full measure of success. The author discusses means for insuring continuity of service, with comments on the investment in protective apparatus and spare equipment which may be justified under varying conditions. A typical transmission network is described, and the application to this system of the principles of selective relaying is taken up in detail.—Editor.

The sum total of human happiness is probably greater than it would be if we could see into the future. Notwithstanding this, there are certain lines of endeavor which would apparently benefit from a dependable power of prophecy. One of these is the industry of electric power supply. Unable to foresee clearly the trend of future developments, the present day power systems have, like Topsy, "just growed" from small stations with local distribution areas. Few companies have been without extensive plans for expansion and development; few have been able continuously and consistently to follow the same plans for any considerable period. Confronted by continually augmented and shifting demands for power on the one hand, and, on the other by frequent inventions or improvements in the art of generating and transmitting power, the electric supply companies have been forced to become opportunists; to discharge first the most pressing obligation, and rejoice if they were able to keep ahead of their demands. Thus, the present physical layouts of many systems may not be ideal for conditions as they now exist, but they represent unamortized investment, and, as such, must be used to the best advantage.

These power systems, developed from small plants located sometimes hundreds of miles apart, have expanded until now many have been combined into larger systems, while both those that remain as individual units and the larger combinations are serving territory more or less contiguous and overlapping. There is today, for very good reasons, a strong tendency toward interconnection of these systems. Here another set of problems is presented. Not only have these individual systems grown up with no very distinct picture of their own ultimate future in mind, but they have had even less idea of ever interconnecting with neighboring systems. Where the lines are of different voltage, and perhaps frequency, the interconnection necessitates the interposition of transformers or frequency converters or both, with the added investment, losses and troubles incident thereto.

There is now much discussion of Secretary Lane's proposal for a super-power line from Boston to Washington, taking power from large mine mouth and tidewater steam stations, and numerous hydro plants, and supplying it to the large cities and industrial centers. Undoubtedly some such system will be in operation in a relatively short time, though what form it will take and by what means accomplished are not now self-evident. Such a project introduces complex problems for which solutions must be found. Before any of our present or future systems can supply ideal service at a reasonable cost, many problems must be solved and many difficulties avoided. Whether or not we have yet reached a stage of development in the electrical art where the demands of the furute can be foreseen more clearly than has been possible in the past, there is no reason for withholding a strong plea that operating companies take notice of what is going on around them; that they formulate their policies for caring for future business not only with due regard to the demands of their own present territory, but that they carefully analyze the effect of probable future interconnections with nearby systems on their own development.

Whether one agrees, with a certain portion of the public, that the function of a power company is to supply power at a reasonable rate, arbitrarily fixed by a Public Service Commission, or whether one believes with the operators and owners of the companies, that the primary purpose is to earn a profit on the investment represented, the essential fact remains that the business of a power company is the generation, distribution and sale of electric power. Due to the pecular inherent characteristics of this form of energy, its merchandising is circumscribed by numerous conditions not associated with other commercial transactions. Lacking economical and adequate means of storage, the first requisite is that its delivery to the consumer shall be continuous and adequate to his need. It should be delivered by such means as to prevent, in so far as possible, abnormal conditions originating on the lines of the power company to injure the customer's apparatus. The potential and frequency must be maintained within commercial limits; and the shape of the voltage wave must conform to a certain standard. These requirements may be summarized as follows:

(1) Reliability of supply.
(2) Avoidance of abnormal conditions on power companies lines which injure customer's apparatus.
(3) Constancy of potential and frequency.
(4) Conformity of wave form to a certain standard.

These conditions, particularly the first three, are so interrelated as to make difficult a consideration of any one without also taking cognizance of the others. For example, an important load may be carried over duplicate feeders; the primary purpose of which is to insure continuous service; the voltage regulation over both lines may be acceptable, while with one line out of service it may not be. Generally a disturbance on the power system of sufficient magnitude to injure a customer's apparatus will also interrupt his power supply; but it is a matter of little interest to the customer whether or not the power company temporarily loses its line, if his own transformer is broken down. His plant has been shut down and from a cause of which he believes himself innocent. The first requirement mentioned, that is, continuous service, is usually the most difficult to meet.

Reliability of supply presupposes adequate generator, transformer and line capacity. Barring such emergencies as war, and its abnormal demands for power, a reasonable alertness on the part of operating managers should find little difficulty in meeting this condition. It is lightning, storms, sleet and other manifestations commonly attributed to the Almighty, which cause the larger number of interruptions to service, and the most worry to the operator. Insulator failures, wire breakage, and acts of willful destruction have added their quota of troubles.

When planning the layout of a large system or subsequent changes thereto, one fundamental principle should be kept constantly in mind—the greatest good to the greatest number. Certain portions of the system, embracing the principal generating stations and substations and the lines between them, may be regarded as of primary importance, all other lines and stations being secondary. The ruling motive should be to keep the primary portion of the system in operation at all times. It is, of course, very desirable to keep all the secondary circuits in continuous operation as well. Indeed, certain operators have been under the impression that equal service could be maintained over the entire system. But the essential point is that the attempt to maintain continuous operation of all secondary circuits must never jeopardize the safety of the primary circuits. The analogy of the railway system is not inopportune. Between certain points, the primary generating stations and substations, express service is maintained. There may be local stations between these points, and there may be local branch lines radiating from the main stations, or, indeed, connecting them. But this local service, while possessing in itself a certain degree of importance, must never interfere with the express service, and should always be subordinated thereto.

The second fundamental principle is that any portion of the system which is in trouble should be disconnected as soon as possible. In a case of necessity it may be permissible to operate a low or moderate voltage line whose neutral is isolated with one wire partially or completely grounded. When such a line constitutes the only source of supply to a substation or customer, such operation may seem necessary in order to avoid a protracted interruption. However, there are some who incline to the opinion that the avoidance of an interruption by this means is only a postponement of the day of retribution, and may in the end be more injurious to the service than if the trouble were promptly remedied. Such a condition, however, will exist only on the secondary circuits. It is not considered good practice, even where possible, to permit a ground to remain on the primary circuits; the danger from the abnormal voltage strain on the ungrounded wires is too real and its possibilities for damage too great.

The maintenance of express service between primary points necessitates the use of at least two circuits. In some cases it has been thought advisable not only to provide two circuits, but to support them on two sets of towers over different rights of way, in order to minimize the chance of an interruption to both lines from the same cause. Frequently it is desirable to maintain two circuits to certain points in the secondary system, as for instance, a large and important customer. Sometimes this may be done for commercial policy, or because the details of certain industrial processes are such that a few moments interruption will cause losses out of proportion to the actual duration of delay. In such a case it may be possible to secure such a rate for the power as to carry the extra investment necessitated by the additional line. In other cases it is possible partially to justify the second line by evaluating the probable loss in revenue from interruptions which might be eliminated by using two lines and from the reduction in line losses.

Some customers may desire service over a line entirely distinct from the rest of the system, even when the tapping of an existing line is quite feasible, in order to be entirely independent as to voltage regulation and interruptions. If such a course involves much additional expenditure, it should be analyzed very carefully, for it may be that the voltage variation is less and the service just as good or better, when taking power from the system as when using a separate line to the generating station.

There has in the past been some uncertainty in opinion as to the value of a solidly grounded neutral as a means of alleviating transmission line troubles. Entirely aside from any theoretical considerations, it is the experience of a number of power companies operating high voltage systems which extend over wide areas, that the troubles experienced with an isolated system decrease after solidly grounding the neutral. A number of such systems have operated under both conditions, first isolated, and later grounded, and it is noted that none have cared to return to the former condition.* A fault on a system having the neutral grounded causes a comparatively large current to flow, whose magnitude can be readily predicted, within reasonable limits, from a knowledge of the reactance of lines and transformers and of the characteristics of the synchronous apparatus which may be connected. This is of considerable value in relaying the system.

Considerable progress has recently been made in the design of accurate and dependable relays, as well as in the number of forms and variety of their application. With the modern induction type time limit overload relay, the directional relay, and the balanced current relay, it is possible to work out many schemes and combinations which a few years ago were beyond the realm of practicability. This improvement, taken in conjunction with the possibility of predicting with considerable accuracy the current which will be caused by a fault on the system, makes possible the application of intricate and complex relaying schemes, which, however, when properly worked out, are quite dependable. By undertaking a comprehensive and exhaustive study of short circuit possibilities in all parts of the system under all probable operating conditions, and in conjunction therewith the use after careful examination of available types of relays best fitted for the service, the Alabama Power Company† has been enabled materially to reduce the number and duration of its interruptions. More and more companies are coming to recognize that money spent for relays and in a very careful study and analysis of their application is an excellent investment.

A very important factor in the problem of maintaining uninterrupted service has been the unexpectedly high depreciation which has been manifested in the suspension and strain type line insulators. This proved to be the cause of very serious worry to operators until the practice of regular periodic testing and renewal of insulators, expensive though it was, became generally adopted, and in a measure served to alleviate the conditions. The seriousness of the situation has stimulated extensive research in the whole problem of insulator design and manufacture, with the result, happily, that we now seem to be on the way toward a solution. It is quite probable, therefore, that one of the most fertile sources of service interruptions may shortly be under control.

Considerable attention is likewise being given to the development of extra high speed lightning arresters in order to remove surges of lightning frequency from the line before a flashover or puncture of the insulators and apparatus bushings occurs. Unfortunately, however, due to the very steep wave fronts of such disturbances a lightning arrester at the end of a line, while it may afford complete protection to the apparatus in the station, is of relatively little value as a safeguard to line insulators some distance away. To alleviate the effects of line insulator flashovers, which on an isolated system may set up disturbances which injure other insulators, and in a grounded system usually trip the line out of service, various devices such as arcing ground suppressors and short circuit suppressors have

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* The relative merits of each method of operating are discussed by Mr. W. W. Lewis in his article, "High Voltage Power Transmission Problems," see page 927 of this issue.

† A description of this system is given in "The Alabama Power Company's System, Its Development and Operation," by Messrs. Oliver, Nikiforoff and McManus, page 980 of this issue.

been tried with more or less success. There is continual progress toward a state where such causes of interruptions to service as cannot be eliminated are reduced to comparative impotence.

The electrical layout of a new generating station or substation always brings up questions of policy with regard to the arrangement. Shall double or single busses be installed, or some combination? Shall selector oil circuit breakers, or disconnecting switches be used? What method of excitation shall be employed?

The answers to these questions may be found in considering whether the station is of vital importance to the system; that is, whether it is a primary or secondary station. If it be a part of the primary circuit, no pains compatible with a reasonable expense should be spared to prevent an accident to the switch gear from interrupting the operation of the station. Usually the switch gear, busses, connections and supports constitute but a small part of the total expense of the development, and the difference in cost between the simplest and the most elaborate switching schemes represents only a few per cent of the total station cost. It cannot, therefore, be called good engineering to jeopardize the output of the entire station for a relatively small item of cost. While an oil circuit breaker of high rupturing capacity, whether for a high or low voltage circuit, is, by itself, somewhat expensive, its cost is a small proportion of that of the generator or transmission line which it protects. The advantage of having an extra circuit breaker, for purposes of inspection, cleaning, and as a spare in case of emergency, is fully worth the slight additional expense. In a similar manner, the use of a double bus, or some arrangement whereby a large capacity circuit is not incapacitated by a failure of any one bus insulator, is justified. It is also desirable to be able to remove a section of bus occasionally for purposes of cleaning without any impairment to service.

The excitation system is also a relatively minor item in the total station cost, and it does not pay to take chances with it. A scheme which is rather popular is the use of direct connected exciters, with a spare motor driven set. If the units are of large size, it is customary to use a separate voltage regulator with each unit; a separate regulator may or may not be used for the spare exciter according to whether there are few or many machines in the station. When the units are quite low speed, there is some tendency toward the use of motor or water wheel driven exciters. If the units are of large [illegible] are more usual than a common [illegible] in which case they will be motor-driven, since it is manifestly impractical to install for each generator a separate exciter wheel. The question of a proper source of power supply for the motors must then be decided. In some stations as, for example, the plant of the Mississippi River Power Company at Keokuk use is made of two separate a-c. generators, each with direct connected exciter, and each large enough to drive the entire exciter plant. A cheaper and less reliable method is to make the station service transformers large enough to drive the exciter plant. If this course is adopted the question of starting up the station after a complete shutdown is presented. For this purpose, two of the main generators may be equipped with direct connected exciters, and these need be only of sufficient capacity to excite the generators to partial voltage at no load. Some hazard, though not very great, would be introduced by thus equipping only one generator, since this machine might be down at the time of a complete interruption.

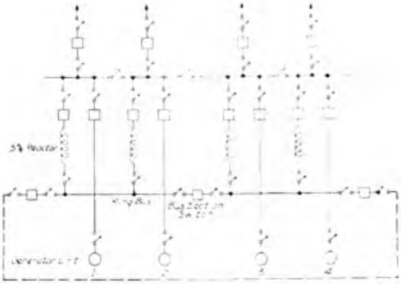

Fig. 1. One Proposed Arrangement of Switching Apparatus for Generating Station of Four (Ultimately Fifteen) Units, Using the Ring Bus and Reactors Between Each Machine and Bus to Limit Short Circuit Currents

If the station is supplying a system which will probably remain in operation independently, some, though not complete, reliance may be placed in this means of starting up the exciter plant. In such a case it would be desirable as an additional precaution to make the station storage battery of sufficient capacity to excite one generator to nearly normal no load voltage for five or ten minutes, until an exciter set can be started.

Opportunity has recently been afforded to study the preliminary plans for the development of a large hydroelectric project. This scheme contemplates an ultimate installation of fifteen 20,000-kw., 12,000-volt generators, four of which are included in the first installation. Fig. 1 shows one proposed scheme of connection for the first four units, and four feeders. It is anticipated that the other eleven units, when installed, will be used largely to supply nearby power systems through stepup transformers.

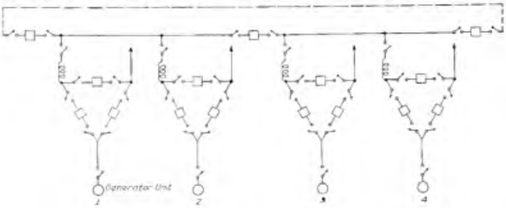

Fig. 2. Arrangement by Which Complete Reliance in One Oil Circuit Breaker (the Disadvantageous Feature of the Scheme Shown in Fig. 1) is Avoided by the Addition of One Disconnecting Switch

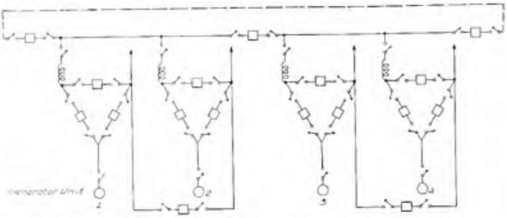

Fig. 3. Arrangement Whereby the Interchangeability of Generators and Feeders Afforded by the Scheme of Fig. 1 May be Secured from the Arrangement in Fig. 2

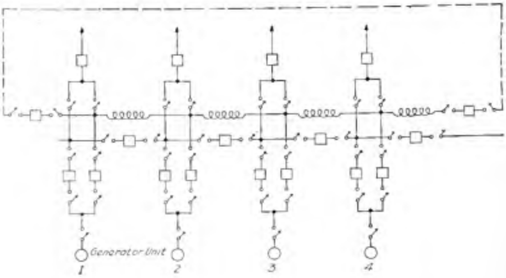

Fig. 4. Arrangement Using Double Bus and Selector Oil Circuit Breakers. Main bus sectionalized by current limiting reactors and auxiliary bus by oil circuit breakers. Note the flexibility afforded by this arrangement

The scheme is to make the feeders and generators of equal capacity, and connect the generators in parallel on a ring bus through reactors of 5 per cent, based on generator capacity. In order to permit serving a feeder from another generator than its own, without going through two reactors, the connection shown dotted may be utilized. This connection might be made through a disconnecting switch or through an oil circuit breaker, with a disconnecting switch on either side. The latter, while more expensive and necessitating a longer structure, is the more flexible. The main objection to this scheme is that there is but one generator oil breaker and no opportunity is afforded to inspect or clean it, nor is a spare immediately available in case of emergency. An accident to this circuit breaker would shut down 25 per cent of the generator capacity during the first installation. After all fifteen units are installed, the loss of one machine would decrease the plant capacity only about 7 per cent, so this objection is less serious for the final arrangement. Fig. 2 shows one method of decreasing this hazard without increasing the number of oil circuit breakers, though the number of disconnecting switches is somewhat increased. In addition, a disconnecting switch may be placed in the outgoing line from each corner of the delta which will afford still more flexibility to the system. Somewhat of a problem is now encountered in providing the interchangeability between generators and feeders, which, in the scheme shown in Fig. 1, is accomplished by a stub bus tie, because the stub bus itself has disappeared. Fig. 3 illustrates one means by which this can be accomplished, though there are other connections of equal advantage. Fig. 4 represents another method of connection, which contemplates a double bus, a main and auxiliary. In the main bus 5 per cent reactors are inserted between each pair of machines and feeders, while the auxiliary bus is sectionalized by oil circuit breakers between each pair. It will be desirable to insert sectionalizing breakers in the main bus about every fourth machine, in the ultimate installation.

While this scheme uses more circuit breakers than the others, it is the most flexible and possibly the best arrangement when considered from all standpoints. The number of oil circuit breakers can be reduced by replacing one of the feeder breakers by selector disconnecting switches as shown in Fig. 5. This procedure is more defensible than the omission of double circuit breakers from the generator circuits, since it is, or should be, possible to carry temporarily the total load over three feeders, with only slight impairment to the operation.

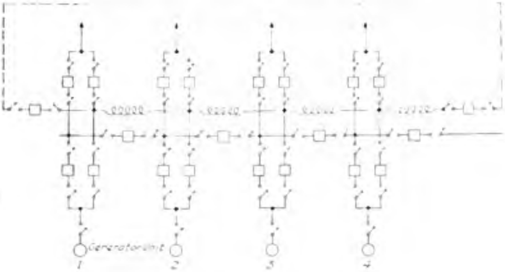

Fig. 5. Arrangement by Which the Flexibility of the Scheme in Fig. 4 is Attained Without Increasing the Number of Oil Circuit Breakers. Note that the omission of double circuit breakers from the feeder circuits is less objectionable than the omission from the generators

Many power stations are operating with the neutral of the generators earthed, even when there is no local distribution, and the only connections to the low tension busses are the generators themselves, the stepup transformers and the stepdown station service transformers. It is possible that this practice may to some extent prevent damage to the low tension apparatus from static disturbances caused by abnormal conditions on the high voltage system. In some cases the earth connection is made through a current limiting resistance. The practical value of this resistance, however, is not above question. It is the general practice, when earthing the low voltage side at the generating station, to earth only one machine at a time, as trouble has sometimes been experienced when connecting the neutrals of two or more machines together at once, from circulating currents. Theoretically, if the generators are all duplicate, any irregularities [illegible] be the same in all machines so that [illegible] harmonic current should circulate [illegible] neutrals; and, in fact, some com[illegible] found it possible to connect the neutra[illegible] two or more machines together with quite satisfactory results.

An excellent illustration of the practical application of the principles here enumerated is afforded by a study of the layout of the Alabama Power Company.* The main generating stations, the 110-kv. substations and interconnecting lines, together with some of the more important customers may be regarded as the express portion of the system of primary importance. The radial feeders and their customers constitute the local, or secondary circuits. It will be noted that there are at least two lines to all primary points and usually one line to other points. At the express stations elaborate relay schemes are utilized to prevent an interruption of service in case one line goes out. Operation was started with an isolated neutral; subsequently, one and later two points in the high tension system were grounded. The rather extensive 44-kv. system has also been grounded in two places in order to secure the beneficial results already obtained by grounding the 110-kv. lines.

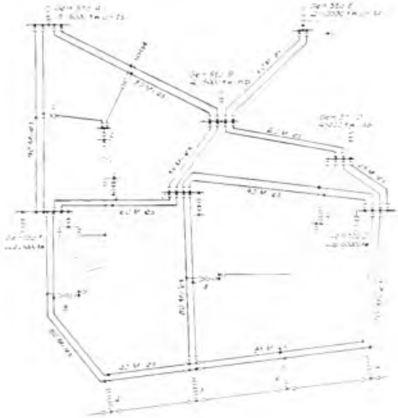

Fig. 6. Geographical Layout of Extensive Power System

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* A diagram of the layout of this system is given in Fig. 4 on page 981 of this issue.

The geographical layout of an extensive transmission system is represented by Fig. 6. This system, like many others, is the result of the growth and combination of several smaller companies. Stations *E* and *F* were first in the field, and each served a purely local load. Other small plants began to appear in the territory, and some of these, located on the southern end of the territory, were more or less interconnected. Then hydro stations *A* and *B* and steam reserve station *D* were built with a large part of the present 132-kv. system. Lastly station *D* was developed. Most of the smaller plants have been abandoned and dismantled, only the two largest, namely, *E* and *F*, being retained as cold steam reserves, and used occasionally as synchronous condensers for voltage regulation. The river on which the hydraulic plants are located has little storage above *B*, but a considerable amount between *B* and *C*, so it is possible to use *C* somewhat as a reserve for seasonal storage. The *B* 132-kv. system is solidly grounded at substation *10*. On the diagram, the heavy lines indicate the high voltage transmission network, and light lines the distribution system, most of which is for 44 kv.

In relaying this network, the best operation demands that the system as a whole be considered, rather than individual stations or lines. The principle of express and local service should be kept in mind. The purpose will be so to select and arrange the relays for each and all operating conditions that when any line is in trouble, the circuit breakers controlling it, and only those, will be opened immediately. To accomplish this, the short circuit currents flowing in all portions of the system should be calculated for faults at a sufficient number of points to give comprehensive data, and under all probable operating conditions. This includes not only such changes in the method of operation as are due to the shifting of the load among generating stations, according to water conditions, but also includes the changes caused where various of the lines are out of service, as they may be for testing, repairs and construction. It will seldom be possible to have the relays at both ends of a line set for instantaneous operation and usually some time delay will be required at both. It is, therefore, important to calculate not only for conditions at the instant the fault develops, but also the amount and distribution of current in the system after the first breaker has tripped. This will serve as assurance that the proper breaker will be next and only one to go. In both calculations, particularly the latter, due weight should be given to the fact that sustained conditions are being approached, and to the effect of the automatic voltage regulator on the output from each station. These calculations entail considerable labor and are next to impossible of performance, if carried out by the ordinary algebraic methods. A device which greatly shortens the amount of work is described in the October, 1916, and the February, 1919, issues of the REVIEW. A description is also given of the method whereby the reactances of generators, transformers and lines are all reduced to a common basis and laid out on the table. When the table has once been set up for the system it is an easy matter to assume faults at any desired point and to read the current distribution throughout the system for each fault.

With complete data as to the current distribution under all possible conditions, consideration of the selection of relays and determination of the settings may be taken up. It should be kept in mind also that the relaying will depend largely on the method of operation. For instance, if all high tension lines are tied solidly together at each station, a very different relay scheme may be demanded than if they are more or less separated and paralleled only on the low side. In the following discussion it will be generally assumed that all high tension lines are paralleled on a single bus.

On a network as large as this it will not be possible to keep in mind all parts of the system and their various requirements at once. Consideration must be given to certain sections by themselves, and then determine the effect of the scheme selected for each section upon the rest of the system. Take first the portion adjacent to station *A*. The four lines to *F* and *B* may be considered the express lines and the aim should be to keep them in service at all costs. The relays at the *A* end of the *A-F* lines must, therefore, be set so as to select the proper line in case of a fault, even at the far end; but they must not trip in case of a fault on the branch line of substation *2*. This would indicate that the breaker at switching station *12* should be instantaneous, with enough delay on the relays at *A* to give time to open. However, *12* cannot be instantaneous, since it could not distinguish, if a fault occurs close to *2*, whether it is on the *12-2* or the *2-1* line. The relay at *12* must, therefore, have sufficient delay to permit *2* to clear first, if the fault is between *2* and *1*. With a simple time delay relay it will be impossible to obtain proper selection between the two breakers at *2*, for no matter on which of the branch lines the fault occurred, practically the same current would pass through each breaker and time delay cannot be used, since for a fault on the *2-1* line, that switch should go first, while for a fault on the *2-12* line, the other should go first. It is, therefore, necessary to make use of a directional relay, so the *2-1* line will trip only with current flowing from *12* to *1*, while the *2-12* line will trip only for current flowing from *1-12*. Equipped thus with directional instantaneous relays at *2*, relays at *1* and *12* may be given sufficient delay to be sure the breaker at *2* has cleared for a fault beyond *2*, and the switches at *A* can be given still more time to be sure the breakers at *1* or *12* have gone in case the fault is on either branch line.

It will be desirable, though not always possible, so to select and set each relay that no change in setting is required with changes in operating conditions. For example, one may be forced to use one current setting for the relays at *A* when all generators at *A* are running, and another when only one or two are in operation.

In case of a fault on one of the *A-F* lines close to station *F*, the current flowing from *A* would be fairly evenly divided and no selective action would be obtainable between the good and the faulty line. In order to prevent both lines, or neither, from tripping at *A*, the switches at *F* must operate quickly. Again, in case of a fault near the *A* end of the line the current from *F* to the fault might be rather small so the relays on the *F* end of the *A-F* line must be set both quick and low. This would require either directional or balanced current relays, as otherwise they would both trip for faults beyond F, which is not permissible. However, they must not operate on a fault on the *12-2* branch line, which is protected at *12* by a time delay relay. All these various requirements can only be met by a nice adjustment between the current and time settings of the relays at *A*, *F* and *12*. Careful study should now be made of the calculated short circuit data and of the time current curves of the various relays to determine exactly the settings required so that only *12* shall trip on a fault on the *12-2* line, while the proper *A* and *F* relays will trip on a fault on the *A-F* line.

It may be desirable to equip the 2 end of the *2-11*, 44-kv. tie line with a directional instantaneous relay, so connected and set as to operate only on a transformer failure, or in case the high tension breaker at *2* failed to function. If the total local load at *2* is too great to be carried satisfactorily from *11*, this relay may be set to trip on overload, thus dropping the local load at *2* but continuing service to the line customers. On the other hand, if the local load at *2* can be carried from *11* temporarily, though with some drop in voltage, this relay may be put on the transformer breaker and save the local load on transformer failure, loss of high tension power, or failure of a high tension breaker at *2* to function. Similar arrangements may be made at *11* and *3*. In addition the 11-kv. tie lines should be given overload time limit protection against faults in the lines themselves.

At the B end of the *A-B* lines, essentially the same conditions obtain as at the *F* end of the *A-F* lines, except that there will always be at least one generator on the bus at *B*.

For the *B-E* lines, which have no local stations, probably the most satisfactory arrangement would be balanced current relays at *B* and directional relays at *E*. This scheme would also be desirable for the *B* end of the *B-D* lines and for both ends of the *B-10* lines.

A fault on either *10-F* line should open the breakers at each end, and in order to get positive selection with the least time delay, perhaps balanced current relays will be most desirable. A directional relay on the low side of the transformer at *11* would save the *11* local load, carrying it from *2*, *F* and *3*, in case the fault were on the line supplying *11*.

The breakers in the *F* end of the *F-5* lines will be required to trip on any fault between *F* and *5*, but they should not go on a fault beyond *5*. Since all six lines at *5* can be given directional or current balance, relays with very small time delay, a little time on the breakers at *F* will permit the *5* breaker to clear first if the fault is beyond *5*. Directional relays on the low side of the transformers at substations *3* to *7* would save the load at those stations on failure of primary supply, provided it were not too heavy for the tie line to adjacent stations. The same applies to *8* and *9*.

The breakers at the *C* end of the *C-5* line will require the same treatment as the ones at the other end of the line in *F*. Adjustment of current settings will undoubtedly be required according to whether the load is largely on stations *A* and *B* or on *C* and *D*.

Since there are no taps therefrom and since each end is on the same bus, each end of the *C-D* lines may be given balanced current protection, which will permit getting a fault off one of these lines with the least delay.

If the pairs of lines betwen stations are split at either end, and terminate on different high tension busses, a different problem is presented. However, the same principles will apply, and the same objects are to be accomplished, though the methods may be somewhat different. For example, suppose at station *F*, normal operation is with one of each pair of lines on one high tension bus and the other three on the other. The relaying at *F* would be dependent upon whether both lines were solidly tied together at the other stations, or were there similarly separated, making, in effect, two separate systems on the same towers. Were such a course adopted, it is probable that best operation would dictate that for such stations as *F*, *10*, etc., where there are two or more banks of transformers in multiple, that they be paralleled only on the low tension side, with the high side of each connected to each bus. While there are at least two sources of power to each station, so any one line failure would hardly cause an interruption, still were this scheme adopted, a failure of one high tension bus, or even the loss of one entire system would not cause an interruption since the bank remaining in service would carry the load until the other could be put back. The proper protection would be directional relays on the low side of each transformer, to trip on reversal of power.

With this system of operation less use will be made of balanced current relays, which might have been used to good advantage on the *A* end of the *A-F* lines, when all lines were on the same bus at *F*. But with the two *A-F* lines separated at *F*, a fault on one of the *F-5* lines or on one of the *F-10* lines would also cause some unbalancing at *A*, and it might not be possible to get such a setting at *A* as would give proper selection between faults on the *A-F* lines and faults on *F-5* or *F-10* lines.

Whatever relay system is adopted, it must be designed with full consideration of the proposed method of operation, and any departure therefrom may necessitate a radical revision of the whole scheme of relaying.

It is unlikely, however, that perfect operation will be obtained from the start on a newly designed relay scheme for an extensive system, no matter how much study is given to the probable sources of trouble, distribution of short circuit currents and settings of relays. Unforeseen conditions are likely to arise, errors in connections and settings will creep in, and sources of trouble, due to special operating conditions, will occur that are bound to upset some of the plans. To get the best results from the use of relays in promoting continuity of service, every large company should have a competent man whose business it is to work out the problem, have charge of the setting of relays and follow up every case of trouble Accurate records of relay performance, including cases both of failure to operate and wrong operation, as well as correct operation with appropriate notation on system conditions, cause of trouble and other pertinent information, should be kept by the relay engineer. These records will serve as a basis for checking relay operation and for any changes in the general scheme which may be considered or necessitated as the system grows. Several power companies have already adopted the policy of employing an engineer, sometimes with one or more assistants for just this kind of work, and they report that the results are worth many times the expense involved.

High Voltage Power Transmission Problems

By W. W. Lewis

Power and Mining Engineering Department, General Electric Company

The voltages which have come into use for power transmission within the past ten or [illegible] presented many problems not encountered in dealing with more moderate potentials. Electro[illegible] is a factor which cannot be neglected in calculating the characteristics of long, high voltage lines, [illegible] general, the charging current is beneficial to the operation of a fully loaded line, it [illegible] serious consideration on a lightly loaded circuit. For the calculation of any lines which have so far [illegible] one or two terms of the formulae developed by Dr. Steinmetz and discussed by Mr. Peek in the [illegible] issue of this paper are sufficiently accurate, but it is possible that voltages and lengths of lines [illegible] reached where it will be necessary to employ the rigid hyperbolic formulae. The author discusses with [illegible] familiarity of long association some of the phenomena encountered in high voltage transmission, the practical aspects thereof and the theoretical considerations involved.—Editor.

The art of transmitting power by high voltage lines has progressed steadily since the first 100,000-volt lines were installed in 1908 and 1909. The problems arising in connection with such transmission, however, still appear to be innumerable and inexhaustible. A few of the present day features of high voltage transmission and the problems that frequently arise in connection with such transmission will be briefly discussed in this article.

Voltage

The range of voltage has extended upward until now there are at least two 150,000-volt systems in active operation and voltages up to 220,000 are being discussed. In Table I are tabulated the systems of 70,000 volts and above with data as to their normal voltage, altitude of stations, grounding of neutral and frequency. The normal voltage here given is the voltage of the highest tap of the generating station transformers, and this is the voltage which should be considered in insulating the transformers and other apparatus on the line, as it is apparent that all the apparatus may be subjected to this voltage or greater during certain periods of operation. Thus, at times of heavy load the generating station apparatus is subjected to this voltage and at times of light load the substation apparatus receives this voltage or higher.

