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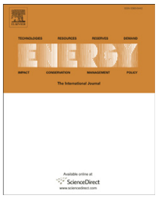

An improved risk-benefit collaborative grey target decision model and its application in the decision making of load adjustment schemes

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ABSTRACT

Power generation plan formulated based on the forecasted runoff is an important basis for the actual operation of hydropower station. However, due to the forecast error, the load adjustment is necessary in the actual operation, and how to find out the most satisfactory load adjustment scheme from the scheme set is an important topic. So, in order to comprehensively reflect the risk and benefit state of hydropower station operation, a risk-benefit collaborative evaluating indicator system of load adjustment scheme is established firstly in this paper, and aim at the strong subjectivity of present evaluation methods, an improved grey target decision model based on moment estimation method is proposed, and the combinatorial weight integration technology and the Mahalanobis distance are coupled in this model. Taking the cascade hydropower stations of Yalong River in China as an instance, six schemes are evaluated by the proposed model, and the results are compared and analyzed with another six evaluation models. Results show that the proposed model can effectively coordinate different weighting methods and overcome the shortcomings of traditional grey target decision model about the insufficient consideration on the importance and correlation of evaluating indicators, and it has a good value of popularization and application.

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1. Introduction

The power generation plan is an important basis for the practical operation of hydropower station, which is usually formulated based on the results of short-term runoff forecasting, and the plan is generally assigned to the water sector one day in advance by power sector. Considering the safety and stability of power grid operation, the change of the predetermined power generation plan in the actual operation usually not allowed by the power sector, but beset by the unavoidable uncertainties of runoff and forecast models [1], the operation water level of reservoir may break through the feasible range at some time [2]. So, there is the actual situation to adjust the predetermined power generation plan by the water sector to ensure the safe operation of reservoir and improve the utilization efficiency of water resources [3], and this process is commonly referred to as “load adjustment” [4]. The process of load adjustment is simply shown in Fig. 1.

Load adjustment is one of the problems urgently to be solved in the later period of development and utilization of water resources [5], its purpose is to effectively solve the problem of output shortage or water abandonment of hydropower stations caused by the uncertainty of runoff forecast, and improve the utilization efficiency of water resources on the premise of ensuring the safe and stable operation of power grid. However, with the difference of the starting time and the amplitude of load adjustment, many feasible load adjustment schemes (non-inferior set) can be generated within the feasible domain. So, how to find out the most satisfactory scheme is the important and necessary research content after the load adjustment scheme set established.

Due to the change of the predetermined power generation plan, the load adjustment scheme may bring a certain impact on the safe and stable operation of the power grid. Therefore, the security of the selected scheme is the primary concern of the decision-makers, of course, the economy needs to be considered too, which is the initial purpose of load adjustment [6]. There are differences on the security and economy for different load adjustment schemes, and the scheme selection is essentially a multi-attribute decision-making problem [7]. The indicator evaluation method is an

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Nomenclature

Parameters

A	the number of subjective weighting methods
B	the number of objective weighting methods
C	electricity price
G	the total number of discretized forecast error points
M	the total number of the runoff processes
Num	the total number of evaluating indicators
n	the number of hydropower stations in the cascade system
S	the total number of load adjustment schemes
T	the number of stages over the whole operation period
T^*	the number of stages in which the adjusted output process is inconsistent with the planned output process in the load adjustment scheme
x_1	non-consistency rate of output process
x_2	deviation rate of total power generation
x_3	risk rate of water level exceeding the limits
x_4	risk rate of output shortage
x_5	risk opportunity loss
x_6	benefit evaluating indicator of the load adjustment scheme
$Z_{i,t}^{\max}$	the upper limit of $Z_{i,t}$
$Z_{i,t}^{\min}$	the lower limit of $Z_{i,t}$
ρ	water consumption rate of the hydropower station, which indicates the amount of water needed for the production of 1 kWh electricity

