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Research on Ecological Operation of Three Gorges Cascade Hydropower Stations

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Abstract: This study present the general model on the ecology operation of reservoir containing four steps: Finding the points of ecological protection, confirming the ecological variables, searching the ecological relation, standardizing the variables. The study research the ecological operation of three gorges considering the breeding of the Chinese sturgeon, for which we structure a multi-objective programming model. Last, the method of decision-making about the Pareto-solutions to the above model is provided.

Key words: Multi-objective programming, ecology operation model, generating operation, three gorges

INTRODUCTION

The Three Gorges-Gezhouba Hydro-junction Project have brought huge economy and social benefits and changed the allocation of the natural runoff of the downstream in Yangtze River to some degree, but it also leads to the river channelization and discontinuity, even takes negative influence to the ecological environment of the downstream (Yu, 2007). The ecological environment problem bought by the Three Gorges-Gezhouba Project is understood correctly and that we take the effective action so as to achieve the corresponding ecology goal have become an important topic in the reservoir operation studies (Zhu and Chang, 2004).

Ecological factor has been considered as an important role in rivers resources management at abroad long time ago, foreign scholars developed comprehensive and systematic research about the negative impact of reservoir operation on the river ecosystem until the 1970s. Junk proposed the concept of ecology flood pulse. Petts studied the ecology water demand as well as the relations of water biology growth, reproduction and river discharge. Hug studied the reservoir operation model which satisfied the ecology water demand. Since, the 1980s, some scholars have started to study various ecological operation problems such as reservoir operation, survival requirement of fish, concentration of nutrient and air bubble in the water and so on (Yu *et al*., 2005; Dong, 2003), these studies focus on seeking river ecology target, keeping it the natural feature and the lowest ecological water demand. Many scholars home and abroad are considering ecology as an operation goal even studying the problems of various ecology goals as operation goal in recent years (Shiau and Wu, 2007; Yang *et al*., 2013).

Ecology operation theory hasn't consistent definition and the concept of reservoir operation is also ambiguous, the basic research is lagging and independent, the ecology problems considered are so one-sided at present, increasing water is the mainly method of improving the water quality and no biological shield object is explicit, it doesn't start to research the reservoir operation problems from the whole rivers ecosystem.

In present, the multi-objective optimization is often transferred to a single objective optimization, when it emerges on the reservoir operation. So, the relationship among those objectives is seldom analyzed, or says that the relationship isn't quantized. It is due to that the complexity of the reservoir operation with many decision variables and constraint conditions. Many intelligent algorithms validly solving common multi-objective optimization fail to it.

This study will discuss the standard research model after analyzing the relationship chains between reservoir operation and ecology. It will structure a multi-objective programming model for the operation, calculate the model using a modified intelligent algorithm with preprocessing constrains and propose a advised solution after analyzing the value of operational objectives.

STANDARDIZATION OF RESERVOIR ECOLOGICAL OPERATION

The reservoir ecological operation mainly refers to changing flow volumes, controlling water temperature and sediment shift by reasonable technological means. The key problems are what for the appropriate living environment and how to think about this problem when studying reservoir operation. The following questions existed in reservoir operation are clarified in this study.

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- Finding the points of ecological protection. The process of water discharge q(t) of reservoir always (water discharge) influences downstream water discharge and hydrological regime and so as to influence the city ecological environment along the route indirectly. However, the ecological factors affected are multiple and considering all ecological factors from one problem is no possible, so considering to select important ecological factors of part important ecological target points is indispensable, such as considering the downstream ecological water demand, the living environment of freshwater fish of the Three Gorges-Gezhouba and the water level of Yangtze River and so on
- Confirming the ecological variables. Selecting appropriate ecological variables φ is necessary. The selection must satisfy two conditions: a. the change of ecological variables φ can reflect the change of ecological factors commendably. b. The ecological variables φ is influenced by the water discharge q(t) directly or indirectly.
- Searching the ecological relation between the ecological variables and the ecological points $q_i(t) = \varphi_i(q_i(t), Z_i(t))$, where are the i-th ecological variables, water discharge and water level, respectively. The hydrology characteristic of ecological target points influences the ecology variables directly but the hydrology characteristic of ecological target points relates with the process of water discharge directly. So, establishing the relations between the ecological variables and the hydrology characteristic is indispensable, so the ecological problems can reflect to hydrology problems
- The relations between water discharge process and the hydrology characteristic of downstream ecology target point $q_i(t) = \xi(q(t))$
- Formulating ecological standard

The ecological standard here refers to the goal or condition that the ecological quantity must satisfy in the ecological target point. That is $\varphi_i(t)\in\Phi_i$, where Φ_i is the condition of the ecological variables $\varphi_i(t)$ in the i-th ecological target point. For example, $\varphi_i(t)$ is the content of some mineral substance, $\varphi_i(t)\in\Phi_i$ is the scope of this mineral substance; $\varphi_i(t)$ is the flood process or the water temperature change process that some water-based creatures needs where it lives, $\varphi_i(t)\in\Phi_i$ is the ideal target-the flood process of the ecological point coincides with ideal process completely.

