A Study on the Optimum Control of stair Step Hydropower Plant by the Considering Operation Characteristics of Turbine

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0.ABSTRACT

Long - term optimal control of hydroelectric power plants plays an important role in improving the utilization efficiency of the water resource, but it is not elaborate to calculate the calculation results of the optimization model by using the established output power.

Speaking of this problem, in general, the hydraulic turbine efficiency in the total efficiency of hydroelectric power plants depends on the power generation head and power.

Changes in the generation head during the mid-long-term operation of hydroelectric power plants lead to changes in the efficiency of the turbines.

The relationship between power generation head - output and efficiency is show in the overall operating characteristic curve of the turbines.

However, considering the calculation methods so far, it is consider that the average output power is use in the mid - to long - term optimal control of the stepped hydroelectric power plant and the calculation is not detailed and the operation characteristics of the turbines are not considered.

In this case, the total operating characteristic curve of the turbine is use to obtain the change of the turbine efficiency according to the change of the generation water head of the long-term optimum control process of the hydroelectric power plant, and the output of the power plant is obtained based in theory.

As shown in the long series calculation of the stair Step hydroelectric power station of Chong-chon River, the relative error of the between this method and multi - year average generation amount of stationary side method is 2.7%, which is more suitable for production practice.

Therefore, this method has a relatively good reference effect on the development of mid - and long - term subdivision management of stepped hydroelectric power plants.

Keywords: hydroelectric power station, segmentation management, total operation characteristic curve of turbines, Medium and long-term optimal adjustment

1. Introduction

Output calculations in hydropower operation control is the one of important tasks, and water energy calculations in the calculation of actual optimum of hydropower controls is required further refinement

The determination of the total output coefficient is very important in relation to the accuracy of the water energy calculation.

Currently, there is a way to take the output coefficient K as a constant in calculating the power output of the hydroelectric power plant. This does not take into account the operational characteristics of the expectation and the actual condition of the hydroelectric power plant, so it cannot actually reflect the complex nonlinear characteristics of water energy calculation.

If the output power can be converting to a constant value, the dynamic value reflected in each power plant decision variable is important for improving the hydro power plant best control study.

The literature [1] obtained the output number by the using the digitization process of efficiency curve of the hydraulic turbine, and easily realize the coding; the calculation accuracy is relatively good.

The literature [2] calculated the total output power of each month as result of actual operation of a hydroelectric power plant in 2005, the relative error between the maximum value and the minimum value was 2.25, and the error was large and not accurate under the condition use of fixed value of K

At the same time, the literature was studied concepts such as every hour output coefficient and daily average output coefficient.

Literature [3] analyzes the influence factor of the expected output power as an example for a certain time, and establishes a linear relationship between the output power K and the power factor k.

As the results of the calculations show, comparing the formula using the output coefficient change and the single coefficient method is more applicable to the evolution of the optimum control process of middle-short time.

Since the selection method of the output coefficient number K is unreasonable in the calculation of the reduction rate of the water energy reuse in the literature [4], the K value distribution method is proposed, and the result is applied to the calculation of the increase of generation amount by the water control.

It shows that this method is very reasonable and valid.

Using the statistical method, Literature [5] establishes short-term output coefficient of hydroelectric power plant and simulates the model, and it is found that the number of the dynamic output coefficient is more accurate and conforms to the practice.

Literature [6] takes the reservoir level and power generation (or output) as the primary influencing factors through analysis of the influential factor of output coefficient, and then uses the optimum internal load optimum distribution model to obtain the relation of output- reservoir water level- final output coefficient , and then applied the optimal control mathematical model for the long term power plant development.

As like this, the preceding researchers have developed research related to changing the output coefficient, but the influence factor considering the output coefficient is not complete.

At the same time, while considering the actual operating conditions of the power plants, they did not consider the stepped hydroelectric power plants operated by each other different hydraulic turbines.

Therefore, in this study, based on a comprehensive study on the total operating characteristic curves of the various turbines of the actual running stair step hydroelectric power plants, it is three-dimensionally digitized and applied to the long-term optimum control of the stair step hydroelectric power plant.

