

DISCUSSION ON, "TIME-LIMIT RELAYS", AND "DUPLICATION OF ELECTRICAL APPARATUS TO SECURE RELIABILITY OF SERVICE", AT NEW YORK, MAY 16, 1905.

H. G. STOTT: The ordinary overload relay as described in Mr. Chellis' paper is employed to do the opposite of what the telegraph relay does: that is to say, the telegraph relay is used to apply a strong current to operate the receiving apparatus, while the purpose of the overload relay is to apply a comparatively weak current to operate a switch apparatus, because the main current has reached such pressures and strengths that it has become exceedingly expensive if not impossible, to design relays to work on main-line current. Different requirements have called for the design of different types of relays. The principal types mentioned in the paper—the overload, the differential, and the reversed-current, all have an application which is very concisely described in the paper.

I think that in this paper the principal points having to do with the control of a large amount of energy, are given on page 264; there the author recommends first opening the switch at that end of the feeder having the highest current and by that means making use of the resistance of the transmission lines to reduce the current on the short circuit when the second and final relays open on that current. This, of course, is an extremely important point in reducing the possible limit of current to be broken on short circuit.

Passing to Mr. Buck's paper, it contains a general and timely treatment of several important subjects. I do not quite agree with the recommendations in regard to the treatment of some of the apparatus. There seems to be a tendency nowadays to believe that the limit in size of stations has been reached. What the reason for that belief is it is rather difficult to tell. A capacity of at least 50 000 kw. has been attained, and there is no reason why power-houses should not be constructed with a capacity of 100 000 kw. or even more.

The principle of design in modern power-stations is to make each unit virtually a separate power-station in itself. The isolation of the generators, the main cables, the individual cables connected with them, the oil-switches, bus-bars, etc., permits all operating devices in almost all modern stations to operate as one unit, back to the boilers. Economy does not, however, dictate this separate operation. The question of how large to make the station is simply a question of how safe each unit can be made. I do not think the impression should be conveyed that the limit in size in large power-plants has been reached, unless there is some special point, where there is unreliable apparatus, such as the dam, flume, forebay, tailrace, etc., that regulates the entire amount of energy. In the steam-plant there is no one operating element of the plant that controls the whole amount of energy; the nearest approach to this condition is found in the water supply. In practically all

stations the water supply is in duplicate and is also further assured by the use of large storage-tanks.

In regard to the safety of underground cables, one point has been rather neglected in the paper, which is that the higher the voltage the less the damage that is likely to be done to surrounding cables. It is a fact, which has been proved by experience, that the safety of a cable, in regard to its neighbors, varies inversely with the voltage; in other words, the larger the current carried, the greater the danger to surrounding cables, and the damage done is proportional to the square of the current. For instance, the damage done to itself by a short-circuit in a three-conductor, 11 000-volt cable, is very small, and practically no outside harm results. The limit now is not the amount of energy that can be transmitted, but the amount of voltage which can be carried safely, or for which the cables can be constructed. I think that shortly cables will be built to withstand pressures of 25 000 volts, as danger to the surrounding apparatus is much lessened by using high voltage.

On page 267, Mr. Buck emphasizes the importance of having several power-stations, at least more than one energizing electric railroads, in order to avoid the failure of the energy supply to the trains. I think too much stress has been put upon this point: I do not think the liability of failure of energy in this way is so important. I have examined the statistics of the percentage of time of interruption of train service in three years due to various causes, and find that of the total interruptions those due to the failure of electric energy are less than one per cent. If by the duplication of a station one per cent. of the interruptions could be avoided the other 99 per cent. due to such causes as derailments at switches, cross-overs and collisions, etc., would not in any way be affected by the use of two, three, or more power-houses. I think that is a rather important thing to emphasize, as it increases our respect very materially—at least it has mine in the investigations I have made—in regard to the reliability of service which can be given by one power-house.

PHILIP TORCHIO: The problem of protecting high-tension systems against shutdowns is of great importance, and it has necessarily received the careful attention of the engineers who have been concerned with the operation of central-stations. It is probably true that our largest central-stations are now equipped with protective devices to meet almost all of the exigencies of the service for each particular condition. It is also true that these conditions vary greatly in different stations, and it is doubtful if the same devices would be applicable to all cases.

