Research on Development Pathway of New Energy Supply and Consumption System in China

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Abstract. China has put forward the concept of "new energy supply and consumption system". In the overall carbon peak and carbon neutral goals, wind energy and solar energy will become main energy in China, it is necessary to study how to build a good new energy supply and consumption system. In this paper, we give a broad understanding and propose three modes of new energy supply and consumption system. Then, a regional power planning quantitative analysis is carried out which considering constraint of carbon emission, and installed capacity of new energy power generation is predicted. Lastly, development suggestions of distributed new energy, large new energy bases and offshore wind are given respectively.

Keywords: power planning; wind power; solar power.

1. Broad understanding of new energy supply and consumption system

In January 2022, China put forward the concept of "new energy supply and consumption system"[1], to increase efforts to plan and build a system which is based on large solar and wind power bases, supported by clean, efficient and advanced thermal power, as well as stable, safe and reliable UHV transmission lines.

In our opinion, construction of new energy supply and consumption system needs to focus on combining China's new energy resource endowment, regional major strategies, regional advantages and grid location conditions, etc., and optimize development and utilization modes of new energy according to local conditions. As follows, three modes [2] of new energy supply and consumption system are proposed.

Mode 1: Focus on new energy development and utilization mode combined with new energy industry layout adjustment and west to east power transmission strategy. The typical representative is large new energy power bases in north and west China region, focusing on desert, gobi and wilderness areas. Forward looking, large new energy power bases will be adjusted from current supported of thermal power to concentrating solar power, which also have characteristics of flexible regulation and strong support ability.

Mode 2: Focus on new energy development and utilization mode combined with rural revitalization and urbanization strategies and improvements of user-side power emergency capacity and power supply reliability. The typical representative is large-scale distributed new energy development in eastern and central regions. Considering that distributed new energy resources in central and eastern China are difficult to fully support existing and increasing local power demand, this mode is mainly fully developed in the near and medium term.

Mode 3: Focus on new energy development and utilization mode combined with construction of a maritime power and “blue economy” towards marine, as well as cultivating development of eastern coastal wind power industry and industrial output. It is mainly to develop offshore wind power bases in eastern coast with focus on offshore energy islands and integrated utilization.

Considering gradual improvement of offshore wind power's technical economy, this mode is mainly fully developed in the medium and long term.

2. Quantitative analysis method and model

This paper's quantitative analyses use muti-regional long-term power planning model. The overall framework is shown in Figure 1. Specifically, total cost of electricity supply in the whole planning period is the optimal variable, and mainly considering balance of power resources, water resources constraints, environmental space constraints and non-fossil energy development targets, and is preferred to coal, gas, wind and solar power and other types of power supply development timing and scale, and the corresponding cross-regional power flow planning and flow. The model is optimized according to the principle of lowest total cost of power supply, and solved by self-developed GESP-V software. [3]

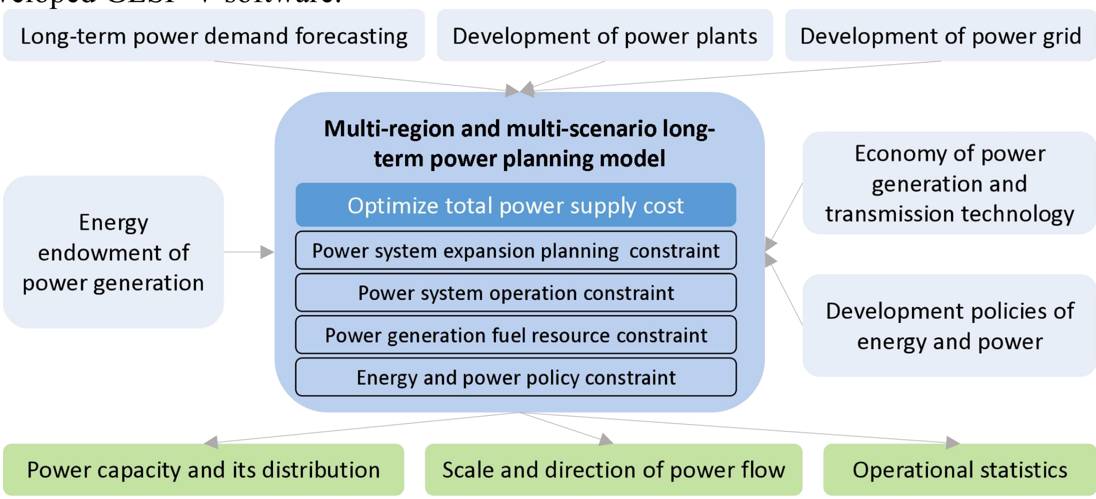

Fig. 1 Quantitative analysis framework

2.1 Optimization objective of muti-regional long-term power planning model

Optimization goal is to minimize total cost of electricity supply during planning period, including the investment, operation and maintenance costs, fuel costs, emission costs and equipment salvage value of different levels in each region.