First, the power generation head is calculated based on the upstream water level and the downstream water level given during the calculation, and then the generation flow amount is calculated by using the water balance equation.

Next, the output is calculated by using the average output power coefficient and the water energy calculation formula, and then the efficiency of the turbine is calculated again in the water head-output-efficiency relation curve (turbine operating characteristic curve) and the general output power coefficient K is Induce on the contrary direction.

Finally, it is applied to a long-term power generation control model of a hydro-power plant of a stepped hydroelectric power plant, and the result is compared with a calculation result in which the output side is a constant.

1. Write of Total three-dimensional operation characteristic curve of turbine

Two main power indicators, a guaranteed output and a multi-year average power generation measure the effectiveness of a hydropower plant.

The most important primary task of water energy calculation is to calculate these two hydroelectric power indexes. The output calculation formula of hydraulic power plant output is as follows.

$$N = KQH \qquad (1)$$

Where:

N - hydroelectric power plant output , kW; K - power plant output coefficient; Q - Hydropower generation flow rate, m3 / s; H - generating head, m

K represents the efficiency with which the potential energy is converted to electrical energy as a total coefficient. Potential energy is affected by conversion characteristics such as expected characteristics (hydraulic turbine and generator efficiency), irrigation system location, pipeline characteristics, watertight conditions, load sharing factors between plant internal expectations, and corresponding energy loss exists[7, 8].

Expected Efficiency the number of sides, output, and head are related, and there is a relationship between head and reservoir level and generation flow.

From equation (1), we can know that there is a monotonically increasing relationship (linear relationship) between the output and the amount of generated flow.

Next, considering the total operating characteristic curve of the turbine, it can be seen that the efficiency of the turbine is related to the power generation water head and output, and the following function relation can be established between the output coefficient K and the reservoir water level and output.

$$K = f(Z, N) \qquad (2)$$

Output coefficient k also related with a way to operate the in the operation type of the hydropower plant (day, month or month).

This problem is relatively complicated and difficult to solve in one aspect.

Because the output coefficient is change with the reservoir water level and the flow rate of the generator, if the effect is considered, the fixed output side number cannot be used.

Then, we can know that there is a certain rationality and accuracy problem in the results of the middle-long term optimal adjustment calculation.

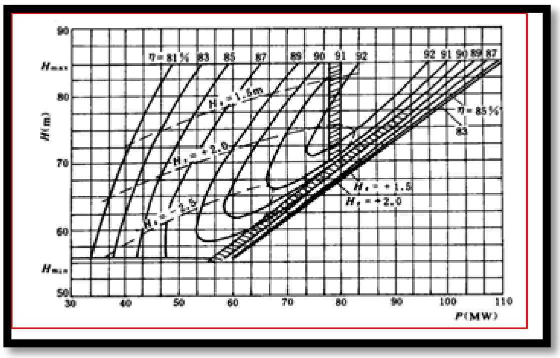

Figure1. Total operating characteristic curve of turbines

Considering the operating characteristic curve of the turbine, the efficiency of the turbine is related to the power water head and the output, where the output is the decision variable amount.

Therefore, it is necessary to iteratively calculating the efficiency of the turbine according to the change of the power head and the output, and the specific solution method is as follows.

First, gain generation water head H by the base on the reservoir up flow water head and down flow water head according to the time-stage, as the same time solve generation flow amount Q

Next, the output N * is calculated by using the average output power and the hydropower plant power calculation formula, and the turbine efficiency is obtained again from the operating characteristic curve of the turbine.

Then must again Calculate the output coefficient K and recalculate the output N 'of the plant.

If the accuracy requirement is satisfied between N * and N ', repeat calculation is performed by stopping the calculation and otherwise again obtaining the efficiency of the turbine.

Output coefficient K equation is as follows.

$$K = 9.81\eta_1\eta_2\eta_3 \qquad (3)$$

Where η_1 is the generator efficiency, η_2 is the turbine efficiency, and $\eta_3$is the transformer efficiency.

