A Method for Obtaining the Residual Load Duration Curve of the Project Power After the Completion of a Run-off-River Hydro-Power

By

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A method for obtaining the residual load duration curve of the project power is developed in the case of planning for the electric power generation of a large combined hydro-steam power system, after the completion of a new run-off-river hydro-power.

1. The Load Share to be carried by Newly Planned Power Plants

It is steam-power that gives us the criterion for economic comparison between various methods of electric power generation. In planning a scheme of electric power generation for a large combined hydro-steam power system, it is necessary, first, to determine the share to be carried by existing hydro-plants so that the utmost use may be made of their stream flow, capacity and characteristics, in carrying the total future load including the probable increase in load demand. Then it is necessary to examine whether it is profitable or not to replace that part of the load beyond the share of the existing hydro-plant—so called project power—by newly planned hydro-power, comparing such plans, with plans where the project power is to be supplied by existing steam plants as well as by those to be newly built.

In planning electric power generation, we should have in view the load duration curve when we treat the load, because the shape of the load as well as the output and the generated energy, is necessary for representation of the load shared by the steam-power.

If the new hydro-plant is of the run-off-river type, the load assigned to it is always on economic principle the base part of the project power; but in a large combined hydro-steam power system, the duration curve of the load carried by the run-off-river plant is, as is clear from the above, is not relevant, so that we have to know the duration curve of the project power minus the load carried by

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the newly planned hydro-plant.

In past years, the steam-power of a system has been identical with the above project power. The daily maximum and minimum load of the steam-power of a system, for a certain year, arranged in the order of calendar days, is shown in Fig. 1, while the daily load curve of the steam-power of a system in wet and dry months is shown in Fig. 2, and its duration curve in Fig. 3, in which are also shown the duration curves of the total load demand at the sending end, the hydro-power and the excess hydro-power.

As is evident from the above, the load of the steam-power of a system not only decreases to a great extent on Sundays and holidays, but is liable to fluctuate considerably on weekdays also. Hence it seems impossible to represent faithfully the condition of the load throughout the year by only the load curve or the load duration curve of a particular day or period, so that all the data for every hour through the year are required to represent the load.

Since it is difficult, however, to predict the daily duration curve of the project power for the future year, we have to obtain the desired result upon the basis of the duration curve for each month, which is possible to predict. That is, we must find some way to formulate the relation between the monthly duration curve and the result obtained by computation from the data of the actual daily load curve (since, as we have seen, the steam-power of a system was, in past years, identical with the project power), and by making use of this relation come to the desired result upon the sole basis of the predicted monthly load duration curve for the future year in planning.

It is the same with respect to the daily average available hydro-power, which fluctuates from day to day. It is necessary, therefore, to know the value for each day through the year in order to represent the condition of stream flow; but since it is difficult to predict this for the future year, we have to obtain the desired result upon the basis of the monthly average available hydro-power, which is possible to predict.

The Reader is referred to Ref. 1), for the method of obtaining the monthly duration curve of the project power from that of the total load demand, and the monthly average available hydro-power in the system for the future year.

He is also referred to Ref. 2), for the method of computing the monthly average available hydro-power in the system for the future year.

2. The Generated Energy of a Run-off-River Hydro-Power Plant and the Monthly Residual Load Duration Curve of the Project Power