The speaker has been connected with the development of the system of protective devices used by a prominent New York company; it may be interesting to describe the general features of the system that has, for the particular conditions of that company, given most satisfactory results. Seven years ago

the company adopted for use on all of its high-tension switchboards two types of relays; one type a fixed time-limit overload relay installed at the generating end and one at the receiving end of each high-tension feeder, and the other an instantaneous reverse-current relay placed at the receiving end of the feeders. At the beginning the company did not feel confident of the reliability of these safety devices, so the relays were connected only to signal lamps. The relays were not entirely satisfactory and for considerable time a lot of experimental work had to be done before it was felt safe to connect a few of these relays to the trip mechanisms in a few stations. Then followed a period of investigations to find out whether the relays did more good than harm. About 3 years ago the experience was quite discouraging. Investigation of relays used on other systems proved equally unsatisfactory. A careful study of the problem clearly demonstrated two facts; one, that the existing type of relay was inadequate to fulfil all requirements of the service; the other, that to accomplish satisfactory results it was necessary to develop a well coördinated scheme of relays in which each element should have its proper relation to the other elements of the protective system. It was thought that the solution of this problem lay in the development of a time-limit relay which would operate in an interval of time in inverse proportion to the amount of current. The only relay of this nature available at that time was the dash-pot device attached to the ordinary overload relays; this was found to be unsatisfactory in service, and was dismissed from consideration. The manufacturers had been urged to develop a better relay to meet certain specifications which were given in detail. Developments along such a line of apparatus were, however, slow to materialize and in the meantime the New York Edison Company was not making great headway in protecting its increasing high-tension system.

A form of overload bellows-type relay which gave a characteristic curve somewhat similar to that of Fig. 8 of Mr. Chellis' paper, was brought to the speaker's attention and upon this type of relay a scheme of safety appliances was designed for the system. Aside from the system of protection of auxiliaries at stations and sub-stations, the continuity of the service of the system is safeguarded by the following relays:

*Generators.*—It has not been found desirable to install automatic circuit-breakers on the generators, as reliance is put upon the attendant to disconnect the generators by hand operation of the oil-switches whenever he finds it necessary so to do. To guide him an overload relay, operating signal-lamps, is mounted on each generator. This relay is without time-limit.

*High-Tension Feeders, Waterside Station.*—On each feeder is mounted an overload relay with a variable time-limit in inverse proportion to the amount of current. Curve I, Fig. 1 shows the characteristic curve of this type of relay, the points at which it

is adjusted, and its relation in time and load to other similar relays at the sub-station end of the feeder.

*High-Tension Feeders, Sub-stations.*—The feeder-switch is automatic and is controlled by a relay similar to the one at the Waterside end of the feeder. The relay itself is identical and by suitable current transformer ratio a curve is obtained as shown in curve ?

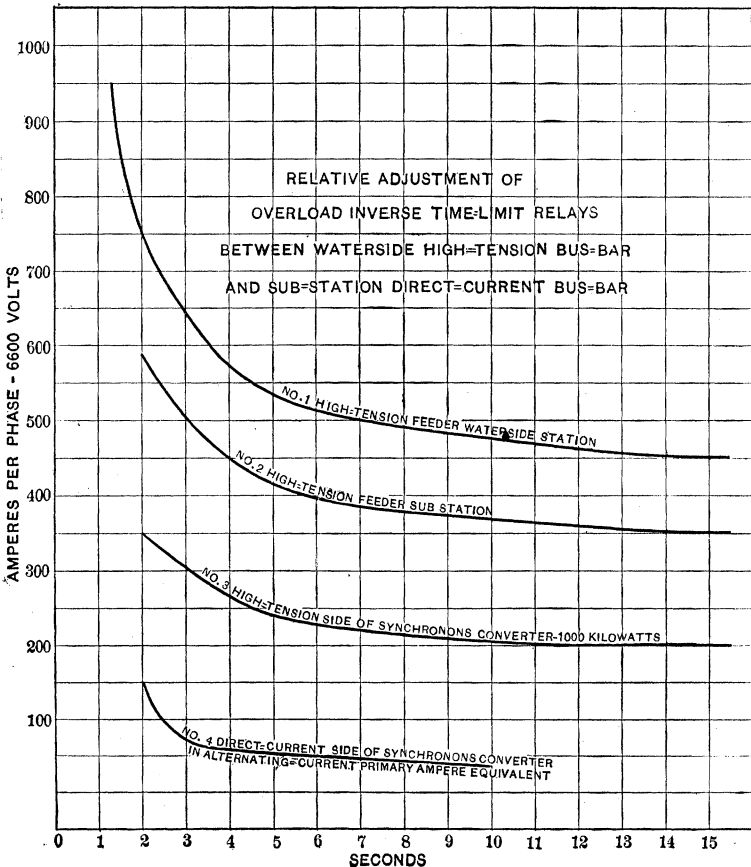


FIG. I

*High-Tension Side of Synchronous Converters.*—Each synchronous, or rotary converter, is equipped with a relay of the same kind as previously discussed, its load being proportioned by the current transformer ratio. Curve 3 shows the calibration of this relay.

