Energy 162 (2018) 444–452

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Optimal allocation of hydropower and hybrid electricity injected from inter-regional transmission lines among multiple receiving-end power grids in China

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A R T I C L E I N F O

Article history:
Received 24 February 2018
Received in revised form
2 August 2018
Accepted 6 August 2018
Available online 7 August 2018

Keywords:
Peak shaving operation
Inter-regional transmission electricity
Mixed integer linear programming
Multiple receiving-end power grids
Optimal generation allocation
Hydropower and hybrid electricity

A B S T R A C T

In China, due to the unbalanced distribution of energy center and load center, numerous transmission projects are built to improve the national energy allocation efficiency and the external electricity is playing an increasing important role in the daily operation of receiving-end grids. The current fixed-proportion method for energy allocation is relatively simple and easy to implement, but may produce unreasonable energy injection with the features of a straight line or “anti-peak regulation” in some cases, increasing the peak operation pressure of power systems. Thus, it is of great necessity to further improve the allocation scheme of inter-regional transmitted electricity among receiving-end power grids. As a new contribution to the research field, this paper develops a mixed integer linear programming model with the goal of minimizing the weighted peak-valley difference of multiple remaining load curves to address this problem. The presented model is applied to the East China Power Grid, and the results show that the presented model can obtain satisfying results in reducing the peak loads of multiple power grids. For instance, in the long-term simulations, the presented model can make about 23.7%, 5.9%, 5.7% and 8.3% reductions in the maximum loads of Shanghai, Jiangsu, Zhejiang and Anhui, respectively. Then, it can be concluded that optimizing the allocation of inter-regional transmitted electricity will be a viable way to reduce the peak operation pressure of multiple receiving-end power grids in China.

1. Introduction

During the past decades, China has experienced a booming period in both economy and energy development [1]. However, there is an uneven balance between load centers and energy centers [2]. Fig. 1 compares the distributions of hydropower generation and energy consumption in China. It can be clearly observed that more than half of energy consumptions are located in mid-east China, while 70.61% hydropower generations are provided by the southwest China [3]. Fig. 2 illustrates the sketch map of electricity transmission from energy center to load center in China. It can be seen that more than half of the China's hydropower installed capacity are located in three provinces (Sichuan, Yunnan and Hubei), while about 26% gross domestic product of China are provided by five provinces in the eastern region. In order to effectively enhance the energy utilization efficiency of this country, numerous transmission lines with different voltage levels (like 220 kV, 500 kV and 750 kV) have been built over the past decades [4]. By the end of 2015, the maximum transmitting capacity has reached up to about 70 GW, accounting for approximately one quarter the hydropower installed capacity in China. The generation produced by large and medium-sized hydroplants and other hybrid energy systems (like photovoltaic plants and wind farms) in the mid-west China (like Sichuan and Yunnan) need to be transmitted to economically developed areas in east China (like Yangtze River Delta and Pearl River Delta). The proportion of the transmitted hydropower capacity in the East China Power Grid (ECPG) and China Southern Power Grid are about 17% and 26%, respectively. Hence, the electricity injected from inter-regional transmission lines is playing an increasingly important role in the safe operation of receiving-end power grids.

For the receiving-end grids, the maximum peak and peak-valley

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https://doi.org/10.1016/j.energy.2018.08.045
0360-5442/

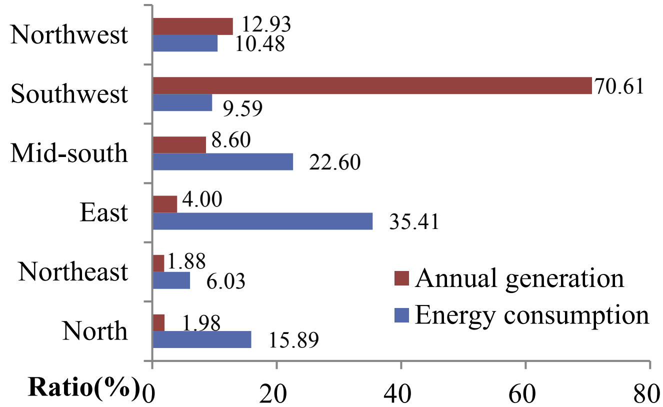

Fig. 1. Distribution of hydropower generation and energy consumption in China.