We have employed all the data on the output of steam-power of a system

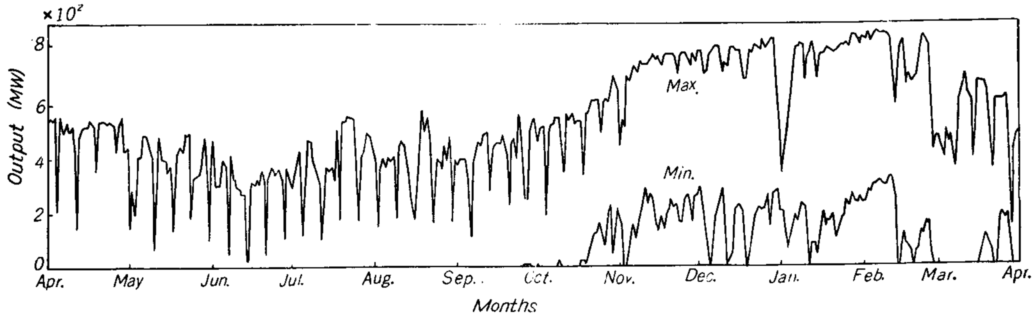


Fig. 1. Daily maximum and minimum output of the steam-power in a system

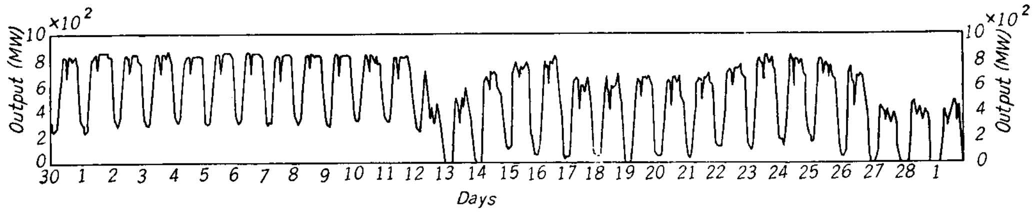


Fig. 2-(a). Daily load curve of the steam-power in a system (May)

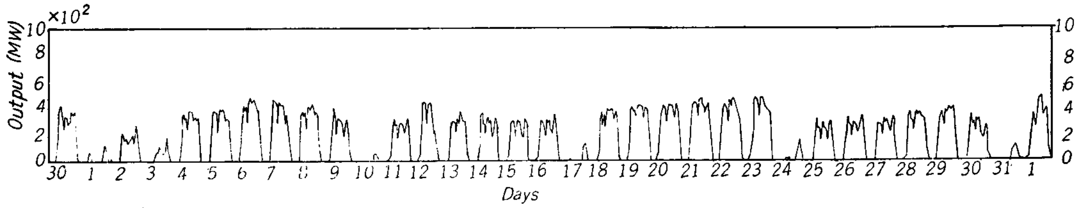
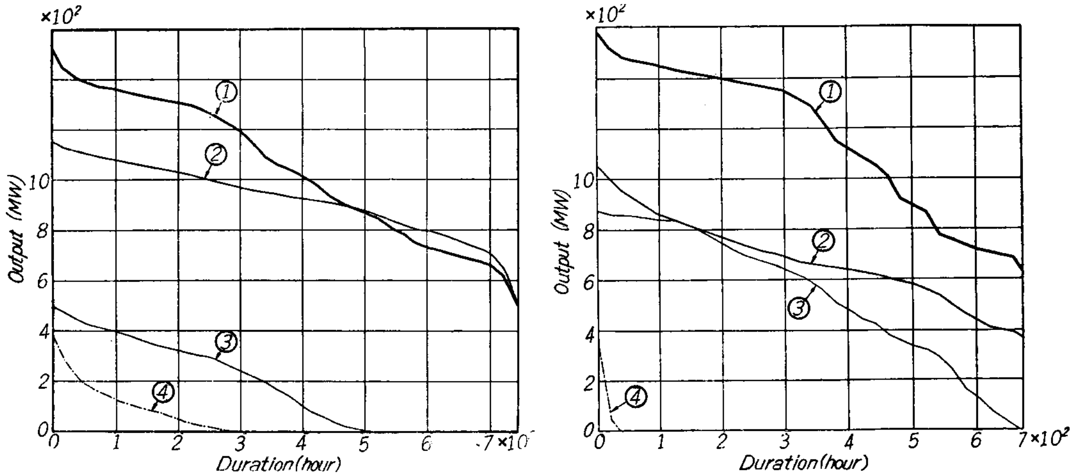


Fig. 2-(b). Daily load curve of the steam-power in a system (February)



(May) (February)

Fig. 3. Monthly duration curves of a system

①: total load demand ③: steam-power
②: hydro-power ④: excess hydro-power

for every hour of the past two years to represent the project power. Next, we have chosen one of the existing run-off-river hydro-plants in this system to stand for the newly planned hydro-plant, in which we are supposed to set up from one to five generators, of 25 MW capacity each, using the daily average stream flow of the past two years. The solid line in Fig. 4 shows the relation between the stream flow and the power output.

Fig. 5 shows the vertical distance between the monthly duration curves of the project power and the residual load, the base part of the project power, as remarked above, being shared by the run-off-river hydro-power; and Fig. 6 shows the annual duration curves of the project power and the residual load. Due to lack of space, only the duration curves for May (one of the wet months) and for February (one of the dry months) are here represented.