In the interest of standardization of apparatus it is important that the number of voltages be kept as small as possible. It has happened usually in the past that a voltage was selected strictly with regard to local conditions, whereas the nearest standard voltage would have been equally suitable and had it been adopted fully developed and standardized apparatus for that voltage would have been available. The following normal voltages for systems 44,000 volts and above have been proposed and seem to fit all the usual requirements for present-day operation in this country.

Standard Normal System Voltages*

44,000	132,000
66,000	154,000
88,000	220,000
110,000	

In systems employing transformers the normal voltage of the system is defined as the highest rated voltage of the secondaries of the transformers supplying the system. This voltage rating shall apply to all parts of the system. It is to be understood that the A. I. E. E. Standardization Rules on dielectric strength tests are based on the normal voltage of the system, as defined above, on which the apparatus is to be installed. All dielectric strength tests shall be based on the normal voltage of the system, even if apparatus is to be applied on a part of the system which ordinarily operates below normal voltage.

It is to be hoped that operating companies in planning new systems, or extensions to old systems, will adhere to the above voltages, as it is believed that mutual benefit will result to all from the adoption of this practice.

The choice of voltage is based on a number of factors, the main ones of which are economical considerations as shown by the calculation of line losses and voltage drop. The voltage thus selected may be modified by practical considerations, such as the limits of apparatus developed. The size of conductor chosen is likewise based mainly on consideration of losses, but also on consideration of mechanical strength and other factors. The tendency has been largely to adopt a size of conductor that would not give corona loss at normal operating voltage. This frequently leads to a much larger size than necessary for carrying the power current and the tendency

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* If a voltage intermediate between 154,000 and 220,000 is required, 187,000 should be used.

TABLE I

PRINCIPAL POWER SYSTEMS—70,000 VOLTS AND ABOVE

No.	System	Altitude of Stations Feet	Normal Voltage	Freq. Cycles	Neutral Ground
1	Aluminum Co. of America (Tallassee Dev.)	1000	150,000	60	Dir.*
2	Southern Cal. Ed. Co.	0–5000	150,000	50	Dir.
3	Southern Sierras Pwr. Co.	1000–4500	150,000	60	No
4	Consumers Pwr. Co.	750	140,000	30/60	No
5	Nevada-Cal. Pwr. Co.	5000	140,000	60	No
6	American Gas & Elec. Co.	600–1000	138,500	60	Dir.
7	Central Pwr. Co.	600–1000	138,500	60	Dir.
8	Utah Pwr. & Lt. Co.	4000–6000	130,000	60	Dir.
9	Catalana de Gas y Electricidad Cia.	0–3000	130,000	50	
10	Pacific Gas & Elec Co.	0–4500	125,000	60	Dir.
11	Compagnie des Chemins de Fer du Midi	3300	120,000	50	
12	Tennessee Pwr. Co.	500– 900	120,000	60	No
13	Wisconsin-Minn. Lt. & Pwr. Co.	800	120,000	60	Dir.
14	Minneapolis General Electric Co.	500	120,000	60	Dir.
15	Columbus Pwr. Co.	350– 950	115,000	60	No
16	Inawashiro Hydro-Elec. Pwr. Co.	0–2500	115,000	50	No
17	Hydro-Elec. Pwr. Comm. of Ont.	600	110,000	25	Res.†
18	Hamilton Hydro-Elec. System	600	110,000	25	Res.
19	Lauchhammer A. G.	500	110,000	50	No
20	Georgia Rwy. & Pwr. Co.	600–1600	110,000	60	Res.
21	Alabama Pwr. Co.	200– 800	110,000	60	Dir.
22	Mississippi River Pwr. Co.	460– 530	110,000	25	Dir.
23	Lehigh Navigation Elec. Co.	1000	110,000	25	Res.
24	Aluminum Co. of America (Massena Dev.)	300	110,000	60	No
25	Virginia Rwy. & Pwr. Co.	0– 100	110,000	60	Dir.
26	Mex. Northern Pwr. Co.	2000–3000	110,000	60	Res.
27	Ebro Irrigation & Pwr. Co.	0–3000	110,000	50	Dir.
28	Chile Exploration Co.	0–9000	110,000	50	Dir.
29	New England Pwr. Co.	0– 500	110,000	60	Dir.
30	Washington Water Pwr. Co.	2000–4000	110,000	60	Dir.
31	Puget Sound Trac., Lt. & Pwr. Co.	0– 600	110,000	60	Dir.
32	C., M. & St. P. R. R. (Western Elect.)	0–4000	110,000	60	Dir.
33	Southern Pwr. Co.	400– 850	110,000	60	Dir.
34	City of Los Angeles	200–2100	110,000	50	Dir.
35	Yadkin River Pwr. Co.	100– 400	103,900	60	Dir.
36	Carolina Pwr. & Lt. Co.	100– 500	103,900	60	Dir.
37	Palmetto Pwr. & Lt. Co.	100– 400	103,900	60	Dir.
38	Montana Pwr. Co.	4000–6000	102,000	60	Dir.
39	C., M. & St. P. R. R. (Eastern Elect.)	5000	102,000	60	Dir.
40	Great Falls Pwr. Co.	3300–5500	102,000	60	Dir.
41	Anaconda Copper Min. Co.	3300–5500	102,000	60	Dir.
42	Thompson Falls Pwr. Co.	4000–6000	102,000	60	Dir.
43	Great Western Pwr. Co.	0– 500	100,000	60	No
44	Colorado Pwr. Co.	5000–10500	100,000	60	No
45	Tata Hydro-Elec. Pwr. Supply Co	0–1000	100,000	50	No
46	Andhra Valley Power Supply Co.	0–1000	100,000	50	Dir.
47	Sierra & San Francisco Pwr. Co.	0–2000	104,000	60	Dir.
48	Truckee River General Electric Co.	4000–6000	104,000	60	No
49	Shawinigan Wtr. & Pwr. Co.	100– 300	100,000	60	Dir.
50	Pueblo Tramways, Lt. & Pwr. Co	7000–7500	100,000	60	
51	Appalachian Pwr. Co.	1000–2500	88,000	60	No
52	Societa Italiana di Elettrochimica	0– 500	88,000	42	No
53	Rio Janiero T. L. & Pwr. Co.	0–1000	88,000	50	No
54	Tasmania Hydro-Elec. & Metal Co.		88,000	50	Dir.
55	Sao Paulo Elec. Co.	0–1000	88,000	60	No
56	Energia Electrica de Cataluna	0–1000	88,000	50	Dir.
57	Victoria Falls & Transvaal Pwr. Co	1000	88,000	50	Res.
58	Sou. Sierras Pwr. Co.	1000–4500	87,000	60	No
59	Toronto Pwr. Co.	300– 750	86,500	25	No
60	Mexican Lt. & Pwr. Co.	3000–7500	85,000	50	Dir.
61	Northern Pwr. Co. (N. Y.)	300	80,000	60	No
62	Hannawa Falls Pwr. Co.	300	80,000	60	No

* Dir. = Direct

† Res. = Resistance

TABLE I—*Continued*

PRINCIPAL POWER SYSTEMS 70,000 VOLTS AND ABOVE

No.	System	Altitude of Stations Feet	Normal Voltage	Cy.	[illegible]
63	Racquette River Paper Co.	300	80,000	60	[illegible]
64	Swedish State Railways	1000–2000	80,000	15	
65	Katsuragawa Hydro-Elec. Co.	0–1000	77,000	50	Re
66	Nagoya Elec. Lt. Co.		77,000	60	
67	Milwaukee Elec. Rwy. & Lt. Co.	600	76,200	25	
68	So. Cal. Ed. Co. (Kern River No. 1 Dev.)	2700	75,000	50–60	Dir.
69	So. Cal. Ed. Co. (Kern River No. 3 Dev.)	2700	75,000	50–60	Dir.
70	So. Cal. Ed. Co. (Los Angeles District)	200	72,000	50	Dir.
71	New England Pwr. Co.	0–500	72,000	60	Dir.
72	City of Milan	800–1000	72,000	42	Re
73	Consumers Pwr. Co.	600	72,000	30	No
74	Societa Generale Elletrica dell' Adamella	500–2000	72,000	42	No
75	City of Winnipeg		72,000	60	
76	Hydroelectrica Espanola Molinar	0–1000	70,000	50	No
77	Penn. Wtr. & Pwr. Co.	0–500	70,000	25	Re
78	Guadalajara, Mexico	1000–3000	70,000	50	No
79	Societa Ellectrica Rivera di Ponente	0–1000	70,000	50	Re
80	Swedish State Railways	1000–2000	70,000	25	Dir.

now is to allow a reasonable amount of corona loss, which combined with the other losses should not give an economically excessive total loss.

Calculation of Regulation and Losses

Voltage regulation and line losses are the limiting features in determining transmission voltage and size of conductor. In calculating these the writer has found most useful the method outlined by Peek in the GENERAL ELECTRIC REVIEW of June, 1913, and for longer lines and more rigid calculations the hyperbolic formula given below:

$$E_1 = E_0 \cosh ns \pm I_0 Z_0 \sinh ns \qquad (1)$$

$$I_1 = I_0 \cosh ns \pm (E_0 / Z_0) \sinh ns \qquad (2)$$

in which

E_1 and I_1 are respectively voltage and current (expressed in vector quantities) at one end of the line.

E_0 and I_0 are respectively voltage and current at other end of line.

If E_0 and I_0 are voltage and current at the receiving end of line, the plus sign (+) between the two terms of the right-hand member should be used. If E_0 and I_0 are at the generating end, the minus sign (−) applies.

Voltage is from line to neutral and current for one conductor.

$$n = \sqrt{ZY} = A + jB$$

$$A = \sqrt{\tfrac{1}{2}\left[(gr - bx) + \sqrt{(gx + br)^2 + (gr - bx)^2}\right]}$$

$$B = \sqrt{\tfrac{1}{2}\left[-(gr - bx) + \sqrt{(gx + br)^2 + (gr - bx)^2}\right]}$$

r = resistance per mile in ohms.
x = reactance per mile in ohms.
g = conductance per mile in ohms.
b = susceptance per mile in ohms.
s = length of line in miles.
$Z = r + jx$ = impedance per mile.
$Y = g + jb$ = shunted admittance per mile.

$$Z_0 = Z / n = \frac{r + jx}{A + jB}$$

$$\cosh ns = \cosh (A + jB)s = \cosh As \cos Bs + j \sinh As \sin Bs$$

$$\sinh ns = \sinh (A + jB) s = \sinh As \cos Bs + j \cosh As \sin Bs$$

Angles As and Bs are in radians.

When power-factor angles are plus (+), the power-factor is leading; when minus (−), the power-factor is lagging.

An example will be given showing the method of using these formulas:

Assume:

Receiver voltage 200,000 between lines.
Spacing conductors 20 ft.
Conductor 750,000 cir. mil. copper 1-in. diameter.
Frequency 60 cycles.
Length 250 miles.
Leakage losses 2-kw. per mile per conductor.

Then

$r = 0.119$ ohm per mile.
$x = 0.805$ ohm per mile.
$g = 0.15 \times 10^{-6}$ ohm per mile.
$b = 5.28 \times 10^{-6}$ ohm per mile.

$$gr-bx=0.15\times10^{-6}\times0.119-5.28\times10^{-6}\times0.805=-4.23\times10^{-6}$$

$$(gr-bx)^2=17.9\times10^{-12}$$

$$gx+br=0.15\times10^{-6}\times0.805+5.28\times10^{-6}\times0.119=0.7498\times10^{-6}$$

$$(gx+br)^2=0.56\times10^{-12}$$

$$\sqrt{(gx+br)^2+(gr-bx)^2}=\sqrt{(17.9+0.56)10^{-12}}=4.3\times10^{-6}$$

$$A=\sqrt{\tfrac{1}{2}[(-4.23\times10^{-6})+4.3\times10^{-6}]}=0.184\times10^{-3}$$

$$B=\sqrt{\tfrac{1}{2}[4.23\times10^{-6}+4.3\times10^{-6}]}=2.07\times10^{-3}$$

$$n=A+jB=(0.184+2.07j)10^{-3}$$

$$Z_0=\frac{Z}{n}=\frac{0.119+0.805j}{(0.184+2.07j)10^{-3}}=391-22.8j$$

$$\frac{1}{Z_0}=\frac{1}{391-22.8j}=(2.545+0.1485j)10^{-3}$$

$$\frac{E_r}{Z_0}=115{,}500\ (2.545+0.1485j)10^{-3}=294+17.18j$$

$$(A+jB)s=(0.184+2.07j)10^{-3}\times250=0.046+0.5175j$$

$$\cosh As=\cosh 0.046=1.0011$$

$$\sinh As=\sinh 0.046=0.046$$

$$\cos Bs=\cos 0.5175=\cos 29.65^\circ=0.869$$

$$\sin Bs=\sin 0.5175=\sin 29.65^\circ=0.495$$

$$\cosh ns=1.0011\times0.869+0.046\times0.495j=0.871+0.02275j$$

$$\sinh ns=0.046\times0.869+1.0011\times0.495j=0.04+0.495j$$

For line open at receiver end, $I_r=0$.

$$E_g=E_r\cosh ns=115{,}500\ (0.871+0.02275j)=100{,}706+2625j$$

$$E_g=\sqrt{100{,}700^2+2625^2}=100{,}800$$

$100{,}800\times1.73=174{,}000$ volts between conductors

$$I_g=(E_r/Z_0)\sinh ns=(294+17.18j)\ (0.04+0.495j)=3.26+146.49j$$

$$I_g=\sqrt{3.26^2+146.49^2}=146.5$$

$$\tan\theta=\frac{2625}{100{,}700}=+0.0261\qquad\theta=1^\circ\ 30'$$

$$\tan\alpha=\frac{146.49}{3.26}=+45\qquad\alpha=88^\circ\ 44'$$

$$\phi=88^\circ\ 44'-1^\circ\ 30'=87^\circ\ 14'$$

$\cos\phi=0.048$ leading

Kv-a. $=3\times146.5\times100.8=44{,}400$

Kw. $=44{,}400\times0.048=2130$

These formulas are especially useful where a number of lines of different lengths having the same constants per mile are to be calculated.

On systems transmitting considerable power over a long distance it is necessary for good regulation and reasonable losses to employ synchronous condensers of from 50 per cent to 75 per cent of the rating of the load. Without these condensers operation usually would not be feasible.

The Grounded Neutral

There has been a steady drift in the past few years away from the isolated neutral and toward the grounded neutral among the large, high voltage power systems.

The chief argument in favor of the isolated neutral is the possibility of continuing operation in case one line becomes grounded. That this has been done in some cases is unquestioned. Reports in general, however, indicate that this operation is not practicable on a line of high voltage or great length because of (a) the rise in voltage on the ungrounded lines causing danger of breakdown on these lines; (b) the increased charging current and corona due to the increased voltage of the two lines above ground, and (c) the telephone interference due to the unbalanced electrostatic conditions, which experience has demonstrated makes it almost impossible to operate telephone lines in the vicinity of the power lines, especially the power company's own telephone system.

Experience has shown that arcing grounds on an isolated neutral system usually results in insulator breakdowns on one of the ungrounded lines, which may be followed by secondary breakdowns at other points on the system. A ground on an isolated neutral system usually results in an arcing ground as the ground originally takes place by arcing over an insulator, the charging current of the line discharging into the ground. The combination here of capacitance, inductance and arc produces an arcing or oscillating ground, which is capable of producing very high overvoltages on the ungrounded phases. Often this results in breakdowns on several feeders, either simultaneously or successively, and several switches may trip out on different parts of the system, in which case there is no definite manner of quickly selecting the faulty line to clear the cause of the trouble.

A ground on a grounded neutral system, on the other hand, produces only a short circuit, which causes a reduction of voltage on the shorted leg and produces no over-voltage on the ungrounded phases. In the case of a grounded neutral system, there will occur practically as many first cases of line failure, such as breakdown of insulators or other apparatus, but as soon as one phase becomes grounded there is a short circuit on one leg of the grounded neutral transformer and a reduction in voltage on all three phases due to armature reaction in the generators, which causes no over-voltage stress on any part of the system. In consequence, secondary breakdowns are almost unknown on a grounded neutral system. Most of the troubles on a grounded neutral system will be confined to one point and the current in the short circuit flows over definite and known paths which makes it possible automatically to select the line in trouble and save the service on the remainder of the system. Selective action by relays, therefore, becomes more positive with this connection. For these reasons the grounded neutral system is finding more and more favor with operating companies.

Operation with grounded neutral lends itself most readily to networks where a section of line in trouble may be isolated without cutting off the service from the customers. On single circuit transmission systems it is not desirable to cut off the line every time a ground occurs and for this reason such systems are usually operated with isolated neutral.

Even here, however, the advantages of the isolated neutral are doubtful. Hanging on to a ground in order to avoid interruption to service frequently results in destruction of the insulator or a burned-off conductor. This undoubtedly causes a more serious interruption than would be experienced if the line were pulled off at once and then put back into service immediately.

At the Pittsfield meeting of the A.I.E.E. in May, 1914, the writer analyzed with respect to isolated or grounded neutral a list issued by the *Electrical World* of systems 70,000 volts and above. This analysis showed of thirty-five systems in North America, eighteen with grounded neutral and of nineteen systems in the remainder of the world, six with grounded neutral. It is interesting to compare these figures with similar figures of systems at the present time. Of fifty separate systems in North America, thirty-two have grounded neutral and of twenty-two systems in the remainder of the world, ten have grounded neutral. Thus, a gain is shown in both cases, not only in the absolute number of grounded neutral systems, but in the percentage of the total.

This increase is brought about partly by changes in systems that previously had isolated neutrals and partly by new systems. Among the systems that changed from isolated to grounded neutral may be mentioned the Utah Power & Light Co. operating at 130,000 volts and the Montana Power Company, operating at 102,000 volts. Our records show the following foreign systems which were given in the 1914 list with isolated neutral now operating with grounded neutral: Ebro Irrigation & Power Co., 110,000 volts; Chile Exploration Co., 110,000 volts; and Energia Electrica de Cataluna, 88,000 volts. The following new systems have grounded neutral: Aluminum Company of America (Tallassee Development) 150,000 volts; American Gas & Electric Co., 138,500 volts; Wisconsin-Minnesota Light & Power Co., 120,000 volts; Virginia Rwy. & Power Company, 110,000 volts; Washington Water Power Co., 110,000 volts; and the Andhra Valley Power Supply Co., 100,000 volts.

The following systems which were formerly grounded through resistance have made changes in their arrangement: Southern Power Company, from resistance ground to direct ground; Shawinigan Water & Power Co., from 120 ohms at the power station to direct ground at both ends of the line; Hydro-Electric Power Commission of Ontario, from high resistance of approximately 5000 ohms to 100 ohms water resistance. The Turners Falls Power & Electric Co., which is almost in the 70,000 volt class, has changed from isolated neutral to direct grounded neutral.

In most cases one grounded neutral is considered sufficient. This is usually at the generating station. If, owing to the transformer connections, it is not feasible to ground at the generating station, then the ground is usually placed at some centrally located sub-station. This was done, among others, on the systems of the Montana Power Company and the Utah Power & Light Company. The Turners Falls Power & Electric Co. ground at a standby steam plant, the ground being kept on at all times even though the steam plant is not running. The direction of current flow in case of a ground on the line is different with the substation neutral grounded than with the generator neutral grounded. Nevertheless, the relaying is practically the same and seems to give equally good results. A discussion of the direction of flow of current with substation neutrals grounded and the selection of the proper size of grounding transformer was given in a previous number of the REVIEW.*

Two or more grounded neutrals are sometimes employed. This is to insure that even though part of the system is cut off by trouble or otherwise, the remainder of the system will still have a grounded neutral. It also has the effect of reducing the length and impedance of the path for the short circuit current and insures that the grounded line is brought to approximately zero potenial from the accidental ground to the grounded transformer. The ground current will cause telephone interference in case of a short circuit if either one or the two grounded neutrals are used, possibly more severe in the latter case but also of shorter duration. Of course a ground on an isolated neutral system would also produce telephone interference.

The question arises whether under normal operation there will be a circulating current between the two grounded neutrals sufficient to produce telephone interference. If the low voltage side of the transformers is connected delta, this is not probable, although there have been some cases reported in which even with this delta winding neutral currents have circulated of sufficient magnitude to cause serious disturbance. A circulating current could be produced from one of three causes: (a) An unbalanced voltage due to a difference in the three legs of the transformer, (b) an unbalanced current due to single-phase load; (c) a difference in the characteristics of the transformers at each end of the line, resulting in a small residual third harmonic voltage. In (a) and (b) the ground current would be of normal frequency, and in (c) of three times normal frequency.

In case Y-Y transformers were used with grounded neutral and there was a Y-delta bank on the system with grounded neutral, then there would circulate between the transformers the third harmonic magnetizing current of the Y-Y bank. Such a connection is very seldom encountered in this country. Three-phase transformers of the three-legged core type greatly reduce the amount of third harmonic magnetizing current required, and hence reduce the circulating current that can be obtained. If it is necessary, therefore, to use a Y-Y connection for any reason, then the transformers should be of the three-phase, three-legged core type, or else a tertiary delta winding should be provided to take care of the third harmonic magnetizing current. It is well even if a three-legged core type transformer is used to have the tertiary winding also as a precautionary measure.

A number of systems are operating with more than one neutral ground. Among these may be mentioned the New England Power Company, the Alabama Power Co., the Shawinigan Water & Power Co. and the Pacific Gas & Electric Company. The evidence as to the value of this operation and as to the danger of telephone interference is not at all conclusive. Where so many variable factors are involved and local conditions govern so largely, experience is more valuable than theory and so like many another problem in power transmission, this question is being worked out in practice.

Telephone Interference

The matter of interference of power systems with communication circuits has received a great deal of attention in the past few years. This matter has been most thoroughly investigated by the Railroad Commission of the State of California through its Joint Committee on Inductive Interference. The conclusions of this committee were embodied in a final report issued last year.

General experience has shown little interference from three-phase power systems. What interference has been experienced has been due mostly to single-phase systems and direct-current railway circuits with a very small amount of trouble due to circulating currents between grounded neutrals on three-phase power systems. As a rule, the three-phase currents and voltages are fairly well balanced and this coupled with the fact that the communication circuits are usually well removed from the power circuits renders danger of interference slight. In the single-phase and direct-current circuits the interference results from slot harmonics, which are usually taken care of by resonant shunts at the terminals of the machines. Modern machines are designed so that the slot harmonics are a negligible quantity. Where there is danger of interference it is possible in most cases to so arrange the telephone circuit that such danger is reduced to a minimum.

Such questions as arise are usually satisfactorily worked out by co-operation between the power and telephone companies. Both companies recognize the fact that their service is necessary to the public and that they should get along with as little interference with each other as possible.

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* "Short Circuit Currents on Grounded Neutral Systems," by W. W. Lewis, GENERAL ELECTRIC REVIEW, June, 1917.

Lightning Protection

Lightning protection has progressed with the remainder of the art. The aluminum cell arrester continues to be the standard for transmission voltages. The efficiency of these arresters has been greatly improved by increasing the speed of the gaps by the use of spheres. The oxide film arrester is coming into use for the moderate voltages and at locations where the charging of aluminum arresters would be a hardship. The high frequency absorber has proved its value in a number of installations.

There has been manifested a tendency to omit lightning arresters in some instances, for example, when tapping off a high voltage line for a small power load. Here it is necessary to keep the cost of installation down to a minimum in order for the substation to pay. Extra insulated transformers have been used in these cases, but the safety of the venture is still to be proved. As an alternative to these expensive high voltage stations a number of operating companies run, wherever feasible, secondary distribution circuits of 33,000, 44,000 or 66,000 volts, finding it cheaper to run such lines and install substations on them than to install substations on the high voltage line, even though that line passes by the substation. In discussing a proposed 220-kv. line a recent writer* advocated the entire omission of lightning arresters. The wisdom of such a policy is problematical and must be determined in the future.

There is this to be said for such practice: The apparatus on a 220-kv. line will be insulated for at least 350,000 volts. It is probable that insulation of this strength will be able to withstand all usual voltages induced by lightning. Direct strokes are rare and frequently result in breakdowns in spite of protective apparatus.

High frequency and steep wave front disturbances resulting from switching, arcing grounds, charging lightning arresters without resistance, etc., act to build up voltage against the end turns of transformers. The causes of such disturbances are largely eliminated by judicious switching, grounding the neutral and charging arresters through resistance, and those that remain are as a rule amply cared for by the extra insulated end turns of modern transformers.

The question resolves itself into one of taking a chance on the possibility of breakdown due to a disturbance of unforeseen severity rather than undergoing the large expense involved in protective apparatus [illegible] voltage. The geographical [illegible] conditions must also have their [illegible] decision reached.

So-called "static" potential [illegible] causes breakdown on the low [illegible] either in generating station or [illegible]. This is potential induced through the electrostatic capacitance of the transformer and results, usually, from an unbalanced condition on the high voltage side, such as a ground on the line, one of the three line switches closing before or after the others, etc. Such static potential is usually protected against by a combination of an aluminum cell lightning arrester and a surge absorber. The latter consists of a condenser in series with a resistance connected directly to the bus without a gap in series. This absorber acts as a constant drain to any static that may appear on the bus, thus preventing the static from gradually eating into and destroying the insulation of the generator windings, etc. If a disturbance or charge of unusually high potential should appear on the busbars, the aluminum cell arrester would act through its horn gap to reduce the potential. The horns of the aluminum cell arrester also act to limit the voltage that can be impressed across the condenser. Such a combination has also been used to good advantage in substations on cable systems, at the junction of overhead lines and cables, and on busses to which overhead lines are brought directly without transformers intervening. The absorber takes care of low voltage, high frequency disturbances and static and the arrester takes care of low frequency, high voltage disturbances. In some special cases the aluminum cell arrester has been eliminated and the condenser shunted by a horn gap, the combination being in series with a resistance. The high frequency takes the direct path through the condenser and resistance and the low frequency high voltage passes over the horns and through the resistance. Such a combination has the advantage that the impedance of the condenser varies inversely as the frequency, so that the higher the frequency the greater the discharge through the absorber.

Absorbers have been developed for 6600, 13,200 and 22,000 volts. Among the systems on which they have been installed are the Narragansett Electric Light Co., Montreal Light Heat & Pr. Co., American Gas & Electric Co., Tallassee Power Co., Fall River Shipbuilding Co., Montreal Tramways Co. and Blackstone Gas & Electric Co.

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*A. E. Silver in A.I.E.E. Proceedings, June, 1919.

Arcing Ground and Short Circuit Suppressors

Devices for suppressing arcing grounds and short circuits have been in use to a limited extent. These operate on the principle that when a ground occurs at any point on the line, such a ground usually being due to an arc over an insulator, another and positive ground is placed on the same conductor just outside the station. The potential of this conductor is thus dropped to zero and the arc becomes extinguished.

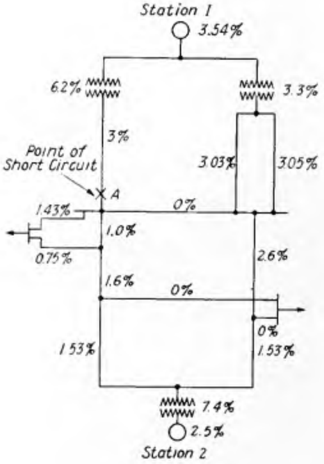
The arcing ground suppressors are used on isolated neutral systems. On some systems, especially of low or moderate voltage, they work very well. On others of higher voltage and lower safety factor the artificial ground created at the station on one conductor raises the potential above ground of the other conductors to such an extent that one of them arcs over, the operation being repeated until the switch locks, if it is a switch type of suppressor, or until all of the fuses blow if it is the fuse type of suppressor.

The short circuit suppressor is used on a grounded neutral system. The danger here is that when the artificial ground at the station is removed either by opening a switch or blowing a fuse the sudden opening of the dead short circuit at the station causes a rise in voltage, which, in turn, is liable to cause another arc-over and short circuit. This second arc-over may take place between the suppressor and the station and therefore not be capable of being extinguished by the suppressor. Again, the suppressors have a limited range, especially on a network which is fed by a number of generators at different points, and in this case several suppressors are necessary to take care of arcs at different points on the system.

The main object of these devices is to suppress the arc before it damages the insulators. On a grounded neutral system this can be done as quickly and positively by relays. On an isolated neutral system the relays will not operate until there is a short circuit. On such systems there is some basis for consideration of the suppressor. Even here, however, it is necessary to investigate thoroughly the conditions before using them. Although good results have been obtained with suppressors on a few systems, sufficient experience has not been obtained with them to warrant their general adoption.

ERRATUM

In the illustration for Fig. 1 of the article, "Calculation of Short-circuit Currents in Alternating-current Systems," by W. W. Lewis, in our February, 1919, issue (p. 141), there was through error no electrical junction shown between the circuits crossing immediately below the letter *A*. The corrected diagram for this illustration is shown here.



Effects of Short Circuits on Power House Equipment

By E. G. Merrick

Power and Mining Engineering Department, General Electric Company

The widespread tendency toward the interconnection of power systems and the development of generating stations of capacities measured by the hundreds of thousands of kilowatts has created grave problems in properly handling the vast amounts of energy which can be concentrated in a single fault. In dealing with this class of problems, the author draws on considerable experience to analyze troubles which are likely to occur in power house equipment due to the electro-magnetic stresses and abnormal temperatures resulting from short-circuit. —Editor.

The demands made upon electric power systems, as regards the quality of service rendered, are becoming more and more exacting. Whether the power is developed for public or private use, continuity of service must be maintained in so far as it is possible to do so.

In order to meet this condition, there must be no weak link in the chain of apparatus constituting the plant equipment; each piece of apparatus must be adequate for the duty to which it is subjected.

In the case of new installations, whose ultimate capacity is fixed, there should be no difficulty in selecting the proper equipment. The greater problem lies with plants whose installed capacity has grown by successive additions until it greatly exceeds the original contemplated limits. In such cases, it is almost certain that some of the older apparatus is no longer suitable and constitutes a menace to reliable operation.

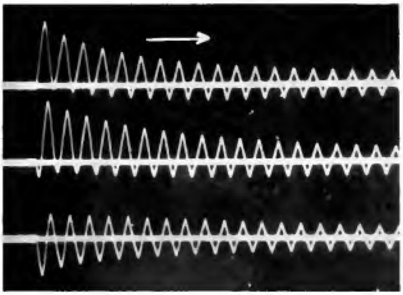


Fig. 1. Oscillogram of a 3-phase Short Circuit on a 2-pole, 9375-kv-a., 1800-r.p.m., 7200-volt Revolving Field Turbine Alternator. Armature currents are shown for all three phases

If normal conditions could be maintained at all times, the danger of failure of any part of the plant equipment would be very remote. Abnormal conditions are certain to arise at some time, however, and it is against those that full protection is required.

The object of this article is to point out the duty imposed on various apparatus during those transient periods. This may serve as a guide to the proper selection of equipment for new installations and as a caution against the overtaxing of that which has already been installed.

Generators

If an alternating current generator is suddenly short circuited at its terminals when operating at normal voltage, an abnormal condition results as shown in Fig. 1. The armature current rises almost instantly to a value limited mainly by the transient reactance and gradually dies down to a sustained value determined by the synchronous impedance. The characteristic variable displacement of the current in the different phases with respect to the zero axis, shown by the oscillogram, depends on the period of the voltage wave at which the short circuit occurs.*

The transient current in the armature windings not only causes abnormal heating of the copper, but also produces forces of repulsion or attraction between coils far in excess of those due to the normal current. These stresses vary as the square of the current and at the instant of short circuit may be several hundred times their normal values.

Experience gained from the results of actual short circuits has led to various methods of bracing the armature coils so as to obtain sufficient rigidity to prevent deformation.

