A Plan of Electric Power Generation for the Future Expansion of Japanese Power Industry

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Pre-view:

In this paper, general characteristics of power plants which have to be considered in planning electric power generation for the present and future expansion of Japanese power industry are developed.

I. Historical background:

In the early period of power industry in Japan the electric power generation depended exclusively upon steam power. However, as hydro power began to be developed, steam power was gradually replaced by hydro power because of the economical superiority.

In this premature stage of hydro power development, however, the capacity of plants was determined by the primary power which was based on minimum stream flow, that is, the average annual minimum of past records.

To make up for the severe power shortage during the World War I, many hydro plants based upon much higher stream flow than the minimum were constructed, so that they could supply much more energy in the wet season with cheaper generating cost for secondary power use.

However, immediately after the War, the load demands for secondary power suddenly subsided due to the world-wide economic depression, resulting in abundant power in the wet season without any use being made of it.

Therefore, utilization of the secondary power as a part of the primary power supply had to be taken into consideration for gradually increasing load demand for primary power. For this purpose it was necessitated installation of additional steam plants, which could supplement the same amount of energy in the dry season as the secondary power in the wet season.

This combined operation of hydro and steam plants could also be justified by the economical merit that the generating cost per KWH can be lessenned by increasing the capacities of hydro plants even with the necessary additional cost of supplementary steam plants.

In this way, stream flow base of hydro plant planning was gradually taken larger and larger, from the minimum to nine-month, or six-month stream or more, combined with supplementary steam plants economically.

In this period, however, hydro plant was still dependent upon the natural stream flow variation; that is of the run-of-river type. Consequently, some amount of power in new power plant was wasted during midnight even in the dry season, as the load demand during midnight could not increase so much in accordance with expansion of power system, and on the contrary considerable amount of energy had to be supplemented by steam plants in peak hours in the dry season due to water shortage. In order to solve this problem, the flow regulating pondage was constructed in new hydro plants, by which regulation of stream flow was made in accordance with, at least, the daily load variation, excess water being reserved during the midnight and utilized to generate power during peak hours.

With this regulating pondage of sufficient capacity, hydro plants can supply peak load, even in the dry season, up to its full capacity without any supplementary steam plants, increasing the utilization of stream flow.

The preferable choice between the regulating pondage and the supplementary steam plants was made by economical comparison of investment and operational expense between both types.

In a power system which is operated by hydro plants only without any steam plants in the wet season, however, the newly added pondage plant has to carry only peak load even in the wet season in accordance with daily load curve, because the already existing hydro plants are carrying the base load part to their full capacity. Therefore, utilization of stream flow in the new power plant has to be very low.

In order to obtain a more economical system operation by increasing the utilization of the new pondage plant, another auxiliary steam plant with almost the same capacity was necessitated. This can carry peak load in the wet season and near the base load part in the dry season, thus making the pondage plants carry peak load in the dry season and near the base load part in the wet season.

By such a joint operation of hydro and steam plants, power generating cost has come to be lessenned one more step further, increasing the utilization of stream flow.

The function of a pondage plant can be expressed by two terms, namely, normal peak output and daily peak duration in the dry season in accordance with the minimum stream flow and regulating capacity of the pondage.

These two terms are not independent of each other and are determined by considering what part of peak load is to be carried economically by the plant, in connection with other power plants under planning, by referring to the typical daily load curve of the system in the dry season.

In other words, at first we determine the daily hours of operation of a pondage plant in the dry season, and then fix the plant capacity.

Thus if the capacity of a pondage plant is taken very large in spite of its low minimum stream flow, it is then to carry peak load for short duration in the dry season.

Accordingly, capacity of pondage plants became larger and larger until some of them reached nearly three-month stream flow base.

In this way, the pondage has come to be planned to regulate not only daily but also weekly or monthly stream flow, in order to increase the available amount of minimum stream flow on heavy-load day.

Although the fundamental weakness of a Japanese power industry standing on poor fuel resources compelled hydro plants to be in a superior position than steam plants, steam plants have also taken a very important function, not only as supplementary or auxiliary plants for improving the utilization of hydro power, but also as plants supplying seasonal primary power economically which is generally maximum in the dry season, or primary power in some localities where fuel condition is more favourable.

In such a power system, notwithstanding the interconnected system operation under the run-of-river and pondage plants, steam plants of a larger scale were still needed in the dry season, even though hydro plants retained considerable amount of excess power during off-peak hours in the wet season. This tendency increased further as load expanded.

For such a situation, a storage plant with natural lake or artificially constructed reservoir has come to be planned where abundant water can be stored in the wet season and power is generated by reserved water supplementing the minimum stream flow in the dry season so that a storage plant is able not only to eliminate a supplementary or auxiliary steam plant but also to take the role of steam plant for a supplementary, auxiliary or seasonal primary power use if the storage capacity is ample enough and the discharge of reserved water is free.

Especially after the World War II, hydro plants with large reservoir have been keenly needed on account of the severe fuel scarcity.

On the other hand, a pumped storage plant has come to be planned where abundant water can be pumped up to a reservoir by excess power of the run-of-river or pondage plants during off-peak hours in the wet season and power is generated in the dry season or even during peak hours in the wet season by the reserved water, taking the role of steam plant for a supplementary, auxiliary or seasonal primary power use to the extent of the amount of excess hydro power and storage capacity of the reservoir.

A storage or pumped storage plant was installed on the upstream as much as possible, which can supplement a minimum stream flow and increase a primary power of every other plant in the downstream. However, the construction of these storage reservoirs tends to be of a very large scale compared with that of a regulating pondage, so that several difficulties hindered hitherto its desirable development.

II. Load curve consideration:

In a power system consisting of varieties of loads, it is rather difficult to attempt to predict load growth and it is much more difficult to realize daily load curve in future.

However, in order to determine the necessary capacity of a pondage plants, the knowledge not only of necessary maximum peak load but also of daily load curve for the assigned load growth becomes very essential because, as mentioned above, the necessary normal peak output and daily peak duration for such a plant in the dry season is determined by a shape of daily load curve, just as the primary power of a run-of-river plant is fixed by the minimum stream flow.

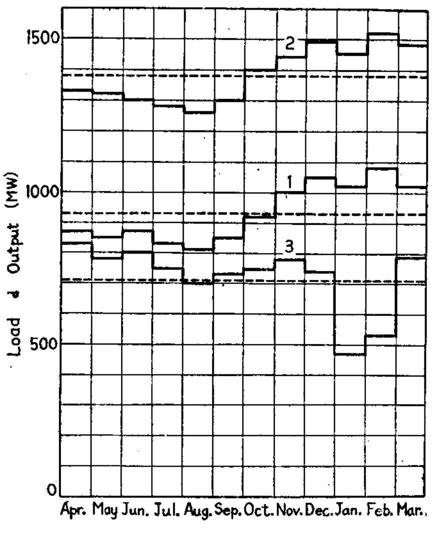

Fig. 1 Annual and monthly average value of load and hydro power through a year.

In this connection a set of load curves is assumed as an example.

The load always varies throughout a year but variation of the monthly average value of load is repeating almost regularly every year.

Fig. 1 shows typical annual load curves of a certain power system; curve No. 1 shows the present load throughout a year, No. 2 is the load forecasted for five years ahead in future, where the full line is monthly average value of load, while the broken line is the average load throughout a year.

Through these examples, it can be fairly well understood that the load is relatively low from April through September and rises up higher during the latter half of the year especially from November to March. On the contrary, the total available output of hydro plants in the system varies throughout a year as shown in curve No. 3 of Fig. 1, where the full line is monthly average value of output while the broken line is the average output throughout a year; thus the wet season prevails from April to June, and the dry season from January to February.

In general, load decreases in the wet season while it increases in the dry season. But strictly speaking, load is a minimum and stream flow decreases partly in August. Nevertheless the situation is not so serious in August as in January to Feburuary, because ample supplementary steam plants are ready to be put into operation, finishing the repairing work after long run in the dry season before August.

Therefore, the difference between maximum output in the dry season, when output of the steam plants becomes maximum, and the wet season, when output of hydro plants becomes maximum, is defined the seasonal primary power for conventional use.

From the maximum load in the wet season we can estimate necessary outputs of the run-of-river, pondage and storage plants, and sometimes of steam plants for primary power and auxiliary use for joint operation of pondage plant, and also their alternative, the storage or pumped storage plant.