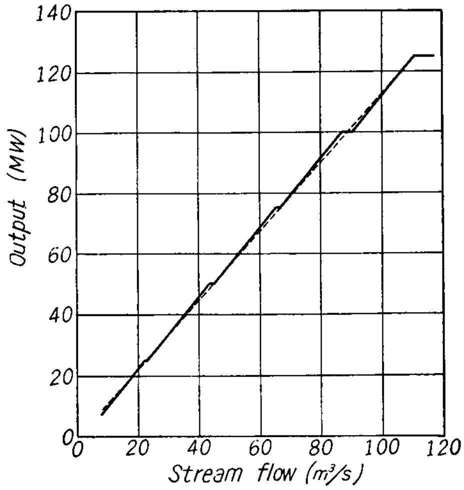


Fig. 4. Stream flow—power output

Note —: daily stream flow—daily power output
…: monthly average available stream flow—monthly average available power output

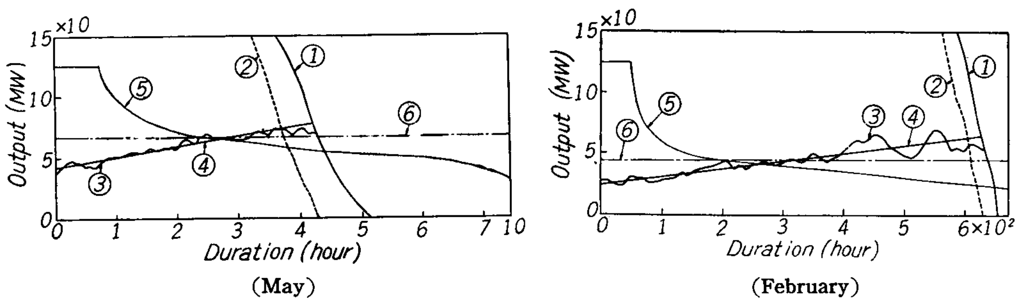


Fig. 5. Vertical distance between the monthly duration curve of the project power and that of the residual load after the completion of a run-off-river hydro-plant

①: duration curve of the project power
②: duration curve of the residual load
③: vertical distance between the above two duration curves
④: straight line equivalent to curve ③
⑤: duration curve of the available hydro-power
⑥: monthly average available hydro-power

As is evident from this, the vertical distance between the above two duration curves for any month can be in this instance approximated for practical purposes by a straight line. Since the project power means by definition the total load of a system minus the load shared by the existing hydro-plants, the output of

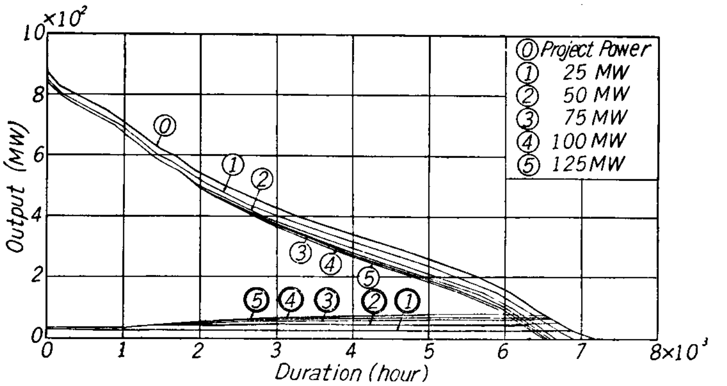
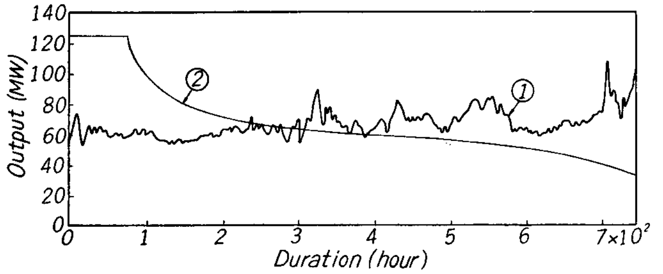
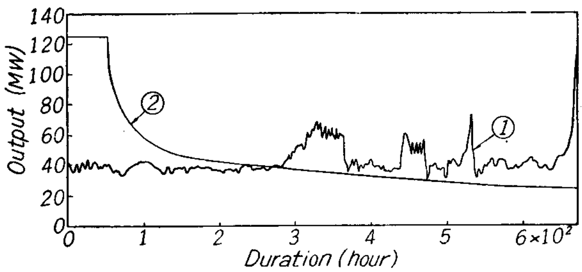


Fig. 6. Annual duration curves of the total load of a system and the residual load after the completion of a newly projected run-off-river hydro-power
(0): vertical distance between (0) and (1)~(5) respectively

the steam-plants of a system tends to decrease on days when the available power of the hydro-plants is great, and on the other hand to increase when it is small, so that the vertical distance between the duration curves of the project power and the residual load after the completion of a new run-off-river hydro-power is



(May)



(February)

Fig. 7. Vertical distance between the monthly duration curve of the total load of a system and that of the residual load after the completion of a run-off-river hydro-power
(1): vertical distance, mentioned above
(2): duration curve of the available hydro-power

likely to show a rising gradient for the right hand side in Fig. 5.