difference of load demands keep growing, while only a very small percentage of generation capacity is from the flexible energy represented by conventional hydropower and pumped-storage [5]. As shown in Fig. 2, the installed capacity of Jiangsu and Shanghai are composed of more than 92% thermal power, and the share of hydropower in Zhejiang is less than 5%. Obviously, the share of dispatchable flexible energy is too small to satisfy the requirements of peak operation [6]. Hence, it is hoped that the electricity from inter-regional transmission lines can be used to respond the peak loads of multiple receiving power grids [7]. However, most of large rivers at the sending-end of China are located in the remote mountainous regions with undeveloped traffic facilities and insufficient consumption demand, and it is difficult to find appropriate places to build hydroplants with large reservoir storage capacity, and then a large number of medium-small-sized hydroplants with poor regulation capability are built in the past decades [8]. The proportions of large and medium-sized reservoirs in both Sichuan and Yunnan are less than 20%. As a result, during dry seasons, the hydropower generation will be dramatically reduced due to the reduction of natural runoff, and then the receiving-end power grids have to use their limited dispatchable power stations to respond the huge load change; at flood seasons, a majority of hydroplants often provide electricity with the level of installed capacity to reduce the abandoned energy as far as possible, which may easily lead to irrational hydropower transmission scheduling with the features of a straight line or "anti-peak regulation". On the other hand, the fixed proportion method based on engineering experience is being adopted to allocate the injected electricity from transmitted lines to different provincial power grids. This method is simple and ease of implementation, but the practical situations of multiple receiving-end power grids are not given full consideration. Then, a mass of generation may be injected from the transmission lines at valley periods, increasing the peak operation pressure of power system [9]. Thus, how to rationally allocate the inter-regional transmitted electricity among multiple receiving-end power grids is becoming a new giant challenge for the operators of power system in China [10].

The typical load curves of several provincial power grids at the receiving end are drawn in Fig. 3. It can be clearly seen that due to various reasons like population and economy, there are significant differences in the load characteristics of three receiving-end power grids, such as the numbers and occurrence time of peak loads, load magnitudes and shape, peak-valley difference. For instance, in summer, the peak loads of Jiangsu occurring two times (10:30 and 15:00) are up to 55 GW, which is larger than 24 GW in Shanghai. In addition, due to the seasonal variation of energy consumption, the annual variance of load demand in a single power grid often shows a remarkable regularity. As shown in Fig. 3, the peak loads in summer often tend to be greater than that of winter due to the higher temperature. Thus, when using the experience-based fixed proportion approach to allocate the electricity from inter-regional transmission lines, the peak loads of receiving-end power grids will not be reduced in most cases, affecting the overall operational efficiency of modern electrical power system. From Fig. 3, it serves to show that there are significant differences in the load demands of three receiving-end power grids, which means that there are certain spaces to improve the transmitted generation allocation among multiple receiving-end power grids. Then, motivated by this

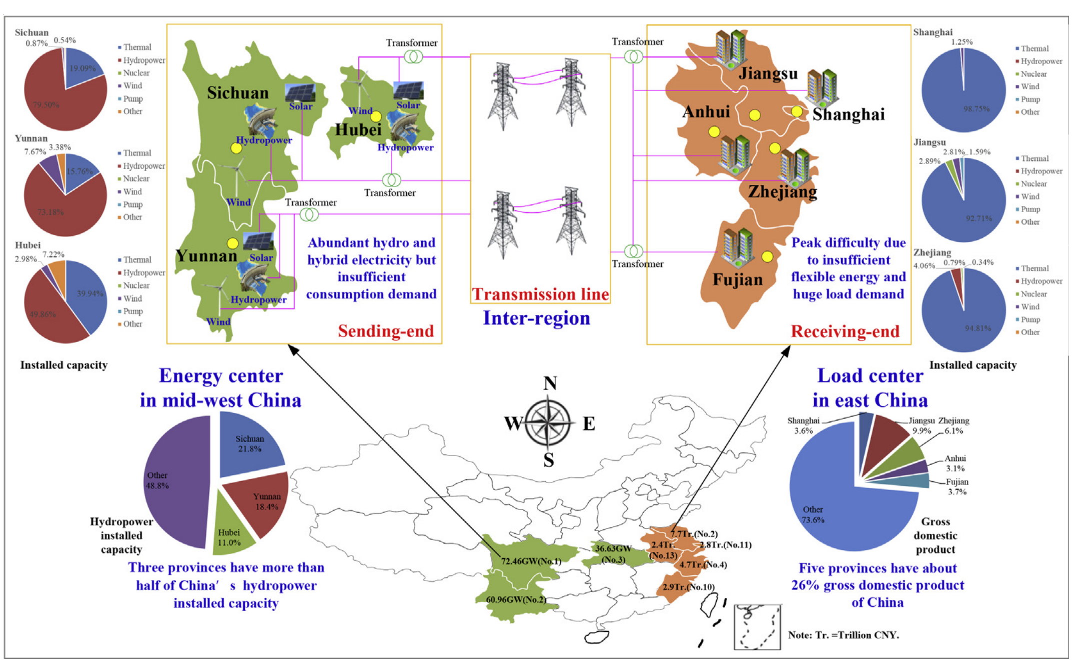

Fig. 2. Sketch map of electricity transmission from energy center to load center in China.