Also, from the maximum load in the dry season, steam plants necessary for the seasonal primary power as defined above and for supplementary use for the run-of-river plants, and also their alternative, the storage or pumped storage plants can be fixed. In this estimation, the typical maximum loads in the critical dry and wet seasons should be taken into consideration.

However, in practical operation, the average monthly maximum loads are a little lower than the estimated maximum, and on Sundays or holidays the load goes down very low, so that more desirable operation is obtainable by saving fuel of steam plants in the wet season, and by saving water of pondage, storage and pumped storage plants combined with steam plants in the dry season.

It can be said conclusively that by considering two representative daily load curves for the maximum load in the dry and wet seasons instead of ones for every day, capacity of necessary power plants can sufficiently be estimated.

Fig. 2 shows one of the representative daily load curves in the wet season, and Fig. 3 that in the dry season. Curve No. I for both is the present load, and No. II is the load forecasted for five years ahead in future. Curve No. III is the load expansion for the coming five years, and although it might appear to be a little over-estimated, the absolute value of load growth itself does not change the nature of the present discussion.

Fig. 4, 5, 6 and 7 are the corresponding daily load duration curves which can be derived by rearranging the load for every hour shown in Fig. 2 and 3 according to its magnitude.

In the above mentioned discussion collective load curves associated with primary substations are to be considered, because in estimating load division for each power

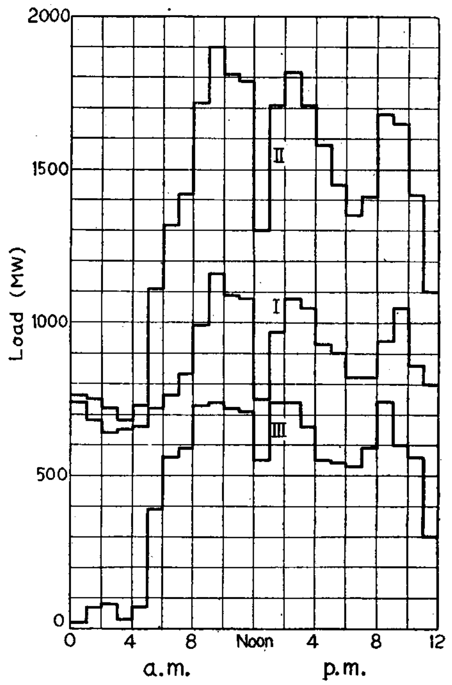

Fig. 2 Daily load curve in the wet season.

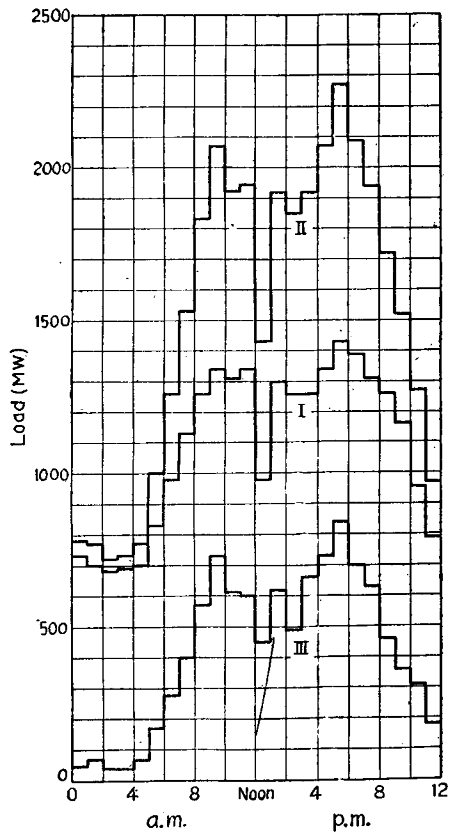

Fig. 3 Daily load curve in the dry season.

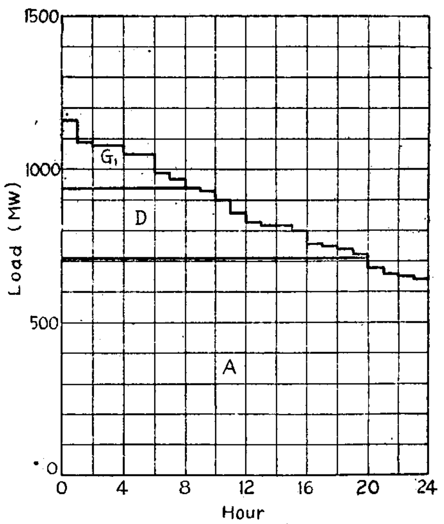

Fig. 4 Daily load duration curve in the wet season, at present.

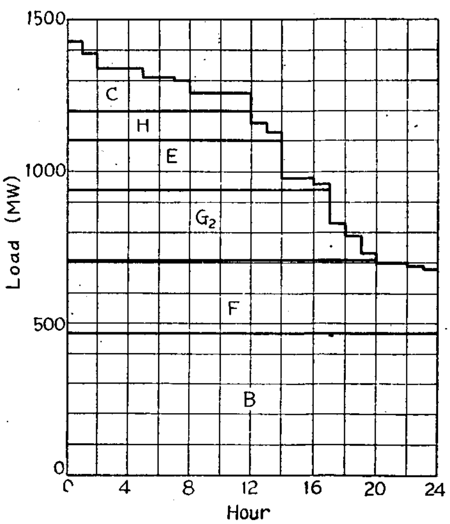

Fig. 5 Daily load duration curve in the dry season, at present.

plant, comprehensive economical comparison, including not only the generating cost but also transmission cost and line loss, is necessary.

Therefore, the load division for each power plant, estimated from these curves, must be the corresponding output value in which the line losses are subtracted from the actual plant output in accordance with the power flow diagram.

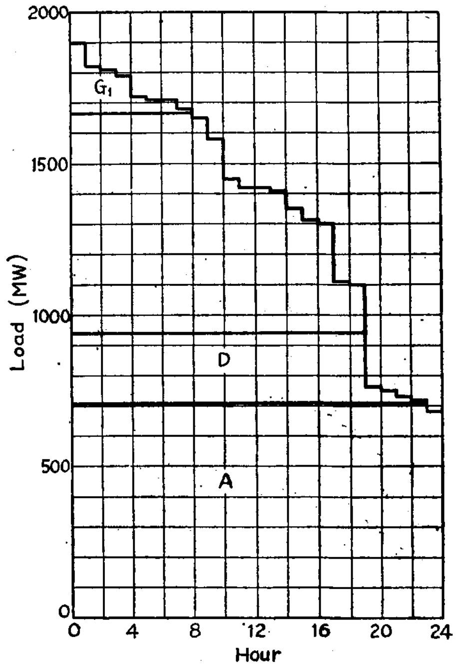

Fig. 6 Daily load duration curve in the wet season, forecasted for five years ahead in future.

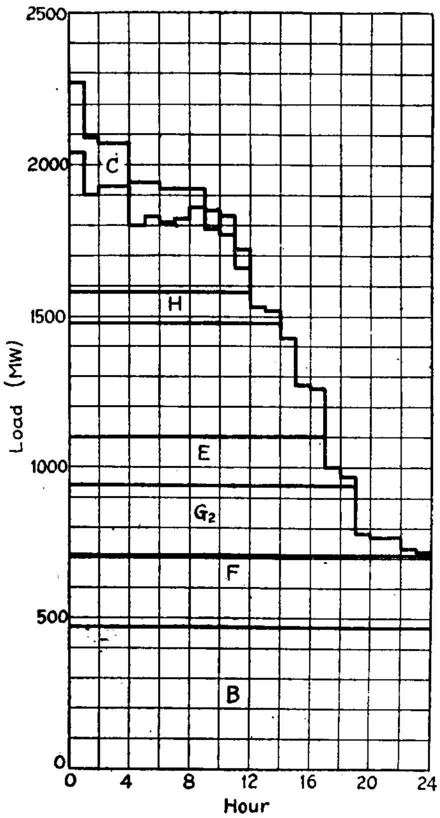

Fig. 7 Daily load duration curve in the dry season, forecasted for five years ahead in future.

Furthermore, these load curves are based upon the average loads for every hour, so that the actual instantaneous maximum load during the hour naturally becomes a few percent greater than the average value. Therefore in order to keep the system frequency at the rated value, a few percent greater capacity than the above is necessary in both the wet and the dry seasons.