*Direct-Current Side of Synchronous Converters.*—To be consistent with the general scheme above outlined the direct-current

side of each converter should be equipped with a reverse-current inverse time element direct-current relay. A relay with an instantaneous opening could not be used at this point unless set to operate at a very heavy reverse current, which would in itself largely defeat its purpose. A fixed time-limit irrespective of current would render the relay of very little value, as the short circuit on the direct-current side might reach disastrous proportions before the fixed time of the relay had expired. The selection of the reverse-current direct-current relay in this instance is made feasible by the fact that each sub-station is equipped with large storage batteries which can always energize the pressure coils of the reverse-current relays. Curve 4 shows the characteristic curve of this relay, figured on a basis of primary amperes for the purpose of comparison with the curves above it. It will be noted that Curve 4 has only approximately the same characteristics as the other curves, but as the relay is not called upon to operate in a fixed relation with other relays this difference in the characteristics of the curves is not material.

These relays are now being installed to operate only signal lamps, until such time as they may demonstrate their ability to meet the emergencies for which they are eventually intended.

Two years ago in a paper before the INSTITUTE the speaker outlined the respective features of the relays just described and he then summarized the subject saying:

"All relays at the different points of the system and their time elements must be properly adjusted to operate the different circuit-breakers in the proper order, so that if the trouble is once cleared by the opening of certain circuit-breakers, the other relays reset themselves in the normal position, leaving the rest of the system in operation".

It is gratifying to report that expectations have been fully realized by subsequent experience. The success of such a system of protection is dependent upon the care that is given to the maintenance of the several relays, but it is also a fact that apparatus is now available which is not freaky and unreliable and certainly sturdier than most of the other switchboard instruments.

It is probable that as further experience is obtained it will be found that a number of these intricate and delicate pieces of auxiliary apparatus may be advantageously omitted, but as matters now stand inconvenience of this kind must be put up with. Experience proves that a system based on the use of the inverse time-element relays gives a solution free from serious drawbacks.

There are cases in water-power installations where a short circuit on one line reduces the speed and voltage of the generators, and when the short circuit is cleared the speed and pressure increases, while the synchronous motors operating on the other lines fall out of step, overload the lines, and cause their circuit-breakers to open. Troubles of this kind have created a feeling of uncertainty as to the desirability of installing automatic relays in such cases.

The speaker does not wish to advocate a complex system of protective devices, if such can be omitted with advantage; but if it is found necessary to install these relays, he would emphasize the necessity of not confining the installation of the relays to only a portion of the systems, but to extend them to the whole installation so as to coördinate the different factors into a protective scheme in which every element bears the proper relation to the other elements.

C. O. MAILLOUX: The relay question is a very interesting one. As Mr. Torchio has pointed out, there have not been any satisfactorily working relays until recently. Having had occasion to study the question closely both in this country and abroad, I was surprised to notice the impatience, so to speak, with which the relay question is discussed by most operating engineers. This is especially so in the far West, where it is found that if the designing engineer does put in relays the operating engineer insists on making no use of them. He prefers to take his chances with machinery without the relays rather than with the relays in the state of their development up to two or three years ago.

In a case where there are synchronous converters, it is indispensable to have some device that will prevent the synchronous converters from running away. In cases where the distribution is by alternating currents, as well as the transmission, and therefore converters are not required, for example, where the load is principally or wholly lighting, it may be said that there is scarcely any necessity for relays. In New York city and many other large cities, the transmission is by alternating current at high pressure, and the distribution is by direct current at low pressure. In such cases synchronous converters must be introduced to convert the alternating current into direct current, and it is necessary to have some system of relays.