The efficiency of the generator and the efficiency of the transformer are assumed to be constant when given device.

When using the operating characteristic curve of a turbine, it is easy to obtain the value to be obtained when it is placed on the curve, but in general, it is often placed between the two curves.

In this case, we have to find a value between two curves. Since the efficiency of the turbine is related to the two factors (equation (2)), it is inconvenient to use the operating characteristic curve as it is.

Therefore, the operating characteristic curve is use in three dimensions. First, an operating characteristic curve is obtained to obtain coordinates corresponding to the parametric curve, and a digital three-dimensional operating characteristic curve corresponding to various turbine is obtained by interpolating the nodal points there between.

2. Mid/Long-term Optimal Control Mathematics Model Based on Output coefficient-Order

When the use maximum principle of total power generation effectiveness within the variational control period, the corresponding objective function is as follows [9].

$$E^* = max\left\{\sum_{t=1}^{T}[K(\bar{Z}_t, Q_t)\ Q_t\ H_t\ \Delta T_t^h]\right\} \quad (4)$$

Where:

T-The total time-stage number of control periods;

ΔT_t^h-Length of each time-stage, h;

$\bar{Z}_t$, H_t- The average water head of reservoirs at the time-stage t and the water head of the hydroelectric power plant, m;

Q_t - Flow rate of hydroelectric power generation at the t time-stage, m3 / s

The basic constraints are:

Reservoir water amount balance condition:

$$V_{t+1} = V_t + 3600 \times (I_t - Q_t - q_t)\Delta T_t^h \quad (5)$$

Reservoir Volume Curve Limitations:

$$Z_t = f_{zv}(V_t) \quad (6)$$

Reservoir Limitations:

$$Z_{t+1}^{min} \leq Z_{t+1} \leq Z_{t+1}^{max} \quad (7)$$

Hydropower station water head:

$$H_t = \bar{Z}_t - f_{zq}(Q_t + q_t) = \frac{Z_t + Z_{t+1}}{2} - f_{zq}(Q_t + q_t) \quad (8)$$

Where:

q_t –Abandon flow amount of t, m^3/s; $Z_{t+1}^{min}, Z_{t+1}^{max}$ – The lowest, highest reservoir water level at the end of t, m

In addition, limit conditions such as the expected output of hydroelectric power plant, total power range, maximum through flow ability, limitation of flow rate of total using of reservoir, limitation of initial and binding reservoir water level.

3. Application Examples

The ChongChon river stair type hydroelectric power plant starts from the upper part of ChongChon river in the Pyongan north province and is composed of 13 power plants down the river.

The reservoir has a normal reservoir level of 704m, Flood limit level of reservoir is 695m (June to August), a dead water level of 685m, and an imperfectly regulated reservoir.

The number of equipment's at every power plants is 2 units, the capacity of one equipment is 40 MW, the power plants of rest is 10MW, the capacity of total equipment is 320MW, the guaranteed output is 78MW, and the corresponding generation guarantee rate is 92%.

The hydro-power plant process of ChongChon River is based on power generation, and combines with flood prevention and navigation something like that

3.1 The three-dimensional total operating characteristic curve of the turbine

Based on the data related to the hydro-power station of the ChongChon river, the three-dimension of the overall operating characteristic curve of the hydroelectric power plant is proceeded according to the method described in up.

Figure 3 shows the three-dimensional total operating characteristic curve of the typical turbine obtained from the calculation.

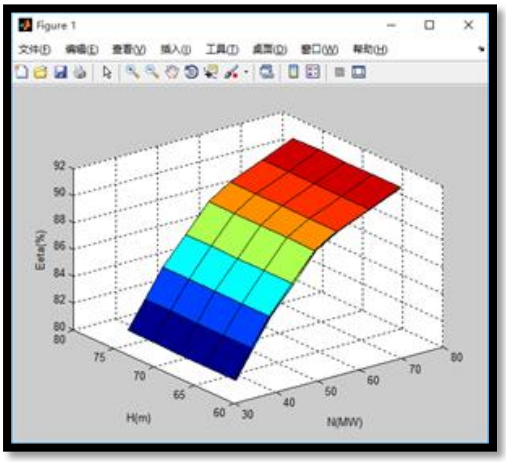

Figure 2. The three-dimensional total operating characteristic curve of the turbine 3.2 Long-term optimal adjustments based on output coefficient change

The flow rate data is used for long - term flow data corresponding to the design year of this reservoir.