However, the load of a power system is maximum in the dry season, while it decreases in the other season having some allowance in system output.

Therefore, for this situation it is sufficient to consider for the dry season, but the matter is not so serious because the variation is of short duration and for a temporary overload a power plant is generally made flexible to some extent. That is, the water way construction is given some allowance and prime mover usually has a 5% overloading capacity, and electrical equipment can be overloaded because ambient and water temperature in winter are lower than the designed value.

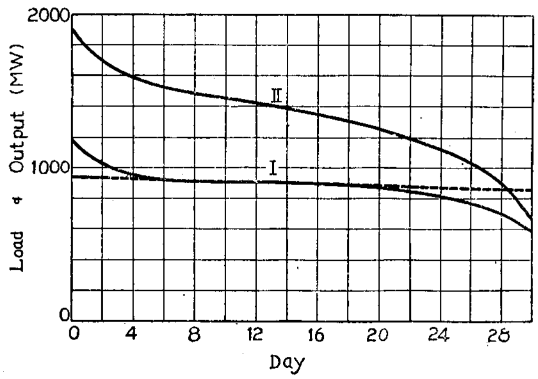

Fig. 8 Monthly load duration curve in the wet season.

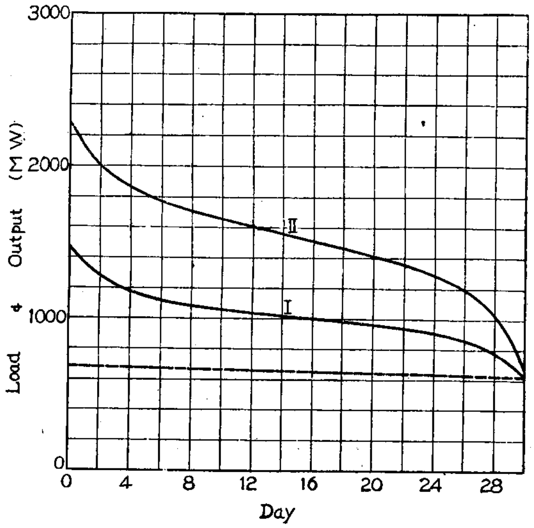

Fig. 9 Monthly load duration curve in the dry season.

When the above is not permissible, the frequency controlling power plants should take this load, and this must be taken into account for determining the plant capacity.

Annual energy generated in KWH for each power plant can be obtained by integration of output duration curve of a power plant throughout a year, combined with load duration curve. But as the generated energy varies in accordance with the amount of load and stream flow, they have to be deduced from, at least, the monthly records.

In Fig. 8 and 9, curve No. I and No. II in full line are the monthly load duration curves, at present and forecasted for five years ahead in future for the wet and dry season respectively and the broken line is the present monthly output duration curve of the total hydro power plants in the system.

In the case of excess water estimation, integration through off-peak hours in midnight is especially important, because the output of hydro plants do not always match load variation.

In March or April comes the turning point of stream flow from dry to wet season, in which load balance between hydro and steam is suddenly reversed, therefore this month has to be divided into two parts at this critical point in the case of energy integration.

In this connection, when a load curve is reformed into the corresponding load duration curve, it can be expressed by a mathematical formulae, and there is a mathematical method of solution.

However, in planning the power plant, it must be studied for various sites of power plants with different characteristic and construction cost based on the typical daily load curve and monthly load duration curve.

Consequently, discussion is developed through graphical method without any help of mathematical calculation in this paper which will be shown on a later occassion.

III. Operation of existing power plants:

In a large interconnected power system, as it is in Japan, consisting of a number of power plants of several types and supplying large amount of power to a wide service area, it is not so simple to estimate the load division for a new power plant to be installed as in an undeveloped district.

In the first place, it is necessary to estimate the output and characteristics of the existing power plants reasonably in accordance with the present system.

The outputs of run-of-river plants, and the partial output of pondage plants, which cannot be regulated like as a run-of-river type, are estimated by summarizing the output of each power plant from the past operational data, considering several conditions, such as; inspection, repairing work, operation in series on the same river, transmission loss, etc. This part is shown in the area A and B in Fig. 4 and 5 respectively for the wet any dry seasons.

The normal peak output and daily peak duration of each pondage plant in the dry season are also estimated in the same way from the past operational data, taking into account of the responsible water discharge downstream stipulated by regulation, silt deposit in the regulating pond, reservoir upstream, inspection, repairing work, frequency controlling, load regulation necessary for steam plants, series operation of the other plants on the same river, reverse flow regulation downstream, load decrease on Sundays and on holidays, unpredictable load and water flow variation, transmission loss, etc.

In order to make the existing plants generate their full capacities operating at their most economical conditions, the normal peak output of the pondage plants is to be held as large as possible, and its duration be held accordingly as short as possible for typical day in the dry season with critical peak load, except the system where the pondage plant has comparatively large capacity compared with total system output or the light-load day when the maximum output of the system is smaller than the total available output of the power plants.

In Fig. 10, curve C shows the total daily output duration curve of the pondage plant group in the dry season, which can be derived from a comprehensive study of the normal peak output and daily peak duration of all pondage plants by summerizing the outputs of the plants for every hour and arranging the outputs according to its peak duration.

Curve D also shows the total output of the pondage plants group in the wet season corresponding to the normal peak output in the dry season.

The total output of various kinds of hydro plants are shown in Fig. 4 and 5 for the daily load duration curve of the dry and wet seasons respectively.

As to the relation among steam plants, the power plants with higher efficiency generally should carry both the annual and the daily load part of a longer duration of operation, and in the light-load hours the method of operation may be somewhat changed in accordance with the rate of load division whether some of the plants partly stop operation for the sake of high efficient operation, inspection or repair work, or not.

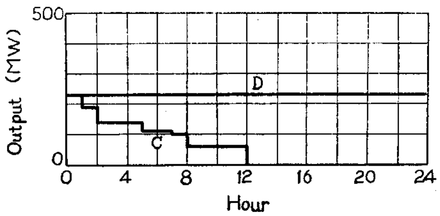

Fig. 10 Daily output duration curve of the pondage plants.

But generally speaking, in the power system with pondage plants, the steam plants are to carry the peak load part in the wet season and rather near the base load part in the dry season as mentioned above, allowing for a few exceptions of temporary variation of load division due to repair jobs of plant equipment.

Thus abundant flow in the wet season can be utilized very effectively, and also pondage plants can clip off the peaks of the load curve and thus permit steam plants to carry the load which is lowered down to almost constant flat line on the load curve as in this example, when the characteristics of pondage plants matches well the shape of peak load.

In this way, the necessary output of steam plants becomes minimum and almost constant during its operation. Thus the highest economical operation of steam plants is obtained, lessenning the total investment cost and fuel consumption per KWH.

In practical operation there is of course some variation in the load division due to unexpected discrepancy between load and stream flow, but the difference is not so large as to be considered.

In this connection, when the excess stream flow in the off-peak hours is not enough to fulfill necessary regulating capacity of the pondage plant, even with additional steam power in the off-peak hours the regulating capacity has to be utilized to its maximum in order to get the normal peak output and its duration in the peak hours, because it can minimize and keep the output of the steam plants nearly constant when it is running, resulting the most economical operation.

The load division for the several types of steam plants are also shown in the load duration curve of Fig. 4 and 5, i. e., the load division for supplementary plants is in area F, that for auxiliary one is in area G_1 of Fig. 4 and area G_2 of Fig. 5. The height of G_1 in the wet season is to be equal to that of G_2 in the dry season on account of the principle of joint operation of hydro and steam plants.

The area E in Fig. 5 ahows the load division for steam plants supplying seasonal primary power, while the area H in Fig. 5 shows the load part to be carried by the total storage and pumped storage plants. In this example, these hydro plants are used as an alternative to the steam plants for seasonal primary power use.

In order to utilize the stream flow as much as possible in the wet season, the capacity of pondage plants has to be much more increased as compared with primary power; therefore in such a case the daily peak duration will be very short.

But the storage or pumped storage plant can reserve the abundant stream flow in the wet season with their ample storage capacity, so that in the power system with pondage plants the storage or pumped storage plant has to carry the remaining part excluding the peak load for pondage plant if the decrease of generated energy in pondage plants is not so significant due to the reduction of effective head after the full utilization of regulating capacity and also it has to carry the intermediate part of the load division for steam power in order to meet the regulation for the wet and dry years and for the variation of daily maximum output as shown in Fig. 18.