Referring to Mr. Buck's paper, the preamble, so to speak, contains an interesting statement of what might be called the equation of obligation, where he equates the obligation of the company to its stockholders with the obligation of the company to the public. That is an important question, and one that every engineer has to consider, whether he is designing a station or operating it. Unfortunately, it is difficult to define and formulate the quantities that enter on each side of the equation. On the one hand too much disregard of the quality of the service may be shown, with the object of reducing the initial cost and fixed charges; and on the other hand many engineers are inclined to err in the other direction by taking too many precautions for the security and continuity of the service, the result being that there is a large investment and an expensive one. The evolution of central-station design is greatly increasing the obligation of control and of safety. The switchboard and all the appliances that go with it and are part of it, which originally were but a small part of the central station,—have now become not only a large part, but an important part and in many cases

a very expensive part of the equipment. It may be said that in some cases there has been too much elaboration, just as there has been too little in others. The reference to what is called the "store-room" reserve, is a sensible and timely one. There are many instances where the reserve can be provided in just that way, and where it is possible to avoid incumbrances of extra parts at the switchboard and elsewhere. The reference, made by the last speaker, to the station where everything is accessible is also important; every one who has visited modern stations and studied the question of the requirements of their design realizes that they should be made that way; otherwise they could scarcely be managed or operated at all. The reference to the cost of replacement, as affected by the size of the unit, is indeed a very important question, but as the last speaker pointed out it is a question which the engineer should really discuss and consider at the time the system is designed. One sees, especially in electrical traction stations, the wonderful growth which they have had; they have had suburban extensions which have called for increased power and compelled the company to resort to all manner of expedients in order to get current at all to operate its lines. The difficulties are sometimes great, but where it is at all possible to anticipate such growth, the question of the number and size of the units should be carefully considered. That has a great bearing, not only upon the initial cost of the plant, but also upon the cost of the reserve apparatus, as Mr. Buck points out. There are cases where large units would be desirable, but of course the reserve must be larger, and here the character of the load-curve comes in. It is important to consider that. If the load-curve is comparatively flat, the reserve capacity required might be quite different from what it would be if there was a heavy peak; and the size of the units for reserve would be different.

It is almost always the rule in Europe that polyphase transformers are used for polyphase transmission and distribution, while here the general rule is to use single-phase transformers. So far as I have been able to ascertain, this difference in practice is due to the fact that it costs less in America to make single-phase transformers, and in Europe to make the polyphase transformers; the reason for the difference in cost being, perhaps, that more handwork is required to make polyphase transformers than to make single-phase transformers. I am not familiar enough with the methods of manufacture to understand the reasons for the difference, but it is a fact that the cost of the reserve capacity is greater when polyphase transformers are used than when single-phase transformers are used. I have been compelled to use single-phase transformers, not only because polyphase transformers could not be obtained, but because in the case of the three-phase plant, for instance, the reserve transformer only added one-third, making four single-phase transformers, instead of adding another polyphase transformer.

S. D. SPRONG: The proper selection and adjustment of the various relays in a system of this nature is one of the determining elements in the continuity of service.

Referring to the last paragraph on page 249, it is said that some of the characteristics of the relay referred to for generators would be as follows: Short circuit current, 4.95 amperes; overload current at normal pressure, 8.8 amperes.

Is it not probable during periods of light load when only one or two units are running that a short circuit on one of the feeders, if occurring close to the power-station, would so depress the generator voltage as to cause the relays to operate under the characteristics of "short-circuit" rather than under those of "overload" at normal pressure? if so, this would reduce the opening point to nearly one half of what it should be for any kind of feeder trouble, which is in its relation to the generators an overload. If it is essential to maintain the differential factor, it would seem for these reasons that the differential feature is not desirable in a generator relay at all points of the 24-hour load.

The question arises, however, whether a generator that gives 6.6 amperes on short circuit will give the necessary overload current to trip at 8.8 amperes at or near normal pressure. In other words would the generator under any conditions ever trip its relay by overload?

In the last sentence before Fig. 6 on page 254, it is said that a time limiting device such as a bellows or dash-pot, while ideal from the standpoint of simplicity, is not positive. One of the large operating companies in New York has had a varying number—more than 150—relays of this type in operation for a period of about 18 months and has not experienced failure in operation in a single instance, nor has the regular periodic inspection and test made on all the relay devices disclosed any of them in an inoperative condition due to the air type of time-limiting device.

Referring to the broad question of relays in the generator circuit, does Mr. Chellis consider it essential for good operation to have automatic opening of switches in the generator circuit under any conditions. It is not the practice among some of the larger companies that have been in operation for some years to have automatic operation of the generator switches. Their practice of having a relay that will signal the operator only at times of extreme load has proved entirely satisfactory.