ECOLOGICAL OPERATION MODEL OF THE THREE GORGES-GEZHOUBA

Question descriptions: The Three Gorges stave power plant includes the Three Gorges hydroelectric hydropower station and the Gezhouba hydropower station, it is the typical large-scale stave hydro-junction project on the Yangtze River and it has many combined revenues such as flood prevention, electricity generation, navigation and so on. The total installed capacity of the hydropower station is 18200 MW and there are 26 equipments installed and the single rated power is 700 MW. the Gezhouba Hydro-junction has the function of electricity generation, shipping and so on, its total installed capacity is 271.5 MW with 21 equipments and the single rated power is 125MW. The water in the Three Gorges power station enters the Gezhouba Reservoir directly because of the short distance of 28km between them, the water waves disseminate quickly in the Gezhouba reservoir and change the water level in 30 min, the two Hydro-junction projects is a whole because there is only a small adjustment storage capacity of 1.86×107 m^3 between them. The system parameters of the Three Gorges-Gezhouba power station are as following Table 1.

Operation model: The Three Gorges stave power plant includes the Three Gorges hydroelectric hydropower station and the Gezhouba hydropower station; it is the typical large-scale stave hydro-junction project on the Yangtze River.

Goal of power generation: In the non-flood season, the primary mission of the Three Gorges-Gezhouba hydroelectric power station is generating electricity, the max power rate is selected here as the goal:

$$\max E = \sum_{t=1}^{T}\sum_{i=1}^{2}\overline{P}_i(t)\Delta T_t \quad (1)$$

$\overline{P}_i(t)$ is the average power output in the ith reservoir during period ΔT_t, ΔT_t is the smallest time interval, E is the total power generation at operation time:

Table 1: Parameters of the three gorges-gezhouba power station

Parameters	Three Gorges power plant	Gezhouba power plant
Discharge range (m^3s^{-1})	[1580,98800]	[3200,86000]
Water level of downstream (m)	[63.00,71.80]	[38.00,58.63]
Power coefficient	8.5	8.4
Range upstream water level (m)	[145,175]	[63,65.5]
Range of the power coefficient (107 W)	[0,1820.0]	[0,271.5]
Rising water level (m)	155.0	64.5

$$\overline{P}_i(t) = \int_{\Delta T_t} k_i \overline{H}_i(t) q_i(t) dt \Big/ \Delta T_t = k_i \overline{H}_i(t) \overline{q}_i(t)$$

$H_i(t)$ is the flood peak in the ith reservoir during period ΔT_t, k_i is the power coefficient.

Ecological objective: The construction of the Three Gorges-Gezhouba has brought tremendous influence to ecological environment of middle and lower Yangtze River, for instance, October and November is egg reproduction of Chinese sturgeon as well as the storage time of the Three Gorges reservoir, it will bring negative influence for the spawning and reproduction of the Chinese sturgeon and four major Chinese carps (Guo and Xia, 2009), how to realize the ecology target of protecting the spawning and reproduction of the Chinese sturgeon in the electricity generation operation in non-flood season is studied in this study.

The ecological target of guaranteeing the normal spawning and reproduction of the fish in the Yangtze River is considered as the main ecological target when Carrying on the daily optimization operation for this month: the downstream of The Gezhouba section in Yichang must supply suitable hydrology condition for the spawning and reproduction of the Chinese sturgeon in November (Guo and Xia, 2009). The ecological target is manifested through the hydrology characteristic here, so the hydrology quantity is selected as ecological quantity directly, the ecological standard is shown in Table 2.

The discharge process of Gezhouba can be seen as the process of Yichang dam because of the short distance from Gezhouba to Yichang Dam, this simplifies the research the process of the water discharge of the reservoir and the relation link of hydrology characteristic at ecological target point. There are four hydrology constraints (ecological standard):

$$e_k^{min} \le e_k(t) \le e_k^{max}, k = 1, 2, \cdots, 4 \tag{2}$$

$e_k(t)$ is the ecological variable, e_k^{min}, e^k_{max} are the maximum and minimum ecological constraint. Therefore, the ecological target can be seen that the distance from ecological variable to the ecological standard is zero.