In conclusion, the load division between several types of power plants in general are as mentioned above. However, even if there is no problem in fuel supply, the reasonable load ratio between steam and hydro, run-of-river and pondage plant and also load division between storage or pumped storage hydro and steam plants are generally very difficult to obtain and it has to be studied thoroughly for each case, because it is influenced by the investment cost and characteristic of each power plant and also by the back ground of the development.

IV. Necessary conditions for power plants under contemplation:

After drawing the representative daily load duration curve, forecasted for five years ahead in future for the typical maximum-load day in the wet and dry seasons and allotting the corresponding output area of the curve for each type of existing power plants, namely, run-of-river, pondage, storage, pumped storage and steam plants, as mensioned above, we can get the necessary load division for the power plants to be installed in future as the remaining part of the load area, The blank parts in Fig. 6 and 7 correspond to this area, and in Fig. 11, they are again shown in broken line J for the wet season, and in full line K for the dry season.

On the other hand, the broken line L and full line M in Fig. 12 show the corresponding daily load duration curves for the expanding load demand increased during coming five years in the wet and dry seasons respectively, which can be derived from area III in Fig. 2 and 3.

There is a considerable difference between the curves in Fig. 11 and those in Fig. 12. This difference also appears in the monthly load duration curves which are necessary for the calculation of generated energy.

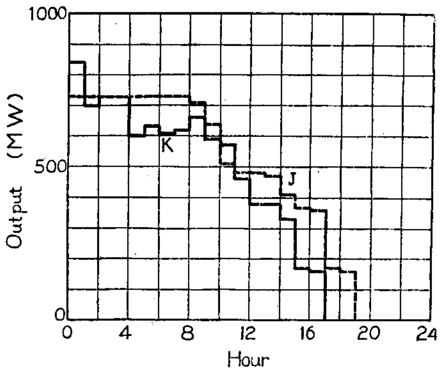

Fig. 11 Daily output duration curve of the power plants to be installed in future.

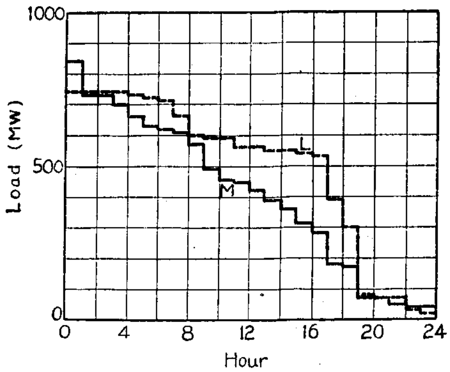

Fig. 12 Daily load duration curve for the expanding load demand increased during coming five years.

This is due to the fact that many run-of-river plants have already been developed, and at present the pondage plants still have some waste of excess water in off-peak houns in the wet season as shown in Fig. 4, and the output duration curve of the pondage plants does not entirely match with the new load duration curve in the dry season, and also the present load in off-peak hours in the wet and dry seasons is very small with lower load increasing rate compared with that of peak hour.

This phenomenon generally happens for the time being after the exploitation of hydro power in the power system composed of large hydro power with comparatively small steam power.

In Fig. 13, a comparison is made of the outputs in Fig. 11 necessary for new power plants in the dry and wet seasons; the full line shows the common output for both seasons and the broken line shows the seasonal difference of the outputs. It is clear from Fig. 13 that the necessary seasonal primary power is not very large in this example.

Even if the characteristics of existing pondage plants match well the peak part of the daily load at present in the dry season, during five years ahead in future peak load will appear as shown in K of Fig. 11; otherwise the curve K takes in general a more complicated form.

Although, in some cases where the change of peak load form is so irregular to be carried economically by the existing pondage plant or the decrease of generated energy is so significant due to the reduction of effective head after the full utilization of regulating capacity, the characteristics of the existing pondage plants should be reformed by increasing or reducing some capacity of the plant for other purpose, the new peak load should be carried generally by the new power plants.

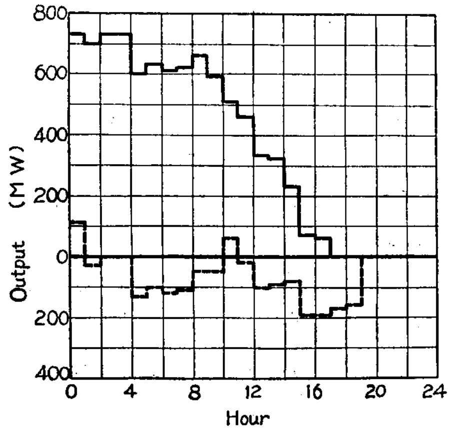

Fig. 13 Comparison of daily output duration curve for the wet and dry seasons.

The existing steam plants for auxiliary use in the wet season and for supplementary, auxiliary and seasonal primary power use in the dry season were considered to carry the peak load and near the base load part in the wet and dry seasons respectively in the future load curve as at present in the above discussion, but the operation of steam plants can be rather free in so far as the fuel condition permits, while the operation of hydro plants is quite different.

Therefore the existing hydro power only is to be excluded, and then the

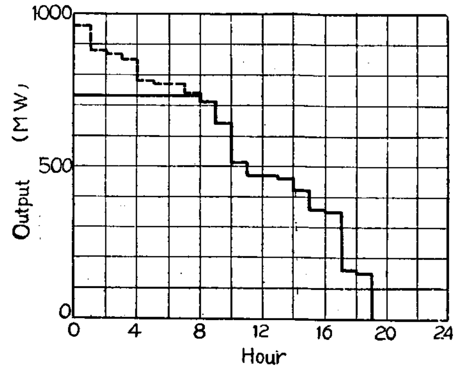

Fig. 14 Daily output duration curve of the power plants to be installed in future, including the existing steam plants, in the wet weason.

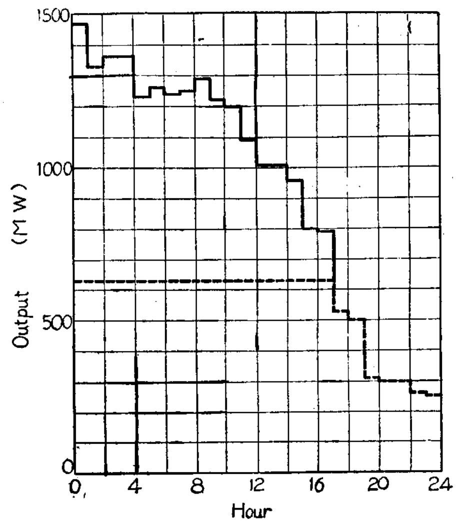

Fig. 15 Daily output duration curve of the power plants to be installed in future, including the existing steam plants, in the dry season.

remaining part is the load division for the newly installed hydro power including necessary existing steam power as shown in Fig. 14 and 15 for the wet and dry seasons respectively.

In these curves, the area corresponding to the broken line shows existing steam power which carries peak load part in the wet season and rather base load part in the dry season as shown.

From Fig. 14 and 15, it can be said that the generating hours of the new hydro power are of the wide range, changing from 8 to 19 hours in the wet season and from 1 to 24 hours in the dry season in this example.

V. Different types of power plants for the increase of output necessary in future:

The increase of output necessary for the future load expansion in Japan has been discussed in the preceding chapter, as shown in Fig. 14 and 15 for the wet and the dry seasons respectively.

These curves show the necessary output including existing steam power. The tendency shown in those curves generally appears after the new exploitation of hydro power in the power system composed of large hydro power with comparatively small steam power.

The new power plants are to be well planned in accordance with their reasonable characteristics taking into consideration of the economical load division with existing steam plants and others under contemplation in order to attain the highest utilization of plants with the minimum waste of water.

At the same time the rate of future load expansion during planning is considerable in such a large system as that in Japan and it has to be carried by a large number of power plants instead of a few ones since there are very few sites capable of power generation in large capacity.

The following five types of power plants are to be considered:

1) Steam plant supplying primary power:

The increasing load, as shown in this example, can also be carried completely or partially by steam plants and the new plant has to be operated most efficiently in combination with the existing steam plants.

However, in Japan the amount of coal which can be used for electric power generation has already reached near the limit, because primarily the fuel resource is very poor and its annual production is barely sufficient to supply the necessary demand at present and also in future, and there are many kinds of manufacturing industries requiring coal.

