Applied Energy xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

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

Inter-regional power grid planning up to 2030 in China considering renewable energy development and regional pollutant control: A multi-region bottom-up optimization model

Bo-Wen Yi [a], Jin-Hua Xu [a,*], Ying Fan [b]

[a] Center for Energy and Environmental Policy Research, Institute of Policy and Management, Chinese Academy of Sciences, Beijing 100190, China
[b] School of Economics & Management, Beihang University, Beijing 100191, China

HIGHLIGHTS

- A multi-regional bottom-up optimization model for power sector is developed.
- Detailed power transmission and coal transportation are introduced in the model.
- The inter-regional power transmission planning and its impacts are analyzed.
- Inter-regional power transmission is economical and feasible for energy transition.
- Power transmission is an effective way to relieve regional environmental pollution.

ARTICLE INFO

Article history:
Received 7 July 2016
Received in revised form 25 October 2016
Accepted 7 November 2016
Available online xxxx

Keywords:
Power sector
Inter-regional power transmission
Multi-region model
China
Renewable energy
Air pollutant control

ABSTRACT

China's energy resources and electricity load show reverse regional distribution, along with serious imbalance of energy supply and demand between eastern and western regions. Inter-regional power transmission is considered to be the key strategic measure to balance the national resources allocation and satisfy various regional long-term benefits. In this study, a multi-region power sector optimization model is developed from the perspective of bottom-up modeling. Power transmission technologies are considered in detail. Moreover, the sub-module of inter-regional coal transportation is introduced into the model. Based on above framework, this study analyzes quantitatively the optimum inter-regional power transmission planning under various policy scenarios, and estimates its impacts on renewable energy, NO_x and SO_2 emissions, and coal transportation from a long-term perspective. The results show that ultra high voltage lines will become the main carrier of inter-regional power transmission in the future. The construction of transmission line between some regions such as from East Inner Mongolia to northern China, and from northwest China to central China can bring economic savings. Inter-regional power transmission is an effective way to promote the utilization of renewable energy in Inner Mongolia and northwest China, and plays an important role in controlling NO_x and SO_2 emissions in central and eastern China but has limited effect on the national total emissions. Moreover, it could reduce the inter-regional coal transportation significantly.

1. Introduction

In recent years, China's industrialization and urbanization reforms have led to the rapid growth in electricity consumption from 2477.2 TWh in 2005 to 5523.3 TWh in 2014 [1], which caused serious environmental pollution and climate change problems. In 2013, the sulfur dioxide (SO_2) emissions of China's power sector reached 8.2 million tons (Mt), accounting for 40.1% of national total emissions. Meanwhile, the nitrogen oxide (NO_x) emissions reached 8.34 Mt, accounting for 37.4% of national total [2]. Especially in the developed eastern coastal areas, the bad weather caused by excessive coal combustion occurs frequently. Optimizing the power structure and regional distribution has become a major issue faced by China' power sector.

The Chinese government actively responded to current environmental and climate issues. In 2013, "Air pollution prevention and control action plan" was launched to improve the air quality of Jing-Jin-Ji, Yangtze River Delta, and Pearl River Delta regions within five years [3]. The "U.S.-China Joint Announcement on Climate

* Corresponding author.
E-mail addresses: xujinhua111@163.com, xjh@casipm.ac.cn (J.-H. Xu).

http://dx.doi.org/10.1016/j.apenergy.2016.11.021
0306-2619/

Change" was further issued by the Chinese government, intending to increase the share of non-fossil fuels in primary energy consumption to about 20% by 2030 [4].

However, China's energy resources and electricity load show reverse distribution, along with serious imbalance of energy supply and demand between eastern and western regions. The power demand in resource-rich northwest region is relatively low, causing a part of clean energy cannot be consumed. In contrary, the natural resources in high power demand regions such as eastern China are scarce. Therefore, these regions need to meet their electricity demands mainly by thermal power, which not only leads to the problem of environmental pollution, but also increases the inter-regional coal transportation. With the maturity of ultra high voltage (UHV) power transmission technology, large-capacity long-distance power transmission is becoming more and more feasible. In this context, inter-regional power transmission has been considered to be a key strategic measure to balance the national resources allocation and to satisfy various regional long-term benefits in China.

The Chinese government attached great importance to inter-regional transmission line construction, especially for the UHV lines, and clearly put forward to solve the environmental issue of eastern regions by increasing the proportion of electricity import in the "Air pollution prevention and control action plan" [3]. In 2015, National Energy Administration (NEA) released the "Guide for the design of the 13th Five-Year-Plan for renewable energy development" to promote renewable energy development by inter-regional power channels as much as possible [5]. Until 2015, nine UHV lines have been constructed to relieve environmental issue and promote renewable energy consumption in China. Thus, inter-regional power transmission will become an important direction of the power grid planning in the future.