$$\min \sum_{z\in Z}\sum_{t\in T}\left[\frac{C^I_{z,t}}{(1+r_z)^{t-1}} + \frac{1}{(1+r_z)^t}\times\left(C^{OM}_{z,t} + C^F_{z,t} + C^C_{z,t} - C^S_{z,t}\right)\right] \tag{1}$$

in which, Z and T represent regions set and planning period set; r_z represents discount rate; $C^I_{z,t}$, $C^{OM}_{z,t}$, $C^F_{z,t}$, $C^C_{z,t}$, $C^S_{z,t}$ are investment, operation and maintenance costs, fuel costs, emission costs and equipment salvage value at year t of region z respectively, and can be calculated as below:

$$C^I_{z,t} = \sum_{m\in M_z}\sum_{i\in M_{z,m}} c^{NG}_{z,t,m,i}X^{NG}_{z,t,m,i} + \sum_{l\in L^S_z} c^{NL}_{l,t}D^L_{l,t}X^{NL}_{l,t} \tag{2}$$

$$C^{OM}_{z,t} = \sum_{m\in M_z}\sum_{i\in M_{z,m}} c^{GF}_{z,t,m,i}X^G_{z,t,m,i} + \sum_{m\in M_z}\sum_{i\in M_{z,m}} c^{GV}_{z,t,m,i}E^G_{z,t,m,i} + \sum_{l\in L^S_z} c^{LF}_{l,t}D^L_{l,t}X^L_{l,t} + \sum_{l\in L^S_z} c^{LV}_{l,t}D^L_{l,t}E^L_{l,t} \tag{3}$$

$$C^F_{z,t} = \sum_{m\in M_z}\sum_{i\in M_{z,m}} c^F_{z,t,m,i}E^G_{z,t,m,i} \tag{4}$$

$$C^C_{z,t} = \sum_{m\in M_z}\sum_{i\in M_{z,m}} c^C_{z,t,m,i}E^G_{z,t,m,i} \tag{5}$$

$$C^S_{z,t} = \sum_{m\in M_z}\sum_{i\in M_{z,m}} c^S_{z,t,m,i}X^{RG}_{z,t,m,i} \tag{6}$$

in which, M_z represents power generation type set of region z; $M_{z,m}$ represents type m power generation unit set of region z; L^S_z represents transregional power lines set start from region z;

$X_{z,t,m,i}^{G}$, $X_{z,t,m,i}^{NG}$, $X_{z,t,m,i}^{RG}$ represent total capacity, increased capacity, retired capacity of unit i in type m at year t of region z; $X_{l,t}^{L}$ and $X_{l,t}^{NL}$ represent total capacity and increased capacity of line l at year t start from region z; $E_{z,t,m,i}^{G}$ represents total annual generation of unit i in type m at year t of region z; $E_{l,t}^{L}$ represents annual exchange energy of line l at year t start from region z. $c_{z,t,m,i}^{NG}$ represents new power unit capacity cost; $c_{l,t}^{NL}$ represents new transmission line capacity cost; $D_{l,t}^{L}$ represents transmission distance of line l start from region z; $c_{z,t,m,i}^{GF}$ and $c_{z,t,m,i}^{GV}$ are respectively fixed O&M cost per unit capacity and variable O&M cost per kilowatt-hour; $c_{l,t}^{LF}$ and $c_{l,t}^{LV}$ are respectively fixed O&M cost per unit distance and variable O&M cost per kilowatt-hour of cross-area line; $c_{z,t,m,i}^{C}$ represents emissions cost per kilowatt-hour of unit i in type m at year t of region z; $c_{z,t,m,i}^{S}$ represents coefficient of residual value per unit capacity of unit i in type m at year t of region z.

2.2 Major constraints of muti-regional long-term power planning model

The constraints considered include power system expansion planning constraints, power system operation constraints, power generation resource constraints, power system carbon emission constraints, energy and power development policy constraints. Details can be found in Ref [3], we won't explore it in this paper.

3. Development path analysis of wind power and solar power

3.1 Scenario setting

Anchoring China’s carbon peak and carbon neutrality goals [4-7], this paper focuses on power system development vision of China's carbon-neutral goal by 2060. Based on comprehensive consideration of power transmission and receiving relationships of existing power grids, China's power grid is divided into 7 regional power grids, as shown in Table 1.