And for the future expansion of electric power, it can be said that hydro power is the only resource available and its rapid exploitation is keenly needed. In this connection, however, the new supplementary or auxiliary steam plants are still necesrary for the economical operation of hydro plants, as mensioned above.

Therefore as the exploitation of hydro power develops, the demand for fuel will increase further and it has to be fulfilled by domestic coal within the range of present supply. As the result, old steam plants have to be gradually replaced by new plants of higher efficiency or else the foreign fuel supply must be necessary.

Steam plants especially those supplying primary power require much more fuel than the supplementary or auxiliary steam plants.

Therefore, if many steam plants are installed for primary power in the future, they will interfere with the desirable exploitation of hydro power which is the only resource still undeveloped in Japan.

Conseqently, the situation of fuel condition does not allow the erection of this type of steam plant except in some cases where hydro power is not easily at hand, or in some coal mine areas where coal of poor grade is utilized for power generation.

2) Run-of-river plant with supplementary steam plant:

In a system with a rather high steam to hydro power ratio, the increasing load can be carried effectively by the new run-of-river plant, especially when steam power is needed to supply even the midnight load in the wet season. In this case, erection of a new plant or enlargement of the existing plant can be considered.

However, in a power system in which there is a considerable amount of water wasted at midnight in the wet season, as shown in Fig. 4, the utilization of the new plant will be very inefficient in the wet season.

Also this type of power plant requires supplementary steam power.

Consequently, in order to cut down the generating cost per KWH by the highest effective utilization of stream flow in the wet season, this type of power plants has to be compensated in their output duration characteristics by the following two measures, except in some cases where captial investment for the plant per KWH is very low:

a) Storage plant in the upstream:

Hydro plants with the existing or newly constructed reservoir in the upstream can reserve surplus water during the midnight in the wet season and can supplement the minimum stream flow in the dry season by the reserved water, thus eliminating entirely or partially the supplementary steam plants for new run-of-river plant downstream, with highest utilization of stream flow.

Also if the capacity of reservoir is large enough to keep not only the surplus water over the normal stream flow of a run-of-river plant but also that of flood, the stream flow can be utilized 100%, being effective for the flood control also.

Thus all other power plants downsteam are also benefited by the reservoir, increasing their primary power to a certain extent although some waste of water must be tolerated due to the time differences by series operation on the same river if there is no intermediate pond.

b) Pumped storage plant:

In case when a reservoir of sufficient capacity cannot be constructed in the upstream, or where the surplus water during the midnight has to be continuously discharged downstream in a new run-of-river plant, the alternative pumped storage plant will be effective, which can utilize the excess electric power to pump up the stream flow into some reservoir in the near localities within the power system and discharge this reserved water for the necessary power generation in the dry as well as in the wet season, thus nearly 60% of the excess energy can be utilized.

Especially when there are many run-of-river plants downstream, the same result can be obtained as the storage plant upstream and, in addition to this, the efficiency of pumped storage plant can be over 100% because all the heads of the plants downstream can be utilized.

In this case the new run-of-river plant carries the base load in the dry season in Fig. 15, while the existing steam plant carries near the base load corresponding to the part which lies on the load division for this new power plant.

But with the above mentioned measures by the storage plant upsteam, the new run-of-river plant can take partially the same role as a storage plant.

3) Pondage plant:

Pondage plants, which are designed suitable for the peak part of the daily load duration curves in the dry season in Fig. 15, matches the increasing load well.

In this case also, erection of a new plant or enlargement of the existing plant can be considered.

When the existing pondage plant is expanded, there will exist some difference in the plant characteristics so that the shape of peak part in Fig. 10 and 15 has to be changed accordingly.

In the dry season, the less the amount of continuous water discharge necessary for downstream during the off-peak hours, the more this type of plant can increase the ability.

Especially when there is a pondage plant of reverse flow regulation for downstream, the pondage plants upstream can regulate their stream flow freely even in the dry season, and thus they can use their total output for as short a duration as desired, as shown in Fig. 15.

In this connection, in order to utilize water in the wet season more effectively, a reasonable capacity of auxiliary steam plant is to be used, as mentioned above.

Thus the pondage plant carries the base load and the auxiliary steam plant carries the peak load in the wet season, and the operation is reversed in the dry season. The auxiliary steam plant in this case has to be operated very efficiently in close coordination with the other existing steam plants.

For the purpose of utilizing the stream flow in the wet season as much as possible, the capacity of pondage plants is taken comparatively larger than for their primary power use so that the daily peak duration in the dry season becomes rather short, requiring a very high ability of stream flow regulation.

In the example under discussion, the excess water in the wet season cannot be utilized fully even with the aid of auxiliary steam plant as the operating time of the plant is shorter than 19 hours even with the base load part in the wet season, as shown in Fig. 14.

Therefore it is necessary to have a storage plant in the upstream or a pumped storage plant in the near vicinity within the power system, as in the case of a run-of-river plant, in order to utilize the excess water in the wet season more perfectly and to realize the cheapest power genetation.

And when there are many pondage plants with daily flow regulation downstream of a storage or a pumped storage plant, all plants are able to operate very effectively without any losses even in the series operation on the same river which usually is the case with the run-of-river plants.

4) Storage plant:

A storage plant, having a capasity ample enough to store the excess water in the wet season and supplement the minimum stream flow by the reserved water in the dry season, can utilize the excess water effectively by itself in the wet season without any aid of supplementary or auxiliary steam plant.

Furthermore, if it can reserve not only all excess water in the wet season but also that of flood, the stream flow can be utilized 100% by the plant as mentioned above.

The primary power of all the run-of-river and pondage plants downstream can also be increased by the reservoir and thus these power plants can be operated very efficiently in the wet season as mentioned above.

The normal peak output and daily peak duration in the dry season of the storage plant can be fixed by the minimum flow of stream and the quantity of water available from the reservoir in the dry season.

As mentioned in Chap. VI, the storage plants are to carry intermediate part of the load division corresponding to steam plant in a power system with the run-of-river and pondage plants, and also can sometimes take the role of steam plants partially or completely for supplementary, auxiliary or seasonal primary power use when the reserving capacity is large enough and the condition downstream is permissible.

Thus the storage plant can eliminate the erection of steam plants and can save the fuel.

This is the reason for the preference of this type of hydro plants for future erection. However, in Japan, owing to the peculiar topography, the slope of the rivers are very steep and very few localities are suitable for such reservoir construction.

In addition to this, the dense population and the higher order of civilization, extending into deep valley, very often make for it practically impossible to submerge large area.

Natural lakes are also often unsuitable for such control, because they have already been used for other public purposes, and the water often has to be discharged even in the wet season to keep the water level low before the typhoon comes in September, in order to prevent flood damage.

Also, sometimes the reservoir often cannot be fully utilized because of practical difficulty in installing a reverse regulating pond in the downstream, necessary for the free regulation of stream flow.

Even in the case of a very suitable location being at hand, the economical difficulty caused by large installation cost and many years necessary for construction often hinder the development of the storage plant and in order to overcome the present severe power shortage usually many pondage plants of small scale are intended to construct successively, because which is rather easy.

However, the hydro plants have a very long life of operation compared to the steam plants, and their construction involves a great amount of investment cost, so that the planning of hydro power exploitation has to be carried out with a deep consideration, avoiding temporary conventional measures.

Looking from this point of view, the construction of storage plants is keenly advisable.

5) Pumped storage plant:

There are three types of pumped storage plants as follows:

a) For daily use:

This type of pumped storage plant is to pump up water during the off-peak hours and to generate power by the reserved water during the peak hours every day throughout a year both in the wet and dry seasons, and thus can neutralize daily output variation. As a result the capacity of the reservoir is not necessarily very large.

This type of plant is well developed in Germany since early days in order to make steam plants operate continuously with almost constant output throughout a day on account of particular quality of German coal.

In the power system composed only of the run-of-river plants, this type of plant is also well adopted.

However, in Japan, this type of plant is not generally adopted because it is uneconomical to pump up water with low efficiency by steam power in the dry season.

b) For seasonal use:

This type of pumped storage plant is to pump up excess water by excess hydro power in the wet season and to generate power in the dry season by the reserved water, with a reservoir of a rather large capacity.

This type of plant is well developed since early days in Switzerland and other places where fuel condition is not favourable.

In Japan also, this type of plant is to be considered in the planning of future hydro power exploitation although its efficiency is not more than 60%, since there is a considerable amount of excess hydro power during the midnight in the wet season in the power system where the run-of-river and pondage plants exist and are now under planning, and where the load does not seem to increase during the midnight notwithstanding a considerable increase of the daytime load.