The transient short-circuit current in the armature produces in turn a transient alternating current and voltage in the field winding as shown in Fig. 3. The induced field potential may be greatly in excess of the normal direct-current voltage and sufficient insula-

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*See article by R. E. Doherty, General Electric Review, August, 1918, and paper by Hewlett, Burnham, and Mahoney, A.I.E.E., February, 1918.

tion must therefore be provided to insure against a failure to ground.

The danger of damage to the field insulation can be lessened by the installation of aluminum cells connected across the field terminals. These act as a safety valve by limiting the induced voltage to the value at which the cell films break down. This additional protection is sometimes recommended for early types of machines which have given trouble, but it is not usually considered necessary for generators of modern design.

Fig. 2. An Early Type of Turbine Alternator Armature with Insufficient Bracing of the End Windings, showing effects of short circuit at normal voltage. Note grouping of coils by phases

If the source of driving power, i.e., water, steam, gas, etc., could be interrupted at the moment of short circuit and there was no kinetic energy in the rotating parts, the latter would stop revolving instantly due to the locking action of the flux on the field structure and to the I^2R loss in the armature circuit. As the tendency to stop is resisted by the sources of energy mentioned, intermittent stresses are induced in the shafts, rotor arms, coupling bolts, pole fastenings, foundation bolts, etc., due to the transforming of mechanical energy into electro-magnetic energy and vice versa with varying positions of the field poles relative to the armature. Although the ratio of transient stress to normal stress in these parts may not be as high as in the armature coils, experience has shown the necessity of liberal design factors to prevent undue strains.

Generally speaking, alternators of modern design are subject to lower stresses during short-circuit conditions than earlier types of machines of similar rating. The close voltage regulation demanded in the past resulted in lower values of transient and synchronous reactance and hence higher values of short-circuit current than those realized at present with regulation limitations removed.

While a generator may be designed with ample factors of safety to withstand the effects of short circuits occurring at its terminals, when operating at full rated voltage, it is possible for the operator to subject it to even more severe conditions. This may happen if an alternator is paralleled considerably out of phase with a much larger source of power. Carelessness in synchronizing has thus resulted in serious damage to the incoming machine.

The sustained short-circuit current of an alternator corresponding to the excitation for full load and 0.8 power-factor usually reaches a value two or three times the normal rated current. If this condition is maintained, it is obvious that the armature winding will be subjected to abnormal heating. Automatic protection is therefore required for disconnecting faulty feeders from the bus before the coil insulation is endangered.

As generator switches are ordinarily non-automatic as regards disturbances external to the machine, a failure in the bus or in the generator leads necessitates hand operation of the generator switch at the earliest possible moment. Differential relays are provided in certain cases which are actuated only in case of internal generator trouble. For this condition, the generator switch becomes automatic and disconnects the machine instantly from the bus; at the same time, the field

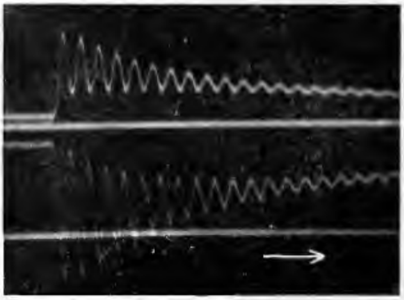

Fig. 3. Oscillogram Accompanying that of Fig. 1, showing Transient Field Current (upper curve) and Transient Field Voltage (lower curve)

circuit is opened, thus "killing" the machine completely. As fires once started in generator insulation may continue, due to the strong ventilation produced by the rotor, it is sometimes considered advisable to install special fire extinguishing equipment. This applies almost exclusively to high-speed totally enclosed machines, which continue to revolve for a considerable time after all power is cut off and whose windings are inaccessible. The equipments generally recommended consist of piping for the admission of water spray or steam.*

Voltage Transformers

If voltage is applied to the primary winding of a transformer and the secondary is suddenly short circuited, the resulting current will tend to force the individual coils into a circular shape and will also produce forces of attraction or repulsion between the coils. If the windings are originally of circular form, the internal forces in each being radial and equal, there is little possibility of deformation provided the tensile strength of the copper is not exceeded. By a proper arrangement of spacers between coils and rigid clamping, the danger of axial displacement of the coils and crushing of the windings can also be avoided.

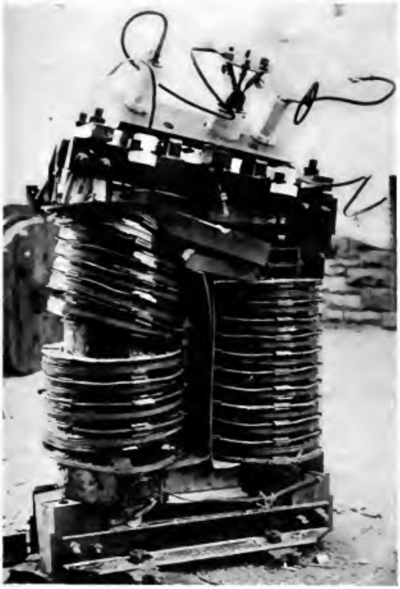

Fig. 4. Transformer Tested to Point of Mechanical Failure Under Abnormal Short-circuit Conditions. Transformers of weaker construction may be similarly damaged by short-circuit stresses due to normal impressed voltage

Modern transformers are generally guaranteed to withstand momentarily the effects of sudden short circuit at their secondary terminals with full sustained primary voltage. The fulfillment of this guarantee is a matter of proper construction for which only the designer is responsible. The sustained application of a short circuit, however, will quickly cause abnormal heating which may damage the transformer insulation; it is therefore the province of the operator to provide, and to maintain in good condition, the proper automatic devices for interrupting the short circuit with the least possible delay consistent with continuity of service.

As in the case of generators, the short-circuit duty of the modern transformer has been lessened due to the less rigid conditions imposed regarding close voltage regulation.

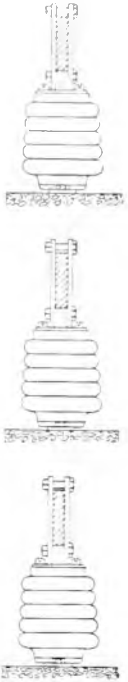

Fig. 5. Vertical Arrangement of Busbars with Supports One Above the Other

The guarantee mentioned, while given generally for all transformers, is of particular interest only as applied to units of very small kilovolt-ampere capacity as compared with that of the system in which they are used. The larger and more important transformers on the system will never be required to meet this extreme condition, for the reason that their reactance is relatively lower compared with the total reactance determining the short-circuit current.

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*See article by M. A. Savage, GENERAL ELECTRIC REVIEW, January, 1918, and the Report of the Committee on Electrical Apparatus presented at the Atlantic City Convention of the N.E.L.A., May, 1919

Oil Circuit Breakers

The duty imposed on oil switches under short circuit conditions is one of the most important and difficult phases of this general subject. Recent collaboration of the leading American switch manufacturers has resulted in a greatly increased general knowledge of the factors which are involved and the data which have been published* furnish a far more exact basis for the proper selection of breakers than existed heretofore. Recent European projects for the development of large power stations and the formation of system networks far more extensive than any heretofore considered have also awakened considerable interest among foreign engineers in this subject.

On account of the accessibility of the data mentioned, it is unnecessary to present it in detail at this time. The discussion of the selection of circuit breakers was limited, however, to the duty imposed at the instant of parting of the switch contacts. Later investigations have shown that the initial values of current must also be considered on account of the high mechanical stresses which they produce, due to the tendency of all current loops to assume a circular shape.

From the operating standpoint it must be borne in mind that every circuit breaker has fairly definite limitations as regards rupturing and current carrying capacity, and that initial arrangements of systems and also future modifications must be made with due regard to these points if reliability of service is to be maintained.

Busbars

Busbars are usually constructed of bare copper strips which are supported at intervals of several feet on porcelain posts. The spacing between bars and the height of the insulator support are determined mainly by the voltage of the circuit.

If currents are flowing in two adjacent bars, forces of attraction or repulsion are produced depending on whether the currents are in the same or opposite direction. In either case, the instantaneous value of the force F is approximately $\frac{5.4\times I'\ I''\times 10^{-7}}{d}$ lbs. per foot run; where I' and I'' are the instantaneous values of the currents and d the spacing between the bars in inches. The relative proportions of conductor width and height introduce modifying factors but, except for comparatively small values of d, they can generally be neglected.

In a three-phase circuit, the maximum forces are those occurring during a single-phase short circuit between phases and the preceding formula applies; at this time $I' = I''$ and as they are in opposite directions the force exerted between bars is that of repulsion.

The value F multiplied by the distance in feet, L, between supports gives the total force exerted on each insulator post.

While the busbars themselves have a certain amount of flexibility, the porcelain supports may be considered to have practically none. To be entirely safe, therefore, in the estimation of the possible stresses, it is customary to base the calculations on the maximum peak value of current corresponding to a totally displaced wave.

As an example, let the maximum possible peak value of current be 100,000 amperes, $d = 18$ inches, and $L = 5$ feet; then

$$F = \frac{5.4\times 100{,}000^2\times 10^7}{18} = 300 \text{ lbs.}$$

per foot run and

$$FL = 5\times 300 = 1500 \text{ lb.}$$

If the plane of the conductors is parallel to the axis of the supports, see Fig. 5, the insulators will be under tension and compression; whereas a 90 degree relation between the two, see Fig. 6, will subject all posts to bending moments. Tests made under these two conditions on a certain type of support gave breaking values of $F\times L$ in the two cases of 2000 lb. and 550 lb. respectively; these values would of course vary with different designs.

If the stresses in the single type supports cannot be reduced to safe amounts without employing excessively large posts or busbar spacings, it becomes necessary to adopt the more expensive "compression type" supports as shown in Fig. 7. With this arrangement the porcelain post is under compression only, in which sense it may be subjected to far greater stresses than when under tension or shear.

Single-conductor feeders may be considered as extensions of the supply bus and are subject therefore to the same considerations as outlined for the bus proper.

Current-limiting Reactors

In performing their well understood function of limiting the current under short-circuit conditions, reactors are subjected to high values of transient voltage and current whose

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* See paper by Hewlett, Mahoney, and Burnham, Trans. A.I.E.E., February, 1919.

effects must be guarded against both by proper design and installation.

Reactors may seldom be called upon for protection but, when this does occur, it is necessary to place absolute confidence in their reliability. The cast-in-concrete type of construction has proven to be a most satisfactory one. The coils being of circular shape, there is no tendency to deformation from radial forces, and being rigidly supported by the concrete at sufficiently frequent intervals, there is no danger of movement due to the mutual attraction between turns. Furthermore, no fibrous or organic material is used for insulation, which eliminates the danger of charring and consequent deterioration due to the heating produced by the short-circuit currents. The open type of construction also permits of easy inspection and cleaning. Transient potentials between the top and bottom layers of the reactor may be many times the normal value, therefore the presence of any magnetic material—such as through-bolts—offers a possible source of failure; this is obviated in the concrete construction.

Reactors are generally guaranteed to withstand the effects of short circuits, limited only by their proper reactance, for a definite period which may be from two to five seconds and to operate normally with a certain temperature rise. Such guarantees should cover all of the points mentioned above.

As there are also forces of attraction and repulsion set up between reactors, they must be so installed as to prevent any movement during short circuit. If sufficient space is available, this condition is satisfied by proper spacing of the coils; otherwise some form of bracing must be used. Connections are usually made so that the maximum forces are those of attraction. In the case of the bracing shown in Fig. 8, the porcelain separators are therefore subjected mainly to compression stresses.

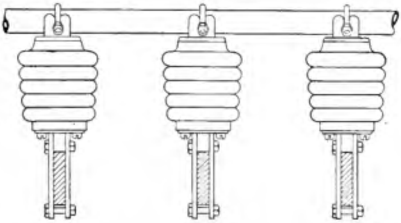


Fig. 6. Horizontal Arrangement of Busbars with Supports Parallel to Each Other

Single-phase reactors are sometimes installed one above the other, and as the mutual forces may exceed the dead weight, provision must be made not only for preventing movement but also for sufficient strength in the supporting I-beams, or other structures, to withstand the total thrust.

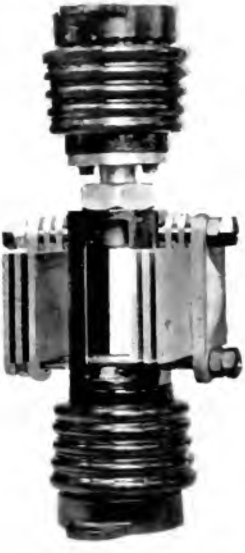


Fig. 7. Compression Type of Busbar Support for Cell Mounting

Formulæ have been developed for the calculation of the mutual forces between reactors and these agree closely with actual measured values, but on account of the data involved they are not suitable for general use. The results, however, can be obtained for any specific installation.

Current Transformers

In many cases the application of current transformers has been based solely on the normal operating conditions of the circuits in which they were to be installed—the selection being governed by the primary voltage and load current, the proper current ratio, and the volt-ampere loading of the secondary. The fallacy in this method of selection lies in choosing the transformer with reference only to the individual circuit in which it is to be installed and not with reference to the system of which the circuit is a part.

If several feeders of different ampere capacities are connected to a common bus and short circuits occur consecutively one after the other, the actual short-circuit current will be the same in each instance—assuming the reactance between the bus and point of short circuit to be equal on all feeders – and its value will be determined by the constants of the system. The ratio of this current to the normal ampere capacity of each feeder is therefore a variable quantity. Assume, as an example, four feeders of 1000, 500, 100, and 50-ampere ratings and a short-circuit current in each feeder of 10,000 amperes; then the ratios of transient to normal current will be 10, 20, 100, and 200 respectively.

If standard transformers of primary ampere capacity equal to that of the circuit in which they are installed are unsuitable to meet transient conditions, others of higher current ratio may sometimes be substituted; should the normal secondary currents obtained with the latter be of too low a value to give accurate instrument indications, however, it becomes necessary to use special transformers having the correct current ratio and of greater current carrying capacity than the standard units. It is, of course, possible to reduce the short-circuit current, by means of reactors, to values which will be safe in all cases for the standard transformers, but this method is expensive if protection of the current transformers only is desired.

The failure of a current transformer may not of itself be a serious matter, but contingent developments may be disastrous. The loss of secondary control current would, for instance, render an automatic switch inoperative at a time when it should function and this might result in an entire loss of load or possibly damage to some of the apparatus from overheating before the faulty circuit could be disconnected.

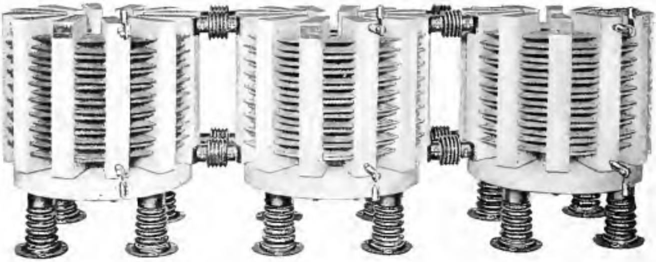


Fig. 8. Horizontal Arrangement of Three Single-phase Reactors. The small axial spacing requires bracing between coils

Each design of current transformer is limited in the amount of current which it can safely carry, both by mechanical stress and heating considerations, and their selection must be governed accordingly. For the type of construction in common use, the A.I.E.E. standards recommend that the transformer shall stand a current of forty times the normal rated value for one second; this is supposed to be a safe limit within which the compounds used will not vaporize and will therefore prevent porosity of the insulation. For the same temperature rise the permissible current value will vary inversely as the length of time the current is applied. On the basis of the above recommendation, therefore, it would be expected that from a heating standpoint the transformer would stand 160 times normal current for one quarter second.

Choke Coils

The remarks which have been made with reference to current transformers apply in general to choke coils used with lightning arrester equipments. Installations must therefore be investigated to ascertain the possible magnitude of the short-circuit transients in order that the mechanical stresses in the coils shall not exceed safe values.

Conditions unsuitable to the ordinary hour-glass type of coil require special constructions of greater rigidity; in extreme cases, it may even be necessary to adopt designs similar to those of current-limiting reactors.

Disconnecting Switches

Where knife-blade disconnecting switches are mounted horizontally with blades opening downward, it is customary to provide locks which hold the switch securely in the closed position; otherwise, if subjected to vibration, the blades may open accidentally due to insufficient pressure of the clips.

Regardless of the position of the switch, however, positive locking is sometimes required to meet severe short-circuit conditions. It has already been pointed out in preceding paragraphs that the tendency of a current loop is to assume a circular form; this action in the rectangular shaped switch circuit may force the blade outward, unless held as mentioned.

The formula given under the section on "Busbars" can be applied equally to the parallel switch blades of the different phases and also to the free lengths of conductor between the switch and adjacent supports. The resulting force is transmitted to the porcelain posts at the extremities and therefore produces bending moments—the case being similar to the busbar arrangement of Fig. 6.

In the case of switches which are back connected on one or both terminals, the formula can also be used for calculating the reactions between the conductors passing through the insulator posts of adjacent phases and those of the same phase; these two forces are at right angles to each other. As they are distributed over the length of embedded conductor, which may be considered as a beam fixed at one end, the equivalent forces applied at the extremity of the insulator post would be one half these values; combining these with the forces mentioned above gives the total bending moment of the porcelain support.

On account of the forces occurring in the switch circuit proper, it is evident that the spacing between the switch and adjacent supports must be less than can be allowed between succeeding supports if a given stress in the porcelain is to be maintained.

Insulated Cables

The heat conductivity of cable insulation being comparatively low, transient currents of high value or sustained currents of greater value than the normal rated capacity of the cable cannot be permitted without danger of deteriorating the insulating material.

If faulty cables are cut off quickly from the source of power, the damage can frequently be localized; if the short circuit continues, however, for an appreciable time, a considerable length of cable may be entirely destroyed.

Fig. 9. Unbraced Choke Coil Deformed by Short circuit Current. The vibration of the coil in a vertical position tends to force it downward, resulting in a pronounced distortion

Single-conductor cables are subject to the stresses discussed under the heading of "Busbars," and all cable runs should therefore be rigidly clamped to prevent movement.

Conclusion

In pointing out the abnormal conditions to which power house equipment is subjected, it is not the intent of this article to create a feeling of distrust on the part of power plant operators or power purchasers in the reliability of electrical equipments and service. It is true that the increasing concentration of power in our modern stations tends to increase the severity of the duty imposed on certain apparatus; this in itself is not a serious matter, however, as we are now able to analyze the nature of the duty and also predict its amount with a considerable degree of accuracy. The problem of realizing continuity of service is therefore actually simpler at present than it was in the past, being limited to the design and proper application of apparatus to meet known conditions.

Hydro-electric Power and Its Use for Industrial Purposes

By Eric A. Lof

Power and Mining Engineering Department, General Electric Company

The development of electro-chemical and electro-metallurgical industries has attained great importance in the last few years and has created a demand for electric power in large blocks. Other industries, such as the manufacture of paper and wood pulp, farming and agricultural work, irrigation, etc., require electric power in constantly increasing quantities. The successful development of these industries requires a cheap power supply in large quantities. The development of our water power resources should be encouraged by the enactment of just laws governing their use and large economical supplementary steam plants be constructed at "strategic" points.—Editor.

The importance of the electric power situation, as an essential factor in our industrial life, has never been more marked than at present and there is every indication that this condition will continue, possibly to an even greater extent, as time passes by. The nation is now facing a very grave crisis in its history and a radical readjustment of social as well as economical conditions seems imminent. Labor's constantly increasing demand for shorter working hours is unfortunate at the present time when *increased production* would be the most sure and far-reaching cure against the existing high prices of even the necessaries of life. Our productive capacity must therefore be kept up and even greatly increased, and the threatened shortage of labor must be made up for somehow. The remedy which at once suggests itself is, naturally, an increase in the substitution of machinery and efficient mechanical devices to carry out the work which has hitherto been chiefly done by manual labor, and which must be conserved for more important functions. Besides this, new manufacturing processes must be more extensively introduced by means of which raw materials or finished products can be more quickly and cheaply produced, as, for example, the manufacture of artificial fertilizers which naturally would be of immense benefit in increasing the food production.

Very closely related to this increase in the use of mechanical appliances, or chemical manufacturing processes, is the electric power problem. As a matter of fact, they are inseparable, as it is now universally conceded that electricity is the only form of power worth considering in a modern industrial manufacturing establishment. Its advantages are so numerous and self-evident, and have been brought out so often in the technical press, that they will not be repeated here.

Electricity is not in itself a source of energy, and some sort of primary power is required for its generation. The two chief sources of this are found in the chemical energy of our fuel deposits and in the energy of falling water, due to its position or head. The former can certainly be exhausted, especially if the present enormous drain is to be continued, while with the latter this is not the fact. The logical conclusion would therefore be to increase the development of our water powers, as the waters which constantly pass through the rivers without performing useful work are naturally a total loss of valuable energy. As a matter of conservation, water power should therefore be developed in order to save our coal supply that is being so steadily depleted, or at least to provide for the ever increasing demand for more and more power, and thus prevent the yearly coal consumption from increasing, if it cannot well be materially reduced.

Unfortunately a large, if not the largest, part of our water powers are so situated, or are of such a nature, that their development is not practical and we shall always have to use steam power, and it has been well proven by actual practice that a combination of steam and water power will, in many cases, work out as the most ideal solution of the power problem. Water power will, therefore, never replace steam power, but will merely supplement it.

As compared to a steam plant, a water power development is a far more complicated and, from a financial point of view, a much more risky undertaking. With a steam plant the conditions that are to be met can, as a rule, be very closely predetermined, and the financing and design become a rather easy matter. With a water power development, however, the conditions are far more uncertain, with the result that the financing of the project will be more difficult, which naturally means a greater discount on the bond issue, or an increased rate of interest. The determination of the amount of power for which a development can safely be built requires a painstaking study of the rainfall and stream flow conditions for a period of many years, and even with the best expert advices, abnormal conditions may occur due to nature's whim which will upset all calculations and cause serious difficulties and inconveniences. It is these abnormal conditions, such as drought and flood, which are constantly met with in water power developments and must be absolutely guarded against, and which naturally result in further increasing the cost of the already expensive undertaking.

In speaking of the cost of water power, it is a common fallacy to base this only on the cost of the power station with its dam and headworks, and frequently the enormous investment in the last two items, especially with low head developments, is not realized. As there are very few hydro-electric developments so fortunately situated as at Niagara Falls, where the manufacturing industries are so closely located, it follows that most water power developments will require long and expensive transmission lines over which the energy must be transmitted to suitable market centers. Not only is it the interest on the investment in these lines but also the value of the power lost therein and the maintenance, which must be chargeable to the actual cost of hydro-electric power and used in a comparison with the cost of steam power. Large storage reservoirs and auxiliary steam plants for regulating the stream flow and for reserve, are also in many cases important items of the cost.

Fig. 1. Wasted Energy

Fig. 2. Large Hydro-electric Atmospheric Nitrogen Fixation Plant in Norway

A hydro-electric development as a whole requires from two to three times the capital investment of a steam plant, and the cost of water power is steadily increasing, while that of steam, if not now actually falling off, is not increasing. This is due to the fact that the increased cost of labor, fuel and material for a steam plant has been about offset by the continued improvements in the efficiency of conversion of chemical energy into electrical. The efficiency of the utilization of water power has, however, evidently reached its maximum, or nearly so, and to offset this disadvantage the only means to obtain a really cheap power seems to be the development on a very large scale, and the utilization of so-called "secondary power" for industries and processes which do not necessarily require an absolutely continuous power supply. From the above it is plainly evident that investments in water power developments are in many instances difficult to obtain, and the stimulation of a rapid development of this industry requires in the first place, the confidence and encouragement of the general public, and the creation of just but more liberal laws and regulations by the governing bodies of the States and of the Federal Government. Only in this manner will it be possible to raise the capital necessary for an early resumption of developing our vast water powers which are now going to waste, thus supplementing the steam power and conserving the coal supply, not to speak of possibly preventing a repetition of the coal shortage of two winters ago (and which is predicted even for the coming season) when some of the large power houses in New York city were running with only a few hours supply in their bunkers, and others had to shut down entirely for lack of coal.

In the above, the necessity for a rapid and intensive resumption of the development of our water power has been discussed, and it may be of interest also to briefly touch on some of the industrial fields for which the early solution of the water power problem is of the utmost importance.

Of these the electro-chemical industry unquestionably comes first, as the industrial processes founded upon electro-chemistry have a large and important part in the manufacture of a very wide range of commercial products. Among these may be mentioned fertilizers, explosives, iron and steel, aluminum, copper, ferro-alloys, chlorine, soda, etc.

The most important ingredients in a successful fertilizer are nitrogen in some bound form, and phosphoric acid. Chile has been supplying practically all our demand for nitrogen in the form of Chile saltpeter or sodium nitrate, and it is just recently that this country has witnessed the establishment of at least one large plant where the inexhaustible supply of Nature's free nitrogen can be fixed or combined with some other element so as to form a useful product. With the aid of electric power it is thus possible to produce artificially unlimited quantities of nitrates to be used on our farms, and thus create an intensive production of crops of which the world is now so sadly in need and will be for a long time to come.

Phosphoric acid in the form of phosphates is also an indispensible fertilizer. Unfortunately, however, the large deposits of phosphate rock which are to be found in many places in the country, are available as fertilizers only through its treatment with sulphuric acid, and even then only a small percentage of the phosphoric acid is made water-soluble and is readily again reconverted into an insoluble form by the action of ingredients present in the mixed phosphates. By means of electric power, however, all

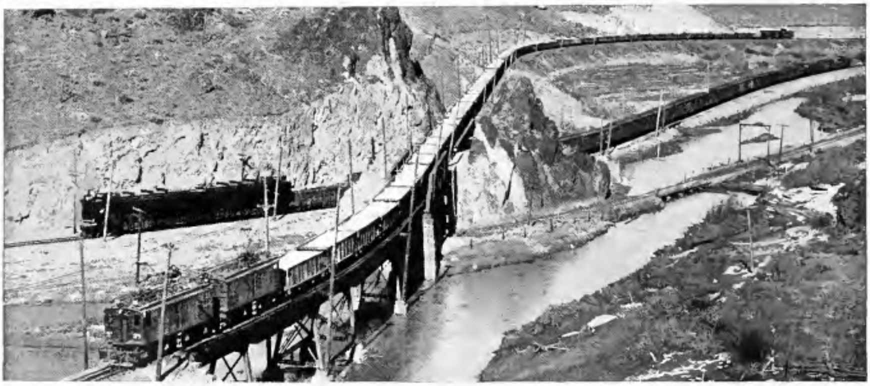


Fig. 3. Application of Hydro-electric Power to Railway Operation

this phosphoric acid can be made water soluble, and in addition the phosphoric acid obtained can be absorbed by various bases to form salts, which in themselves will form complete fertilizers of highest value, such as ammonium phosphate.

Nitrogen, in the form of nitric acid, is the principal constituent of explosives, and was, until quite recently, obtained entirely from Chile saltpeter. Even this industry will possibly before long be entirely independent of this raw material, as electro-chemical processes are now available by which nitric acid can readily be obtained from the free nitrogen contained in the atmosphere or in the coal. It is evident, therefore, that the nitrogen fixation industry must in the future be of considerable importance and magnitude as a stimulus to our food production in times of peace, besides being capable of an easy conversion for preparedness in case of war.

Several hundred thousand horse power of hydro-electric power is used in the manufacture of aluminum, and for the refining of copper, zinc, etc. The ever increasing demand for these metals necessitates a constant building of new plants, or additions to existing ones, and it is difficult to foresee the ultimate expansion of this important industry.

The successful use of the electric furnace for refining of steel and for the production of ferro-alloys have resulted in a rapid development of this industry, and it is to be hoped that before long the problem of directly smelting the iron ore in the electric furnace will be successfully solved.

Another group of electrolytic processes which is rapidly extending is the conversion of cheap salt into more valuable products, such as chlorine and caustic soda. The manufacture of these two products is closely allied in that when the electric current is passed through the cell, the brine splits up into its components; chlorine will escape at the anode and caustic soda will be produced at the cathode. The uses of chlorine are only beginning to be touched, and its manufacture will increase many times in the near future. Among its many uses may be mentioned: bleaching in the paper and textile industry, sterilization for potable water, antiseptic disinfection, sterilization of sewage, etc. The caustic soda can readily be converted into carbonate of soda by a simple chemical operation. Both are used in the manufacture of other materials such as glass, soap, paper, drugs, paints, leather, etc.

Fig. 4. Application of Hydro-electric Power to Canal Operation

Cheap power is an essential factor in the manufacture of paper and wood pulp. A considerable part of its cost of manufacture consists of the cost of power, and the imports of these products have been growing at an enormous rate. Canada and Sweden with their developed water powers which have been extensively utilized in this industry have been our main source of supply, but with the production of cheap electric energy, through the development of our own water powers, it is to be hoped that the pulp and paper industry will soon come back to its own in the United States.

The possibilities of the use of hydro-electric power in connection with farming and agricultural work are many, and offer one of the most promising fields of the future. The unqualified success that the application of electric power has had in this line of work indicates that it has become a factor of such importance that it must now be seriously considered as affecting both the cost and quality of the products of the modern farm. The power supply may be obtained from the extensive net-works of high-tension transmission lines which are now being erected in so many sections of the country, and which are continuously being extended at a very rapid rate. While this supply, without doubt, offers the simplest and cheapest source of power, there are thousands of small streams whose wasted energy might readily be transformed and applied to useful work on farms by the installation of small and inexpensive water-power plants .

The advantages of hydro-electric power for irrigation purposes have been clearly demonstrated by the excellent work which is being done by the United States Reclamation Service, The United States Indian Service, and numerous co-operative and individual enterprises. Electric power is generated on the nearest available river, and the energy readily transmitted to pumping stations scattered over the territory to be irrigated.

The electrification of portions of our vast railroad systems will consume very large amounts of power and will be dependent for their success to a very great extent on their ability to obtain cheap energy from the water power developments in the territories which they traverse.

A careful review of the situation therefore shows that there is a vital and imperative need for early development and industrial utilization of the enormous quantity of energy that is now going to waste in our streams. This power is required to increase the country's production of the necessaries of life, to the end that the high cost of living may be reduced and the comfort and happiness of the country increased.

Centralization and Conservation in Power Supply of Central Massachusetts

By F. L. Hunt

Chief Engineer, Turners Falls Power and Electric Company

The author brings out very forcibly the economies that can be effected by the use of power from [illegible] central stations, equipped with up-to-date machinery, and the economical use of water power. He shows that by closing down 121 isolated plants and using central station supply nearly 100,000 tons of coal were saved in one year in this particular instance. There are still many localities where this good example could be imitated with great profit to the community. The description of the equipment in this modern system should be of considerable interest to many of our readers.—Editor.

With the completion of the stations, substations and transmission lines which have been put into operation during the past year by the Turners Falls Power & Electric Company, and the operating arrangements that have been worked out between that company, The United Electric Light Company, of Springfield, and the Greenfield Electric Light & Power Company, the power supply for central Massachusetts has been arranged for in a manner which typifies the present rapid movement in all parts of the country toward conservation, by centralization of power manufacture and by utilization of water supply.

A consideration of the complete electrical system of the Turners Falls Power & Electric Company as it now exists, forming the trunk lines for the interconnection of its own power stations with those of the other two companies mentioned, and with several other distributing companies in this part of Massachusetts, will indicate how soundly this theory, advocated now by all the leading engineers of the country, has worked out in practice, and may point out how similar possibilities in other localities should be developed.

Fig. 1 is a geographical sketch of the territory served by the three companies mentioned. This sketch also shows the general scheme of distribution throughout the territory.

Fig. 2 is an operating diagram, showing in detail the circuits interconnecting the generating stations, the general scheme of switching and the relay protection used.

Holyoke is the only town or city with a power load of more than 100 kw. in the territory which does not have a connection to this system. The power facilities of that city are at present entirely inadequate for its requirements, and the authorities there are now discussing the question of how they should proceed to insure the future power needs of the city on the soundest economic basis.