In the last paragraph on page 256, it is said that in an ideal combination the sub-station end of the feeder should have an instantaneous reverse-current relay. This seems open to question, unless the relay is set at a high figure in consequence of which it would lose much of its value for the purpose intended. If set at a relatively low point, practice shows that the momentary reversals due to synchronizing a synchronous converter, or short depressions of voltage due to short circuit, will cause the converters to reverse for an instant due to the energy stored in



them, and trip the relay, thus cutting out one or more good feeders. This will occur whether there are storage-batteries in multiple with the system or not.

In the second paragraph on page 257, it is said that a direct-current reverse relay operating a circuit-breaker on the direct-current side may be used to open the circuit of an inverted converter thereby preventing the converter from attaining destructive speed in case of open field circuit. It would seem that relays of the type described, and without time-limit either fixed or inverse, would be very liable to disconnect the converter during momentary depression in the system voltage resulting from short circuit on a feeder, or other causes. This applies to sub-stations where storage-batteries are employed, or where a system is divided into two or more sections operated independently, each section supplying a portion of each sub-station's load. The next paragraph says that the relays referred to are adjusted to operate at about 15 per cent. rated current in the reverse direction, and that such relays have a value for limiting the speed of the converters. It seems to be the opinion of most engineers that when a speed-limiting device is found necessary, it should be a device designed for that purpose only, and its operation should depend solely on the speed of the converter.

In the first sentence of the paragraph on page 258, beginning with the bottom line of the preceding page, it is said that the order of operation of relays may be determined by the value of the time adjustments. This, of course, is true up to a certain point, but does not hold over the whole range of current flow in cases of severe short circuit. It has been found in practice that even with a considerable difference in time adjustment a number of relays that may be in series would all operate and open their respective switches. This is possibly due to the fact that two relays which are adjusted for series working, and have a considerable difference of time in operation at certain overloads, will both come within a certain minimum time if the overload is carried to the extreme point which is sometimes reached in operation. This minimum time is that which is required for an oil-switch to operate. It is therefore easily seen that while the relay with the lesser time will start the operation of the oil-switch, if it does not actually open and free the circuit of the load before the second relay has reached the operating point, both switches will open. The practical result of this is that no discrimination is possible between relays in series if the load goes above a certain point.

This is referred to again in the last paragraph on page 258 where it is said that they will discriminate at all loads; they no doubt will at all ordinary loads or overloads, but when current flow reaches an extreme figure, as sometimes occurs in a large system, all the relays connected in series are very liable to open their switches.

W. F. WELLS: In the opening paragraph Mr. Buck says,

"The question of the proper amount of reserve capacity in an electrical installation is purely a practical one, for which no definite laws can be enunciated". Experience is reputed to be a good teacher and the general practice of a large lighting company, deduced from the experience of a number of years, may be of interest. This company generates alternating current at 6 600 volts, which is transmitted underground to sub-stations, where it is transformed to direct current at 120-240 volts.

In general sufficient equipment is installed and operated to render it possible at all times to disconnect instantly any individual or group unit, without interfering with the service. As the number of units increases, the proportion of investment in emergency or spare equipment diminishes and soon becomes of relatively minor importance. The interest and depreciation charges on account of this spare equipment are partly offset by the greater flexibility in operating, and decreased transmission losses. The proportion of reserve required in each of the seven classes of apparatus mentioned by Mr. Buck, depends to a large extent on the reserve in the following class. It is simpler to discuss them in reverse order.

Commencing with the distribution net-work supplying customers; sufficient feeders connect this with the sub-stations to maintain the pressure in case any of them should burn out. In growing districts this simply means the installation of feeders a year or so in advance, and the fixed charges incident thereto.

In the sub-stations, the reserve is proportionately of as great importance as in the generating stations, as it must provide not only for accident in the sub-station but also for part interruption of supply caused by accident to the transmission system, or in the generating station. In general, the practice has been to design the sub-station to contain from 4 to 8 transforming units and to install one more unit than is necessary to carry the maximum load. A storage-battery has been found absolutely necessary, the capacity of which at the one-hour discharge rate, is equivalent to one of the transforming units. Where more than 5 units are installed the battery capacity exceeds 25 per cent. of the maximum load. An important part of the reserve of each sub-station is the assistance that can be rendered by the adjacent sub-stations.

All the transmission cables are underground and in order to avoid interruptions from "congested mass of ducts and cables crowded in manholes" as referred to by Mr. Buck, 4 separate and distinct lines of subway have been constructed, starting from 4 separate manholes in front of the generating station. Each sub-station has at least one more cable than is required for its maximum load, and these cables are divided among the different subway routes. In this way the greatest possible harm to the transmission system by a violent short circuit in a manhole would be to put out of service, and perhaps destroy less than 25 per cent. of the transmission system. Should this amount of damage occur at the time of the maximum load, the overload

capacity of the cables following the other routes would be sufficient to maintain the service.

