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Multi-objective decomposition-coordination for mix-connected hydropower system load distribution

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Abstract

The multi-objective decomposition-coordination method for mix-connected hydropower system load distribution was proposed. Firstly, decomposition-coordination approach was applied to create link and compensation, and three-level structure of decomposition-coordination was adopted to decompose the optimal problem. Secondly, improved entropy approach was developed for calculating load compensation and allocation. According to results of simulative optimal operations premised on several representative hydrographs, joint optimal operation yields indications of superior performance.

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Keywords: load distribution; mix-connected hydropower system; multi-objective decomposition-coordination; improved entropy approach; simulative optimal operations

1. Introduction

There are some limitations in traditional researches [1-3]: Optimization operation of mix-connected hydropower often focuses on long-term operation in order to make each year schedule. In this study, multi-objective decomposition-coordination for mix-connected hydropower system 24h load distribution is presented, and it is applied to hydropower dispatching system in Hubei province.

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Nomenclature

N_{i,t} \quad \text{output of } i^{th} \text{ hydropower station in the } t \text{ period;}

P_{i,t}, \Delta t_{i,t} \quad \text{online power price of } i^{th} \text{ hydropower station in the } t \text{ period, measures the calculate time}

V_{i,t-1}, V_{i,t} \quad \text{the initial and final storage of } i^{th} \text{ hydropower station}

I_{i,t}, Q_{R,i}, Q_{i,d} \quad \text{inflow, local inflow and outflow of } i^{th} \text{ hydropower station}

\alpha_i, \beta_i \quad \text{coefficients describing temporal-spatial variation of flow}

Q_{i,t,min}, Q_{i,t,max} \quad \text{minimum release volume, maximum discharge volume}

Z_{i,t}, Z_{i,t,min}, Z_{i,t,max} \quad \text{operating water level, minimum water level, maximum water level}

N_i, N_{i,t,min}, N_{i,t,max} \quad \text{denote load demand of system, minimum output, maximum output}

m, n \quad \text{sample number of evaluation, index number of evaluation}

H_i, H_k, H_j \quad \text{the entropy of } i^{th} \text{ index number, } k^{th} \text{ one, } l^{th} \text{ one}

\nu_{i,t}, \gamma_{i,t} \quad \text{the entropy weight of } i^{th} \text{ index number, K-T multiplier of output coupling constraint}

\mu_{i,t}, \lambda_{i,t} \quad \text{Lagrange multipliers of water balance equation, close hydraulic coupling constraint}

2. Multi-objective decomposition-coordination for mix-connected hydropower system load distribution

Hubei hydropower dispatching system is a mix-connected hydropower system. Three Gorges cascade are built by order of Three Gorges (TG) and Gezhouba (GZB) hydropower stations from upstream to downstream. Qingjiang cascade are composed by order of Shuibuya (SBY), Geheyan (GHY) and Gaobazhou (GBZ) hydropower stations from upstream to downstream. There are three objective functions of whole system in scheduling period: meeting the load demand of two cascade systems and pursuing maximum power generation benefit of the whole system. The three objective functions:

\begin{equation}
F^1 = \min \sum_{t=1}^{T} \left| \frac{N_{i,t} - \sum_{t=1}^{2} N_{i,t}}{N_{i,t}} \right| \quad (1)
\end{equation}

\begin{equation}
F^2 = \min \sum_{t=1}^{T} \left| \frac{N_{Q,t} - \sum_{t=1}^{2} N_{i,t}}{N_{Q,t}} \right| \quad (2)
\end{equation}

\begin{equation}
F^3 = \max \left( \sum_{t=1}^{2} \sum_{t=1}^{T} P_{i,t} N_{i,t} \Delta t_{i,t} + \sum_{t=2}^{5} \sum_{t=1}^{T} P_{i,t} N_{i,t} \Delta t_{i,t} \right) \quad (3)
\end{equation}

Subject to the following constraints:

- The water balance equation: \( V_{i,t} = V_{i,t-1} + (J_{i,t} - Q_{i,t}) \Delta t_{i,t} \) \quad (4)

- The water level limit: \( Z_{i,t,min} \leq Z_{i,t} \leq Z_{i,t,max} \) \quad (5)

- The hydropower output limit: \( N_{i,t,min} \leq N_{i,t} \leq N_{i,t,max} \) \quad (6)
The release constraints:
\[ Q_{i,t,min} \leq Q_{i,t} \leq Q_{i,t,max} \] (7)

The close hydraulic coupling:
\[ I_{i,t} = \alpha_i + \beta_i Q_{i-1,t} \]  \(i = 2, 4, 5\) (8)

Where scheduling period \(T\) is one day, dividing into 24 hour; \(i\) is the number of hydropower station, TG, GZB, SBY, GHY, GBZ denote 1,2,\ldots,5 from upstream to downstream. Temporal-spatial variation of flow can describe close hydraulic coupling between cascade hydropower stations. According to research idea from [4], piecewise function formulation is introduced to reflect Stage-discharge Relation of GBZ, which influencing by Yangtze River lever.