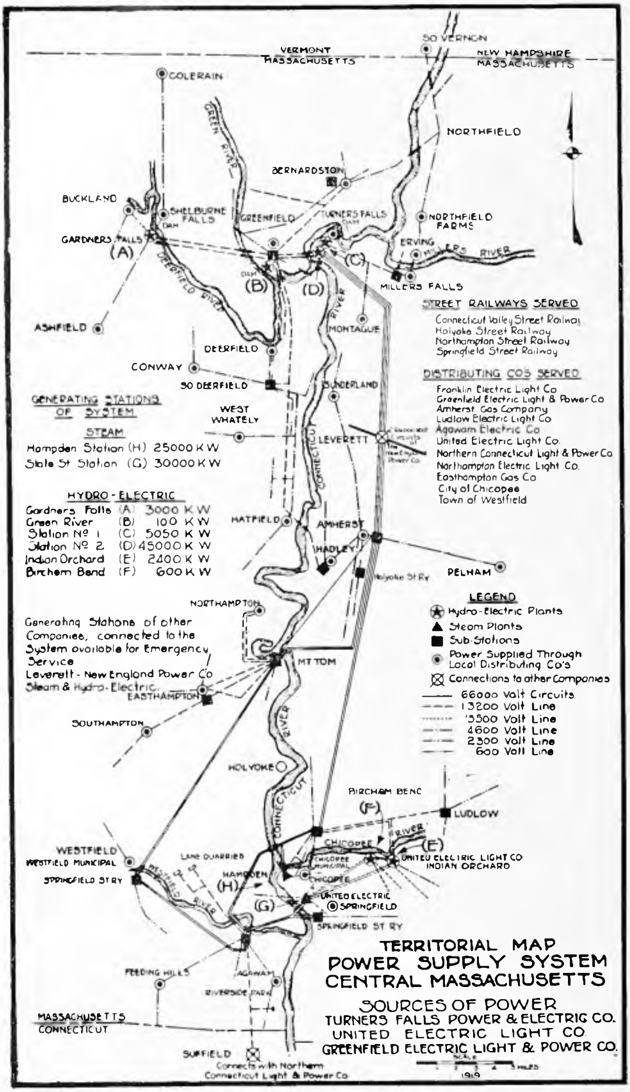
Outside of the city of Holyoke practically all the power used in this territory is supplied from the electrical system shown in Fig. 1. This is generated in six hydro-electric plants and two steam plants, as follows

Gardner Falls Greenfield Electric Light & Power Co.	(A)	—Hydro-electric	3,000 kw.
Green River Greenfield Electric Light & Power Co.	(B)	—Hydro-electric	100 kw.
Turners Falls Turners Falls Power & Electric Co.	(C)	—Hydro-electric	5,050 kw.
Cabot Station Turners Falls Power & Electric Co.	(D)	—Hydro-electric	15,000 kw.
Indian Orchard United Electric Light Co.	(E)	—Hydro-electric	2,400 kw.
Bircham Bend United Electric Light Co.	(F)	—Hydro-electric	600 kw.
State St. United Electric Light Co.	(G)	—Steam	30,000 kw.
Hampden Turners Falls Power & Electric Co.	(H)	—Steam	25,000 kw.

Letters indicate the location of these stations in Fig. 1. The combined permanent load on these stations amounts to approximately 50,000 kw. The maximum load during the past year, including surplus, was 60,000 kw. The total yearly output, including surplus, for the same period was a little over 212,000,000 kw-hr. Of this 172,000,000 kw-hr. were generated from water.

The territory served by the United Electric Light Company consists of the city of Springfield and nearby towns, with a population of 150,000. The load served by this company directly, amounts to about 14,000 kw. In this territory not less than 38 isolated steam plants have been closed down permanently, and the power taken from the central station. This is in addition to 1000 industrial power customers whose loads have always been on the central station.

In the territory served directly by the Greenfield Electric Light & Power Company, whose total load is approximately 3000 kw., 22 separate isolated steam plants, varying in size from 25 to 150 h.p., have been replaced by central station power. In the town of Greenfield, of 15,000 inhabitants, and a power



N. B.—Station No. 2 is known as Cabot Station

Fig. 1. Map of Central Massachusetts, showing location of Power Stations, Transmission and Distribution Lines

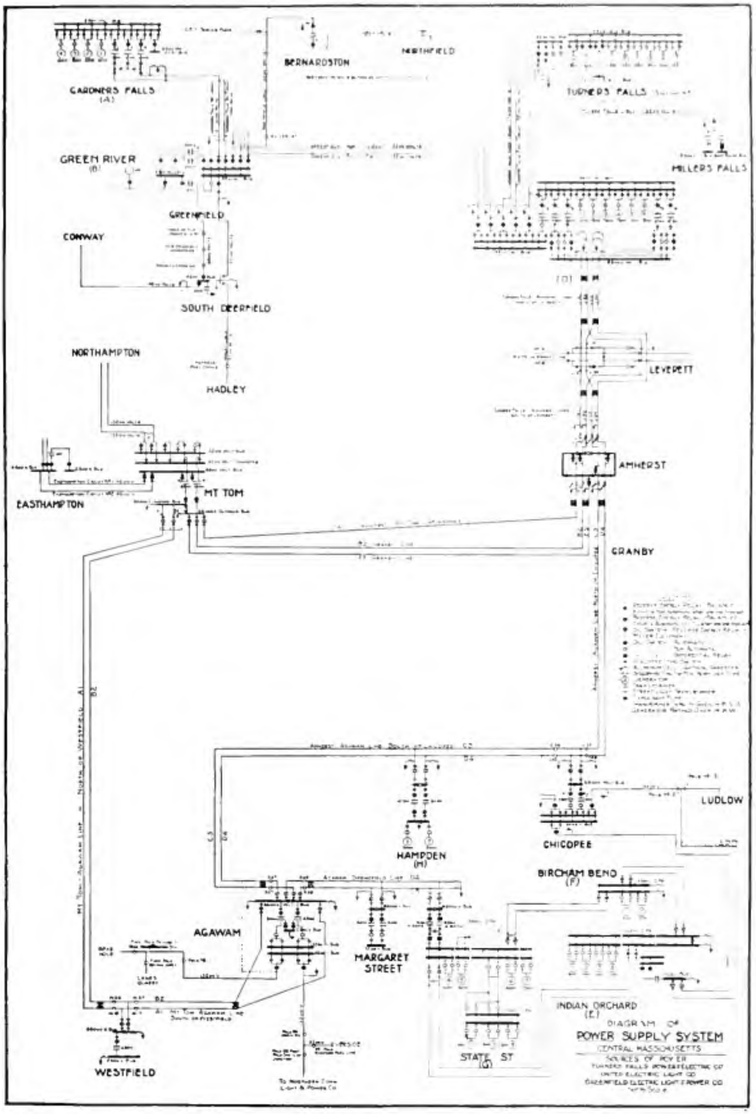


Fig. 2. Operating Diagram of Power System of Central Massachusetts: Turners Falls Power & Electric Co., United Electric Light Co., and Greenfield Electric Light & Power Co.

Fig. 3. Gardners Falls Station; Greenfield Electric Light & Power Co.

Fig. 5. Indian Orchard Station; United Electric Light Co.

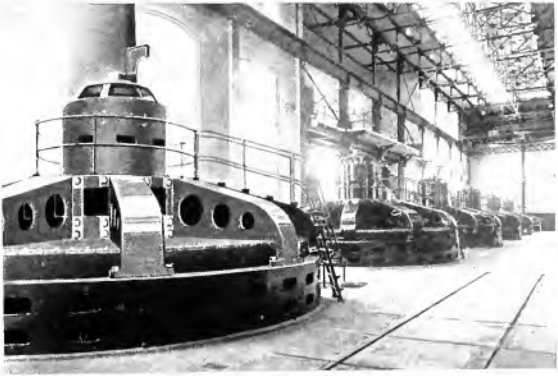


Fig. 4. Cabot Station; Turners Falls Power & Electric Co.

Fig. 6. Bircham Bend Station; United Electric Light Co.

load of 2000 kw. divided among 15 industrial customers, there exists today only one steam plant, of 100 h.p. capacity, where sawdust from the industry is used for fuel. Even the 3250-kw. steam plant of the central station company has been shut down and dismantled, its output to be replaced as far as possible by water power from its enlarged hydroelectric development at Shelburne Falls, and the balance to come from the main trunk line system of the Turners Falls Power & Electric Company.

The completion of the interconnecting transmission lines of the Turners Falls Power & Electric Company and of its larger hydroelectric and steam plant developments has made possible a much more extensive centralization of power production for the central part of the State, and has increased materially the proportion of water power used. It has also made possible the interchange of power between these three companies, so that water power available to any one company may all be made use of before coal is consumed by any other company, and has further conserved capital by putting the reserve capacity of each company readily available for use by either of the other companies, eliminating the necessity of each company keeping an available reserve capacity of generating equipment, which would otherwise be necessary for the proper protection of their business. There also exists a connection at Leverett, see Fig. 1, of 20,000 kw. capacity, between the Turners Falls Power & Electric Company and the New England Power Company [illegible] interconnect. The [illegible] achusetts with that of the [illegible] eastern Massachusetts and Rhode I[illegible]

Fig. 8. State St. Station; United Electric Light Co.

Fig. 7. State St. Station; United Electric Light Co., Boiler Room

Fig. 9. State St. Station; United Electric Light Co., Turbine Room

In addition to the service of interconnection outlined, the Turners Falls Power & Electric Company's system serves, directly, 34 other customers, including nine smaller distributing companies and four street railway companies. The combined demand of these 34 customers is 33,000 kw. The power requirements of these customers was formerly supplied by 31 separate and distinct steam plants, varying in size from 50 to 8000 h.p., all of which have been permanently closed down by the present arrangement, with the result that all their power is supplied either by water or from one of the two modern steam plants connected to the system of the Turners Falls Power & Electric Company.

Fig. 10. State St. Station; United Electric Light Co. Switchboard Room

Twenty-nine small steam plants have been permanently closed down, and their output replaced by central station power from the feeder circuits of the nine distributing companies mentioned in the previous paragraph. A summary of the steam plants that have been closed down by the various companies is as follows:

Turners Falls Power & Electric Co.	31
United Electric Light Co.	38
Greenfield Electric Light & Power Co.	23
Other distributing companies	29
Total number of steam plants shut down	121

There are several months in the year when it is not necessary, with the present load, to operate either one of the two steam plants now connected to this system. This method of operation has been tried out thoroughly enough to warrant its permanent adoption. As the total combined load of all the companies increases beyond the capacity of the hydro-electric plants, one or more steam units will be operated as required, and the use of the water will become even more complete than now.

At the present time during low water periods, when steam power is required, the fluctuations in load are taken on the water power stations and a constant 24-hour, 7-day per week load is put on one or both steam plants to give the highest steam plant efficiency possible with the load to be handled. Waterwheels are only operated when sufficient water is available to allow their operation at a reasonably efficient gate opening. Arrangements are being made to float waterwheel generators on the line as synchronous motors, with gates closed during low water periods, so that waterwheel generators and turbo-generators carrying load may be run at loads to give the highest efficiency possible on their prime movers, without being required to carry more than their kv-a. rating.

It is evident, therefore, that the completion of the general power system, as described above, and its present method of operation, results in the supply of power, formerly generated by 121 separate steam plants, now being generated entirely from water power during many months of the year, and the balance from steam in not more than two modern stations.

The average coal consumption of the steam plants which have been superseded by this central station power was not less than 4 lb. The average coal consumption in the steam stations which supply the requirements of the system above described is about 2 lb. per kw-hr. If we allow 15 per cent for transmission and distribution losses between generating stations and power customers, and take into account the water power that was applied to this load last year, we see that the conservation of coal during that year alone amounted to approximately 376,400 tons.

This centralization of power supply has included a varied list of industries. In Greenfield and vicinity are many tool and tap and die shops. In Turners Falls are several paper mills, also cotton mills and cutlery shops. In Easthampton and Ludlow are very large cotton mills. In Chicopee and the Springfield district are foundries, municipal pumping plants, stone quarries, ice plants, and large factories building automobiles, motor cycles, tires, electrical machinery, arms, sporting goods and refractory products. Considerable amounts of power are supplied to argiculturists throughout the territory, where tobacco and onions are raised extensively, and much irrigation, cold storage, and electric heating is done in winter.

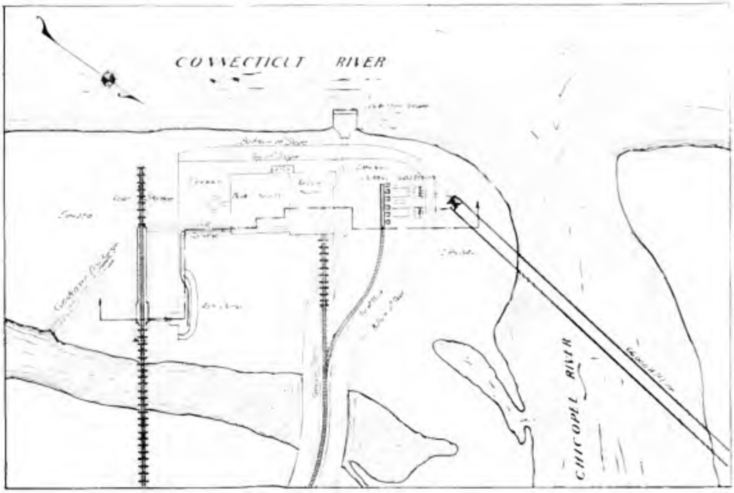


Fig. 11. Plan of Hampden Station Grounds

A brief description of the generating stations that supply this system follows:

Hydro-electric Stations

The Gardners Falls Station of the Greenfield Electric Light & Power Company operates under a head of 34 feet and consists of two horizontal wheels, direct connected to two 500-kv-a., 2300-volt generators and two vertical wheels, direct connected to two 1140-kv-a., 2300-volt generators. The 500-kv-a. generators were installed fifteen years ago and operated for ten years at 10,000 volts. At that time the increase of load of the Greenfield Electric Light & Power Company and its interconnection with the Turners Falls Power & Electric Company created a [illegible] larger market for power developed [illegible] plant, and the old machines were reconnected for 2300 volts and two modern [illegible] units, with single-runner wheels were added to the station. Most of the power from the station is stepped up to 13,200 volts through three 3-phase, 1200-kv-a. transformers and transmitted at that voltage to Greenfield and Turners Falls. An interior view of the station is shown in Fig. 3.

The Green River Station of the Greenfield Electric Light & Power Company is located in Greenfield and is a 100-h.p. development, consisting of one double-runner, horizontal wheel belted by a silent chain to a 100-h.p., 2300-volt induction motor, which is connected to a 2300-volt feeder of the local distribution system in Greenfield, and operates without an attendant. This station is described in the article "Induction Generator Plants" in this issue of the REVIEW.

The Turners Falls Station, No. 1, and the Cabot Station of the Turners Falls Power & Electric Company, were described in detail in the REVIEW in March, 1917. Since that description was written, two more units have been added at Cabot Station, and the head has been increased to 58 feet, increasing the capacity of all the units. There are now six 7500-kw. units in operation here, and 57,000 kv-a. of step-up transformers. Plans have been completed for the addition of another unit in this station as soon as load conditions require it. Fig. 4 is a view of the generator room of this station, with six generators installed.

The Indian Orchard Station, No. 2, of the United Electric Light Company, is located on the Chicopee river, and operates under a head of 36 feet. The equipment consists of three 750-kv-a. and one 690-kv-a., 5500-volt, 2-phase generators, each direct connected to a pair of horizontal wheels. The original installation at this plant consisted of belted generators, driven through jack shafts and clutches by the horizontal wheels. This station is connected to the main station at State street by two routes, each consisting of duplicate 5500-volt, 2-phase transmission lines and cables. In addition it is connected to the Turners Falls distribution system through 13,000 to 5500-volt, 3-phase-2-phase transformers and regulators of 3000-kv-a. capacity. A view of this station is shown in Fig. 5.

The Bircham Bend Station, No. 3, of the United Electric Light Company, is also on the Chicopee River. It operates under a head of 13 feet, and consists of two 400-kv-a., 5500-volt, 2-phase generators, each direct connected to a pair of horizontal wheels. Both of the above stations are operated so as to utilize to best advantage all of the water power available, the wheel gates being generally blocked open, and all the regulation taken care of by the larger stations.

Steam Stations

The State Street Station, No. 1, of the United Electric Light Company, is located in Springfield, on the Connecticut river. The boiler room contains twelve 700-h.p. Edgemoor boilers, with Taylor stokers, superheaters, feed water heaters and turbine-driven feed water pumps, and blowers for forced draft. The turbine room contains one 20,000-kv-a., two 5000-kv-a., one 2500-kv-a and three 1000-kv-a. Westinghouse turbine-driven, 5500-volt, 2-phase generators, the turbines operating at 200 lb. pressure, with 150 deg. superheat. In general, river water is used in the Leblanc condensers with which the tubines are equipped, and this water, with water from the river, is passed through filters and feed water heaters to the boiler feed water pumps, which are turbine-driven.

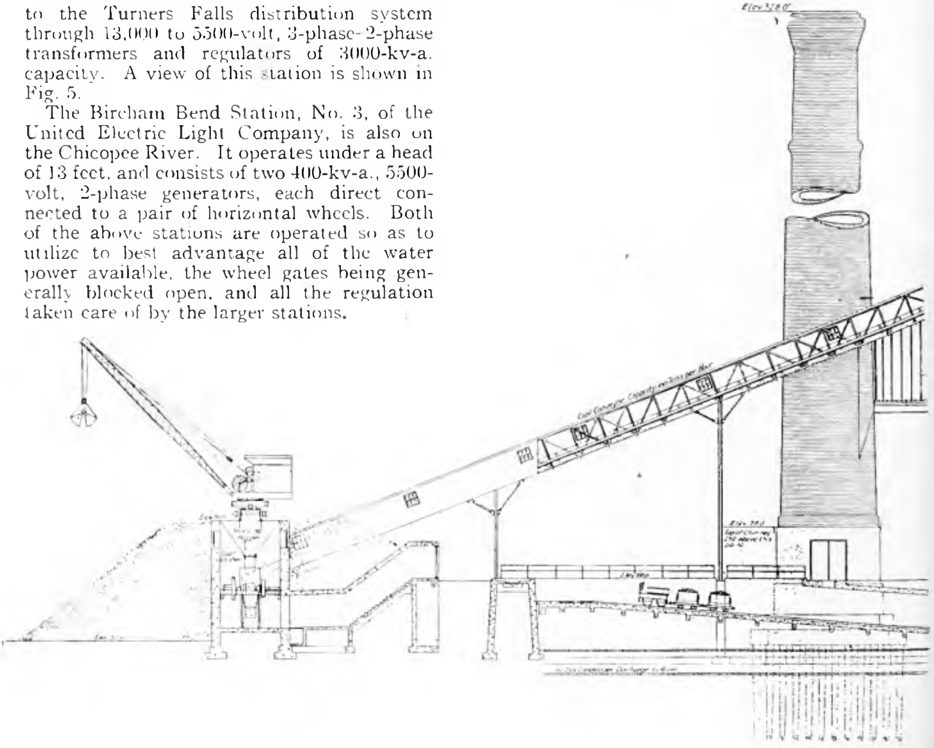


Fig. 12. Cross Section

The exciter sets are 3-unit outfits, and can therefore be driven either by steam or by motor. As the greater part of the other auxiliaries are steam-driven, the use of 3-unit exciter sets allows the amount of exhaust steam to be adjusted to take care of the requirements of the feed water heaters under different conditions of load.

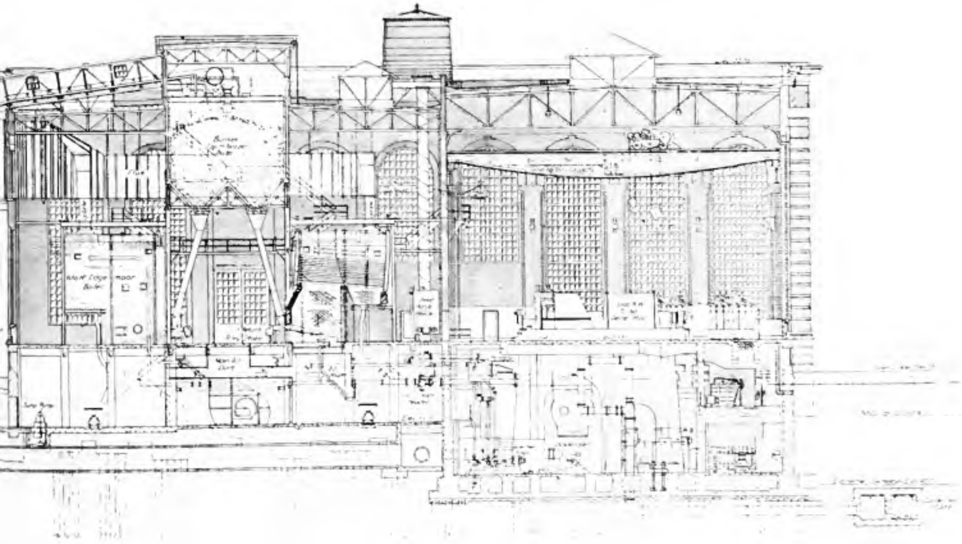
The switch house consists of a three-story, brick structure, housing practically all of the control equipment for the distribution of current in Springfield, as well as the control and switching equipment for generators, transmission lines, etc. This station is connected to the Turners Falls system through 66,000 to 5500-volt, 3-phase 2-phase transformers and regulators, of 18,000 kv-a. capacity. Figs. 7, 8, 9 and 10 show the principal features of this station.

The Hampden Station of the Turners Falls Power & Electric Company is located on the Connecticut river, near the mouth of the Chicopee river, on a 40-acre site of land, where coal may be delivered to it by rail, and whenever the river is made navigable at this point, coal may be received readily by boat. Fig. 11 is a plan of the station grounds, showing the arrangement of condenser water tunnels, coal storage, transmission lines, tracks, etc.

The main building and smoke stack are supported on a foundation of approximately 1000 Raymond concrete piles, varying in length from 20 to 35 ft., and designed to carry 30 tons each. Reinforced concrete was used for the floors, the walls, and the columns of the building, up to the level of the turbine room floor. At times of high water the turbine room basement floor is 25 ft. below water level in the river. This floor was therefore designed with heavy concrete beams to resist the upward pressure of the water under these conditions. The cross-sectional view of the station in Fig. 12 shows the general arrangement.

The boiler room equipment consists of eight 652-h.p. horizontal, tubular boilers, with superheaters, under-feed stokers and forced draft. Two fans for supplying air for the forced draft are driven, one by a motor and one by a steam turbine, each fan being capable of supplying sufficient draft for operating all the boilers at 150 per cent rating. The cooling air from the turbo-generators is delivered to the fan intakes. The boiler room piping is carried in the basement to a header, from which the steam pipes lead direct to the turbine.

The turbine room equipment consists of two 15,000-kw., 80 per cent p-f., Curtis



of Hampden Station

Fig. 13. General View of Hampden Station

Fig. 15. Turbine Room, 15,000-kw. Units; Hampden Station

Fig. 14. Firing Aisle, Boiler Room; Hampden Station

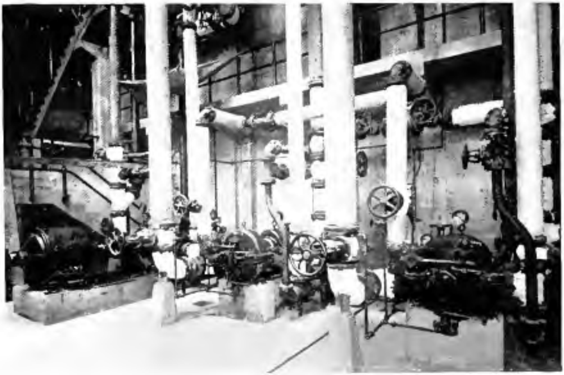


Fig. 16. Boiler Feed Pumps, Turbine Room Basement, Hampden Station

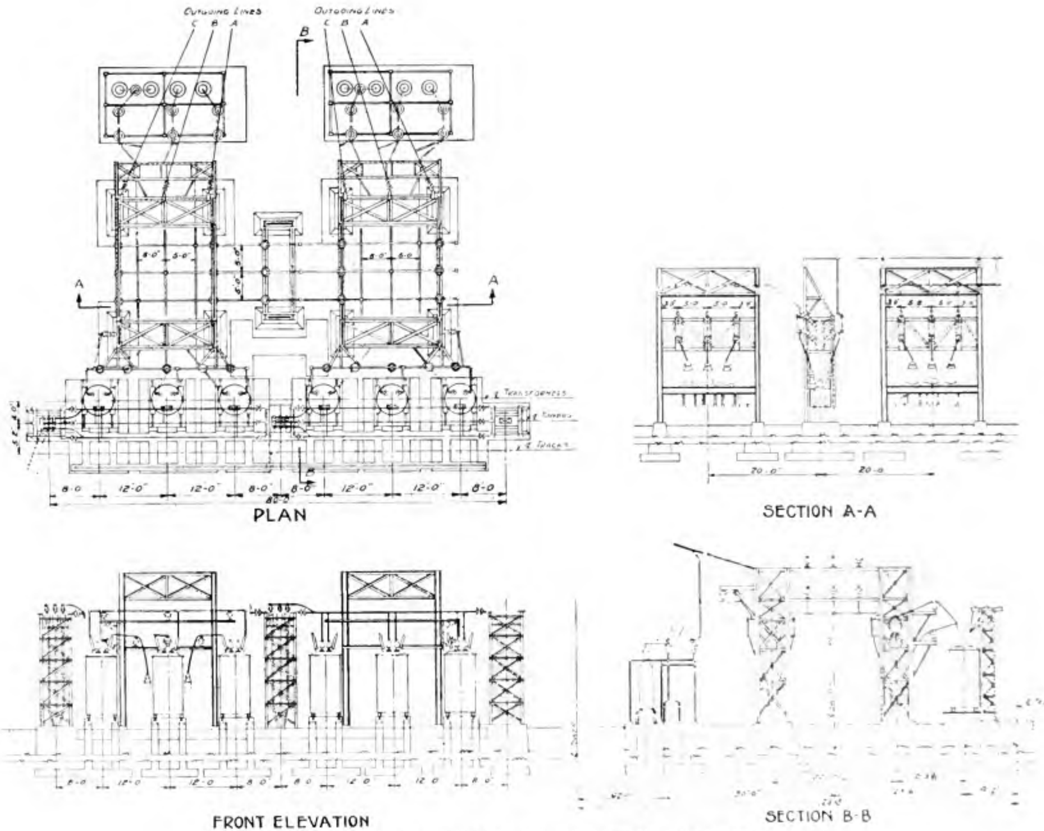


Fig. 17. Arrangement of Outdoor Substation; Hampden Station

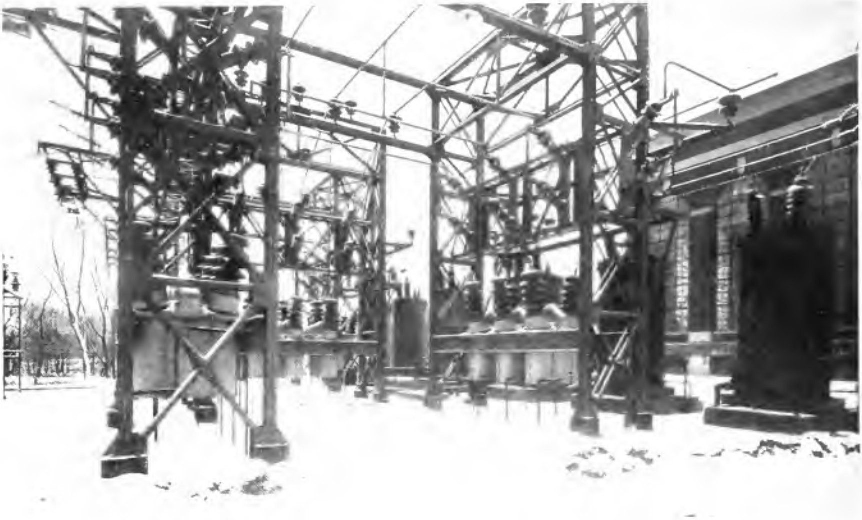


Fig. 18. View of 66,000-volt Transformers and Switching Equipment; Hampden Station

Fig. 19. 66,000-volt Line Construction Through Westfield, Mass.; Hampden Station

turbo-generators, operating at 200 lb. steam pressure, 125 deg. superheat and 28.5 in. vacuum. Each turbo unit is connected to a cylindrical shell, twin-jet condenser, equipped with twin submerged, removal pumps, connected through reduction gears to steam turbines. The condensers give 28 in. vacuum with 70 deg. cooling water when condensing 187,500 lb. of steam per hour. Radojet ejectors are used for air removal. Feed water, taken from the hot well through a heater, may be supplied through two 600-gallon, turbine-driven pumps, or one 600-gallon, motor-driven pump. The turbo-generators operate at 13,200 volts, 3-phase, 60-cycle, with grounded neutral, and are equipped with 250-volt, direct connected exciters. There is a spare motor-driven exciter.

Up to the present time the whole output from this station has been delivered to the 66,000-volt transmission lines of the company, which pass near by. This delivery of power made unnecessary an elaborate switching equipment, as is ordinarily required at a steam plant of this size. Each generator is switched through a motor-operated oil switch to one 13,200-volt bus and the current is then stepped up by two 18,750-kv-a. transformer banks, supplied from this bus through similar switches. These switches are installed on the main turbine room floor, the bus being located just below this floor, in concrete and brick compartments. The step-up transformers are connected [illegible] 13,200-volt delta 66,000-volt Y, with [illegible] grounded on the high side. The [illegible] and the 66,000-volt switching are [illegible] placed outdoors. Each transformer [illegible] on to a cross bus and two 66,000-volt transmission lines are supplied from the bus. Solenoid-operated, outdoor 66,000-volt [illegible] used for the 66,000-volt switching, and the outgoing lines are protected by aluminum cell arresters. The outdoor 66,000-volt bus and switch connections are built of galvanized iron pipe, and are supported on pin insulators, and the vertical disconnecting switches are supported on pin insulators.

Figs. 11 to 19 show the principal features of this station.

The construction of the station has been carried out with a view to allowing indefinite extension in units similar to, or larger than, the part already built. With the growth of the station it is probable that more or less distribution will take place at 13,000 volts from this point. In any case the further extension of this station will probably require a switch house, since the greater number of generators and transformers would make advisable a more complete switching equipment.

The author wishes to acknowledge the courtesies and assistance extended to him in the preparation of this paper by Mr. J. P. McKearin, Electrical Engineer of the United Electric Light Company.

Hydro-Electric Power Collection

By Charles P. Steinmetz

Consulting Engineer, General Electric Company

This article amplifies the author's contribution published in our August issue. He discusses a future power development in which very simple generators are located at many small hydraulic power sources. These pump power to central stations where it is controlled and fed into the power lines. In other words, he does inversely with the generator what we have done so successfully for many years with the electric motor.—Editor.

In hydro-electric plants, by far the largest part of the cost of installation is usually the hydraulic development, and by far the largest part of the cost of operation is usually the interest on the investment. Of our country's potential water powers only a small part can be economically developed by our present methods, since hydraulic power is rarely found so concentrated locally as to make it possible to bring together, in one generating station, a sufficiently large amount of power to have the value of this power pay for the cost of the hydraulic development required to collect the power in one place. As discussed in a previous article,* a much larger amount of the country's water power may be developed by applying to electric power generation the same economic principles which have made the electric motor so successful. That is, to have individual electric generators wherever water power exists, and collect the power electrically, just as economy requires to have individual electric motors wherever power is used, and distribute the power electrically. Thus, when it is economically not feasible to collect all the available water power by extensive and correspondingly expensive hydraulic works in one place and there locate one large generating station, smaller generators may be located along the water courses and throughout the water shed, wherever some power exists, and by a system of collecting lines—analogous to the distributing lines of motor application—the power of all these numerous generators collected in one system. These individual generators would be merely power producers, but the control of voltage, of frequency, etc., would be relegated to one large synchronous generator or synchronous motor station, possibly a steam turbine station acting at the same time as steam reserve on the system.