To guard further against a violent short circuit the cables in all manholes are protected by a fire-proof covering over the lead. In 5 years' experience on a system containing many miles of high-tension underground cable, there has been no case where a cable burn-out has injured an adjacent one.

In the generating plant the high-tension and exciter bus-bars are the only parts of the plant which are common to and necessary for the operation of all power units, and these have been designed and constructed with the greatest possible care. Every known precaution has been taken with each generating unit, consisting of engine with individual condenser, and generator with its armature, field, and control cables, switches, rheostats and instruments to protect them from possible injury from adjoining apparatus or external source. The installation of two oil-switches, of the compartment type, in series in generator leads has not only insured the opening of the circuit between the generator and bus-bar in case of trouble, but has provided an additional means for synchronizing, etc. in case a switch or instrument transformer fails to operate properly. The reliability of the supply of current for the generator fields and control circuits is secured by a storage-battery, connected at all times to the excitation bus-bars. The station lighting and all auxiliaries can be connected by these bus-bars.

It has not been found necessary, as stated in the paper, to operate reciprocating engines at exactly full load on account of steam consumption. The engines and generators are so proportioned that the variation in steam consumption per kilowatt hour as shown by tests, between the limits of 25 per cent. underload and 25 per cent. overload is less than 5 per cent. from the maximum economy. The practice is to operate engine-driven units at slightly under normal load and to depend on their overload capacity in case one is instantly disconnected. Should it be necessary to disconnect two simultaneously, the batteries would supply the necessary energy until an additional unit could be started.

During the maximum, all units carry approximately normal load, and if it is necessary to take one out of service the overload capacity of the remaining units and the batteries can be depended on as a substitute. It has not been deemed commercial, nor has it been found necessary, to hold one unit out of service as reserve during the peak.

In the boiler-plant duplication is avoided by arranging the steam-piping so that all boilers and engines are connected to a ring-main, divided by suitable valves. This renders it possible for any group or groups of boilers to be used with any combination of engines. Boiler feed lines are similarly laid out and at least one more feed-pump operated than is required by load conditions. With such an arrangement it is necessary to run only a very small percentage of boilers for emergency use.

In general each group of transmitting and transforming equipment has sufficient capacity to permit the withdrawal from service of any individual unit without making it necessary to operate the balance beyond the normal capacity. The generating station is capable of carrying the entire load when operating at normal capacity. In case of accidents the substation storage-batteries and overload capacities of the remaining equipment are capable of maintaining service until repairs are made.

G. F. CHELLIS: With regard to the various remarks in connection with relays, I think a great deal of relay trouble is caused by improper connections and adjustments. That is my experience.

H. W. BUCK: Mr. Stott has spoken of the relative damage in underground cables between those operating at high voltage and those operating at low voltage in cases of manhole short circuits. In general I fully agree with this contention, but I have noted a number of instances where 11 000-volt, 3-conductor cable short circuits have caused considerable damage to neighboring cables, due to the fact that the circuit-breakers on that feeder have not opened promptly at the power-house, thereby allowing the short circuit to hang on for some time. That is a condition which may occur on any system.

In spite of what Mr. Stott has said in the matter of one power-house vs. two or more. I still favor two independent plants as the sources of power. In the case of steam-plants, for the reasons stated in my paper, this duplication of generating stations may not be so necessary, but accidents may happen even to steam-plants: boilers and steam-pipes may burst, and fly-wheels or armatures may also burst, due to engine runways, all of which might temporarily wreck the power-station. I, therefore, believe that with either steam or water-power two generating stations are more reliable than one. Whether one plant is reliable enough or not under a given set of conditions is another matter.

The variety of apparatus in the generating station is very important. This applies especially in the case of some of the older plants, where good judgment was not exercised by the engineers who laid them out. There is a tendency sometimes in designing plants to provide generating units for immediate load conditions only, without taking into consideration the possibility of greater demands upon the station in the future. The result is, after a few years, that the station is called upon to meet a load demand of an entirely different character, which necessitates the installation of units not only of different size, but of entirely different type. At the end of 5 or 10 years, then, a miscellaneous assortment of generators will be found, which makes the problem of reserve a difficult one, since the generators installed cannot be used interchangeably on the various circuits.

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