This type of plant also can take the role of the steam plants for supplementary or seasonal primary power use, because it can generate power in the dry season by the water reserved during the wet season.

And it is also the merit of this type of plants that the run-of-river and pondage plants downstream can supplement the minimum stream flow and increase their primary power by the discharged water of the pumped storage plant upsteam in the dry season, and thus partly carry the load part similar to the pumped storage plant.

Moreover, the overall efficiency including all the plants downstream can be more than 100% although the efficiency of the plant itself is not more than 60%, as mentioned above.

c) For auxiliary use:

This is a combination of the two types of pumped storage plant discussed above, it generates power not only in the dry season but also during the peak load hours even in the wet season by the reserved water pumped up by excess hydro power in the wet season.

Accordingly, it can take the role of the steam plant for auxilary use.

Consequently, the capacity of the pump of this type is to be larger than that for seasonal use, but the operation is much more economical because the equipment can be used continuously throughout a year, and also much more of the excess hydro power can be utilized, saving of much coal.

However, there is the difficulty of finding a suitable site for this type of plant which requires a high water head and a reservoir of sufficient capacity to be economical.

Nevertheless, the construction of pumped storage plant is advisable especially in a system having a considerable amount of excess hydro power in the wet season, and where there is little possibility of increase in load demand in the near future which calls for this wasted energy.

VI. Policy during the years of abnormal stream flow:

The capacity of hydro plants is designed on the basis of the average annual minimum of stream flow of the past records, as mensioned above.

Therefore in practical operation, there will be some changes in the generation in the dry season according to the dry and wet years and the planning of hydro plants has to be flexible in order to meet these abnormal conditions.

a) For extraordinarily dry years:

When an extraordinarily dry year comes, the system will undoubtedly suffer from severe power shortage in the dry season if the power system does not have enough reserve capacity.

It may be overcome by partially limiting the power supply or by decreasing the supply voltage or frequency of the source, as it is done at present.

However, from the point of responsibility to supply power, the measure for the contingency of abnormal condition has to be taken more positively in the planning of power generation beforehand.

According to the peculiar topography, it is very difficult in Japan, to find a suitable site for storage plant in large scale which has a reservoir of sufficient capacity to control yearly steam flow.

Therefore it is necessary to provide a reserve plant to be prepared for the extraordinarily dry years.

For this purpose, a steam plant is most economical as it can be erected at a rather low installation cost and can be operated rather freely; and then the deficient energy of the power system due to water shortage in the dry year is to be supplemented by this steam plant.

As regard to the operation of a reserve steam plant, it can also be said that the longer this plant is operated taking near the base load throughout a day, the less will be the generating cost because of smaller plant capacity and less fuel consumption per KWH, making the plant operate at an almost constant output as long as possible.

Generally speaking, the reserve steam plant is of the shortest annual mean duration of operation among the steam plants so that the most obsolete plant in the system is generally used for this purpose.

Fig. 16 shows the load division for each type of power plants in the daily output duration curve in the dry season of normal year forecasted for five years ahead in future, namely,

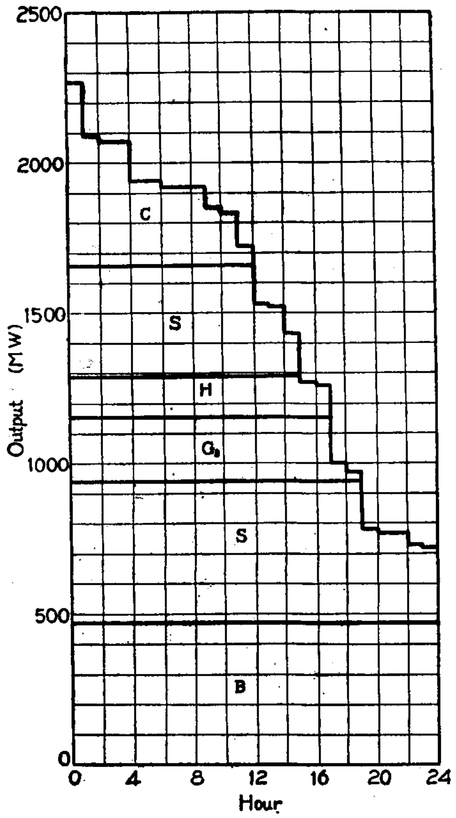

Fig. 16 Daily output duration curve in the dry season of normal year.

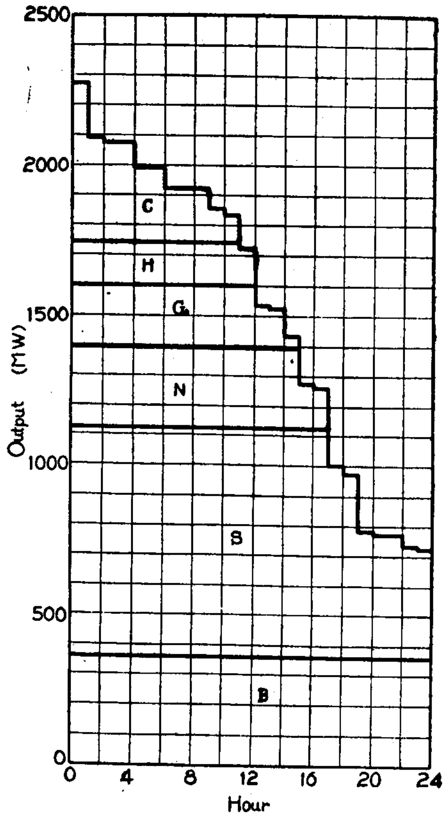

Fig. 17 Daily output duration curve in the dry season of extraordinarily dry year.

C…for the pondage plant

H…for the storage and pumped storage plant supplying seasonal primary power

G_3…for the storage and pumped storage plant in joint operation with pondage plant

S…for the steam plant supplying supplementary, auxliary, and seasonal primary power

B…for the run-of-river plant.

In the above example, assuming simply that there is an equal water shortage of 25% for each type of hydro plants, we can get the daily output duration curve of the assigned dry season as shown in Fig. 17, in accordance with the deficiency of generating KWH.

The necessary reserve steam plant can be estimated as the height of N in Fig. 17, which is equal to about 12% of the total output.

In this case, the hydro plants have to stop operation for an output corresponding to the height of N in the total, its individual division for each power plant

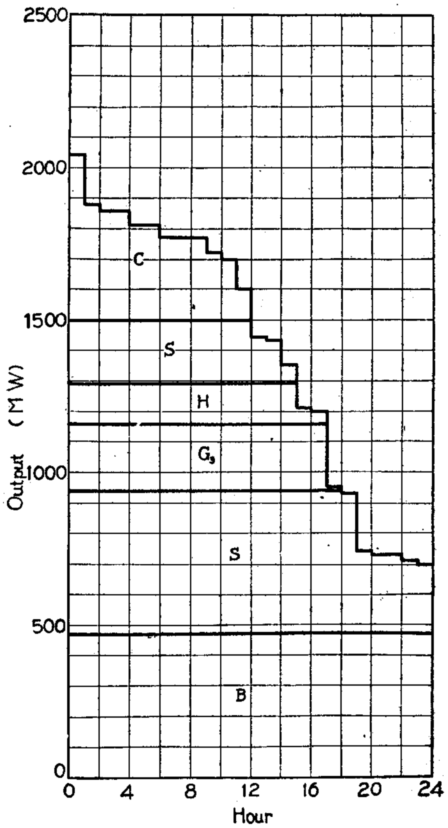

Fig. 18 Daily output duration curve in the dry season of normal year.

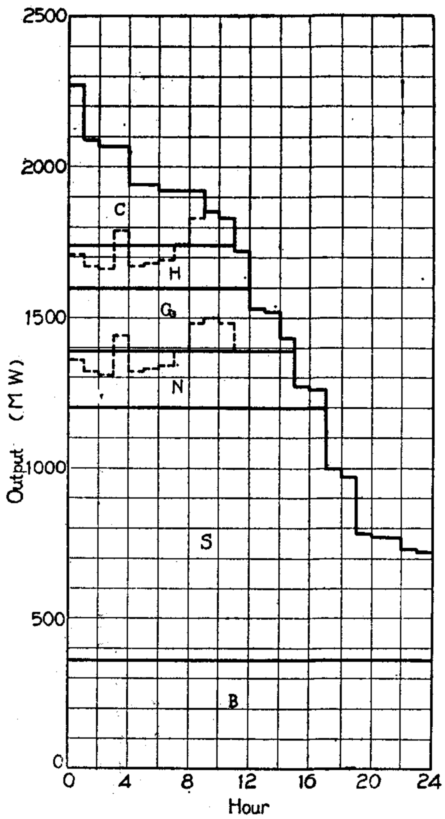

Fig. 19 Daily output duration curve in the dry season of extraordinerily dry year.

being generally fixed by the shape of corresponding daily load curve, excepting the run-of-river plant.