Electric generator and motor are identical machines, and if motor installations usually are very simple, comprising merely fuse and connecting switch, while generator installations contain an elaborate system of controlling and protective devices, the difference is not due to the nature of the machine and its function, but to the size of the installation. Thus very large synchronous installations also have a more elaborate system of operation and control, while the smaller generators used in electric power collection require no more elaborate appliances than a motor installation of the same size, that is, in the extreme case, merely a fuse to cut off in case of accident, and a switch to connect or disconnect. They require no more attention than motor installations, that is, they can be left to run themselves without any attention beyond an occasional inspection.

In larger motor installations, the synchronous motor is preferably used and offers material advantages, except in those cases where specially heavy starting duty is required; but for smaller motor installations, the induction machine is exclusively used, due to its far greater simplicity, and thus reliability under these conditions. Thus also, in power collection by distributed generators, induction machines would be used for all but very large units, especially where—as would usually be the case with smaller installations—the generating station is to be operated without any attention beyond occasional inspection. The induction generator is the typical electric power generator applicable for these smaller stations; it is extremely simple, requiring no auxiliary appliances or machines as exciters; it converts into electric power whatever mechanical power it receives, and as long as it is connected to an electric system capable of receiving electric power; it does not attempt to, and cannot, control voltage or frequency, etc., but leaves all the control to a central synchronous controlling station, as required in such a power collecting system.

Besides the advantage of simplicity, due to the absence of an exciter plant, perhaps the most important advantage of the induction generator over the synchronous generator, in a hydraulic plant, is that the induction generator cannot be damaged by overload, as it cannot be overloaded. The

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*"Electric Power Collection," General Electric Review, Aug., 1919, p. 565.

power output of the electric generator is limited by the maximum power which the hydraulic turbine or waterwheel can give. In the induction generator, current, voltage and power output are definitely and rigidly related to each other, and thus, with a given maximum power (that given by the waterwheel) the maximum current of the induction generator is limited and no excess current can occur. Not so, however, with the synchronous generator. With a given power output, the current in the synchronous machine feeding into a system varies with the excitation, and with wrong excitation a synchronous motor may be overloaded by excessive current, though its power output is below full load. Thus overload current protective devices, necessary in synchronous generators, are not needed in induction generators.

In its simplest form, such a power collecting unit, as located along mountain streams, etc., thus would comprise:

A low dam across the creek, just high enough to raise the water sufficiently to cover the intake to the pipe line.

A few hundred feet of city water pipe.

Some simple form of waterwheel, driving a low voltage induction motor as generator.

A step-up transformer connecting the induction machine with a medium voltage power collecting line, probably of a voltage between 10,000 and 30,000.

A disconnecting switch between transformer and high voltage line.

Fuses between induction generator and transformer, to cut off in case of accident.

To this may be added an integrating wattmeter, to keep record of the total power delivered by the unit.

Ammeters, voltmeters, wattmeters and frequency meters may be installed in larger stations, for the information of the inspector, for test, etc., but are of no use in operation, as neither current nor voltage nor frequency can be controlled in the induction generator station, but are controlled from the main synchronous station of the system.

As the hydro-electric induction generator cannot be overloaded in operation, the fuses between generator and transformer are for the purpose of cutting off in case the machine is held at rest under voltage, as would occur if the turbine were stopped by accident, such as by ice or other obstructions.

If the voltage comes off the line, the turbine races. The voltage then comes on again and temporarily large currents flow while pulling the speed down to normal. Not to cut off in this case, it is desirable to use time limit fuses, that is, fuses which do not blow instantly at excess current, but, due to the presence of a heat-storing element, only after some time, perhaps a minute or more. That is, such fuses as are used to some extent in induction motor installation for the purpose of cutting off if the motor is permanently stalled, but not to cut off under the temporary excess current of starting.

The disconnecting switch between transformer and high frequency collecting line is not really necessary, but in general it is desirable to have some absolute cut off for use in case of inspection, testing, repair, etc.

Lightning protective devices may or may not be installed in the induction generator station, depending on the frequency with which lightning is met in the territory, the value of the station, etc., in similar manner as applies to distribution transformers; or lightning arresters may be distributed along the power collecting lines, as is sometimes done with distribution lines, or located at special strategic points, such as the crest of hills, etc. The OF arrester is specially suited for this purpose.

In general, outdoor installation of apparatus would be used, though the induction generator, especially if large in size, may be housed under a shed.

A speed governor on the turbine appears unnecessary, as the speed cannot be varied by the governor, but is held by the frequency of the system to which the plant is connected, and the speed governor thus, by partly closing the gates, could only reduce the output and thus waste power. An excess speed cut off may be used to limit the speed in case of the voltage coming off the line, to 10 or 20 per cent above synchronism. Temporarily, however, the turbine would probably run up to its free running speed anyway, before the gates are shut by the excess speed cut off. Turbine and generator thus must be built to stand free running speed, and it therefore is simpler and preferable, at least in smaller installations, to omit also the excess speed cut off, and let turbine and generator run up to free speed if the voltage comes off the line. As soon as voltage is again put on, the load pulls down the speed to normal. To be able to pull the induction generator down to normal speed, from free running speed, its speed-torque curve must be higher than that of the turbine, in the entire range above normal speed, as discussed in my previous paper,* otherwise the machine may be stalled at over-normal speed. This, however, is rather more an interesting theoretical possibility, except in large machines of abnormally low armature resistance. The use of a reasonably high internal resistance of the rotor, as customary in squirrel cage motors, eliminates this possibility.

Depending on local conditions, various arrangements can be made in operating the hydraulic turbine:

Where the water supply is fairly steady and uniform, the simplest arrangement is to let the plant run continuously, taking whatever water is available up to the maximum power of the turbine, and letting the surplus run over the dam.

Where, as is usually the case, there are considerable seasonable variations of the volume of water, but the variations occur fairly slowly, the simplest arrangement is the use of a turbine with several nozzles, and the inspector at his daily or weekly round opens or closes more nozzles, in accordance with the available water.

Where there is some water storage, as is often the case, either by a dam impounding at least several hours' supply of water, or in some reservoir back in the hills, the plant may be operated intermittently. Especially is this desirable, if power is more valuable at certain times of the day. A float then closes the circuit of a small motor when the water is high, and the motor opens the gate and thereby turns on the turbine. Inversely, when the water reaches its lowest level, the float closes the circuit of the motor with reversed phase rotation, the motor starts in reverse direction and closes the gate, and thus shuts off the water. Or, the motor may be permanently in circuit and open the gates and keep them open against a spring, until the float reaches its lowest position and cuts off the motor and the spring then closes the gates. If the power then comes off the line, the gates will automatically close until the power comes on again. This gate motor, connected to the power collecting line, starts and turns on the turbine, if the water level is high, and if there is voltage on the collecting line. Thus, if with such intermittent power it is desired to use the power during certain parts of the day, the power collecting line is switched off at the main control station when its power is not needed, and switched on when the power is desired. Thus, when the reservoir is filled and the float closes the motor switch during a part of the day when the power is not needed, the motor does not start until the power is needed and voltage is put on the collecting line at the main control station.

With such an arrangement of intermittent operation between the collecting line and the induction generator a centrifugal cut-in and reverse power cut-out relay is inserted. Thus, when the water gates are opened and the turbine started, as soon as its speed has reached a certain percentage above synchronism, the centrifugal relay connects the induction generator to the power collecting line; it then falls into step and delivers power. When the reservoir is emptied or the water gates closed, the induction machine would still revolve, as induction motor driving the turbine; but now the reverse power relay disconnects it from the power line and it comes to rest.

The same method of control by float is also usable to turn turbine nozzles on or off with the variation of the volume of water, where there is no storage by reservoir. In this case, the overflow of the dam is made narrow and deep, so that the level back of the dam varies appreciably. The float back of the dam then closes the next turbine nozzle, when in the lowest position, where the overflow nearly stops, and opens the next nozzle when the overflow has risen so much that the water flowing over it is ample to feed an additional nozzle.

In this case, where the creek does not run entirely dry, centrifugal cut-in and reverse power cut-out obviously are unnecessary, but one nozzle would always remain open.

In general, the induction generator installation finds its best place where there is a fair head but small volume of water, and thus a very simple arrangement of induction motor direct connected to impulse waterwheel can be used along creeks, mountain streams, etc.

It is not the solution of the problem of the low head water power, however, because the very low speed and thus very large number of poles required for direct connection in low head water powers, makes the induction type of machine even less adapted than the synchronous machine, and small and moderate sized induction generator installations for low head water powers in general require chain, belt or rope-drive.

In small low head powers the cost of the dam will rarely permit economical development. However, there are many cases

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* "America's Energy Supply"—A.I.E.E. Trans. 1918, p. 985.

throughout the country where low head dams have been built or are being built for other purposes: for banking up the water for irrigation, for the use of condensers in big steam stations, for navigation and canalization, etc. Possibly in most of these cases there is a surplus of water which is wasted as overflow, and can be utilized by an induction generator plant. In this case the plant is economically feasible as the cost of the dam is not chargeable against the hydro-electric development, and this constitutes the second important application of the induction generator for hydro-electric power collection.

Induction Generator Plants

By C. M. Ripley

Publication Bureau, General Electric Company

In this issue Dr. Steinmetz discusses a method of power collection, the use of which, to some extent, may be warranted by future economic conditions. In a very few instances, and under specially favorable circumstances, the induction generator plant with little or no attendance is able to justify its installation. The author presents a brief description of such of these as have been in operation for a sufficient time to have demonstrated their practicability. If the prices of coal and labor continue to soar at their present rates, it is possible that the small induction generator plant may soon be economically more feasible than it is at present.—Editor.

Introduction

In the days of our frugal forefathers, coal was neither convenient nor cheap in the Eastern States. And so the streams of rapid flow and the small natural waterfalls were dotted with waterwheel "grist mills," where the farmers had their grain ground into flour, etc. Now nearly all of these grist mills have been dismantled or have fallen into decay—passing out of active use along with the abandoned farms, because the locations are now unsuited for industrial plants. The water powers, however, are still in existence.

In many cases these water powers can now be utilized for collecting this power and feeding it into the electric system of either an industrial plant or an electrical company. The generators best suited for these small plants are regular induction motors of the squirrel cage type, which have no commutators nor brushes and are extremely simple.

The Pacific Power and Light Corporation have had an induction generator plant in operation in the Naches Valley, near North Yakima, Washington, since 1915. The power plant consists of a small building 29 by 30 ft. and contains one Pelton Francis waterwheel of 1900 h.p. which is connected to a 1400-kw. 2300-volt 3-phase General Electric induction generator. The hydraulic head is 50 feet.

The only intruments on the generator panel are a voltmeter, ammeter and two wattmeters, one indicating and the other integrating, and a generator oil switch of General Electric make, equipped with a low voltage release and an overload trip. A tachometer is provided to show the speed when the unit is started up.

Three transformers of 500 kv-a. capacity feed the power into the 66,000-volt transmission system, which is less than three miles from the plant. Because of the simplicity of the outfit, the entire plant is operated without an attendant.

During the first two years of its operation it generated over twelve million kilowatt hours, and it is quite probable that the operating cost of this plant is the lowest ever reached by any power plant of similar capacity.

Those engineers who are familiar with the plant state that it is impossible either to over-excite or under-excite the generator—it is foolproof. It cannot be overloaded because the waterwheel capacity is less than the capacity of the generator; it cannot burn out due to a short circuit outside of the generator, because the short circuit will take away the excitation, and without excitation the generator will not generate. The voltage and frequency of the system are determined by the synchronous generators, which are controlled by governors and voltage regulators. The load dispatcher at the near-by synchronous plant instructs the patrolman how far to open the waterwheel gate of the induction generator plant to deliver the load desired. When the induction generator circuit breakers are tripped the machine speeds up, but since the generator is designed to withstand 100 per cent over speed no damage can result.

After a shut down the machine is put into service as follows: The waterwheel gates are opened gradually until the machine is rotating at about its normal speed. When synchronous speed is obtained, the generator switch is closed. Experience has shown that it is best to close the switch when the machine is running slightly below synchronous speed. A stroboscopic indicator is provided to tell when synchronism is reached. An arc lamp connected with the circuit is so hung as to illuminate a series of black and white stripes painted alternately on the generator shaft. The number of stripes correspond to the number of poles on the generator. The arc lamp, which is placed inside the frame between the generator and the waterwheel, illuminates the striped shaft and the stripes appear to move slowly ahead or backward, depending on whether the machine is running above or below synchronism. When running at synchronous speed the stripes appear to be stationary.

The plant is connected to a transmission system of 300 miles of 66,000-volt lines and 112 miles of 25,000-volt lines. The load is small and the system's power factor is leading except during the irrigation season or at other times when there is a heavy demand for power.

During those periods when ice prevents full operation of the hydraulic plant, the problem of handling the charging current has been a difficult one, until recently. Since the Drop plant has been in operation, however, this difficulty has been considerably ameliorated, because 825 kv-a. is required for magnetization current. This current is supplied by the condenser action of the transmission system and assists the synchronous generator just that much. When ice prevents the operation of the induction unit in the winter, the generator is kept running as an induction motor, merely for the purpose of neutralizing a portion of the line capacity.

On occasions, the generator has maintained a voltage on the system and carried a load when the synchronous apparatus has been tripped off. Under these conditions it has been found that the frequency and load are proportional to the waterwheel gate opening, while the voltage will depend upon the length of line connected and the voltage of the system at the instant the synchronous apparatus is disconnected. The load voltage and charging current will change with the frequency, which changes with a change in the waterwheel gate setting.

The only attention that has been found necessary is given by the canal patrolman, who visits the plant in the morning to inspect the lubrication and record the wattmeter reading and at night to make such changes in the gate opening as may be requested by the load dispatcher. Occasionally the induction generator will trip off the line and it is then the duty of the canal patrolman to put the unit back into service. The beat of this patrolman covers only four miles, one mile above and three below the Drop plant, and as a telephone is installed every mile along the canal it is customary for the patrolman to report to headquarters at each station. He is therefore never more than three miles from the plant during the daytime, and as his sleeping quarters are in a house near the fore bay, with telephone connection, he can be reached at any time of night.

All in all, the engineers are impressed with the fact that the installation is fool-proof, almost proof against neglect, and practically without operation costs. An account of the operation of this plant under various conditions is given in the following abstract from letters written by J. H. Siegfried, Superintendent of Power:

"I am enclosing herewith a copy of the data taken at the Drop plant when the induction generator was running alone, carrying the load from the Drop plant to Keenewick, a distance of 110 miles. There was no synchronous apparatus on the line to furnish the magnetizing current, but the magnetization was taken care of by the capacity current of the high tension line. You will note also that the method of getting data was as follows:

"All generating stations except Naches and Drop plant were disconnected from the line, and the load and current being carried by the Naches plant on the 66 kv-a. line was brought to zero, after which the Naches plant was disconnected from the line, leaving the induction generator to carry the load alone. The speed was then increased gradually from fifty cycles to sixty-four cycles and readings taken at every two cycles, the data showing very plainly that as the speed increased the voltage increased, and with it the charging current of the line. This in turn increased the magnetization of the generator, and the voltage rose still higher due to this. (Table I.)

"At another time we increased the length of the line thirty-five miles, adding 750 kv-a. in high tension transformers to those already showing on the accounting sheet. The load at the two substations was practically zero, but you will note from the data that the load increased on the generator, as did the current and voltage when the machine was at normal speed. (Table II.) The greater part of the increases in load was due to the increase in voltage.

"There was connected to the line 11,750 kv-a. in transformers, which, together with the magnetizing current for the induction generator, brought the power factor to a reasonable figure when the machine was running at normal speed and normal voltage. The load at this time of the morning consisted of lighting load, and the power factor was leading.

"In regard to the stability of the machine running alone and receiving its magnetizing current from

TABLE I

READINGS TAKEN AT THE DROP PLANT WHEN THIS STATION WAS RUNNING ALONE ON THE 66 KV-A. SYSTEM WITH 110 MILES OF LINE

Cycles	Kilowatts	Amperes			Volts			Speed	[illegible]	[illegible]
50	300	210	210	225	75	74	75	174	116	155
52	250	220	220	235	79	79	80	179½	128	175
54	425	240	245	250	88	88	89	186	140	195
56	525	255	260	270	94	94	96	192½	162	197
58	650	285	285	290	99	99	100	200	190	212½
60	675	285	290	295	110	116	110	207	177	223
62	750	295	300	305	117	117	118	212	185	230
64	875	315	325	315	128	126	128	222	197	246

the high tension lines, I would say we have never observed anything which would indicate an unstable condition. In making tests we have dropped the Naches plant when it was carrying 100 amperes of the charging current, but this did not seem to affect the Drop plant operation at all. In the last two years we have had all sorts of line trouble which caused us to lose the stations containing synchronous apparatus, but the Drop plant has hung on and carried the load after all the other stations have tripped off automatically. There are no synchronous motors fed from the 66,000-volt system west of Keenewick."

TABLE II

Kilowatts	Amperes	Volts	Speed
800	320	105	207
...	310	106	...
...	310	105	...

Thirty-five miles of 66-kv-a. line added to the 110 miles already charged.

Kilowatts	Amperes	Volts	Speed
1050	375	125	207
....	380	126	...
...	375	125	

The San Joaquin Light & Power Corporation has in operation two induction generator plants, one of which is known as the Crane Valley power house, and the other the Reservoir 1-A power house. It is estimated that the former will deliver yearly three and one half million kilowatt-hours and the latter practically three million kilowatt-hours. The hydraulic head for each of these plants is created by the main reservoir dam, and they thus utilize the energy which otherwise would be wasted in the flow of the water from the reservoir to the fore bay for the penstocks of the main generating station.

The hydraulic head at the Crane Valley power house varies from 80 to 120 feet. The waterwheel is rated at 1740 h.p., 450 r.p.m. and is connected to a 1000-kv-a., 2300-volt, 60-cycle, three-phase, squirrel cage induction generator. The set is designed to operate safely at 100 per cent over speed. As is customary with the induction generator, no governor is used as the frequency is controlled from the main generating plant. The switchboard contains an automatic oil switch, ammeter, voltmeter and integrating wattmeter. The generator potential is raised to 70,000 volts by three 400-kv-a. transformers, and the energy is delivered to the main network of the system through a transmission line seven miles long.

The Reservoir 1-A plant is located at the fore bay reservoir for Power House No. 1. The hydraulic head is 39 feet and the water is the same as that which earlier supplies the Crane Valley power house. The equipment consists of a 600-h.p., 240-r.p.m. reaction turbine direct-connected to a 425-kv-a., 3-phase, squirrel cage induction generator. The voltage is 6600. This generating unit is also good for double speed. A small magneto belted to the shaft indicates the speed of the set on a direct current voltmeter. A float switch in the ditch controls the motor which regulates the wicket gates of the turbine to maintain the water level at a constant height above the intake to the penstocks of the main power house. No regular attendant is necessary although it is visited from time to time by the patrolman.

It would have been economically impracticable to use these extremely variable heads with a complicated installation requiring continual supervision.

A small 100-h.p. plant of the Greenfield Electric Light & Power Company is operated under the supervision of Mr. C. F. Mosher, Supt. of Stations of the Turners Falls Power & Electric Company. A condensed description of the plant, together with an interesting discussion of the proper charge for the dam, which was needed for condensing water, are best told in the following words by Mr. Mosher:

"The Greenfield Electric Light & Power Company has had in service since late in 1913 a small induction generator hydro-electric plant, located on the Green River at the Mill Street Bridge in Greenfield, Mass., shown in detail on Fig. 1, together with photograph of dam and building exterior, Fig. 2, and described as follows:

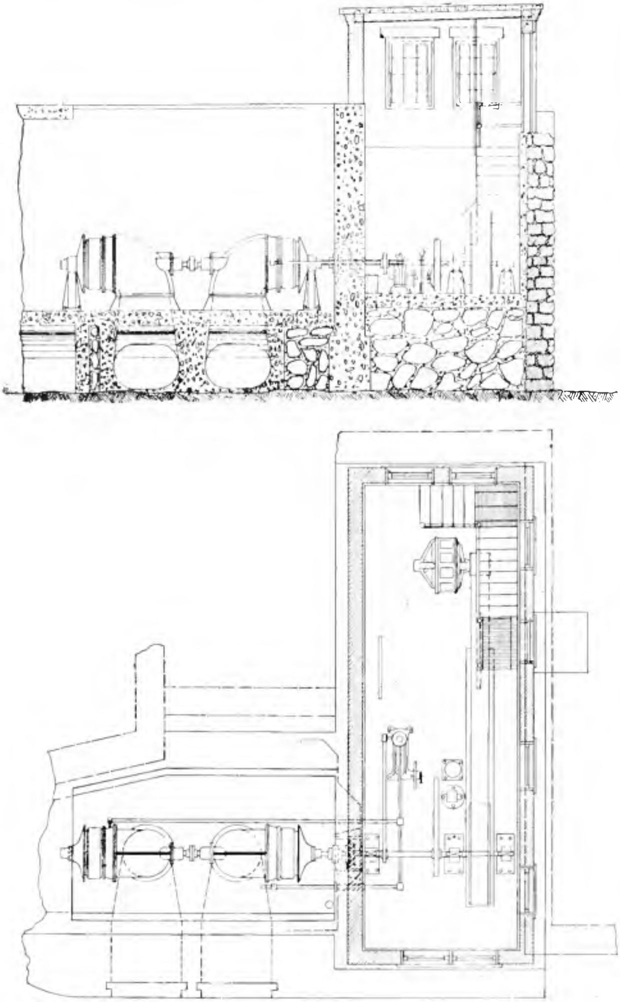


Fig. 1. Plan and Elevation of the Green River Induction Generator Plant of the Greenfield Electric Light & Power Co. as Originally Constructed. Protection against floods has necessitated a rearrangement of the plant, involving silent chain drive

"There is a watershed above the dam with an area of approximately 50 square miles. The dam itself is a concrete gravity type ogee section, with a spillway 164 ft. long, creating a head of 8½ ft. from its crest to tail water. This is increased to 11½ ft. by means of flashboards during the season.

"The wheels are two in number, set in an open flume in a common horizontal shaft.

"The original installation consisted of two 100-h.p., 3-phase, 60-cycle, 2300-volt squirrel-cage induction motors belted to the main shaft in a separate room adjoining the wheel chamber. The switching installation consists of a single panel mounting an ammeter, a watthour meter and an automatic oil switch connecting the motor to one of the Company's distribution circuits adjacent to the plant.

"A hydraulic relay governor is installed to control the no-load speed of the unit to about 15 per cent above normal.

"The generator room is so low and the river rises so rapidly at times that trouble was experienced in the belt pit and once in the room itself, causing such serious belt troubles that in 1916 the motor was reset at a higher elevation and a silent chain drive substituted for the former belt drive.

"The annual output of the plant has been as follows:

	Kw-hr.
1914	174,380
1915	263,360
1916	158,180
1917	238,380
1918	177,180

or a total of 1,009,480 kw-hr. in five years.

"The total plant investment is $26,143.80, divided as follows:

Land and water rights.	$ 3,000.00
Dam.	13,019.31
Bldg. foundations and wheel chamber	5,354.15
Elecl. and hydraulic equipment	4,770.34

The repair and maintenance cost has been as follows:

1914	$61.85
1915	332.98
1916	358.44
1917	86.35
1918	101.17

a total of $940.69 for the five years, or 9325 mills per kw-hr.

"No operating labor is charged to this plant, for it is located about 1/8 of a mile from the Company's steam plant and the only regular attendance given is a visit three times daily from one of the steam plant operators on his way from or to work. On this visit an inspection of bearings, racks, etc., is made, and if necessary, racks raked or the outfit started up or shut down, as may be indicated by the water conditions.

"Most of the repair and maintenance expense consists of flashboard maintenance, these having to be replaced complete once each year. The higher costs for 1915 and 1916 were due to necessary belt repairs and to replacing of belt with silent chain, as referred to before.

"It will be seen that if fixed charges of 15 per cent per annum for the equipment and 10 per cent per annum for the remaining investment is charged against the output the statement would be as follows, assuming an average annual output of 200,000 kw-hr. and an average annual repair and maintenance charge of $200:

15 per cent.	$4770.34—	$715.55		
10 per cent.	21369.46	2136.95		
		2852.50	305250	=$1.52 per kw-hr.
Rep. & Main.		200.00	200000	
Total.		$3052.50		

"The answer in this particular case is this: An old log dam and grist mill occupied this location for years and from the pond above the dam the Company obtained the absolutely necessary condensing water for its steam plant. In the course of years the grist mill was abandoned and the log dam became dilapidated beyond repair, so that the Company, to protect its condensing water supply, found it necessary to purchase the property and build a new concrete dam. Under these circumstances there is chargeable against the hydro-electric plant output only the maintenance charges and fixed charges on the buildings, foundations and wheel chamber and equipment, so the statement becomes as follows:

15 per cent.	$4770.34	$715.55		
10 per cent.	5351.15	535.12		
		1250.67	145067	=.725 per kw-hr.
Rep. & Main.		200.00	200000	
Total		$1450.67		

Fig. 2. Green River Plant of Greenfield Electric Light & Power Co. Photograph shows the dam and tiny Power Plant. The cable running up the side of the electric light pole connects this small generating station with the main system

It would seem to be apparent from the above that this method of utilizing a small power for this particular case under discussion has been a commercially feasible proposition, but it would seem equally apparent from the figures given above that this installation would not carry itself as a commercial proposition if fixed charges on the entire cost of development were charged against the output, on the basis of $7.00 coal."

The Taylor-Wharton Iron & Steel Company at Highbridge, New Jersey, have an induction generator plant operating on a head of 14 feet. Between May, 1918, and May, 1919, inclusive, it generated 126,800 kilowatt hours. The cost of operation amounts to about $150.00 per year. A foundry employee makes an additional 50 cents per day by looking in at

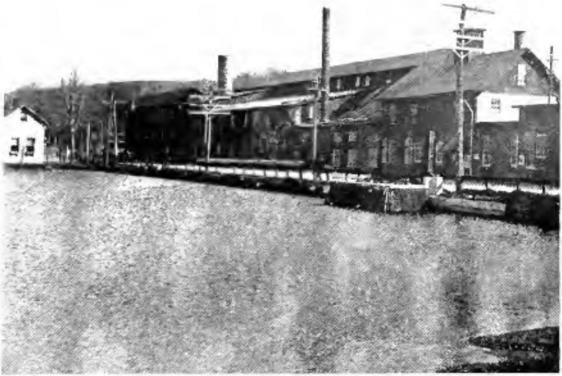


Fig. 4. The "Old Mill Pond" empties through the rack shown at the right
The rack is raked occasionally to remove weeds, and little trouble is
encountered with ice in winter. The power house is in
the rear of the building on the extreme right

Fig. 6. The discharge of the draft tube is on the side away from
the flume. The wires are shown which "collect"
the power and feed it into the system

TAYLOR WHARTON PLANT A

Fig. 5. The turbine is located in the flume, the end of which forms part of the wall of the power house. The turbine consists of two wheels discharging into a draft chest from which the draft tube goes down under the power house

Fig. 7. The turbine shaft comes through a stuffing box in the wall. This induction generator has pumped 126,800 kw-hr. into the power system of the steel plant

HIGH BRIDGE, N. J

the plant in the morning, to see if it is oiled properly. He then locks the door until his return trip home in the evening. The power cost runs between one half cent and one and one quarter cents per kilowatt hour, depending on conditions. The Company has under consideration the deepening and widening of the canal leading from the river to the pond which lies just above the power plant. By this improvement it has been estimated that 30 per cent more power output for the same charge can be obtained. It will be interesting to watch the effect of this improvement if carried out, and the figures a year from now may make a still better showing. The extreme simplicity of the installation is shown by Fig. 3.

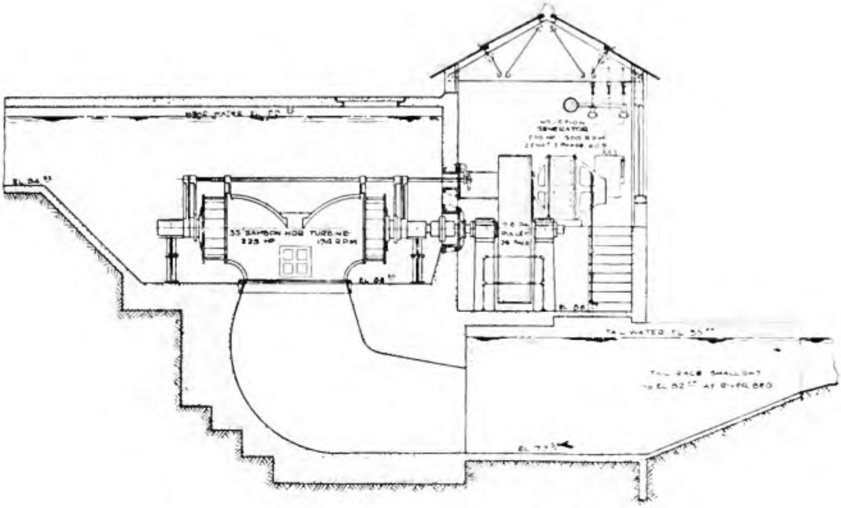


Fig. 3. Elevation of the Induction Generator Plant of Taylor Wharton Iron and Steel Company, High Bridge, N. J. This plant is illustrated in Figs. 4, 5, 6 and 7

This little plant, which is 11 ft. by 22 ft. by 15 ft. high, is located at the lower end of an old mill pond, and is practically built into the end of the flume, thus almost eliminating the expense of a dam. The bank of the mill pond, which is also the main road, forms the dam. The walls of the power house are part of the flume, which is 136 ft. long and 12 ft. wide. A 200-h.p., 3-phase, 2200-volt, 600-r.p.m. General Electric [illegible] serves as a generator.

Mr. B. T. Worth, Vice-President of W. Kidde & Company, of New York, who were the Engineers and Constructors of the installation, is intensely interested in its performance and is highly pleased with the low operating cost and the reliable service which it renders.

CONCLUSION

These Plants Utilize Heads Too Small to be Profitably Developed by Synchronous Generating Plants

Name of Plant	Kilowatt Hours Per Year
Pacific Power & Light Co. Drop Plant (1400 kw.)	6,000,000
San Joaquin Light & Power Corporation Crane Valley Plant (1000 kv-a.)	3,500,000
San Joaquin Light & Power Corporation Reservoir 1-A Plant (425 kv-a.)	3,000,000
Greenfield Electric Light & Power Company Green River Plant (100 h.p.)	250,000
Taylor Wharton Iron & Steel Company	150,000
	12,900,000

Preventing Versus Correcting Poor Power-factor

By H. Goodwin, Jr.

Power and Mining Engineering Department, General Electric Company

All large power companies have the problem of power-factor constantly before them, limiting the capacity of apparatus, causing excess losses in transmission and distribution systems, and making voltage regulation difficult. Other authors have brought out the point that much can be done by fully loading induction motors to avoid the expense incurred by the use of synchronous condensers for corrective purposes. In this article the author makes some valuable practical suggestions for aiding in maintaining the load and power-factor of induction motors.—Editor.

All engineers dealing with alternating current are more or less concerned with "power-factor," and the general subject of poor power-factor has received a great deal of attention. Transmission engineers have been most particularly concerned with power-factor because it is on long transmission lines that its effects are most severely apparent.

The suggestions for improvement in power-factor may be divided generally into two classes: *corrective* and *preventive*. The corrective measure consists in the application of condensers, either synchronous or static. The preventive measures include the improvement of the power-factor of motors by the use of synchronous motors or induction motors operating at full load.

The application of *corrective* measures is usually a problem large enough and so definite that it is placed in the hands of engineers with proper information and facilities for making recommendations. Further, the economy of correction can be definitely evaluated.

The application of *preventive* measures is apt to be a very intangible problem and to be in the hands of persons having little interest in it. However new interest in it is being added, in many cases, by the rapid introduction of demand charges proportional in some measure to the kilovolt-ampere demand instead of the kilowatt demand. So it behooves every power user to make studies of demand conditions in his plant either for present benefit or in anticipation of future benefit, or in an effort toward general national efficiency and economy in the use of our power supply. Many surveys have proved that, in general, industrial plants are largely "over motored."