The average output coefficient is taken as 8.224 for the normal coefficient used by this power plant and the month is taken as the starting power.

Next, by applying the mid - to long - term optimal control mathematical model and the solution method using DDDP, it is 14.52 billion kWh when the multi - annual average power generation is obtained for the entire power plant.

Using the three-dimensional comprehensive operating characteristic curve of the turbine obtained from the upper side, we can obtain the efficiency of the turbine according to the change of the headwater average reservoir level and can directly calculate the output of the power plant according to the change of output coefficient.

Because of calculation of the long - term optimal mathematical model according to the change of the output side by using the DDDP solution method.

The relative guarantee error rate is 92.3%, the multi - year average generation amount is 14.92 billion kWh, and the relative error with the multi - year average generation amount of the average output coefficient is about 2.7%.

Figure 3 shows the variation curve of the output coefficient.

Figure 3 shows that the output coefficients relatively small in the low season when the average value of the wind speed is relatively high. This shows that the influence of the turbine's overall operating characteristic curve is well reflected.

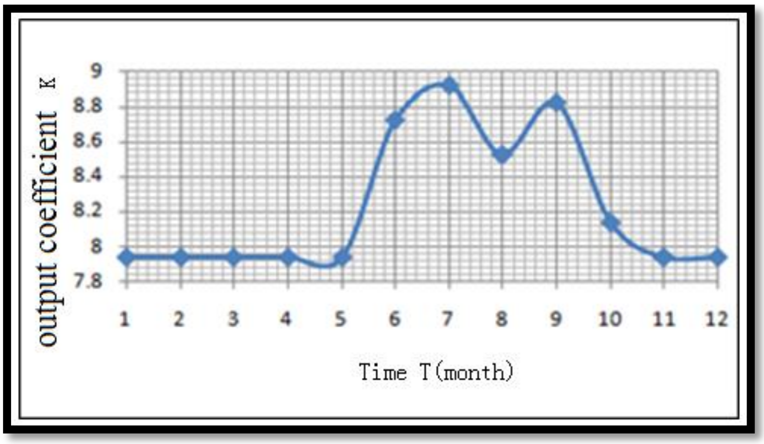

Figure 3. Variation curve of the output coefficient

In order to explain the reasonableness of this method, a relatively small leaking of years (from the beginning of May 1980 to the end of April 1981) and a relatively large of year (from May 1991 to the end of April 1992) And analyzed the hydrological year.

As shown in Table 1, average output is comparative large at this method because the average output coefficient is relatively large even though the average water level is slightly lowered.

Table 1. Comparison table of two methods

Design year	Average headwater (m)		Average output (MW)	
	Average output coefficient method	Coefficient method of Change of output	Average output coefficient method	Coefficient method of Change of output
Year of water shortage	700.6	698.9	10.12	10.45
year of abundant water	701.1	699.5	24.02	24.85

4. Conclusion

In this paper, the total operating characteristic curve of the turbine according to the change of power generation headwater of hydroelectric power plant is three - dimensioned, and the change of the output coefficient order according to the change of the time-satge average water level is obtained, and then applied to the mid - and long - term power optimal adjustment mathematical model.

Because of applying this method to the calculation of the long - term range of hydro - power station in Chong Chon River, the following conclusions were obtained.

① The relative error between the method of this study and the multi-annual average generation of the power output side method is 2.7%.

② The step-by-step hydro-power station best-fit calculation method considering the overall operating characteristics of turbines is more in line with production practice. From this point of view, this method has a very good reference effect on the development of medium and long term subdivision management of hydroelectric power plants.

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