The steam plants corresponding to the height of N are of no use in normal years.

Therefore, in order to utilize the capacity of S and N partly in normal years, load part carried by H and G_3 of the storage and pumped storage plants, supplying auxiliary and seasonal primary power, has to be selected between the intermediate part of the load division corresponding to the steam power, as shown in Fig. 18.

Then these storage or pumped storage plants can be operated to their full capacity corresponding to the area H and G_3 even in the dry year as shown in Fig. 19 with full line, and the installed capacity of these hydro plants can be lessenned by about 20%, that is about 90 MW in this example, while the capacity of steam plants S and N still remains as before.

In this connection, an attempt to force the pondage plants to operate with their full capacity in extraordinarily dry year in spite of the 25% water shortage is unfavourable, as it is necessary to increase the capacity of reserve steam plant N by about 58%, which is 110 MW, as shown with the broken line in Fig. 19.

However, prior to the dry season in the extraordinarily dry year, practically the water shortage for the storage and pumped storage plants can be partly supplemented by steam plants before the dry season sets in and also even in the dry season it can be done on light-load days not only for the storage and pumped storage plants but also for pondage plants with weekly or monthly regulating capacity.

In such a case the degree of water shortage for maximum-load day in the dry season can be partly lessenned, but the principal consideration is as mensioned above.

b) For the extraordinarily wet years:

In the dry season of the year of extraordinarily abundant stream flow the plant output of the run-of-river plant can be increased in KW, corresponding to the degree of abundant stream flow; however, the pondage, storage and pumped storage plants cannot increase their output in KW but only their generating energy in KWH, since they are already operating with their full capacities in the peak hours even in the dry season of normal year.

In the above example of Fig. 18, the degree of abundant stream flow is simply assumed equally by 25% for each type of hydro plants in the system as in the case of extraordinarily dry year. The corresponding daily output duration curve of the assigned dry season is as shown in Fig. 20.

In this case, the hydro plants are also to be so operated that the steam plants operate daily at an almost constant output as long as possible with minimum fuel consumption.

As for the operation of the storage or pumped storage plants corresponding to the area H and G_3, supplying auxiliary and seasonal primary power, they have to retain enough flexibility not only to reserve the abundant stream flow in the reservoir in normal year but also to prolong the daily operating hour corresponding to the degree of abundance of stream flow.

If the output corresponding to the area H and G_3 is carrying the load part between the run-of-river plants and steam plants in normal year, there is no allowance of operating hour for plants H and G_3 to generate the available extra energy in the extraordinarilly wet year.

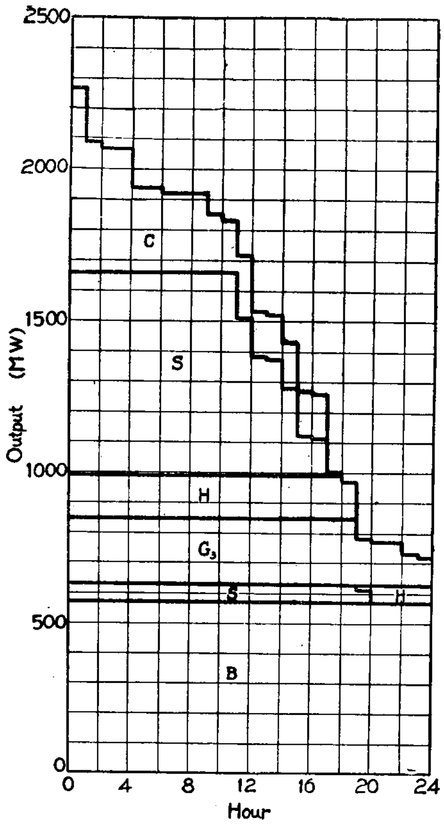

Fig. 20 Daily output duration curve in the dry season of extraordinarily wet year.

As for the operation of the steam plant, the plant of higher efficiency will carry the lower part below the area H and G_3 for the storage and pumped storage plants, while the plant of lower efficiency will carry the upper part above the area H and G_3, as shown in Fig. 18.

VII. Output control on a light-load day:

The output of a power system is generally designed on the basis of maximum peak load in a year which appears in the dry season as mentioned above in the example.

After the expansion plan of power generation will be completed in the near future and there would be no more power shortage necessary to limit power demand as at present in Japan, the peak loads on other days would decrease generally by a few percent compared with annual maximum-load day, not only on Sundays or holidays, but even on some week days, and for this situation it is necessary to control the outputs of power plants.

a) In the dry season:

In this case also, the run-of-river plants do not change their operation, but only the other types of hydro plant, namely, the pondage, storage, and pumped storage plants, so that the stream flow during the off-peak hours is not to be wasted but has to be reserved and utilized effectively, making the steam plants operate daily at an almost constant output as long as posible.

There are two ways of operation as follows:

1) To operate the pondage, storage and pumped storage plants with the same amount of generating energy in KWH as in the maximum-load day, thus reduce the output of steam power as much as possible in order to give the chance for repair and inspection of the remaining steam plants on light-load days.

This is shown in one example of Fig. 21, which is a daily output duration curve on some week day when the maximum peak load decreases by 10% and the minimum load decreases by 3%.

The areas C, G_3 and H show the outputs of the pondage, storage, and pumped storage plants respectively, as defined in Chap. VI.

In this way, the output of steam power can be reduced to 80% of the value on the maximum-load day.

2) To reduce the amount of generating energy of the pondage, storage, and pumped storage plants in order to increrse the available amount of water in the reservoir of these hydro plants on the maximum-load day, utilizing the water reserved on light-load day, within the possible range of steam power allowing a few plants to be stopped for repair and inspection.

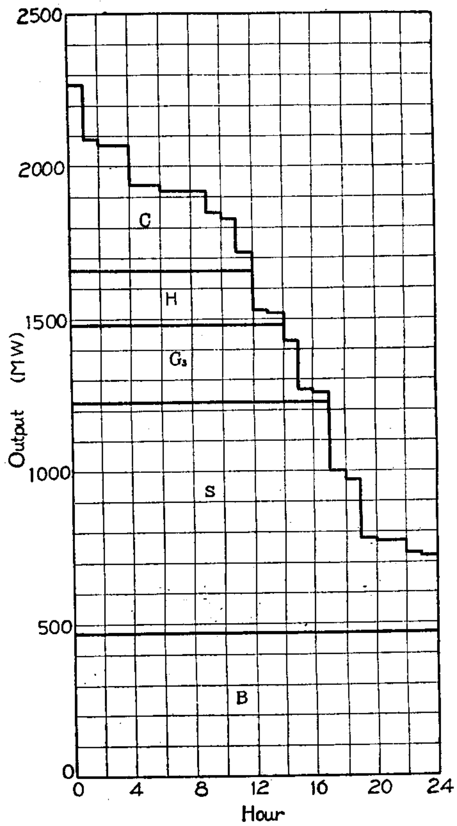

Fig. 21 Daily output duration curve on the light-load day in the dry season.

This is shown in one example of Fig. 22 which is daily output duration curve on a Sunday or holiday when the maximum peak load decreases by 36% and the minimum load decreases by 8%.

The corresponding generated energy in KWH of the pondage, storage, and pumped storage plants, C, G_3 and H respectively, are reduced to 1/3, 1/2 and

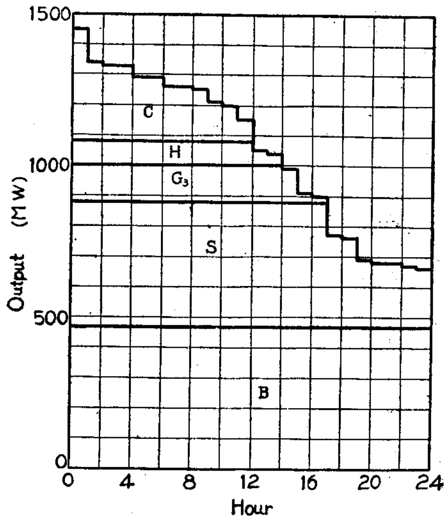

Fig. 22 Daily output duration curve on a Sunday in the dry season.