It is therefore the purpose here briefly to suggest some devices which have proved useful to the practical plant engineer or electrician in meeting problems which really only he can solve satisfactorily. Doubtless many of these have read with interest articles on "over motoring" and the resultant poor power-factor, but have been at a loss as to how to apply them in their particular cases. They may have counted their total motor load and compared that with the demand and seen the large difference, and yet not know just what to do next.

The next step is to make tests, preferably periodic tests, and to keep a *record of the tests*. The accompanying illustrations show means for facilitating these two operations. They need not be followed absolutely, but may be modified to suit conditions in each plant or material already available.

It is essential that tests be made as far as possible without interruption to the service. Switches or fuses, across which instruments may be connected, are often in semi-accessible places where changing of instrument connections would be difficult. To meet both these conditions, it has been found very helpful to connect leads to the switch or fuses in the motor circuit, and carry these to a portable test board with switches and terminals for the ready connection of the instruments. Such a board is shown in Fig. 1. With the current and potential double-throw switches *a* and *b* open, connections are made to the circuit and instruments. Various screw connectors and clamps have been devised for connection to switches and wires and, for moderate sizes, have proved very satisfactory. The connections shown dotted are permanent and may be made on the back of the test board, or on the face with insulated wire. All back connections should be fully protected by another board. The fuses, switch blades or connections which have been bridged are then opened and everything is ready to take readings. Switches *a* and *b* are both thrown to position *A*.

It is noted that the voltage is approximately normal. The current short circuiting switch *C* is opened, with readiness to close it quickly again should the ammeter scale be too low or should the wattmeter read reversed.

The wattmeter connections should be checked carefully, because if the power-factor is below 0.5 the instrument will read reversed, and while it will be necessary to close C′ and interchange the current leads, the reading must be subtracted from the other phase reading obtained. To obtain readings on the other phase it is only necessary to close C′ and "throw over" *a* and *b* and open C″.

Then comes the duty of recording the readings obtained. The value of many important motor tests has been entirely lost because there was no systematic means of recording them. Some plants have made notable records for economy in use of motors and for high power-factor due almost entirely to a record system for motors and tests. Cards are used showing the location of every motor in service in the plant and those in stock or under repair. Other cards show motor locations and on these the test readings are recorded. This will be made clearer by referring to Figs. 2 and 3 which show cards suggested for this purpose. These cards may be ruled by hand, or printed, depending on the number required in each particular plant, and the information contained may be varied with local conditions.

The idea of the two cards is to separate conveniently the information which belongs particularly to the location of a motor from information about the motor itself, so that records of tests which belong essentially to the machine or group of machines driven will not be made inaccessible by transfer of the motor to another location. The "Motor Record Card" contains all the information pertaining to a particular motor and shows where it has been and is installed. On the back may be entered the record of any repairs made or other special information. The motor location card shows all the motors that have been installed at that location from time to time and the motor at present in service. The information about the motor is very brief; just sufficient to identify it so that the motor card may be found if further details are required. Stress is laid on the connected load and tests. The same form is continued on the back. In this connection, care should be used to get tests under average, maximum and minimum conditions and so to note them. Tests should be made after a change in machines in a group to see if a change in the size of the motor either up or down is necessary.

Just filling out the cards for each motor and each location and making a short summary of them will probably bring out some interesting facts; but when the first round of tests is made something is likely to be developed of considerable importance. The plant engineer is now ready to start improvements. If changes appear to be advisable, it will probably be well to check in each case, to be sure that conditions were not abnormal at the time of the first test. If some motor appears to be overloaded, an inspection of the tests of others may show one underloaded with which it may be interchanged with advantage to both. Some may be found enough below their capacity to warrant the purchase of new motors. In other cases, the over-capacity may not be sufficient to warrant the purchase of a new motor immediately, but if extensions are planned, requiring motors of similar rating, new smaller motors may be purchased and the old motors relieved for the new service.

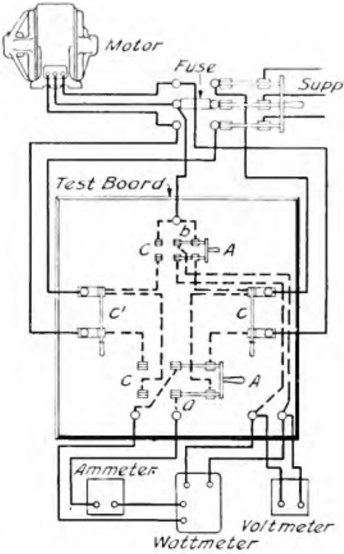
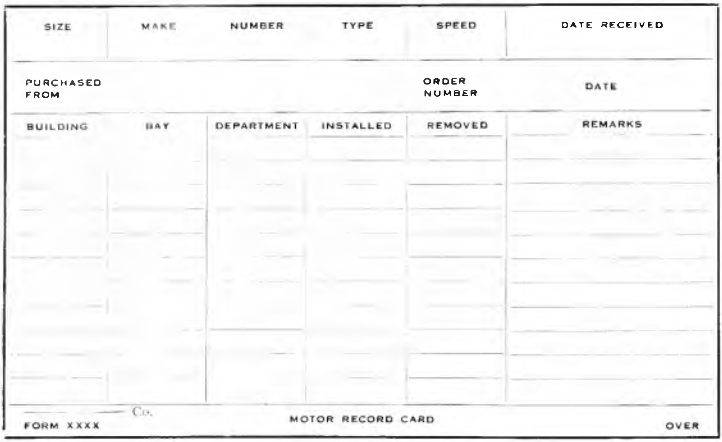


Fig. 1. Diagram of an Arrangement of Instruments, Switches, and Connections for determining the conditions under which a motor is operating without interrupting its service

Tests should also be made under starting conditions. All such facts have a bearing on the motor required and will be invaluable in



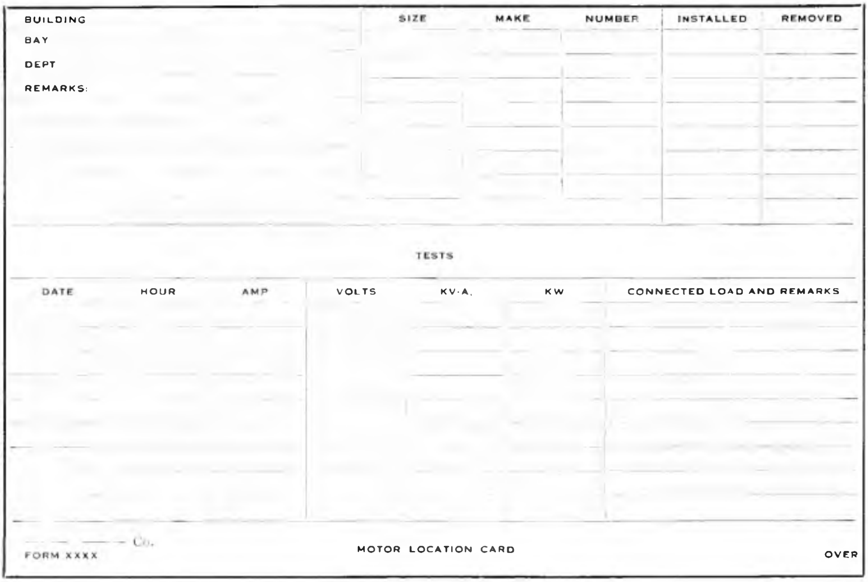
SIZE	MAKE	NUMBER	TYPE	SPEED	DATE RECEIVED

PURCHASED FROM
ORDER NUMBER
DATE

BUILDING	BAY	DEPARTMENT	INSTALLED	REMOVED	REMARKS

———— Co.
FORM XXXX
MOTOR RECORD CARD
OVER

Fig. 2. Card upon which may be recorded all information pertaining to a particular motor and showing where it has been and is installed



BUILDING
BAY
DEPT
REMARKS:

SIZE	MAKE	NUMBER	INSTALLED	REMOVED

TESTS

DATE	HOUR	AMP	VOLTS	KV-A.	KW	CONNECTED LOAD AND REMARKS

———— Co.
FORM XXXX
MOTOR LOCATION CARD
OVER

Fig. 3. Card upon which may be recorded all the motors that have been installed at one location from time to time and the results of tests

considering the purchase of new motors. And this leads directly to another thought. So far we have been considering improvement in power-factor only by running induction motors nearer normal load. Tests may develop good cases for the application of synchronous motors. Synchronous motors have now been developed with ammortiseur windings in the pole faces giving starting torque equal to that of squirrel cage induction motors of the same rating. In the smaller sizes the supply of exciting current still presents a little problem, but it is not beyond comprehension to conceive of a motor-generator set, centrally located, supplying excitation to a number of synchronous motors scattered throughout the plant. The power-factor could readily be controlled on the whole group by varying the exciter voltage either automatically or by hand.

It is not proposed to review here the application of synchronous motors, but it should be noted that if smaller size synchronous motors can be installed throughout a plant, they improve the power-factor on the distributing mains and so increase their capacity. If such synchronous motors can be installed with capacity for leading current, thus providing also for the *correction* of power-factor, so much the better. Care should be used in ordering such motors to specify what leading current or power-factor they shall carry.

One further thought: Would it be going too far to suggest to power distributing companies that they have prepared "Motor Record Cards" and "Motor Test Cards" for distribution to their customers to aid them in using the power they purchase economically and help them to improve the power-factor of their loads?

To sum up: Let us not consider any details in connection with poor power-factor too small for attention, but, by careful tests and records of them, determine upon means for *prevention* of troubles before they accumulate to an amount requiring correction.

The New England Power Company

By E. A. Dillard

Assistant Electrical Engineer, New England Power Company

and

H. R. Wilson

Power and Mining Engineering Department, General Electric Company

The system of the New England Power Company, and its interconnections, is the result of the growth and combination of several smaller stations. Many of the problems of high voltage system operation discussed in several articles in this issue are real problems of vital importance to the engineers of this system. The authors sketch briefly the development of the present system, and then discuss the operating problems which have presented the most difficulty and the means of their solution.—Editor.

The Development of the System

The present New England Power Company originated in the Connecticut River Power Company and the Connecticut River Transmission Company. The installation in 1909 consisted of a 12,500-kv-a. hydro-electric development on the Connecticut River, eight miles south of Brattleboro, Vermont, transmitting power at 66,000 volts to substations at Fitchburg, Clinton and Worcester. All three substations were built under the same general design, the first installation consisting of one 4500-kv-a. transformer bank. The original generating station at Vernon was later increased to 20,000 kv-a. capacity and a second 4500-kv-a. transformer bank was added to each of the substations. The transmission line consisted of 60 miles of double-circuit No. 2 copper with pin type insulators mounted on 40-ft. steel towers.

Three additional hydro-electric stations of 6000-kv-a. capacity each were developed on the Deerfield River near Shelburne Falls, Mass. These stations were connected to the Vernon station by a 15-mile double-circuit 66,000-volt transmission line and the original transmission line was extended from Worcester to Millbury, a distance of ten miles. This work was completed early in 1913. All three of the Shelburne Falls stations are of the same general design, consisting of three 2000-kv-a. generators and two 3000-kv-a. transformers.

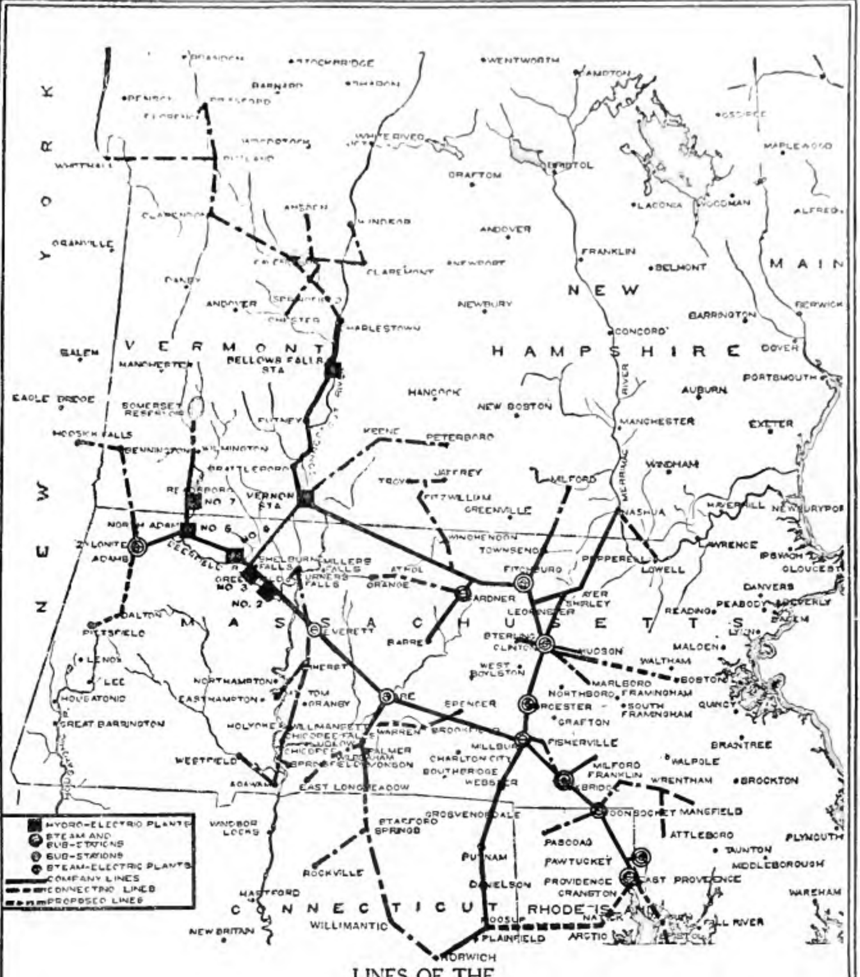
At the same time an outdoor substation of 12,000 kv-a. capacity was constructed in Millbury. This substation is of particular interest inasmuch as it was the first large outdoor station built in New England, and the first attempt to operate large water-cooled transformers exposed to the severe climatic conditions imposed by New England winters. The installation has proven satisfactory and all subsequent substations of importance have been of the outdoor type.

During this same year, a 60-mile. 66,000-volt, double-circuit line was completed connecting the Shelburne Falls stations directly to the Millbury station. This line was constructed of No. 2/0 copper with six disks of suspension insulators mounted on 75-ft. steel towers. The line was designed for ultimate operation at 110,000 volts.

A short time later a 15,000-kv-a. hydro-electric development was completed on the Deerfield River near Hoosac Tunnel, Mass., and connected to the Shelburne Falls plants by a double-circuit, 66,000-volt, No. 1 copper line. This line was also designed for ultimate operation at 110,000 volts.

The next addition consisted of an extension of the Shelburne Falls-Millbury line to an 18,375-kv-a. outdoor substation at Pawtucket; a distance of about 30 miles. The Pawtucket substation was connected to the 35,000-kv-a. steam plant of the Narragansett Electric Lighting Company at Providence. Ten miles from Millbury this line was connected to a small steam plant at Uxbridge and connections were also made to the Worcester Electric Light Company's 22,800-kv-a. steam plant at Worcester. When the Turners Falls Power and Electric Company's plant was developed on the Connecticut River, connection was made between this plant and the New England Power system at Leverett, about 14 miles from Shelburne Falls. The Readsboro development of 3000 kv-a. on the Deerfield River was then completed and connected to the Hoosac Tunnel station over a 7.6-mile single-circuit, 22,000-volt line. The Providence steam plant has been increased in capacity by 45,000 kv-a., and the Worcester Electric Light Company's plant by 20,000 kv-a.

During 1918 a 70,000-volt pole line was built to connect the Millbury substation with the 25,000-kv-a. steam plant of the Eastern Connecticut Power Company at



LINES OF THE

NEW ENGLAND COMPANY SYSTEM

AND

CONNECTING AND PROPOSED LINES

Fig. 1

Norwich and a 70,000-volt pole line built to connect the Clinton substation with the Boston Edison system. There was also constructed this year a 70,000-volt outdoor substation at the Providence steam plant, and a 70,000-volt, double-circuit steel tower line between this station and the Fall River Electric Company's plant in Fall River. The construction of this line is interesting as it involved three crossings of navigable rivers, each demanding 145 ft. clearance. To effect this clearance, two 220-ft. towers and two 177-ft. towers were required in Providence and two 215-ft. towers were required in Fall River.

Fig. 2. Diagram Classifying and Evaluating the Disturbances on the Lines of the New England Power Co.

The system has continued to expand both in hydro-electric and steam equipment and at the present time its total generating capacity and that of the connecting systems is over 500,000 kv-a. The New England Company's system transmits energy, exclusive of connecting systems, some 300 miles at 66,000 volts and the normal week-day output averages about 1,100,000 kw-hr., and the normal week-day peak averages about 80,000 kw.

Operation

A system of this capacity and complexity presents many interesting and difficult operating problems in order to give continuity of service.

Complete records are kept of each system disturbance and studies are made of these records in order to reduce the extent of them. Each disturbance is classified broadly according to its origin, and Fig. 2 illustrates the magnitude of each classification during one year's operation. Another interesting point in connection with these records is the time of day that most of them occur. Fig. 3 indicates that the period when most troubles occur is early in the afternoon as this is the time of day that lightning storms are most prevalent. Disturbances generally originate from an accidental short circuit on some portion of the system, and in order that the remaining part of the system be not seriously affected, it is necessary to immediately segregate the section in trouble. It is essential to keep all generating stations in operation and on account of the number and distribution of these stations it is an unusually difficult relaying problem.

The scheme which has been adopted makes extensive use of balanced power relays to cut out of service that section of the double-circuit line which is in trouble but retain in service all sections that are not involved. Balanced power relays are essential to substations being served from double lines, and they are very desirable for interconnections between generating stations because of their reliability under all conditions of variable capacity. Fig. 4 shows the method of connections of the balanced power relays. Fig. 5 shows the general scheme of relaying on the high tension lines. It will be noted that the

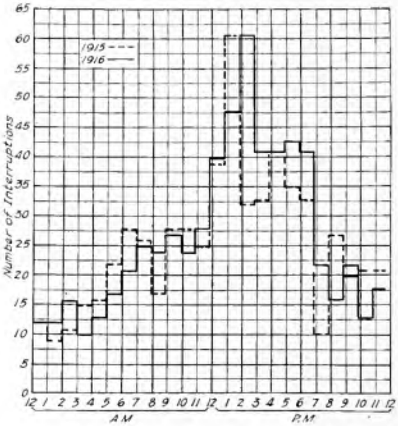


Fig. 3. Chart showing the Relationship Between the Time of Day and Service Interruptions

principal connections between generating stations are provided with balanced power relays on both ends. With these relays, the line in trouble is disconnected quickly and other connections are not disturbed. There is an additional advantage in this relaying scheme inasmuch as a very effective means is afforded for testing a line suspected of being in trouble. By means of small knife switches located on the switchboard, the balanced power relay control circuit is made inoperative on the good line and operative on the line under test. Should this line prove faulty, it is disconnected immediately and there is little chance of disconnecting the good line. In addition to this balanced power scheme there is a "second line of defense" to take care of double-line troubles and sustained short circuits caused by failure of other relays to function properly. This is obtained by use of straight overload relays that are given a low current and a long time setting. Relay settings are made from studies of the value and distribution of the short circuit currents.

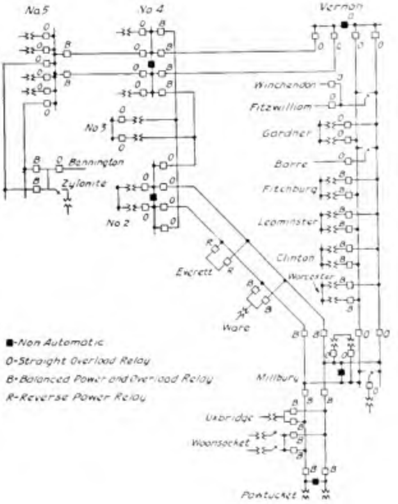


Fig. 4 Relay Diagram of the New England Power System

Calculations are made to determine the limits of these values for various locations of short circuits and for the extreme limits of generating capacity. Selections on low tension circuits are generally obtained by means of inverse time limit overload relays. All relays are calibrated with a c[illegible] and curves are plotted extending to current values such as are expected under fault conditions. One quarter of a second is considered sufficient time to obtain selection between two relays carrying the same amount of current.

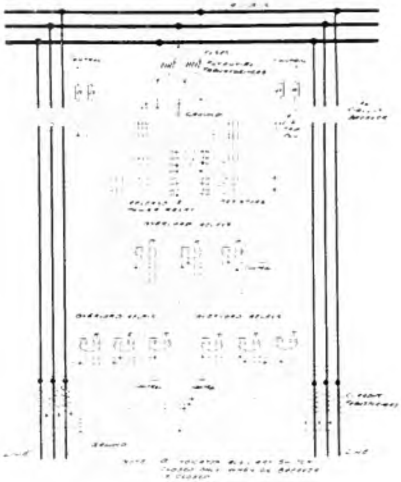


Fig. 5. Diagram of the General Scheme of Relaying on the High Tension Lines

In order to determine the relay "settings," a careful study of the short circuit current values was necessary, and it is necessary to repeat this study with each addition to the system. On account of the complexity of the system, calculations to determine these values would be extremely difficult and lengthy, so there has been constructed a calculating table to represent the entire system in miniature. (See REVIEW issues of October, 1916, and February, 1919, for a general description of a similar table.)

When it is considered that high tension short circuits may develop instantaneous short circuit currents equivalent to 800,000 kv-a., it will be seen that the duty imposed on the apparatus is extremely severe and the handling of this amount of energy presents an important problem. The operation of the system under these conditions necessitated several expedients to reduce the volume of these short circuits to an economical workable value. As an example, the high tension bus at Vernon has been sectionalized by means of an automatic oil circuit breaker so that when a fault occurs on one of the high tension lines from Vernon, this circuit breaker operates in time to effectively introduce the reactance of the Vernon transformers between the generating equipment and the fault. By this means the duty on the high tension line oil circuit breakers is appreciably reduced.

The question of handling low tension short circuits is also an important one. Under war conditions, interconnections with relatively large generating capacities of other systems that had not previously been contemplated, were found essential, and in some instances such connections were made directly to the low tension distribution of the substations. These additions, of course, greatly increased the amounts of energy in low tension short circuits, and as the work was done under practically emergency conditions, it was not possible immediately to provide large enough oil circuit breakers to take care of this additional duty. To overcome this situation temporarily, a scheme has been developed, making use of a reactor which is normally short circuited but automatically introduced between a feeder fault and the source of power until the feeder breaker operates and is then automatically again short circuited. As an example, in Fig. 6, the equivalent instantaneous short circuit value on the low tension side of the transformers of a 24,000-kv-a. substation was 380,000 kv-a. This would normally mean that each feeder breaker would be required to interrupt this value. There was installed an 18 per cent reactor (X) which was normally short circuited by oil circuit breaker (B). When a fault occurs on one of the feeders, circuit breaker (B) instantaneously opens and the reactor becomes effective, reducing the equivalent short circuit to 100,000 kv-a. The circuit breaker in the faulty feeder then opens and circuit breaker (B) automatically closes, again short circuiting the reactor. The result of this arrangement is that there is required only one high capacity breaker which is needed to interrupt (380,000 minus 100,000) 280,000 kv-a., while the feeder breakers are only required to interrupt 100,000 kv-a. Power loss and voltage drop in the reactor are also eliminated.

Insulators

One of the most interesting problems arising in connection with the operation of this system has been that of high tension insulation. On the high tension system proper there are over 9000 70,000-volt pin-type insulators and over 90,000 suspension-type insulator units. Experience has taught the necessity of periodically testing all of these insulators and testing and changing crews were organized to cover the entire system yearly.

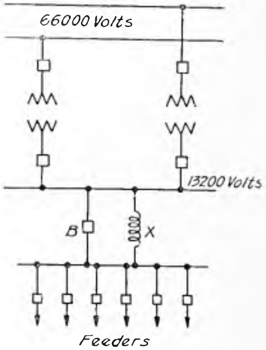


Fig. 6. Diagram showing a Reactance *X*, and a Short-circuiting Switch *B*, Between a Source of Low-tension Power and Distributing Feeders

No very satisfactory method for testing pin-type insulators has yet been learned. A visual inspection is given these insulators and each section is "sounded out," but results do not indicate that this method is thorough. The suspension insulator units were first tested with 1000-volt meggers, but this method was abandoned in favor of the simpler "buzz stick." Megger testing necessitates removing a section of line from service, which is objectionable when the system is operating under even a medium load. Again, megger tests did not prove positive. When tests are made under the proper conditions, there is no doubt but that all units "meggering" low are bad, but it was found that many "meggering" high were also defective. This can be explained by the fact that only a small fraction of an inch of porcelain is sufficient to give a reading of infinity on the instrument, whereas only a few thousand volts would be sufficient to break down this path. The "buzz stick" test is in effect a method of judging the quality of insulator units by visually measuring the charging current of each unit. A small wire fork, attached to the end of an insulating stick, is used to short circuit each unit one by one while the line is alive. The volume and character of the spark drawn out when one prong of the fork is removed from the metal parts of the unit indicate accurately the quality of that unit. Experience is, of course, necessary to pass judgment in this manner, but such experience is soon obtained. Should the unit test badly, it is marked for the changing crew by means of a small paint brush in the crotch of the testing fork. Check tests with high voltage and high frequency indicated very favorably for the "buzz stick" test. Only a small percentage of good insulators have been removed, and many that have tested badly but show high megger readings.

During 1918, 67,156 units were tested by this method, the result being 5513 bad units, about 8 per cent of all tested. The cost of testing these insulators was about one and one half cents per unit.

Voltage and Power-factor

The territory fed by the New England Power system covers a considerable portion of the manufacturing district of the New England States, so that the load on this system is chiefly an industrial one, consisting of mills manufacturing cotton, woolen, paper, wire and rubber products, chairs, forgings, etc. There is also some railway and town lighting load. The industrial load, however, predominates and the character of this load is such as to necessitate wide applications of induction motors. Generally, the manufacturers have shown a tendency to disregard the advantages of selecting motors for their various drives to give the best power factor conditions. Consequently, the system power-factor is not as high as is economically desirable. After extended studies of this situation a 7500-kv-a. synchronous condenser has been installed at the Worcester substation, at the Woonsocket substation and at the Fitchburg substation, and further installations are being contemplated. These installations have materially benefited the system power-factor as a whole and have been the means of obtaining much closer voltage regulation in the different substations. In addition to this, the condensers effect a saving in line loss more than sufficient to pay the cost of their operation.

The hydro-electric stations and steam stations are on opposite ends of the system and they are not operated to capacity simultaneously. During low water periods, the steam plants supply most of the energy consumed in the vicinity of the hydro-electric plants. This, of course, introduces a problem of maintaining good voltage conditions to the customers in the [illegible]. The transmission of the wattless current [illegible] customers is uneconomical. This [illegible] remedied by operating enough generators [illegible] the hydro-electric plants to maintain proper voltage and to absorb the wattless current [illegible] the customers in this vicinity. There [illegible] recently been purchased two 6000-kv-a. generating units for the Vernon station. These units are designed to operate at 6000-[illegible] 4200 kw. at 70 per cent power-factor, or as a synchronous condenser delivering 6000 kv-a. [illegible] 0 power-factor. The power-factor situation is considered so important that a section of the Engineering Department devote their entire time collecting data and studying the problems involved. This section makes careful studies of the motor applications in each mill with a view of rearranging such applications to derive the maximum efficiency and power-factor from the motors. The results fully justify this work as an appreciable reduction of energy consumption and a betterment of power-factor conditions has been achieved.

Inter-connections with Adjoining Systems

This system, like many another, has had a rapid growth during the past few years. In its beginning, when the system consisted of one generating station and a few substations, the operation was a comparatively simple matter. Since then, however, the expansion of the system and its interconnections with adjacent systems, such as Narragansett Electric Lighting, Boston Edison, Turners Falls Power & Electric Company, Colonial Light & Power Company, Worcester Electric Light Company, Blackstone Valley Gas & Electric Company, Fall River Electric Light Company, Eastern Connecticut Power Company, Rockville and Willimantic Lighting Company, and others, has made the operation more difficult. Many complications have been introduced, not only from the viewpoint of the most economical use of the hydro and steam plants, but, also, from the point of continuity of service, as it must not be forgotten that the manufacturing industries are of such a character that an instant shut down often means a considerable amount of damage in the products which are being manufactured. It is to be expected that the future growth of the system will be as rapid as the past and as the tendency at the present time is toward the interconnection of power systems, any changes or additions must take into account all such possibilities.

The Alabama Power Company's System, Its Development and Operation

By J. M. Oliver, B. Nikiforoff, and C. B. McManus

Operating Department, Alabama Power Company

The extension of high tension transmission and distributing systems into vast networks covering large sections of country, serving important industries, presents many operating problems that require careful study for their successful solution. The continuity of power supply has a great bearing on the growth of the transmission and distribution industry and every possible source of interruption should be anticipated and steps taken to minimize the effect on other parts of the system. The authors set forth in a clear and comprehensive manner many of the problems encountered in the operation of such a system and show some remarkable results from the use of relays and protective devices in preserving continuity of service.—Editor.

The products of the industries of Alabama, such as cotton goods, coal and iron, were among the most urgently needed during the war, and every effort was made to increase the efficiency and quantity of production. As a result of this came an increased demand for power. To take care of this demand the Alabama Power Company found it necessary to make several extensions to its system, and to improve methods of operation and protection.

A complete description of the system was given in the June, 1916, issue of the General Electric Review and various parts of the system have been described in other periodicals, so that it will be necessary to give only a brief outline here. The operation of the system, with a total generating capacity of about 150,000 kv-a., and approximately 1000 miles of transmission and distribution lines, presents many problems with regard to the methods of operation, continuity of service, protection against failures and their elimination, together with the organization of maintenance and repair work. A description of work done along these lines, and results obtained, will be the chief subject matter of this article.

General

The main generating stations are: The Lock 12 hydro-electric plant, the Warrior steam plant, and the Gadsden reserve steam plant. Data of interest regarding these plants will be found in Table I.

The main bulk of power is supplied from Lock 12, on the Coosa river, where every effort is made to utilize the full quantity of available water with maximum efficiency, at all times.

Fig. 1 is a general view of the Warrior steam plant, and the 110-kv. and 44-kv. switching yard. Fig. 2 shows the switchboard at this station. The plant is located in the heart of the coal region of northwestern Alabama, on the banks of the Warrior river, and at present constitutes the main reserve capacity of the system. The plant was built in 1916 and had installed one 25,000-kv-a. turbo-generator. In 1918 a second unit of 33,000 kv-a. was installed by the Government for the purpose of supplying power to U. S. nitrate plant No. 2 at Muscle Shoals.

Near Gadsden, on the Coosa river, is located the second steam plant used also as a reserve plant. A small hydro-electric station at Jackson Shoals is used largely for boosting purposes.

The primary substations are Magella, Bessemer, Anniston, Jackson Shoals, Sylacauga and Muscle Shoals. Distribution lines are also fed from Warrior and Gadsden steam plants. A general layout of the system showing the location of generating stations and substations, and territory served by these stations is shown by Fig. 3.

The Bessemer substation was constructed during the past year to take care of the increased load in the Bessemer district, and to form a point of interconnection between the Warrior steam plant and the main system. This station forms the central switching point of the western division of the system. It is connected with Lock 12 by a double-circuit 110-kv. line, and with Warrior steam plant by one 110-kv. line and one 44-kv. line.

A 90-mile, single-circuit, 110-kv. line connects the Warrior steam plant with the substation at Muscle Shoals, serving U. S. nitrate plant No. 2.