The degree of the rising gradient decreases in proportion as:

a) The capacity of the new run-off-river hydro-plant decreases, approaching the horizontal line which represents the monthly average available power, and finally converging to the capacity of 25 MW, which is identified with the minimum flow of the plant in this case.

b) The variation of the stream flow (i.e. the available power) through a month is small.

c) The steam-power overweights the hydro power in a system.

Fig. 7 shows the result obtained by applying the run-off-river hydro-power to the total load of the system and calculating by the same method. The vertical distance between the two duration curves is generally levelled.

It follows that, in order to obtain the residual load duration curve of the project power after the completion of a run-off-river hydro-plant for the monthly duration curve of the project power in the future year, we have only to know the area enclosed within this equivalent straight line and its maximum height, namely the generated energy and apparent maximum output of this run-off-river hydro-plant.

1) *The Generated Energy of a Run-off-River Hydro-Plant*

We define

$$\text{Monthly utility factor} = \frac{\text{Monthly generated energy}}{\text{Monthly available energy}}$$

Then, employing the data of the hourly load of the steam-power of a system and the daily average available power at one of the run-off-river hydro-plants of the system as mentioned above, we can obtain the relation of the monthly utility factor and the monthly load factor of this run-off-river hydro-plant as shown in Fig. 8.

The monthly load factor in this instance is that of the load intercepted by the horizontal line drawn at a distance equal to the capacity of the run-off-river hydro-plant from the base-line of the monthly duration curve of the steam-power of the system.

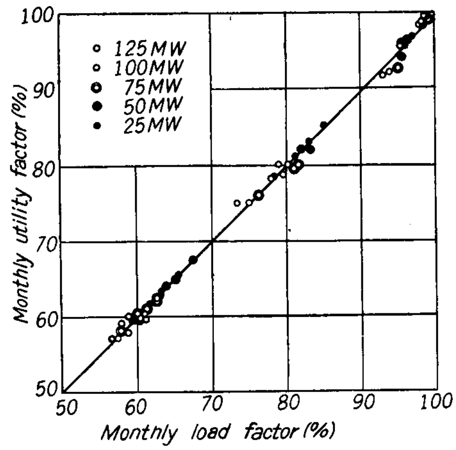


Fig. 8. Utility factor of a newly projected run-off-river hydro-plant

The relationship in Fig. 8 can be represented by a single straight line, irrespective of the capacity and stream flow of the run-off-river hydro-plant, and the load of the steam-power of the system, so long as the monthly load factor of the run-off-river hydro-plant remains constant; and it may be utilized for future years if no large change takes place in the composition of the load demand in this system.

The relation in Fig. 8 is derived from that in Fig. 4 concerning the daily stream flow of the run-off-river hydro-plant. Now, since the hydro-power in the future year in planning will employ the monthly average available power, the relation of the monthly average available power and the monthly average available stream flow as shown in Fig. 9, corresponds with the dotted line of Fig. 4. The relation, therefore, between the monthly average available stream flow and the power of the plant in the future year, can be obtained by drawing a single straight line made up of the relation between daily stream flow and power output.

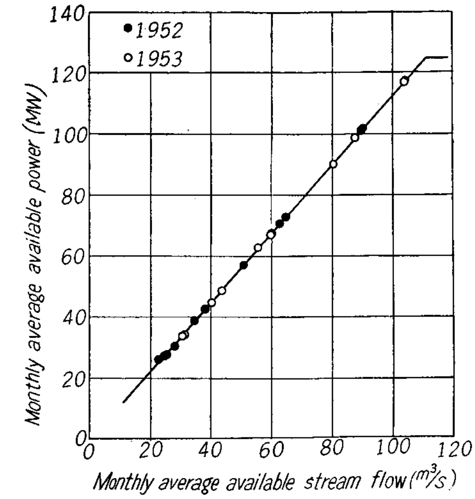


Fig. 9. The relation between the monthly average available power and stream flow

By estimating the monthly duration curve of the project power in the future year from the above result, we can obtain the utility factor for the various capacities of the projected run-off-river hydro-plant and thereby obtain the generated energy.