2.1. load compensation and allocation through improved entropy approach based on multi-objective analysis

This research adopts improved entropy approach to coordinate objective functions \(F^1\) and \(F^3\). Matrix \(B(b_{ij})\) is presented by normalizing data, then entropy and entropy weight can be calculated by (9):
\[
H_i = -\frac{1}{\ln n} \left[ \sum_{j=1}^{n} f_j \ln f_j \right]
\]
\[
W_{ci} = \frac{\sum_{k=1}^{m} H_k + 1 - 2H_i}{\sum_{k=1}^{m} (\sum_{k=1}^{m} H_k + 1 - 2H_i)}
\] (9)

Thus, there is a new objective function of whole system in scheduling period. It can be express as
\[
\max F = \sum_{i=1}^{r} \sum_{t=1}^{T} p_{i,t} w_{i,t} N_{i,t} \Delta t_{i,t} + \sum_{i=2}^{r} \sum_{t=1}^{T} p_{i,t} w_{i,t} N_{i,t} \Delta t_{i,t}
\] (10)

2.2. Decomposition-coordination approach of hydropower dispatching system

The system is decomposed into two sub-systems (Three Gorges cascade and Qingjiang cascade). The objective functions of each third level system (TG, GZB, SBY, GHY and GBZ) are expressed by
\[
\max L_1 = \sum_{t=1}^{T} (p_{1,t} w_{1,t} N_{1,t,1} \Delta t_{1,t} + \gamma_{1,t} N_{1,t} + \lambda_{1,t} \beta_1 Q_{1,t})
\] (11)
\[
\max L_2 = \sum_{t=1}^{T} (p_{2,t} w_{2,t} N_{2,t,1} \Delta t_{2,t} + \gamma_{2,t} N_{1,t} + \lambda_{2,t} \beta_2 Q_{1,t})
\] (12)
\[
\max L_3 = \sum_{t=1}^{T} (p_{3,t} w_{3,t} N_{3,t,1} \Delta t_{3,t} + \gamma_{3,t} N_{1,t} + \lambda_{3,t} \beta_3 N_{1,t})
\] (13)
\[
\max L_4 = \sum_{t=1}^{T} (p_{4,t} w_{4,t} N_{4,t,1} \Delta t_{4,t} + \gamma_{4,t} N_{1,t} + \lambda_{4,t} \beta_4 N_{1,t})
\] (14)
\[
\max L_5 = \sum_{t=1}^{T} (p_{5,t} w_{5,t} N_{5,t,1} \Delta t_{5,t} + \gamma_{5,t} N_{1,t} + \lambda_{5,t} \beta_5 N_{1,t})
\] (15)

Besides constraint of each sub-system are depicted in (4)-(7). POA or IDP can be used to solve the sub-problems during the optimal operation of single reservoir.

3. Numerical test and results

According to decomposition-coordination approach of hydropower dispatching system, several results of simulative optimal operation for several representative hydrographs is represented. Results of joint optimal operation are summarized in table 1. And, to analyze the coordination of two objective functions \(F^1\) and \(F^3\), the contrast of Three Gorges cascade and Qingjiang cascade load distribution in first condition is described in figure 1-2.
Table 1. Simulate joint optimal operation results of different conditions Unit: 10^4yuan

<table>
<thead>
<tr>
<th>Hydropower stations</th>
<th>Three Gorges cascade</th>
<th>Qingjiang cascade</th>
<th>Total benefit</th>
<th>Add value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TG</td>
<td>GZB</td>
<td>SBY</td>
<td>GHY</td>
</tr>
<tr>
<td>First condition</td>
<td>3666.7</td>
<td>675.1</td>
<td>781.8</td>
<td>603.2</td>
</tr>
<tr>
<td>Second condition</td>
<td>7658.3</td>
<td>1092.9</td>
<td>1189.2</td>
<td>868</td>
</tr>
<tr>
<td>Third condition</td>
<td>10811.4</td>
<td>1363</td>
<td>1572.5</td>
<td>1030.4</td>
</tr>
</tbody>
</table>

Notes: Add value = Total benefit of joint optimal operation - Total benefit of cascade optimal operation

Fig.1-2 The contrast of Three Gorges cascade and Qingjiang cascade load distribution in first condition.

It is observed from table 1 that power generation benefit of joint optimal operation is higher than cascade optimal operation. It is presented that decomposition-coordination approach has a good performance for compensating and creating link. Figure 1-2 show the new method is practical to promoting the optimized operation of electric power market, by giving consideration to load compensation and allocation.

4. Conclusion

This new method is practical and beneficial to promote the optimized operation of electric power market. Improved entropy approach is an efficiently method for calculating load compensation and allocation. And decomposition-coordination approach has better operation efficiency and better performance of compensating and creating link.

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