Double-circuit, 110-kv. and 44-kv. lines interconnect the Magella and Bessemer substations; Gadsden and Anniston are connected with Lock 12 by a double-circuit, 110-kv. line, the Sylacauga and Jackson Shoals stations being normally connected to one of these lines. The eastern and western sections of the system are tied together by one 110-kv. and one 44-kv. line between Magella and Jackson Shoals. A 44-kv. tie line interconnects

Fig. 1. General View of the Warrior Steam Plant, 110 kv. and 44 kv. Switching Yard

Fig. 2 View of Switchboard at the Warrior Steam Plant

Jackson Shoals and Anniston. Table III gives various data in regard to the 110-kv. and 44-kv. lines.

As will be seen from Figs. 3 and 4 the main primary substations, Bessemer, Magella, Jackson Shoals and Anniston are interconnected with 44-kv. tie lines. These lines serve materially in reducing the number of interruptions in case of 110-kv. line trouble. Each of the main substations has at least three sources of power, and by a more or less elaborate system of relays, interruptions have been reduced to a minimum. Considerable study has been made in connection with the relay protective system, and the interconnection of the system. This matter will be discussed in detail in another part of this article.

The section of country covered by the transmission and distribution lines is subjected to lightning storms throughout the entire year. Summer storms are unusually severe and at times several storms have been experienced in one day. Table II shows the number of days, during each month, on which lightning storms were observed for the year of 1918, and up to July for 1919. These observations were made by the Weather Bureau at Birmingham, this point being approximately the center of the system.

Such unusually severe weather conditions, together with the fact that many of the lines pass through rough and exposed country offer sufficient explanation for a large percentage of troubles experienced in the operation of the system. The chief troubles on the 110-kv. lines, are, of course, insulator failures and flashovers; however, troubles experienced on the 44-kv. lines have been of a much more serious nature and more numerous, quite a few failures having developed in transformers. Up until the beginning of the present year the 44-kv. system was operated with the neutral ungrounded. The electrostatic unbalance in voltage, and the attendant high frequency surges resulting from a ground on one phase of this system was considered as a possible reason for a part of the apparatus

TABLE I
GENERATING STATION AND PRIMARY SUBSTATION DATA

Location	GENERATORS					TRANSFORMERS						LIGHTNING ARRESTERS	
	No.	Capacity Each Unit Kv-a.	Total Capacity Kv-a.	Volts	R.P.M.	No.	Capacity Each Unit Kv-a.	Total Capacity Kv-a.	Volts	Connections	Single- or 3-Phase	Type	Location
Lock 12	5	13,500	67,500	6,600	100	15	4,500	67,500	6600/110,000	△/Y_1	Single	Aluminum	On lines
Warrior	1 1	25,000 33,333	58,333	13,200	1,800	9 3	6,667 3,333	60,000 10,000	13,200/110,000 13,200/44,000	△/Y_1 △/Y_1	Single Single	Aluminum Aluminum	On lines On lines
Gadsden	2	6,250	12,500	2,300	1,800	6	2,100	12,600	2,300/22,000/110,000	$\frac{\triangle\ \triangle}{\triangle}$	Single	Aluminum	On lines
Jackson Shoals	2	1,000	2,000	2,300	150	3	1,000	3,000	2,300/44,000	△/Y_1	Single	Aluminum	On lines
Total generating station			140,333					153,100					
Bessemer						3	4,500	13,500	44,000/110,000	△/△	Single	Aluminum	110 kv. on buses, 44 kv. on lines
Magella						6 3	4,500 4,500	27,000 13,500	13,200/110,000 44,000/110,000	△/Y △/△	Single Single	Aluminum Aluminum	On lines On lines
Anniston						6	4,500	27,000	44,000/110,000	△/△	Single	Aluminum	110 kv. on buses, 44 kv. on lines
Sylacauga						3	2,000	6,000	44,000/110,000	△/△	Single	Aluminum	110 kv. on buses, 44 kv. on lines
Muscle Shoals						6	6,667	40,000	13,200/110,000	△/Y	Single	Aluminum	On lines
Jackson Shoals						3	2,000	6,000	44,000/110,000	△/△	Single	Aluminum	110 kv. on buses, 44 kv. on lines
Total substation								133,000					

TABLE II

LIGHTNING STORM OBSERVATIONS MADE BY THE WEATHER BUREAU AT APPROXIMATELY THE CENTER OF THE ALABAMA POWER COMPANY'S SYSTEM

YEAR OF 1918				YEAR OF 1919			
Month	No. of Days on which Lightning Storms Occurred	Month	No. of Days on which Lightning Storms Occurred	Month	No. of Days on which Lightning Storms Occurred	Month	No. of Days on which Lightning Storms Occurred
Jan.	4	July	12	Jan.	0	April	2
Feb.	1	Aug.	7	Feb.	1	May	5
March	3	Sept.	8	March	2	June	12
April	8	Oct.	4				
May	4	Nov.	1				
June	15	Dec.	0				

failures. In 1918, the grounding of the neutral of the 44-kv. system was decided upon. The necessary changes were made in station equipment as regards relay protection, etc., and the neutral was grounded through a 10,000-kv-a. transformer bank at the Warrior plant, and a 3000-kv-a. bank at Leeds, early in January of the present year. The neutral of a 3000-kv-a. bank at Jackson Shoals will be grounded at an early date, and the ground at Leeds removed. These transformers are all grounded without resistance. The neutral of the 110-kv. system is grounded at Lock 12 and Warrior. This system has been operated with a grounded neutral for several years, and the results obtained are quite satisfactory.

It is impossible to make a definite statement as to the results obtained by grounding the 44-kv. neutral, due to the short time which has elapsed since it was grounded; however,

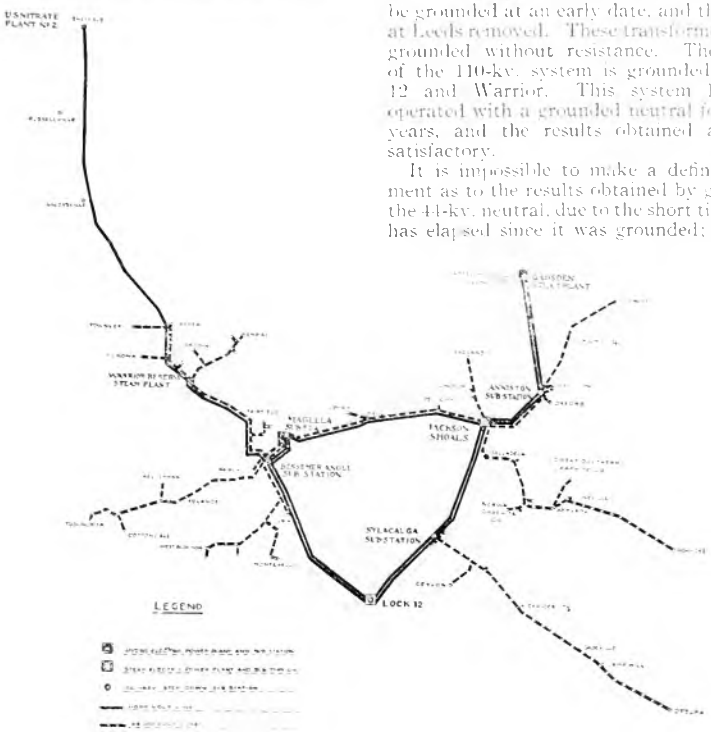


Fig. 3 Map showing Territory Served by the Lines of the Alabama Power Company

even in that time some improvement has been noticed. During the first six months of 1918 failures developed in six transformers and two lightning arresters on the 44-kv. lines. Prior to the month of July of this year, failures have developed in one transformer and one lightning arrester. It is interesting to note that the failure in the transformer developed at a time when the 44-kv. system was isolated from the grounding transformer banks. The failure of the lightning arrester presents also an interesting case. A ground on the Warrior-Bessemer 44-kv. tie line caused the automatic operation of the line switch at Warrior, thereby tripping off the neutral grounding bank at Warrior, and leaving the ground on an isolated system (the Leeds bank being out of service at this time). A continuous arc was set up across the gaps of a lightning arrester on the isolated section, and before the trouble could be cleared failures developed in the cone stacks of two tanks of the arrester.

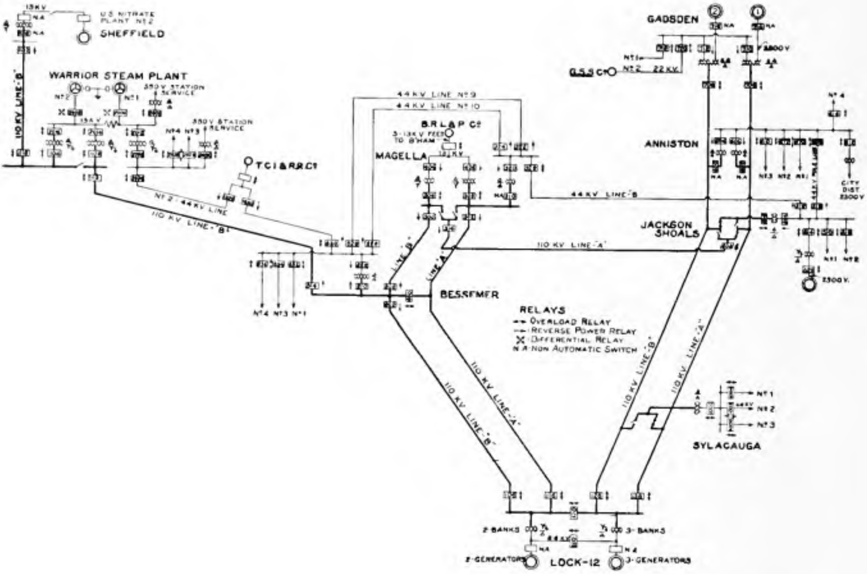


Fig. 4 Single-line System Diagram, showing Normal Connections, Relay Protection, etc.

A classification of trouble for the first six months of this year is given in Table IV. It will be noted from this table that a large percentage of causes of trouble is attributed to lightning. The interruptions attributed to "lightning" represent cases when a line was automatically disconnected during a lightning storm and no damage or failure was located.

Relay Protection

Before describing the layout of the relay protective system it will perhaps be of interest to show how it was worked out.

The reactance of each piece of apparatus and line was determined, and a set of short circuit calculations made, assuming short circuits at various points on the system. The distribution of short circuit current throughout the system was shown for maximum, minimum and average conditions on a single line diagram similar to Fig. 4. A "short circuit calculating device" was used to determine the current values, and the distribution of short circuit current throughout the system, the complicated interconnection of lines and apparatus making accurate calculations by other methods practically impossible. A complete description of the calculating device appeared in the February, 1919, issue of the GENERAL ELECTRIC REVIEW.

The basic principle of the relay system is immediately to disconnect faulty lines and apparatus in a way least affecting the normal operation of the system. The relays are given settings to protect against short circuits, and not against overload. With these principles in view short circuit conditions were studied and the proper relay settings given, all settings corresponding to the minimum connected generating capacity [illegible] the [illegible], however, were checked for maximum, minimum and average conditions, also for conditions in which connections of the system were abnormal. It has been found that the settings as given will take care of practically all methods of operation.

The most important circuits are protected with induction type overload relays, sometimes in connection with reverse power relays. Plunger type relays are used on circuits of

TABLE III

110 KV. TRANSMISSION LINE DATA TOTAL LENGTH, 440 MILES

Length Total Miles	Material Size of Conductor	Spacing	Arrangement of Conductors	Insulators Number and Type	Type of Tower	Ground Wire	Remarks
300	No. 00 cu.	13 ft.	Vertical	Suspension, 7 Strain, 8	Double cir. steel towers	2 [illegible]	[illegible]
88	250,000 cm. cu.	14 ft.	Horizontal	Suspension, 8 Strain, 9	Wooden H-frame poles	2 [illegible]	
52	No. 1 cu.	9 ft.	Vertical	Suspension, 7	Double cir. steel towers	2 [illegible]	
Total, 440 miles							

44-KV. TRANSMISSION LINE DATA TOTAL LENGTH, 535 MILES

Length Total Miles	Materials, Size of Conductor	Spacing	Arrangement of Conductors	Insulators No. and Type	Tower and Poles	Ground Wire	Remark
535	No. 00 cu. No. 1 No. 2 No. 4 (*)	Vertical 3½-ft. Horizontal 5-ft.	Vertical Triangular	Pin	Wooden Poles Creosoted	[illegible]-in. steel 1 wire	45 miles on [illegible] with suspension [illegible] insulators.

* About 63 miles No. 2 0 and No. 1 equiv. aluminum.

TABLE IV

CLASSIFICATION OF TROUBLES FROM JAN. 1, 1919, TO JULY 1, 1919

	SUBSTATION		110-KV. LINES		44-KV. LINES		CUSTOMERS	
	No.	Per Cent	No.	Per Cent	No.	Per Cent	No.	Per Cent
(1) Lightning	1	25	6	33	57	43.7	10	12.05
Line insulators	2	50	11	61	39	29.7	16	19.25
Conductors...	..		..		6	4.55	9	10.85
Poles, guys and cross arms					1	0.76		
(2) H.T. diconnecting switches	1	25	1	6	1	0.76		
H.T. oil switch bushing..	..				1	0.76		
Blowing of H.T. fuses.							32	38.55
Transformer failures...							1	1.20
Trans. bushing failures					12	9.16	6	7.25
Customers' equipment					8	6.05	9	10.85
Operating errors..					1	0.76		
Unknown.. ..					5	3.8		
Total......	4	100	18	100	131	100.	83	100.

(1) When line opens automatically during lightning storm and no failures are discovered.
(2) Switch blade dropped out while in service.

secondary importance. The use of induction relays on all circuits is very desirable due to the fact that it is, in certain instances, a difficult matter to obtain proper selective action between an induction relay on the main circuit, and a plunger type relay on a feeder. Experience has shown that the induction type relays are much more accurate and reliable than the plunger type relays, especially where selective action is essential, and where time settings of two seconds or less are necessary.

In deciding upon time settings the limiting feature was the consideration that no short circuit of appreciable value should be allowed to hold on more than two and one half seconds, this time being found safe for the operation of synchronous machinery connected to the system. A setting of two and one half seconds was given to all relays controlling outgoing lines of the generating stations, this setting corresponding to the minimum short circuit which the relay must clear. For average conditions the relays will operate in from one to two seconds. Main line and tie line relays at substations were set for somewhat less than two and one half seconds in order to obtain proper selective action. The differential in short circuit current between relays on the main circuits is of great advantage in securing proper selective action of these relays. Feeder relays are given time settings of approximately one half second. It was found that about 0.4 second was sufficient time, in most cases, to allow for the operation of circuit breakers, but wherever possible larger differences were allowed.

For convenience in describing the actual layout of relays the system will be grouped in two parts: The eastern division, consisting of the 110-kv. lines extending to the northeast from Lock 12 through Sylacauga, Jackson Shoals and Anniston to the Gadsden steam plant; the western division extending to the northwest from Lock 12 to Bessemer, Magella, Warrior steam plant and Muscle Shoals. These two sections of the system may be considered as being practically independent of each other, with regard to the relay protection, the only interconnection between them being the Magella-Jackson Shoals 44-kv. tie line, since normally the Magella-Jackson Shoals 110-kv. line is left open at the Magella end, this line being used only in case of an emergency, or when other sections of the 110-kv. system are taken out for repairs.

The connections of the main part of the system are shown by Fig. 5. It will be noted that a variety of connections is possible. Fig. 4 shows the normal operating connections of the system, the location of oil switches and the kind of relay protection used. It will be seen from this diagram that one transformer bank at both Anniston and Gadsden substations is connected to each line, and that the banks are operated in parallel on a low tension bus. The Jackson Shoals and Sylacauga substations, having only one bank each, are connected to one of the 110-kv. lines. Jackson Shoals can also be fed from Magella or Anniston over the 44-kv. tie lines. Future developments of the 110-kv. system in the eastern section will probably require the installation of oil switches in the lines at Jackson Shoals and Anniston and the connection of the lines at these points to a common 110-kv. bus, this making necessary, of course, a decided change in the scheme of relay protection.

The western division contains the most important substations of the system, from the standpoint of switching and the amount of load handled. From a glance at Fig. 4 it will be seen that the operation of this section of the system is quite complicated with regard to relay protection, due to the several interconnections between Magella, Bessemer and Warrior steam plant. It will be interesting to note that the connection of all 110-kv. lines to a common bus at the Bessemer substation is one of the first attempts at such operation on the system. To date, the operation of both the reverse power and overload relays has been entirely satisfactory, not one failure to function properly having been charged against the relays.

The 110-kv. lines are connected to separate buses at Magella, and are paralleled on the low tension side of the 13,200-volt transformer banks. A set of reverse power and overload relays are connected in the circuit of current transformers installed on the low tension side of each bank, the tripping contacts of the reverse power and overload relays being connected in series. Closing of these contacts operates an instantaneous direct current relay, and a definite time limit direct current relay. Operation of the instantaneous relay trips the 110-kv. line switch, likewise the definite time limit relay trips the low tension transformer switch. This scheme was adopted with the view of connecting the Magella-Jackson Shoals Line "A" to the Bessemer line "A" at Magella, thereby securing an additional feed into Magella. Trouble on one of the Bessemer 110-kv. lines

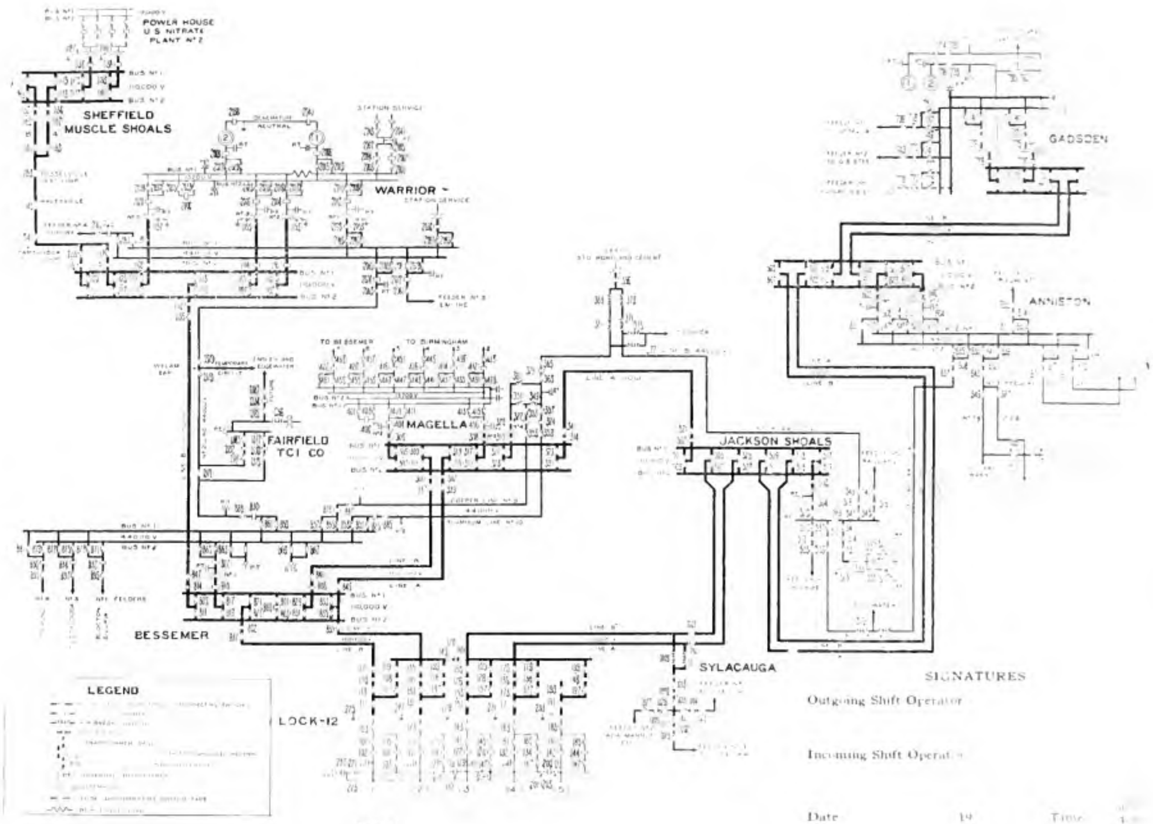


Fig. 5. Switching Layout of the Alabama Power Company's System

SIGNATURES

Outgoing Shift Operator

Incoming Shift Operator

Date 19 Time

causes a reversal of current direction through one of the transformer banks, causing the operation of the reverse power and overload relays and opens the 110-kv. line switch. In case of trouble on one of the 110-kv. buses a similar operation occurs, the low tension transformer switch clearing slightly after the 110-kv. line switch opens. It will be noted that in case of line trouble neither transformer bank is lost, while trouble on a 110-kv. bus or in a transformer bank will be cleared by the operation of two switches leaving the Lock 12 lines in operating condition and the Magella 13.2-kv. load on one transformer bank. The operation of these relays has also proved entirely satisfactory.

The generator switches at Lock 12 and Gadsden are non-automatic. At Warrior steam plant, the generator windings and their connections to the 13-kv. bus are protected by differentially connected relays. These relays operate only in case of trouble in the generator windings or the connecting cables, and trip the main generator oil switch and the source of excitation. This scheme proved successful during a recent failure of the 13-kv. cables interconnecting the generator and 13-kv. bus. For normal operation the neutral of one of the Warrior generators is grounded.

Table V illustrates the duties imposed upon the relays and indicates the system numbers of switches which must trip in order to clear certain cases of trouble. In analyzing each case of trouble it will be seen that interruptions in every instance are confined to the smallest possible section of the system, and that complete interruptions to the most important substations are very unlikely.

It is quite evident from the foregoing that the relays are called upon to perform a very important, and in some cases, a complicated duty; the failure of any relay to operate properly can cause an interruption to a considerable section of the system with a corresponding money loss involved. The question arises, therefore, how far can one depend upon correct relay operation, and what must be done in order to keep the relays in first class operating condition?

Actual experience has shown that the present relays are quite accurate instruments, requiring very little attention. This is especially true of the up-to-date reverse power relays and induction overload relays. The settings as given remain constant for an indefinite time. Time settings of induction overload relays are practically independent of the current settings, that is, the latter can be changed without changing the time setting corresponding to the same percentages of overload on the relay. Plunger type relays require more frequent attention and do not hold their settings for any considerable time.

The operation of relays has proved, in general, to be very satisfactory and of great value in maintaining an uninterrupted service. There have been practically no incorrect relay operations on the system, and in nearly every case when troubles have not been properly cleared, some defect, outside of faulty relay operation, was discovered. Common defects are sluggish oil switch mechanisms, burned out trip coils and faulty control circuits. In order to insure proper protection, regular inspection trips are made for the purpose of checking and testing the operation of relays. As a rule, each relay is tested every two or three months, the trip circuits are tested, and when possible the operation of the oil switches checked.

Relay circuits are provided with small test switches, so that the current transformers can be easily short circuited and the relay disconnected. Switches are also provided in the trip circuits. The use of these switches greatly simplifies testing, for the reason that relays may be quickly disconnected from their normal circuits and connected to the test apparatus. Jewel bearings are inspected and oiled when necessary, and the bellows of plunger type relays oiled, and contacts cleaned or adjusted.

The current coil of the relay is then loaded with an artificial load and the time-current curves checked. The character of the artificial load used affects to some extent the characteristics of the relay; for instance, if the load consists of a bank of large tungsten lamps the relay will trip, for a given setting, in from five to 15 per cent less time than if a standard unit wire resistance were used, the instantaneous rush of current being very much greater in the lamp bank than in the wire resistance. When using a bank of carbon lamps the instantaneous rush of current is greatly reduced.

As some of the relays must operate with a minimum difference in time settings, it was found desirable to test all relays using the same type of artificial load. The standard meter testing resistance with a current range of from one quarter ampere to 30 amperes was adopted and is used for all relay tests.

Trip circuits are tested, where possible, by tripping the circuit breaker with the relay. This test has proved valuable in many

TABLE V

PROPER OPERATION OF RELAYS FOR NORMAL CONNECTIONS OF SYSTEM

Location of Troubles	SYSTEM NUMBER OF SWITCHES WHICH SHOULD TRIP TO CLEAR TROUBLE									Remarks	Case No.
	Lock 12	Bessemer	Magella	Fairfield	Warrior	Sylacauga	J. Shoals	Anniston	Gadsden		
Lock 12, 110 kv. bus, Bessemer side	120 110	802 800*	302*							*Warrior generator on. (Disconnect No. 1 and 2 generator, Lock 12)	1
Lock 12, 110 kv. bus, Gadsden side	120 110						501		706 708*	*Gadsden generator on. (Disconnect No. 3, 4 and 5 generator, Lock 12)	2
Lock 12, Magella "A" line	116	800	302								[illegible]
Lock 12, Bessemer "B" line	106	802									[illegible]
Lock 12, Gadsden "A" line	130							600	710		[illegible]
Lock 12, Hadsden "B" line	126						501	604	712		[illegible]
Bessemer 110 kv. bus No. 2*	106	800 822	300		1112					Bessemer 110 kv. bus No. 1 [illegible] case No. 3 (*) if Warrior [illegible]	[illegible]
Bessemer-Magella "B" line		806	300								[illegible]
Bessemer-Warrior 110 kv. line		814			1112						[illegible]
Bessemer 44 kv. bus		810	322 324	1330							[illegible]
T. C. I. Co. No. 2 line		830		1330							[illegible]
Magella 110 kv. bus No. 1			302 406 320								[illegible]
Magella 110 kv. bus No. 2			300 404								[illegible]
Magella 13.2 kv. bus			306-308								[illegible]
Magella 44 kv. bus		828 826	320				518				[illegible]
Magella-J. Shoals 110 kv. line			314				502				[illegible]
Magella-J. Shoals 44 kv. line			328				518				[illegible]
Magella-Bessemer cu. line		828	322								[illegible]
Magella-Bessemer Al. line		826	324								[illegible]
Warrior 110 kv. bus		814		1332	2011 2016 2020						[illegible]
Warrior 44 kv. bus				1332	2012						[illegible]
Warrior 13.2 kv. bus		814		1332							[illegible]
Warrior 110 kv. Sheffield line					1116 or 1114						[illegible]
T. C. I. Co. No. 2 line				1332	2021						[illegible]
Sylacauga 110 kv. bus	130							600			[illegible]
Sylacauga 44 kv. bus						1000					[illegible]
J. Shoals 110 kv. bus	126						501	611	71[illegible]		[illegible]
J. Shoals 44 kv. bus			328				500 511	608		W[illegible] A[illegible]	[illegible]
Anniston 110 kv. bus No. 1	136							606	710		[illegible]
Anniston 110 kv. bus No. 2	126						504	601	712		[illegible]
Anniston 44 kv. bus							512*	601 606		*A[illegible]	[illegible]
Gadsden 110 kv. bus No. 1	136							606	710		[illegible]
Gadsden 110 kv. bus No. 2	126						501	601	712		[illegible]
Gadsden 22 kv. bus									700 708		[illegible]
Gadsden 2300 volt bus No. 1									706 710	Disconnect N[illegible]	[illegible]
Gadsden 2300 volt bus No. 2									708 712	Disconnect N[illegible]	[illegible]

NOTE.—Automatic switches controlling distribution lines are set to clear the trouble on the line which [illegible]
The feeder relays are [illegible] of overhead type.

instances for detecting trouble in the switch mechanism, or in the control circuits.

A careful record of each relay setting is kept in the office. From the tests, characteristic curves are plotted for each relay. These data, together with the short circuit calculations, facilitate the checking of relay operation, and the analysis of trouble.

Organization

The Operating Superintendent is in entire charge of the operation and maintenance of the system. The Superintendent of Production, Superintendent of Maintenance and Repairs, Relay Engineers and a Chief Clerk report directly to him. The Load Dispatcher, Superintendents of Generating Stations and Isolated Plants report to the Superintendent of Production. The system is sectionalized into two divisions, eastern and western, each division being in charge of a superintendent reporting directly to the Superintendent of Maintenance and Repairs. Primary substation superintendents report to their respective division superintendents as do maintenance foremen and division line supervisors.

It is the duty of the relay engineers to keep in close touch with the actual operation of the system, with regard to relay protection and operation, connections of lines, voltage regulation, improvements in service, analysis of troubles and work of a similar nature.

The general operation of the transmission and distribution system, with regard to switching operations and handling of load, is under the general supervision of a chief load dispatcher. Station operators of course report to their respective station superintendents, but also receive instructions from the Load Dispatcher with regard to switching operations and the handling of load.

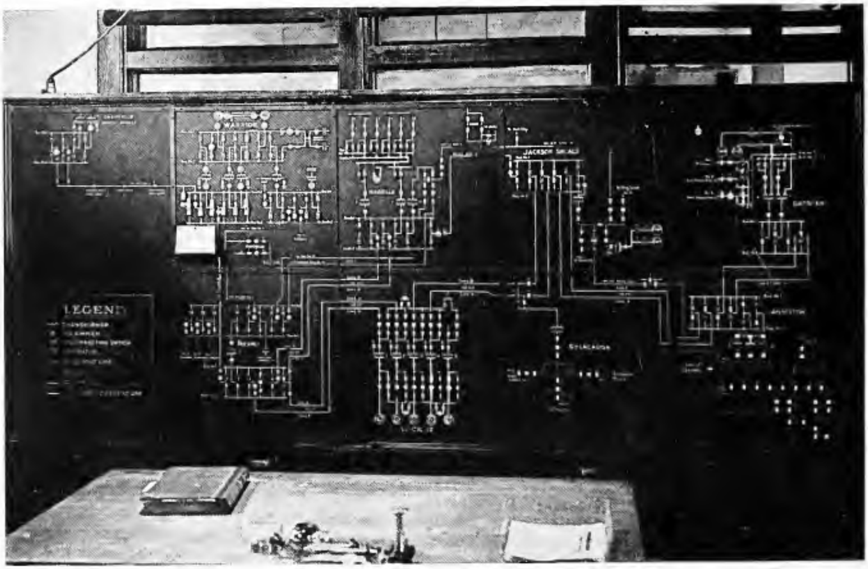


Fig. 6. Mimic Switchboard in Load Dispatcher's Office

Load Dispatching

The Load Dispatcher's office, situated at the Magella substation, is connected with all points of the system by private telephone lines, enabling the establishment of immediate communication with any switchboard operator on the system. Bell telephone service is provided at each of the primary stations, this service being used only in case of trouble on the private lines.

Printed instructions covering in detail the operation of the system, for both normal and emergency operations, are distributed among the employees, and every employee engaged in the operation of the system is required to be thoroughly familiar with them. *First aid methods*, resuscitation from electric shock, safety rules, and, in fact, all points vital to the safety of employees and to the efficient operation of the system are included in these instructions.

For operation of the system, lines and apparatus are divided into two classes:

1st Class. 110-kv. transmission lines, 44-kv. tie lines and all apparatus interconnected for parallel or combined operation.

2nd Class. Distribution lines, with connected apparatus, radiating from stations which do not tie in with some other station on the main system.

Lines and apparatus of the first class are in direct charge of the Load Dispatcher, and cannot be taken out of service or placed in service without his orders. This assures the continuity of service to each station, as the Load Dispatcher is in touch at all times with conditions over the entire system.

Lines and apparatus covered by the second class are handled by station operators, who are at all times responsible for their operation.

All switching operations, unusual weather conditions, lines and customers' interruptions, and, in fact, everything of interest in connection with the operation of the system are immediately reported to the Load Dispatcher. A daily log is kept in the Load Dispatcher's office, covering switching operations, automatic or manual, affecting interruptions to lines or customers, climatic conditions, line and apparatus trouble and other events encountered in the operation of the system.

Station operators keep daily log sheets, showing instrument readings, climatic conditions, power generated or transmitted, switching operations, interruptions to line or customers, etc.