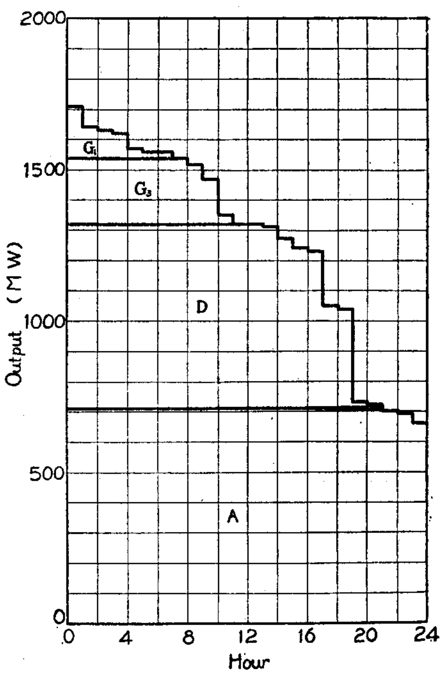

Fig. 23 Daily output duratioh curve on the light-loady day in the wet season.

1/2 of their normal values.

In this case also, if the load part carried by the storage and pumped storage plants are inserted between the intermediate part of the load division, corsesponding to the steam power, their outputs can be held higher at the same KWH, with consequent more reductiou in the output of steam power, as in the case of extraordinarily dry years.

The preference between the two kinds of operation mensioned above depends chiefly upon the degree of necessity for inspection and rapair works of steam plants.

However, in general, the combination of the two kinds of operation will be practicaly undertaken on week days because prediction of the load variation is generally somewhat difficult.

As for the pondage plants there is always some excess capacity remaining in both cases, which can be utilized as reserve capacity as will be explained later.

b) In the wet season:

On light-load day, the run-of-river and pondage plants have to operate at their full capacity, so that the remaining load has to be carried by the storage, pumped storage and steam plants.

The storage plant generally has to carry the load close to the peak in order to save steam power and reserve excess water as much as possible in accordance with the storage capacity of reservoir and the amount of stream flow, making full use of its output in KW, and reducing the generating energy in KWH.

The pumped storage plant has to pump up as much water as possible by the excess hydro power of the system, and also if possible, it has to carry the peak load in order to save steam power.

Fig. 23 shows the load division for each type of power plants in the daily output duration curve on some week day, when the maximum peak load decreases by 10% and the minimum load decreases by 3%.

Fig. 24 shows the load division for each type of power plants in the daily output duration curve on a Sunday or holiday, when the maximum peak load decreases by 36% and minimum load decreases by 7%.

In the latter case, even the run-of-river and pondage plants have excess output.

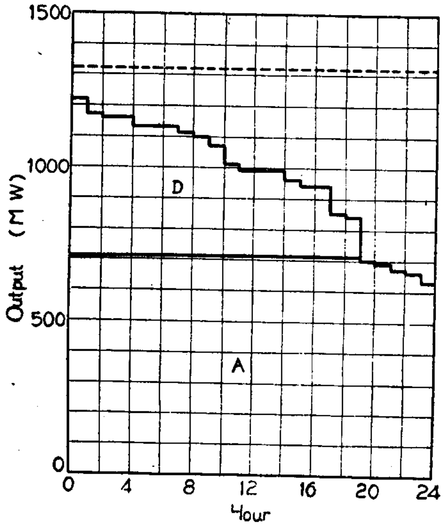

Fig. 24 Daily output duration curve on a Sunday in the wet season.

VIII. Reserve capacity:

In electric power supply industry, continuity of service is essential. However, as it is impossible to immunize it from the hazards of fault even with the generating equipment sufficient for the maximum load demand, once a fault occurs, a temporary power outage would not be avoidable when there is no allowance for the total output of the power system.

In order to retain the continuity of service, a reserve capacity has to be prepared.

In a large power system, which is interconnected with another, permitting a certain amount of power accomodation, if necessary, it has to be gerenally operated with such an amount of reserve at hand as at least one of the largest units can be suddenly taken out of service at any time on account of its fault without any loss of supply and also an additional stand-by unit has to be held in reserve which can be put into operation at once to meet the next contingency.

The allowance for total output of the power system is miuimum at the time when the fault occurs in the peak hour on the maximum-load day of the dry season, especially during the extraordinarily dry years.

In this case, the run-of-river, storage, pumped storage and steam plants are normally operating with their maximum outputs so that there is no more reserve unless they have some excess capacity.

Fortunately, however, as mentioned above, the pondage plant has even in such a severest case some excess capacity remaining which can respond favourably to the emergency call by utilizing the reserved water of the weekly or monthly regulating pond, even though it has no preparation of special generating equipment in reserve.

In the peak hour on the maximum-load day of the dry season of normal stream flow years, the reserve steam plant for the extraordinarily dry years can take the role effectively in case of emergency.

Excepting on the maximum-load day, in normal stream flow years the pondage plant can also handle this situation easily without any help of the reserve steam plants, because they have enough excess capacity even in the peak hour of the dry season.

The easy starting and quick loading of pondage plant add further to its supremacy as the reserve capacity.

From the above discussion, it can be conclusively said that when the reserve steam plants for the extraordinarily dry years are provided, reserving of equipment for hazards of fault would not be required at all, excepting the reserve for allowance of the anticipated maximum peak load.

IX. Criterion of hydro power exploitation:

Due to the fatal condition of poor fuel resources in Japan, a steam plant for primary power use throughout a year has to be avoided as much as possible.

Therefore in accordance with the general principle of supremacy of hydro power over steam power, every effort has to be given to reducing the generating cost of future hydro plants to the extent that it is comparable to that of steam plants by suitable measures as explained in the preceeding chapters.

The capacity of a steam plant can be selected rather freely and its installation cost and operating expense can be generally estimated rather easily in accordance with its capacity and mode of operation.

On the other hand, the installation cost and operating expense of a hydro plant has to be evaluated for the individual power site, because its capacity and characteristic have special economical value for each site depending upon its location, although the load division for each type of hydro plants is generally determined as mentioned above.

For future expansion of electric power, the most suitable hydro plant has to be designed on the basis of the characteristic of load, combined with the supplementary or auxiliary plant, as a criterion of the installation cost and operating expense of a corresponding steam plant, suitably selecting from among the many proposed sites.

In this way, the construction work will be developed one by one from the most economical site.

The practical example of selection of an economical power system will be shown on a later occasion.

Conclusion:

In planning power plants for the future expansion of Japanese power industry, economically the most suitable type of power plants have to be selected for the remaining part of the estimated typical daily load duration curve in future, including the existing steam plants and excluding the part carried by the existing hydro plants corresponding to their suitable load division.

In this way, the run-of-river plants will have to carry base load in combination with supplementary steam plants, whereas the pondage plants will have to carry the load rather near the base in the wet season and the peak load in the dry season in joint operatiou with the auxiliary steam plants.

The storage and pumped storage plants will have to carry the intermediate part of the load division corresponding to the steam plants in order to coordinate their operation for the wet and dry years and also for light-load days in normal years.

In this connection the excess stream flow is wasted during the midnight in the wet season by the existing power plants and there is little hope of the increase in demand to consume this wasted energy in the near future, while the steam plants for primary power use throughout a year are to be avoided as much as possible since the fuel condition in Japan is unfavourable.

In such a present situation it is necessary to construct storage or pumped storage plants for the purpose of utilizing the wasted water in the hydro plants in the wet season and saving fuel in the steam plants, thus lessenning the generating cost as a whole.

The supplementary and auxiliary steam plants, necessary for the economical exploitation of hydro power which is the only resource for future development in Japan, have also to be substituted by the storage or pumped storage plants, if possible.

Since the economical considerations of hydro plants differ widely among the individual sites, the general ratio of hydro to steam plants cannot be easily determined without careful estimation of each case, while the economical situation of steam plants can be easily determined.

Finally, as a criterion of the installation cost and operating expense of a corresponding steam plant, the most suitable hydro plant has to be designed on the basis of the characteristic of load selecting suitably from among the many proposed sites.