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A multi-objective short term hydropower scheduling model for peak shaving

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ABSTRACT

The short-term scheduling problem of a hydropower system in China Southern Power Grid (CSG) is studied. As one of the largest in China, the system consists of 92 hydro plants with total installed capacity of 41GW occupying 14.7% of the national hydropower capacity at the end of 2013. Abundant hydroelectricity of the system is transmitted from the western provinces to the eastern load centers in CSG. Obvious difficulties of the hydropower scheduling of CSG are large-scale system, complex constraints and multiple power receiving grids of single plants and cascaded systems due to huge capacity. A short-term hydropower scheduling model for peak shaving of multiple power grids is developed for the operations of the hydropower system of CSG. The model is composed of multi-objective optimal peak shaving (MOPS) model, inter grid power distribution (IGPD) model and load fluctuation balance (LFB) model. The MOPS model minimizes the maximum residual loads of each power grid in which the IGPD model is embedded to distribute power of a plant among several power grids. To solve the model, an aggregate function and a multi-objective fuzzy optimization model are combined to establish an alternative objective function, and a proposed constraint successively satisfying (CSS) algorithm is used to address the period coupling constraints in local search. A case study shows that the proposed approach is practicable, adaptable and robust to obtain near optimal results efficiently, and is applicable for large-scale hydropower systems with both multiple and single power receiving grids.

Introduction

As one of the two national power grids in China (the other is the State Grid of China (SGC)), CSG constructs and operates power networks in Guangdong, Guangxi, Yunnan, Guizhou and Hainan provinces/municipalities with total area of about 1 million square kilometer and population of 230 million. The total installed hydropower capacity of CSG is near 84.2GW at the end of 2013, accounting for about 30% of the whole country. The hydropower system of CSG is mainly composed of 5 of the 13 largest planned hydropower bases in China: Lancang River, Hongshuihe River, Wujiang River, Jinshajiang River, Nujiang River cascaded hydropower systems, and also composed of a lot of smaller cascaded hydropower systems. In the last decade, the hydropower bases of CSG are fast developed. Hydro plants in Wujiang River and Hongshuihe River will be completely put into production very soon, and hydro plants in Langcang River and Jinshajiang River are being put into production in a fast manner. The total installed hydropower capacity of CSG will reach 100GW by 2015. The position of the service area of CSG is shown in Fig. 1, and the schematic layout of studied hydropower system is shown in Fig. 2. The names and installed capacities of studied hydro plants are shown in Table 1, and the scales of the studied hydropower system in each province are shown in Table 2.

The hydropower of CSG is characterized by the following features:

(1) Large plants number and large capacities of hydropower systems, single plants and units. The number of hydro plants operated by the Dispatching Control Centre (DCC) of CSG and its provincial branches has exceeded 200, and the number of hydro plants operated by Yunnan power grid has exceeded 100. Wujiang River, Hongshuihe River, Langcang River and Jinshajiang River have total planned capacities of about 11 GW, 12.5 GW, 25 GW and 70 GW (about 21 GW planned to be operated by CSG) respectively. In recent-finished plants, Xiluodu, Longtan, Nuozhadu, Xiaowan have planned capacities of 13,860 MW, 6300 MW, 5850 MW, 4200 MW respectively, ranking 2nd, 4rd, 5th, 6th in China and 3rd, 8th, 11th, 14th in the world, respectively. Many newly installed hydropower units belong to 700 MW level.

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(2) Long distance, large-scale energy transmission. Most of the new hydro plants and untapped hydropower potential are located in the western part of CSG, while the major electricity load centers are in the eastern part, especially around Pearl River delta. West-East electricity transmission systems [1] have been developed for long distance and large-scale energy transmission inter provincial power grids.
(3) Multi-objective peak shaving requirements. The plants on a same river may transmit electric power to different regions, and some plants transmit electric power to more than one power grids simultaneously. The hydropower system is required to take up peak load for several power grids that may be far from each other in energy demands, peak loads, and even peak load time.

The short-term scheduling of the system encounters many difficulties [2]: (1) large-scale nonlinear programming model with multiple min–max objectives; (2) complex hydraulic and electrical relations due to the cooperated operation of hydropower systems with more than one power receiving grids; (3) time period coupling constraints of power ramping, minimum continuous generating periods and minimum power up/down periods; (4) power distribution among power grids of single plant.

The objective of a short-term scheduling model is decided by the regulating mode of the service power system. The common scheduling goal of existing models is minimizing the cost for covering a load obligation or maximizing the income if a market is present. The short-term hydropower scheduling is often embedded in hydrothermal scheduling problem [3,4], in which the main cost is the fuel consumption, and hydropower schedule affects the load obligation of thermal power and then the generating cost. For independent hydropower systems, objectives of energy maximization or profit maximization [5,6] are often adopted. The short-term scheduling procedure of CSG's hydrothermal systems is often divided into two phases, hydropower scheduling and thermal power scheduling. Because of the characters of China's power system, reducing peak-valley load gaps is one of the most important tasks for hydropower systems, and optimal peak shaving (OPS) model is a popular actual model, in which the minimization of the maximum residual load is the objective. If hydropower takes up more peak load, power ramping demands and even start/close up times of thermal units can be reduced. It is advantageous to not only thermal power scheduling but also reduction of coal consumption and greenhouse gas emission [7], and the demands for other peak shaving power resources such as gas or oil burned plants and pump storage plants can be reduced too.

The short-term hydropower scheduling problem is a complex mathematical optimization with a highly nonlinear and computationally expensive environment addressed by many researchers in the past decades. Various methods including dynamic programming [8], progressive optimality [9,10], network flow method [11], linear programming [12], mixed integer programming [13–15], Lagrangian relaxation method [16], decomposition approach [17], genetic algorithm [18–20], evolutionary programming [21], particle swarm optimization [22–25], bee colony algorithm [26] have been widely applied to solve this problem. The present study is concerned with the short-term hydropower scheduling of large-scale systems with multiple power receiving grids and complex constraints to obtain executable schedules. The large plants number of studied system, the complicated objective function and the period coupling constraints confine most existing algorithms.

In this paper, an MOPS model is proposed for the short-term hydropower scheduling of large-scale systems with multiple power receiving grids. An aggregated function and a fuzzy optimization model are used to establish an alternative objective function. A local search algorithm is presented to solve the optimal problem in which an improving solution is found by searching the "neighborhood" of current solution using a proposed CSS algorithm. For the problem of energy distribution of one plant to multiple power grids, an IGPD model is presented and embedded in the MOPS model. An LFB model is used to address the problem of frequent fluctuations of residual loads after the MOPS model is solved. To save the time cost, a dynamic dimension reduction strategy is proposed. Case study shows that the problem of peak shaving by hydropower system for multiple power receiving grids can be modeled and solved using proposed methods. The period coupling constraints can be met during solving processes so that

Fig. 1. Position of the service area of CSG.