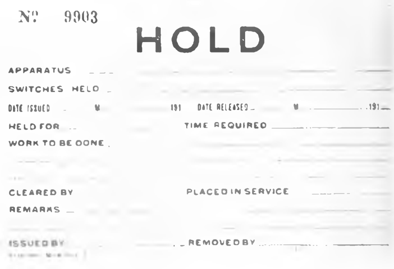
Located in the Load Dispatcher's office is a "mimic switchboard," see Fig. 6, representing in detail the switching layout of all primary stations, interconnecting lines, and feeders connected to station buses. This board consists of a number of sections of beaver board properly drilled and painted to show oil switches, disconnecting switches, buses, apparatus and lines, one section being used for each station. These sections are placed over a frosted glass, the switch numbers being painted on the glass under the holes provided for oil and di[illegible] The switch numbers can [illegible] distance from the board be[illegible] by lamps placed in the rear of the board. Every mimic switch is [illegible] number corresponding to the system number of the switch which it represents. Oil switches are given even numbers, and disconnecting switches odd numbers. A color scheme is used for representing lines of different voltage. Special tags are used to cover holes representing oil and disconnecting switches. A tag covering a hole indicates that the switch is open.

This board represents at all times the actual connections of the system. Whenever a switching order is executed proper changes are made on the board. In all switching orders the switches are referred to by their numbers.

Before giving clearance for work on the lines or apparatus, special tags or "hold cards" are placed upon each and every piece of apparatus which, if operated, might endanger the safety of men doing the work. Two types of "hold cards" are used, a large size and a small size. Small cards cannot be placed or removed except by order of the Load Dispatcher. Large cards are used by the Load Dispatcher in tagging lines or apparatus directly under his control. For instance, in clearing a 110-kv. line the dispatcher orders the proper switches opened and small cards placed, after which he fills out a large card and places it on the mimic switchboard. Large "hold cards" are also used by station operators in tagging lines or apparatus under their supervision. No "hold cards" can be removed until the foreman of the repair crew has reported clear, and that the equipment he has been working on is in condition to be placed in service. In case of more than one gang working on equipment the foreman of each gang must report separately to the Dispatcher, who will place a set of "hold cards" for each of them. Figs. 7 and 8 show the types of "hold cards" used. These cards are filled out in duplicate, one copy being filed in the station at which it originates, and the other in the main office.

The Load Dispatcher keeps a daily report of all switching operations performed at his orders. One side of the report shows the system number of switches operated, time of operation and name of operator doing same. On the other side is a switching layout of the system, Fig. 5; at the end of each shift the retiring Load Dispatcher indicates with red pencil marks the connections of the system at the time, and signs the report. This report presents an accurate record of system connections, and switching operations and is of great value in checking conditions of the system from day to day.

Fig. 9 shows the form used for recording system troubles. A report of this kind is made for each case of trouble causing the automatic operation of switches, or for pre-arranged switching affecting an interruption to customers. On the reverse side is a map of the system and a table for recording the damage or loss of equipment. The Load Dispatcher indicates on the map the approximate location of the fault. Pre-arranged interruptions for a given day's operation are recorded if possible on a single sheet. These reports are of untold value in checking relay operation, and in studying operating conditions of the system.


Nº 9903

HOLD

APPARATUS
SWITCHES HELD
DATE ISSUED M 191 DATE RELEASED M 191
HELD FOR TIME REQUIRED
WORK TO BE DONE
CLEARED BY PLACED IN SERVICE
REMARKS
ISSUED BY REMOVED BY

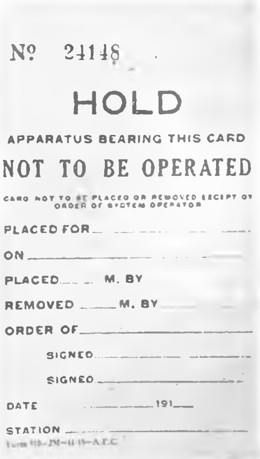
Fig. 7. Type of Large "Hold Card"

Should a 110-kv. line, or 44-kv. tie line trip out it is charged again after a two-minute interval. If it trips again the line will be sectionalized, and tested. When the trouble has been sectionalized the line is turned over to the division line supervisor who directs the patrol and repairs. After repairs have been made the fact is reported to the Load Dispatcher who is responsible for the tests and placing of the line in service.

After the automatic operation of a feeder switch, it is closed twice at two-minute intervals. If it trips upon the second application of voltage the line is held out, the trouble located and the necessary repairs made.

Division line supervisors are responsible for the patrol and upkeep of all lines in their division. As soon as possible after the automatic operation of switches controlling 110-kv. lines, 44-kv. tie lines, and feeders, the line is patroled even if it holds in upon the first or second application of voltage. This is done in order to locate possible defects which may cause serious trouble at a later date.

Emergency instructions cover the operation at various stations when telephone communication with the Load Dispatcher becomes impossible. It is impossible to furnish definite instructions for operation at such times, and the quick restoration of service depends, to a great extent, upon the ability of the operator. In general, however, operators are urged to carefully analyze their troubles and take only such steps as are necessary to restore service. No interconnection of 110-kv. lines and tie lines is to be attempted; operators simply restore service from the first source and communicate with the Load Dispatcher at the first possible moment.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HOLD

APPARATUS BEARING THIS CARD

NOT TO BE OPERATED

CARD NOT TO BE PLACED OR REMOVED EXCEPT ON ORDER OF SYSTEM OPERATOR

PLACED FOR
ON
PLACED M. BY
REMOVED M. BY
ORDER OF
SIGNED
SIGNED
DATE 191
STATION

Fig. 8. Type of Small "Hold Card"

Maintenance and Repairs

Taking into consideration the large extent of the system, as regards both lines and apparatus, it is quite evident that the maintenance and repair work is of the utmost importance. This work is in charge of the Superintendent of Maintenance and Repairs, having under his jurisdiction the up-keep of all properties pertaining to the transmission, transformation and distribution of electrical energy. Activities of the Maintenance and

Repair Department cover, in general, the standardization of methods and materials, general inspections, special studies and investigations, statistical records and preparation of reports, and all maintenance and repair work.

For more efficiently handling this work, the system has been separated into two divisions, the eastern and western, and each division placed in charge of a superintendent reporting directly to the Superintendent of Maintenance and Repairs. The eastern division includes Lock 12, Sylacauga, Jackson Shoals, Anniston and Gadsden, and the western, Bessemer, Magella, Warrior steam plant and Muscle Shoals substation. The divisional plan has proved quite successful, in that competition in all lines of endeavor by the divisions has created a stimulus for further effort on the part of various employees, resulting in better work with greater economies and more careful consideration of details.

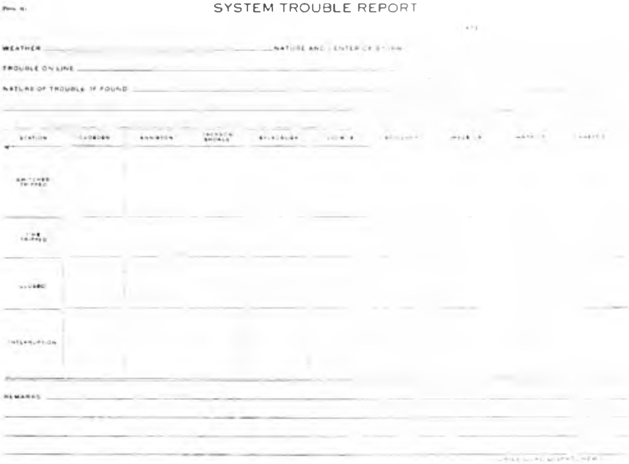
The up-keep of transmission and distribution lines is in charge of Division Line Supervisors, who have charge of all patrol forces and line maintenance crews in their division. With the development of the divisional organization, and the placing of line supervisors in charge of smaller territories, greater opportunities for specializing in the correction of line failures has resulted in minimizing the length of line interruption.

Patrolmen are located at various points on the system, so as to be quickly accessible in case of trouble. When not on patrol they report to their respective line supervisors at least three times daily. Every effort has been made to make the right-of-way along transmission lines easily accessible, by placing wire bridges across streams, and other difficult points along the lines.

Each divisional organization includes an Assistant Division Superintendent who plans, orders materials, and directs various work to be performed by equipment and line maintenance crews.

Routine inspections and tests have proved of great value in improving operating conditions, and in the up-keep of equipment. In many instances serious troubles and long outages have been anticipated. Inspectors are provided with special forms, covering inspection of substation equipment and transmission and distribution circuits. Inspection reports are forwarded to the proper division office where necessary steps are taken to correct deficiencies which are discovered.

Oil in 110-kv. apparatus is tested monthly, and in 44-kv. and 22-kv. apparatus once every three months. Reports upon tests are submitted to the Division Office where a complete record is kept of the condition of oil in every piece of apparatus on the system.



SYSTEM TROUBLE REPORT

WEATHER ____________ NATURE AND EXTENT OF STORM ____________

TROUBLE ON LINE ____________

NATURE OF TROUBLE IF FOUND ____________

STATION	GADSDEN	ANNISTON	JACKSON SHOALS	SYLACAUGA	LOCK 12	[illegible]	[illegible]	[illegible]	[illegible]
SWITCHES TRIPPED									
LINE TRIPPED									
CLOSED									
INTERRUPTION									

REMARKS ____________

Fig. 9. Form Used for Recording System Troubles

The Division Office keeps a complete set of records covering patrols, line apparatus and insulator failures. Patrol records appear in graphic form so that frequency of patrol, hazards existing, storm occurrence, and proper execution of patrol policies may be determined at a glance.

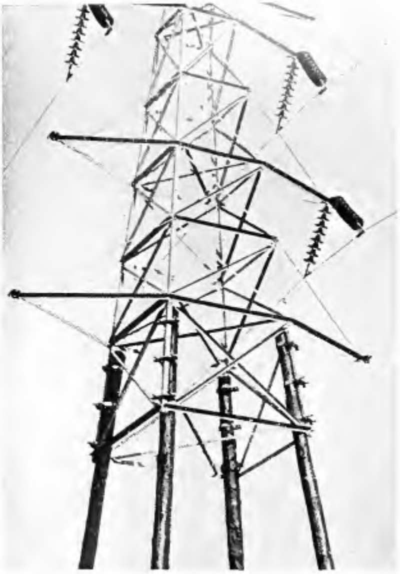


Fig. 10. Type of Anchor Support Used on Warrior—Bessemer 110-kv. Line

A careful analysis of the various reports makes possible the weeding out of undesirable equipment, thereby reducing to a minimum the hazards to continuous service.

Insulators

As will be seen from Table IV, insulator failures constitute a large percentage of the trouble encountered in the operation of the system. Insulators on the 110-kv. lines have been meggered yearly since 1915. A complete description of the methods adopted appeared in the June, 1916, issue of the GENERAL ELECTRIC REVIEW.

A careful analysis has been made of the cost and depreciation of insulator units together with a study of operating hazards involved, to the end that possible revision in meggering may be devised wherein periodic tests will conform more closely with the depreciation observed.

The results of megger tests made during 1918, and an average of tests made during the past four years, appears in Table VI.

As will be seen from this table, the percentage of defective units on strain towers was very much higher than that on the suspension type of support. This is also true of actual failures of insulators as shown by the tabulation on page 995.

TABLE VI

TOTAL RESULTS OF MEGGER TESTS FOR YEAR 1919 ON SUSPENSION DISK INSULATORS

	TOWER LINES			SUBSTATION YARDS			TOWER LINES AND SUBSTATION YARDS		
	No. Tested	No. Defective	Per Cent Defective	No. Tested	No. Defective	Per Cent Defective	No. Tested	No. Defective	Per Cent Defective
Suspension	35,445	734	2.07	1,694	11	0.65	37,139	745	2.00
Strain	12,894	886	6.87	5,677	574	10.10	18,571	1,460	7.87
Total	48,339	1,620	3.35	7,371	855	7.94	55,710	2,205	3.96

TOTAL RESULTS TO DATE

1915-1916-1917-1918-1919

	Number Tested	Number Defective	Per Cent Defective
Suspension	221,804	6,025	2.72
Strain	86,320	8,043	9.32
Total	308,124	14,068	4.57

Percentage of Failures

Type	On Lines	Substation Yard
Suspension	0.812	Negligible
Strain	1.56	2.13

A study was made of the profile of the transmission lines and the strains to which towers would be subjected on change of type of construction. The stress on the suspension unit for the average span of 00 copper wire on the line is about 120 pounds. On strain towers this stress on the insulator unit is about 1400 or 1500 pounds. A plan has been formulated for reconstruction with a type of support planned to limit the mechanical stresses on all insulator units to a maximum of 750 pounds. This means the elimination of strain towers where angle construction does not interfere; and at angles, the substitution of the double yoke strain type of support. Suspension type of support is being substituted where strains are used in all cases except at extreme angles on the lines. Where the contour of the country is such as to make the clearance above the ground of the lower wire less than 25 feet, and also on extremely long spans, it becomes necessary to use double suspension rather than strain type [illegible] of support.

Fig. 11. Front View of Calculating Table Built for and Used by the Alabama Power Co. for the Calculation of Its Short-circuit Problems

The elimination of strain towers [illegible] unusual stress in the line at certain points in cases of breakage of wire. To reduce the possibility of destructive consequences under such circumstances, the anchor type of support is used at intervals of approximately five miles. The plans outlined above have been carried out in part and will be carried to completion as swiftly as possible.

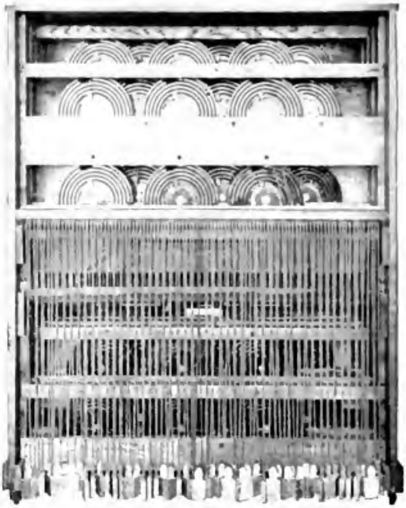


Fig. 12. Rear View of the Calculating Table shown in Fig. 11

Fig. 10 shows the anchor type of support on the Bessemer-Warrior 110-kv. lines. As a point of interest it should be noted that the tower has a steel top and wooden supports. This type of tower was adopted at a time when the price of steel was excessive with the view of ultimately replacing the wooden supports with steel.

Some progress has been made in the testing of pin type insulators on the 44-kv. lines. Tests were made using a 1500-ohm telephone receiver, the receiver being connected between the ground and insulator pin. Defective insulators were detected by intensive noise in the receiver caused by the leakage current. This method of testing has not been used to a great extent on the system, therefore it is impossible to determine its effectiveness. About three per cent of insulators tested have been found defective.

The General Electric Company in the Great World War

PART V. GENERAL WAR AND INDUSTRIAL ACTIVITIES

By John R. Hewett

Editor, General Electric Review

In our four previous issues we have attempted to outline some of the work the Company undertook to help carry out the Government's war program and we still feel that the story has not half been told. In this, the concluding part of our series, we try to point out how broad was the Company's field of activity and how help was extended to practically every industry in the country.—Editor.

The part that the General Electric Company played in the maintenance of the industrial life of the country is brought very vividly to the mind of anyone who is asked to give in writing a general idea of the Company's war work. Because after having dealt with those war activities that at first seemed most notable, there is such a host of other work still to write about that it seems impossible to undertake it. It must be remembered that we are living in an electrical age, where electricity is used for heating in a variety of different ways, for lighting our factories, homes, streets and highways, and for power in such an infinite variety of purposes that it would be almost impossible to catalogue them. The new applications of electricity are as constant as they are varied and every industry is daily becoming more dependent on electrical apparatus for the efficient manufacture of their products. The Company's share in stimulating the war work of the country by supplying others with the means to "do it electrically" will never be fully known for the simple reason that it would take too long to write it. The total amount of engineering work done to assist, and the apparatus made for and installed in, the steel industry alone is a subject for many volumes. The mining and oil industries with their prodigious requirements in motors, coal handling apparatus, cranes, hoists, elevators and conveying machinery are another story. The freight handling problem embraces a variety of work that defies description and includes such items as the equipments for docks, ships, shipyards, canals, storehouses, railroad terminals, etc. The paper and pulp mills, the rubber industry, the sugar industry and the textile industry all made heavy demands on the Company's resources. The number of machine tools equipped with electric drive was tremendous and involved a great deal of engineering work. A great deal of engineering work was done on precipitation equipments, electric furnaces and electric welding and smelting equipments. The work done on the developments for nitrate plants was most notable and the Company at the same time did its full share in the power transmission work of the country, and was all the time doing such as it could to help both great and small public utilities throughout the country to meet the heavy demands that war brought on their plants. It seems quite impossible to write at length on these subjects, so the following paragraphs have been compiled to give some slight idea of the kind of service that the Company was rendering the country in ways that are lost sight of among some of the more spectacular work.

The sale of electric motors to steel mills during 1918 was smaller than for either 1916 or 1917 as such great extensions were made during these periods, but during 1917 and 1918, the Company supplied 93,000 h.p. of motors for main mill drives and did a business of over $7,700,000 in helping the steel mills of the country to do their bit. Like all work of this nature the fulfillment of such contracts involved a great amount of highly specialized engineering and office work. This work was not only spread all over this vast continent, but some of it was carried out as far afield as Japan. The necessity for a high rate of production in the mining and oil industries led to many calls on the Company's already overcrowded facilities. The requirements of these industries cover an extensive field of electrical apparatus, and during the year 1918 the Company received orders for no less than 60 mine hoist equipments and during the same period 889 oil well motor equipments were supplied. As may well be imagined the freight handling business was in a feverish state during this period of greatest business activity the country has seen, and this naturally involved a large amount of engineering work on the part of the Company on such propositions as the equipments of docks, wharves, storehouses, etc. In this connection it is interesting to note, as one item in this category, that the Company received all of the contracts for the electrical equipment for the New York State Barge Canal that were let by the Department of Public Works for 1918.

With all the war work that the Company was doing there was still the imperative necessity to "Keep the Home Fires Burning," and they did their full share in supplying electrical equipment for such everyday unspectacular work as city water supply pumping equipments, city sewage disposal plants, fire pumping equipments, drainage schemes, irrigation plants, dry docks, and the hundred and one other things that are done electrically today; and although seldom thought of by the average citizen would render modern life unbearable if left undone; this class of work would be wearisome if we were even to classify it and then just recite the main classes of work for which the Company supplied its quota to keep the country going.

The annual domestic electrical business for the equipment of machine tools and machine shops amounts to the astonishing figure of about $25,000,000, and the Company carried its fair share of this load, doing some notable work for the Government in not only supplying the electrical equipment to operate many of the new huge war organizations, but also in giving their expert advice which was so essential to doing the job right from the start.

The lay mind does not always appreciate the wonders of the technical world. How would it appeal to the man on the street to know that the Company built electric motors which make 10,000 complete revolutions every minute and to be told that the application of these to certain classes of wood-working machinery increased the rate of production of airplane struts and other parts of airplanes in the ratio of one to eighty? If the man is a human benefactor who makes "two blades of grass grow where one grew before," what of the man who in the vital hours of war makes eighty parts of a war machine in the same time as one was made previously?

We have touched on electric welding before, but it is still interesting to tell that 181 arc welding equipments were sold by the Company in 1918 and that they carried out a most comprehensive campaign of investigations and experiments in many types of electric welding machines. Three commercial sizes of [illegible] welding machines were developed and proved to be entirely successful, so much so that some experts have been led to say that wherever there is a bull riveter there is also a place for a spot welding machine.

We have already told of some of the large electrically heated furnaces that the Company made for special war work such as gun shrinking and the heat treatment of shells, but over and above these more spectacular developments, the Company sold 50 complete arc furnace equipments, 20 of which were for smelting purposes and 30 for steel furnaces. Of course, this is not a complete statement of the electrical furnaces made by the Company during the war, nor does it take into consideration any of the vast amount of the auxiliary apparatus that they made to accompany these equipments. In this connection it may interest the reader to know that a proposition was active for the Company making a 9000-kw. furnace and would undoubtedly have been successfully fulfilled had it been possible at the time to purchase the large amount of power to operate it. Also, it may be of interest to know that among the large number of orders for this class of work the Company installed five 5630-kv-a. Ferro-Manganese furnaces for the Anaconda Copper Company at Great Falls, Montana. Each of these furnaces was to produce at least 20 tons of 80 per cent ferro-manganese every twenty-four hours or one hundred tons for the five furnaces. All such work performed by the Company was stimulating the production of America's huge war machine.

The work that the Company did in connection with the Government's program for the development of nitrate plants is most notable and is worthy of far more space and time than we can give in this memorandum of the Company's war work. It is well known that in peace times nitrates are very extensively used in fertilizers and in certain chemical work, and that in war time the amount of nitrates required for explosives, gases and other war purposes is only limited by the magnitude of the war—and this was a world war. The amount of nitrates needed to meet the requirements of the American army was simply fabulous and the Government's plants were planned to meet these demands, the imperativeness of which will at once be understood when it is realized that we were cut off from most of our normal sources of this essential. We have earlier cited the fact that Dr. Whitney, the director of the Company's laboratory, was put in charge of all the government's research work in connection with its nitrate developments. The Company also did its full share of engineering work to bring the projected plants into physical being. Of course, like practically all phases of our war work, that which was actually accomplished was less than the work planned, because of the armistice. The following paragraphs are but a brief outline of some of the more notable undertakings that the Company assumed, to help materialize the Government's work in connection with nitrate and powder plants.

Orders undertaken by the Company for government nitrate and powder plants alone during the year 1918 amounts to over $3,000,000, and this is in addition to the equipment contracted for in the latter part of 1917. The principal nitrate plants that the Company furnished all or part of the electrical equipment for were:

U. S. Nitrate Plant, Sheffield, Ala.
U. S. Nitrate Plant, Muscle Shoals, Ala.
U. S. Nitrate Plant, Cincinnati, Ohio.
U. S. Nitrate Plant, Toledo, Ohio.
Navy Nitrate Plant, Indian Head, Md.
Nitrate Plant, Perryville, Md.
U. S. Calcium Carbide Experimental Plant, Washington, D. C.
Proposed Government Arc Plant.

They also furnished equipment for the Government's powder plants at Nashville, Tenn., and Charleston, West Virginia.

It is very hard to give the reader any adequate idea of the magnitude of some of the Company's undertakings during the war, especially as they were so spread out that they embraced the supply of electrical apparatus and supplies to nearly every industry in the country, so the following notes on some of these nitrate plants may help to serve as an example to show how the Company's efforts were directed to help in the equipment of these new war undertakings and to facilitate the extension of older plants, to enable them to meet the call for the additional output demanded of them by the war.

U. S. Nitrate Plant, Sheffield

The Government nitrate plant at Sheffield, Alabama, for the fixation of nitrogen from the air was designed for a capacity of 22,000 tons of ammonium nitrate per year and is the first plant in this country designed to produce this chemical on a large commercial scale.

The entire electrical equipment for this plant was furnished by the Company who also did a considerable amount of engineering work. Some of the principal items of equipment were 5000 kw. of turbo-generator units, 4550 kw. of synchronous converters, 300 kw. of waterwheel-driven generators and 50 speed control motors with a total capacity of about 4500 kw. and about 125 switchboard panels.

U. S. Nitrate Plant at Muscle Shoals, Alabama

This Government plant has a yearly capacity of 110,000 tons of ammonium nitrate and is the largest of its kind in the world using the cyanamide process. This process is based on the fact that calcium carbide may be induced with comparative ease to absorb nitrogen forming a combination of calcium carbon and nitrogen. This is technically known as lime-nitrogen but commercially is called cyanamide. The construction of this plant is now practically complete and one half of it was in operation by November 25, 1918.

Up to date the power for this plant is supplied by power plants which were already in existence, but the Company supplied among other apparatus transformers with a total capacity of 146,935-kv-a., motors for driving air compressors with a total capacity of 8000 h.p. with the necessary switching apparatus and panels, 450 induction motors with a total capacity of 12,000 h.p. and such other electrical equipment as 696 control equipments for ammonium oxidization catalyzers, 12 electric furnace control equipments, 37 electrode motors, 1015 flexible furnace cables with specially welded terminals and two four-ton electric locomotives.

U. S. Nitrate Plant, Cincinnati

This Government nitrate plant was intended to be identical with the Muscle Shoals plant, but with only one half the capacity. The Company received orders for all the principal electrical apparatus, but this was held up when the armistice was signed.

U. S. Nitrate Plant at Toledo

This plant was to be identical to and of the same capacity as the Cincinnati plant and the Company had received orders for the electric furnace control equipment and catalyzer equipment, but the entire plant is now cancelled.

Navy Nitrate Plant

All the preliminary engineering work had been completed for the Navy nitrate plant at Indian Head which was to have been operated in connection with their large powder plant there. The Company had received requests for quotations on the equipment, but like many other war projects this plant was abandoned when the armistice was signed.

Ammonium Nitrate Plant at Perryville, Maryland

This plant has a capacity of 500 tons of ammonium nitrate per day. It does not utilize any of the synthetic processes such as are used at Sheffield or Muscle Shoals, but a new British process, the details of which are more or less secret. The Company received orders for the turbine and switchboard equipment for this plant.

Carbide Experimental Plant at Washington, D. C.

This plant was built by the Ordnance Department and was practically completed at the date of the armistice. The transformers, switchboard, motor and furnace cables were all supplied by the Company.

Proposed Government Arc Plant

The interest in the arc process for the fixation of nitrogen was revived in the middle of 1918. An entire division of the nitrogen division of the Ordnance Department was organized to study this subject. After the leading authorities had been consulted it was decided to lay out designs for a plant of 25,000-h.p. capacity. This plant was intended to serve both as an experimental plant and as a war plant. The engineers and experts of the Company were constantly called on for advice and recommendations, but we do not know the ultimate fate of this project, but it may interest the reader to know that in this instance cheap power was the only requirement, as the raw materials consisted simply of air and of water.

Nashville Powder Plant

Turning now to consider some of the Company's work in connection with powder plants, some few notes on the "Old Hickory" Plant, located near Nashville, should be of interest.

This plant was built by the Dupont Engineering Company, who acted as agents for the Government, and a large part of it was in operation before the armistice was signed. The first plant called for a daily output of 500,000 pounds of smokeless powder, but this was soon increased to 900,000 pounds. This plant alone is about eight times as large as the largest smokeless powder plant in the United States prior to 1914. It really consists of nine independent unit plants each, practically speaking, a complete unit in itself. Some appreciation of the size of the plant may be gathered from the fact that it consumes 1500 tons of coal for each working day of 24 hours which is equivalent to 100 car loads or two train loads per day. The complete plant requires 100,000,000 gallons of water a day, which is about equal to the supply for a city with a population of a million people.

The power requirements are quite astonishing as the central power plant contains 68 boilers each of 825 h.p. This will be operated at an overload rate giving about 90,000 b.h.p., supplying steam to generate 12,000 kw. of electrical energy, as well as the steam power required for the treatment of gun cotton and for other purposes.

As almost the entire electrical equipment for this plant was furnished by the Company the reader may be interested in the following notes.

Among the turbo generators and turbines supplied by the Company were four machines each with a capacity of 3750-kv-a., one of 4375-kv-a., two 100-kv-a. turbo-exciter sets, four 85-h.p. turbines with gear equipment for mechanical drive and 12 similar units of 300-h.p. each. The Company furnished 618 induction motors with the control which totaled 18,790-h.p. of induction motors.

One main switchboard consisted of 33 panels and there were 12 substation switchboards furnished in addition. There were many other items such as 96 distributing transformers and a 500-amp. arc welding set.

The operation of this plant began on June 1, 1918, less than three months from the time the ground was broken, and this unquestionably was one of the greatest engineering feats of the country's war work. The cost of this plant is said to be considerably in excess of $50,000,000.

Charleston Powder Plant

This plant is located at Nitro, West Virginia. It was to be a duplicate of the Nashville plant as at first laid out, that is to say, it was to have a daily capacity of 500,000 pounds of smokeless powder; the equipment was, of course, proportioned to its output. Part of the power for operating this plant was to be purchased from the Virginia Power Company and was to be transmitted from Cabin Creek power station at 66,000 volts. The Company received orders for the principal items of the electrical equipment, which included three 1250-kv-a. turbines with exciters, eleven 375-h.p. turbines for mechanical drive, seven 5000-kv-a., 66,000 6600-volt transformers, and a main switchboard with 32 panels and 126 induction motors with an aggregate capacity of about 4000 h.p.

All of the work that the Company did in connection with the nitrate and powder plants was considered more or less confidential in nature, and the many and constantly changing new developemnts demanded the closest attention and co-operation all the time. The amount of engineering work done by the Company in this connection was enormous, but can never be described fully. We might write at great length about what the Company did in the far flung field of electrical transmission and power house work, but it would be wearisome. We have now recited some of the Company's work in connection with nitrate plants and these must serve as an example to show the way a great electrical manufacturing concern not only serves its country in times of peace, but is an essential factor to our safety and a mighty factor in securing victory in times of war. The work of the General Electric Company during the great world war will never be written. We have attempted some few paragraphs which should help the imagination of the reader to grasp the significance of how imperative is the necessity for the machines that turn the wheels of industry. They are turned electrically today, and hence result in the huge scope of the work we have so feebly tried to outline.

Russia as a Fertile Field for American Commerce

An American Committee of the Siberian Agricultural Co-operative Unions, representing several millions of Siberian peasants, has recently been formed with headquarters at 280 Broadway, New York City. In addition to buying agricultural implements and other machinery for its associations, a principal function of this Committee is to inform the American people of the true economic and industrial status of Russia, and to correct as far as possible many erroneous opinions that have been created by newspaper reports. The Committee is in direct cable communication with Siberia and is qualified to give accurate current information to the business public.

Most of us have formed our opinions of Russia from what we read in press dispatches. We think of the country as being destitute of any semblance of law and order, and entirely without financial resources and credit. Few of us realize the enormous size of the country and the population of almost two hundred millions; we are of the opinion that what ails only a small portion of the territory has affected the whole of Russia, and are prone to overlook the great commercial possibilities that will be open, when the situation clears, to the country that has fostered the favor and good-will of the peasants.

In commenting on the general state of business affairs, Mr. Gennady N. Berseneff, honorary chairman of the committee, who is the President of the United Credit Unions of Siberia, and one of the foremost business men of Russia, says:

"I find that Russia is largely misunderstood in America. Your people seem to know little of Russia, save the trouble with the Bolsheviki, and that parts of Siberia are cold. Economically Russia and Siberia have resources that make them the richest country on the earth. The mineral resources there are vast, but slightly developed. We have extensive forests, and immense stretches of fertile farm lands.

"The attitude of the Allies has been a puzzle to us Russians, who are working hard to bring about the regeneration of our country. We do not believe that the Allies plan the impoverization of Russia, yet the activities of the anti-Bolshevik forces, the ultimate winners in the struggle, because they are the producers, have not been recognized.

"Your press dispatches from Russia have little in them save the activities of the warring factions. The balance is going into the work of the peasantry, getting ready for the time when the politics of the country shall have settled and normal commerce can be resumed. We have, at the present time, stores of raw materials that could be put on the world market if conditions were right. The world needs them, and we need agricultural machinery and equipment, in order to permit the development of our resources to go on.

"Russia has reached the point where she must trade with some other great nation. In spite of the trouble there, other nations than America are laying the foundation for future business. We prefer to trade with America. We have profound admiration for your people, and complete trust in your business and commercial methods. For that reason we are trying to overcome your ignorance regarding the real Russia, in order that your people may not be afraid to enter into commercial relations with us in the immediate future.

"Should we fail in this attempt, it will be necessary to trade elsewhere. Our organization is sound, reliable. The members of the Co-operative societies of Russia are those whose activities, politically, will ultimately rule that country. They are democratic, patient, good workers, and potentially all-powerful in Russia. Marauders like the Bolsheviki cannot hope to win against them. Tzarist terrorism was thrown off, not because it was Tzarist, but because it hindered the democratic development of the people. Bolshevism will fail for the same reason.

"When conditions are normal, there will be no hesitation on the part of American business men to enter trade relations with us. That time is much nearer than is generally believed, and the foundations must be laid now, unless you are to lose the greatest market that the world has produced as yet. There are millions of pure-blooded Russians in Siberia, exclusive of all other peoples in our land, who are potential buyers of American goods, if you will go after them. They produce raw materials that you need. Industry in Siberia is too small to be considered as an economic factor at this time."