The inter-regional power transmission planning is a very complex issue. Not only the pathway, but also the time and capacity need to be decided. In addition, the long-term influence of power transmission line construction on power sector, coal transportation, and environmental state in each region should also be considered from an integrated perspective. The purpose of this analysis is to provide suggestions for the long-term inter-regional power transmission planning in China by scientific method, thus achieving relevant policy target with minimum economic cost.

Many studies have investigated the construction of inter-regional power transmission line and its relevant influence in China [6–11]. Above-mentioned studies mainly focused on some particular areas or lines but seldom focused on the national overall inter-regional transmission planning. For instance, Gnansounou and Dong [12] analyzed the opportunity for the inter-regional integration of the electricity market by taking Shandong province and Shanghai as examples. Ming et al. [13] estimated the impact of national policy and industry development on West-East Power Transmission by taking the south route as the research object. It is necessary to include the nationwide power sector into the analytical framework, and to refine the regional differences in resource endowment. This analytical method will complicate the issue, but the interaction between each region could be taken into account, in order to search the global optimum power transmission pathway from a more macro perspective.

Beyond China, many studies analyzed the power sector planning in other countries by multi-region models [14–22]. For example, Bird et al. [23] examined the impact of carbon cap and renewable portfolio standards in U.S. by using a least-cost expansion of electricity generation capacity and transmission model. Li and Chang [24] identified the financial barriers of implementing regional power interconnection in ASEAN. These literatures have provided valuable insight for developing multi-region model in power sector. However, they are not suitable for the study of China's issue due to the significant differences of resource endowment and power grid structure between China and other countries. Most of China's power optimization models simulated the power sector as a single region, without considering the heterogeneity between regions [25–30]. In particular, Wang et al. [9], Cheng et al. [31], and Hui et al. [32] introduced multi-region into power optimization model by adding transmission costs and losses, but they didn't describe the detailed construction of various types of power transmission lines.

Given this, our work better quantifies the inter-regional power dispatch by considering the investment, operation and maintenance, and substitution of different power transmission technologies over planning horizon. Our model further simulates the flow of natural resources by introducing an inter-regional coal transportation sub-module into the conventional power dispatch and capacity expansion model, which enables to compare the economic benefits of power transmission and coal transportation more accurately[1]. Additionally, more detailed regional division is developed in this study to reflect the diversities in resource endowments and power demand between different areas of China. In this study, a Chinese multi-region power dispatch and capacity expansion model is developed from a long-term perspective. Based on this model, this study answers two questions: (1) what is the optimal evolution pathway of inter-regional power transmission line under various energy and environmental policy targets? And (2) what is the impact of inter-regional power transmission on China's power sector form the perspectives of renewable energy utilization, pollutant emissions, and coal consumption? According to the answers of above questions, policy recommendations are formulated for Chinese government to make long-term strategic decisions about inter-regional power transmission planning.

This paper is organized as follows. Section 2 provides a description of detailed modeling and scenario designs. The actual data from the power sector in China are presented in Section 3. Section 4 discusses the construction of inter-regional power transmission lines and its influence on the power sector in different scenarios. Section 5 presents the conclusions.

2. Methodology

2.1. Model framework

This study establishes a multi-region power dispatch and capacity expansion model to analyze the China's future inter-regional power transmission planning and its influences on each region. The construction of power transmission line between each region is allowed in this model. Electricity will be transmitted by the existing or new built transmission lines. In addition, the inter-regional transportation of the primary energy used for power generation is also allowed in this model. Given China's special power generation mix and the characteristics of natural resources, the primary energy that could be transported between areas mainly refers to coal. The objective function is the accumulated total costs paid by China's power sector over the planning horizon. Under a series of constraints, the future optimum power generation mix, the capacity of inter-regional power transmission line, and the amount of inter-regional resource transportation are calculated by the optimization method.

Fig. 1 shows the framework of this model, including four main modules, namely power generation module, power transmission module, resource module, and coal transportation module. In addition, the resources or technologies covered in each module, and the link between each module are also presented in Fig. 1.

[1] Coal is the most important resources for power generation in china. In 2013, the proportion of the installed capacity of coal-fired power in total thermal power is 91.5% [33].

Please cite this article in press as: Yi B-W et al. Inter-regional power grid planning up to 2030 in China considering renewable energy development and regional pollutant control: A multi-region bottom-up optimization model. Appl Energy (2016), http://dx.doi.org/10.1016/j.apenergy.2016.11.021