The ecological constraint can be targeted in order to study the relations between the ecological target and economic target, namely the ecological standard deviation distance from ecological variable to the ecological standard can be minimized:

$$dev_k(t) = \frac{|e_k(t) - e_k^{min}| + |e_k(t) - e_k^{max}|}{2(e_k^{max} - e_k^{min})} - \frac{1}{2}$$

$$= \begin{cases} \dfrac{e_k(t) - e_k^{max}}{e_k^{max} - e_k^{min}}, & e_k(t) > e_k^{max} \\ \dfrac{e_k^{min} - e_k(t)}{e_k^{max} - e_k^{min}}, & e_k(t) < e_k^{min} \end{cases} \tag{3}$$

The following synthesis ecological deviation can be constructed in the Eq. 3:

$$\varphi = \frac{1}{T\sum_{j=1}^{N} n_j} \sum_{j=3}^{N} \sum_{k=1}^{n_j} \sum_{t=1}^{T} dev_{j,k}(t) \tag{4}$$

$dev_{j,k}(t)$ is the relative departure value of the jth hydrology observation station and the kth hydrology quantity. It is zero when the hydrology quantity satisfies the ecological target, but of a relative departure value in a mutative section when the hydrology quantity is greater or less than the ecological target.

φ is synthesis relative departure value of ecological standard in every time intervals, it reflects the size of the whole departure value and is always above zero. When the value is zero, it indicates to satisfy all ecological targets and reach ecological operation target; when the value is above zero, it indicates some ecological targets are not satisfied and the value weights deviation degree. So, we synthesis ecological standard and the whole departure value are constructed to be smallest:

$$\min \varphi \tag{5}$$

Constraints: The constraint condition can be obtained from Table 1:

- The water level constraint before the dam $Z_i^{min} \le Z_i(t) \le Z_i^{max}$, $Z_i(0) = Z^0_i$, $Z_i(T) = Z^T_i$
- The discharge and the output constraint of the hydroelectric power station $q_i^{min} \le \overline{q}_i(t) \le q_i^{max}$, $P_i^{min} \le P_i(t) P_i^{max}$
- $\overline{Z_i^{tail}}(t)$ is the average tail water level, $f_i^{Za}(.)$ is the relation of downstream water discharge, $Z_i(t)$, $V_i(t)$ are the ith water level and reservoir capacity, $\overline{Q}_i(t)$, $\overline{q}_i(t)$, $P_i(t)$, $\overline{H}_i(t)$ the in-flow, the out-flow and the boundary of the net water-head

Table 2: Ecological standard for the Chinese sturgeon

Ecological quantity	Ecological standard
Discharge (m^3s^{-1})	[8064,11470]
Water level (m)	[40.57,42.97]
Flow recession rate ($m^3s^{-1}d^{-1}$)	[105,253]
Water level recession rate ($m\ d^{-1}$)	[0.04,0.10]

- Z_i^{min} and Z_i^{max}, q_i^{min} and q_i^{max}, P_i^{min} and P_i^{max}, H_i^{min} and H_i^{max} respectively present the water level before dam, discharging downstream flow, the output, the boundary of the net water-head

Multi-objective optimization problem (MOP): Here, briefly introduces the multi-objective optimization problem and the algorithm used in the above model.

An MOP can be formally defined as the problem of finding all $(x_1, x_2,\ldots, x_n)^T$ which satisfy the m inequality constraints, $g_i(x)\leq 0$, i = 1,..., I and simultaneously optimizing the vector $\max(f_1(x), f_2(x),\ldots, f_m(x))$.

The aim is to determine the decision variables $x_i(i = 1,\ldots, n)$ in the decision space D which satisfy the m constraints and optimize the objective vector $(f_1(x), f_2(x),\ldots, f_m(x))$. The constraints define the feasible region and any vector $(x_1, x_2,\ldots, x_n)^T$ in the feasible region is called a feasible solution.

The definition about the optimal solution of MOP is different from as in the single objective problem (Deb, 2001). When the amount about the constraints is very large, the feasible region may be so unusual that the intelligent algorithms can find the feasible solution hardly using the usual dominance definition.

In the past few decades there has been a significant rise in the application of Intelligent Algorithms (IA) for solving multi-objective optimization problems. In the current study, our work has been concentrated on Differential Evolution for solving different MOP (Adeyemo and Otieno, 2009; Ergul and Eminoglu, 2014).

Analysis and solution of the model: According to above analysis, the model is a multi-objective optimization model constructed by maximum power generation of the target 1 and the minimizing deviation of the ecological target 5 and contains many constraint conditions such as water level, discharge and so on.

The optimal solution of the single objective optimization means that there is no other better optimal solution to optimize the problem, there exist many optimal solutions because of many targets exist at the same time and these values have no comparability in the natural preference. The corresponding point sets of these optimal solutions in the target space is looked upon on non-inferior frontier surface generally; the first task about multi-objective optimization problems is how to find out the natural non-inferior frontier surface and the corresponding non-inferior solution

According to only two targets in the model, it is hard to simplify the corresponding non-inferior frontier in the target space with a lot of non-inferior solution, so, the other principles are needed to be built and in order to get further chose, so as to add other preferences relationship and the list of each point of non-inferior frontier in the preference. Some new solution can be eliminated and new preference can be continue to increased if the quantity is still excessive, so a series of optimal solutions in the new preference and the nature preference can be obtained, but the difficulty of the target decision are as following:

- How is the non-inferior frontier effectively in the nature preference found out?
- Which relationship of the new preference should to be built to satisfy the decision maker's real preferences?