Variables

D	decision matrix obtained by the normalization of J, where $D = (d_{sk} \| 1 \le s \le S, 1 \le k \le Num)$
E'	the actual total power generation
E	the planned power generation
EL_{1s}	the expected value of opportunity loss of abandoning water in scheme y_s
EL_{2s}	the expected value of opportunity loss of output shortage in scheme y_s
e	a discretized value of error
$f(\cdot)$	probability density function of forecast error
$\boldsymbol{j_s}$	attribute vector of the sth scheme y_s, where $\boldsymbol{j_s} = (j_{s1}, j_{s2}, \ldots, j_{sNum})$
$\boldsymbol{J}$	sample matrix, where $\boldsymbol{J} = (\boldsymbol{j_s} \mid 1 \le s \le S)$
L	risk event
$l(1)_{sg}$	opportunity loss of abandoning water
$l(2)_{sg}$	opportunity loss of output shortage
$N^*(t)$	the adjusted output process
$N(t)$	the planned output process
$N'(t)$	the actual output process
$N'_{i,t}$	the actual output of the ith hydropower station in the tth stage
$N^*_{i,t}$	the adjusted output of the ith hydropower station in the tth stage
P_r	probability value of water level exceeding limits
$P_r(\cdot)$	probability of event $(\cdot)$
p_g	the probability when the error is e_g
$Q_{loss}(t)$	the abandoned water flow of load adjustment scheme y_s when the error is e_g
$r^*(y_s, y_o)$	off-target distance of scheme y_s
$r(y_{sk}, y_{ok})$	the kth component coefficient of the sth scheme in calculating $r^*(y_s, y_o)$
r_s	Mahalanobis off-target distance of scheme y_s
t_1	starting time of abandoning water of the reservoir
t_2	ending time of abandoning water of the reservoir
t'_1	starting time of the output shortage
t'_2	ending time of the output shortage
v	the number of stages that the state variable breaks through the predetermined safety threshold in the whole T stages
W_a	set of subjective weights, where $W_a = (w_{ak} \mid 1 \le a \le A, 1 \le k \le Num)$
w_{ak}	weight of the kth evaluating indicator of the ath subjective weight method
W_b	set of objective weights, where $W_b = (w_{bk} \mid 1 \le b \le B, 1 \le k \le Num)$
w_{bk}	weight of the kth evaluating indicator of the bth objective weight method
$\boldsymbol{W}$	combinatorial weight vector of the evaluating indicators, where $\boldsymbol{W} = (w_k \| 1 \le k \le Num)$
w_k	combinatorial weight value of the kth evaluating indicator
$\boldsymbol{X}$	evaluating indicator set, where $\boldsymbol{X} = (x_k \mid 1 \le k \le Num)$
x_k	the kth evaluating indicator
$\boldsymbol{Y}$	scheme set, where $\boldsymbol{Y} = (y_s \mid 1 \le s \le S)$
y_s	the sth scheme
y_o	the ideal optimal scheme, i.e., the bull's-eye
$Z_{i,t}$	water level of the ith reservoir in the tth stage
α	coefficient of relative importance for the subjective weight
β	coefficient of relative importance for the objective weight
α_k	subjective weight relative importance coefficient of evaluating indicator x_k
β_k	objective weight relative importance coefficient of evaluating indicator x_k
ε_s^*	the ring number of the grey target (score of grey target)
ΔE	additional power generation

Indices

m	index of the runoff process, $m = 1, 2, \ldots, M$
s	index of load adjustment scheme, $s = 1, 2, \ldots, S$
g	index of the discretized forecast error points, $g = 1, 2, \ldots, G$
k	index of evaluating indicator, $k = 1,2, \ldots, Num$
a	index of subjective weighting methods, $a = 1, 2, \ldots, A$
b	index of objective weighting methods, $b = 1, 2, \ldots, B$

effective way to solve this kind of problems [8], which is first to select the evaluating indicators that can effectively represent the problem, and then establish the evaluation model to evaluate the schemes and make the decision finally [9].

Studies have shown that, risk-benefit evaluation and decision-making have always been a hot and difficult problem in the field of reservoir operation research [10], but there is no evaluating indicator system that aims at the load adjustment has been established [11], so it is necessary to carry out research of this topic based on the present research work. In terms of evaluation models, in addition to the commonly used Analytic Hierarchy Process (AHP) [12], approaching ideal point model [13] and comprehensive

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