2) *The Residual Load Duration Curve of the Project Power*

By approximating the vertical distance between the monthly duration curve of the project power and that of the remainder after the completion of the run-off-river hydro-power by an equivalent straight line as shown in Fig. 5, we can represent the relation between the maximum height of the straight line—the apparent maximum output—and the monthly average abailable power of the run-off-river hydro-plant as shown in Fig. 10. It shows cases when the capacity is chosen as 125, 100, 75 and 50 MW respectively, all represented by the same curve.

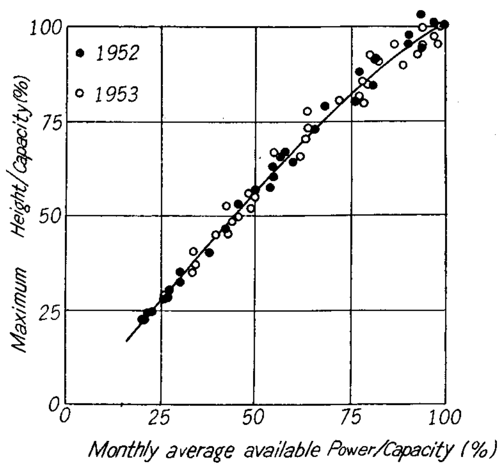


Fig. 10. Maximum height of the equivalent straight line

Since the relation in Fig. 10 can

be shown by a single curve irrespective of the capacity and stream flow of the run-off-river hydro-plant and the total load of the system, so long as the monthly average available power remains constant, it may be utilized for future years if no great change takes place in the composition of the load demand in this system.

It is possible, therefore, to find the maximum height of the straight line in Fig. 5, knowing the monthly average available power for the various capacities of the projected run-off-river hydro-plant, to draw the equivalent straight line in Fig. 5 from the value of the generated energy obtained from Fig. 8, and then to obtain the residual load duration curve of the project power after the completion of the projected run-off-river hydro-plant from the vertical distance between the above straight line and the monthly duration curve of the project power in the future year.

The dotted straight line in Fig. 4 is employed in obtaining the monthly average available power from the stream flow of a run-off-river hydro-plant.

The above method, which represents the vertical distance between the monthly duration curve of the project power and that of the remainder by an equivalent straight line, after the completion of the newly planned run-off-river hydro-plant, is not exempt from some error if examined for monthly details, but the graph is in good accord with the actual data if added up through the year as shown in Fig. 11, in which, however, the vertical distance between the two duration curves only is shown for conveniences sake.

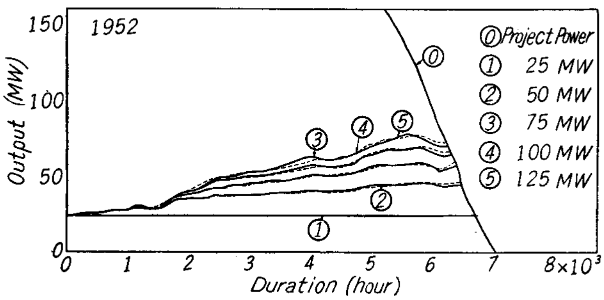


Fig. 11. Vertical distance between the annual duration curve of the project power and the residual load
—: actual data of the vertical distance, mentioned above
…: calculated value of the above

Further, as is evident from Fig. 5, the generated energy of the steam-power of the system is only decreased by the newly planned run-off-river hydro-power even if its capacity is chosen larger than its minimum flow, so that it would seem that it did not make full use of the capacity in its subtracted residual load, as may be clearly seen by comparing ⑤ representing the load duration curve of the hydro-power itself with ③ representing the vertical distance between the two duration curves.

3. Conclusion

In a large combined hydro-steam power system, the residual load duration curve of the project power after the completion of a newly planned run-off-river hydro-plant can be easily obtained by finding the load factor of the newly planned run-off-river hydro-plant as against the project power of the system together with its monthly average available power.

The above results, which have been obtained in this paper by employing the daily load curve of the steam-power of a system for the past two years and the daily average available power of one of the run-off-river hydro-plants in the same year, hold true irrespective of the capacity and stream flow of the run-off-river hydro-plant and the total load of the system, and so are inferred to be applicable to the future years so long as no great change takes place in the composition of the load demand in this system.

When a newly planned run-off-river hydro-plant is built in a large combined hydro-steam power system, it only diminishes the generated energy of the steam-power and seems not to make full use of its capacity even if its capacity is chosen larger than the minimum flow.

References

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2) T. Okubo, H. Nishihara, T. Soma: Trans. of J. S. C. A. No. 61, extra 3-1 (1959) (in Japanese).