The improved and dominant non-inferior classification genetic algorithm is used to calculate the optimal generating capacity based on the characteristics of the model, the minimum ecological deviation constitutes the non-inferior solution sets.

The decision variable is outbound discharge of 30 days $q_i(t)$ and there are 60 in total, search through coding the 60 variables and picking out 20 group model and 100 as the largest iteration times, so there are 20 discharge processes produced, Scatterplot Fig. 1 describes the relationship about comprehensive deviation (CED) and Total Power Generation (TPG) of optimal solutions constituting then on-inferior frontier and the corresponding figures are listed in Table 3.

There is no difference at 1-10 points as shown in Fig. 1, it needs to set up other preferences and select the point again in the non-inferior frontier in the new preference.

Table 3: Target value of each solution

Mark No.	TPG (10^9 Kwh)	CED
1	5.3929	0.362602
2	5.3996	0.363083
3	5.4096	0.364094
4	5.4190	0.364275
5	5.4291	0.364609
6	5.4347	0.364701
7	5.4419	0.364929
8	5.4515	0.365636
9	5.4565	0.382525
10	5.4577	0.386529

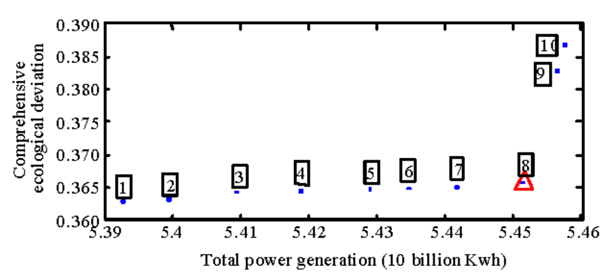

Fig. 1: Scatterplot about comprehensive ecological deviation and total power generation

Table 4: Corresponding value of each $\Delta\varphi/\Delta E$

No.	1	2	3	4	5	6	7	8	9	10
$\Delta\varphi/\Delta E$	0.072	0.101	0.019	0.033	0.016	0.032	0.074	3.378	3.337	NAN

As shown in Fig. 1, the total ecological deviation always increases when the cascade operation Power generation increases, the ecological deviation increases quickly when the generating capacity increases to some quantity, so we can get the conclusion that the power generation hydropower station target and ecological goals are contradictory and restraint, power benefit will increase when the ecological goals reduces, but it needs to dramatically reduce ecological goals to bring power benefit small increase when the power benefit increase to some extent. The balance relationship of the two targets can be measured through the increase of the deviation $\Delta\varphi/\Delta E$ brought by the increase of the unit capacity, namely slewing rate which reflects the decision maker's preferences, so each $\Delta\varphi/\Delta R$ is listed to provide reference to decision makers (Table 4).

It can be found from Table 1 and 2 (1) Power generation is approximately step to increase from scheme 1-10 gradually, (2) $\Delta\varphi/\Delta E$ of each solution is less than 0.2, selecting followed scheme can ensure to bring in certain power generation benefit with less ecological damage, so the scheme 8 is more outstanding than the scheme 1-7 and its value of $\Delta\varphi/\Delta E$ is 3.378, there has huge damage if more power generation benefit is brought based on the scheme 8 compared with previous schemes, so the scheme 8 is best scheme among the 10 schemes from the point of view of avoiding ecological destruction, the choice of the original optimal solution in this preference is the scheme 8.

CONCLUSION

This article analyzed the reservoir is how to affect the downstream ecological environment and proposed several important steps about reservoir ecology operation according to this study: Delimiting ecological target, choosing ecological quantity, seeking for the relations of hydrology characteristic about the ecology quantity and ecological target points. The general pattern of the ecological operation of the reservoir is given in the study.

This article also considered that the factor of the spawning of the Chinese sturgeon, see the ecological restraint as the target and established multi-objective ecology operation model against the problem of the short-term optimization in the Three Gorges stave reservoir non-flood season, many groups of power rate-ecology deviation balance solutions are calculated by the superior NSGA-II method based on the restraint, each optimal solution is selected again based on the slewing rate of the ecology deviation-generated energy and the optimal operation scheme is obtained, it provides a new mentality of formulating the multi-objective ecological operation scheme for the cascade reservoir.

However, the general pattern of the ecological operation needs to be detailed from real factors and relation function. Additionally, the method about the second selection for Pareto solutions is needed to be rationalized.

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