Table 1. Region division

Region	Included Provinces
North China	Beijing, Tianjin, Hebei, Shandong, Shanxi
East China	Shanghai, Zhejiang, Jiangsu, Anhui, Fujian
Central China	Henan, Hunan, Hubei, Jiangxi
Northeast China	Heilongjiang, Jilin, Liaoning, Inner Mongolia
Northwest China	Shanxi, Gansu, Qinghai, Ningxia, Xinjiang
Southwest China	Sichuan, Chongqing, Xizang
South China	Guangdong, Guangxi, Yunnan, Guizhou, Hainan

Main boundary conditions combined with international environment, economic development, industrial transformation, energy structure, technological progress and many other factors, to consider power generation energy resources, regional power demand, cross-region and cross-province transmission corridors and other boundary conditions. In particular, comparative advantages and carrying capacity of different regions, the rhythm and degree of regional transformation also are analyzed and set, as shown in Table 2.

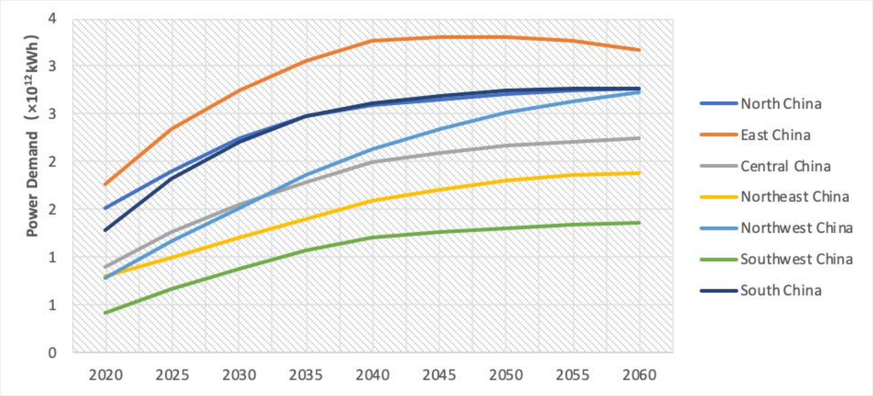

Fig. 2 Regional power demand development trend

Table 2. Region competitive advantages

Region	Location of regional power grid	Power generation resource endowment		Electricity price level
		Non-fossil	Fossil	
North China	receiving end+ sending end	DGPV, offshore wind, nuclear	coal, gas	medium
East China	receiving end	DGPV, offshore wind, nuclear	LNG	high
Central China	receiving end+ sending end	DGPV, nuclear	coal	medium
Northeast China	sending end	wind, solar	/	low
Northwest China	sending end	wind, solar	coal	low
Southwest China	receiving end+ sending end	hydro	shale gas	low
South China	receiving end+ sending end	hydro	coal, gas	high

3.2 Results analysis

Overall, total installed power capacity of China shows a rapid development trend, but different types of power supply development differentiation is more obvious. Regional installed capacity in 2060 is show in Figure 3.

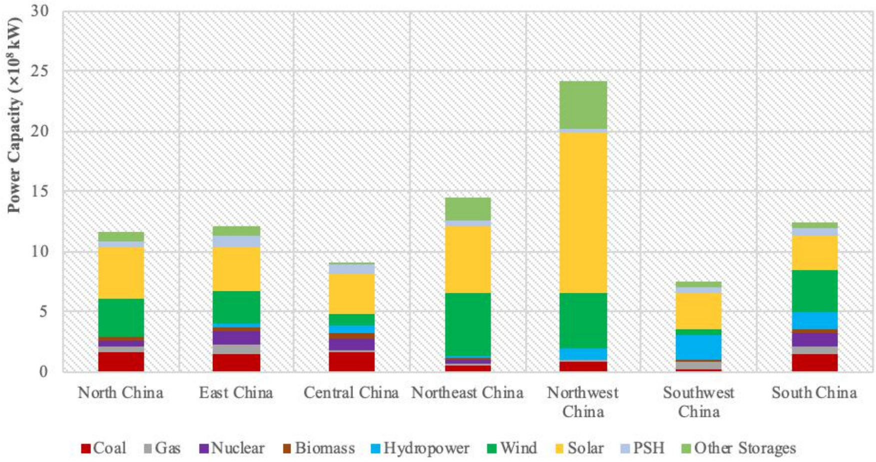

Fig. 3 Regional installed power capacity in 2060

In terms of wind power, with recent fully development of decentralized wind power resources in eastern and central regions, the focus of medium and long-term wind power development will return to western and northern regions, while offshore wind power will gradually expand to deep sea. It is expected that by 2060, installed capacity of onshore wind power and offshore wind power in China will each reach 1.59 billion and 500 million kilowatts respectively, as shown in Figure 4. Among them, installed capacity of onshore wind power is mainly distributed in Northwest China, Northeast China and North China, respectively, 470 million, 500 million and 200 million kilowatts, and these four regions accounts for 74% of total onshore wind power installed capacity. Considering wind energy resources amount, available areas of wind energy resources and the impact of typhoons, offshore wind power installed capacity of East China, South China, North China and Northeast China is 180 million, 180 million, 110 million and 30 million kilowatts, respectively.

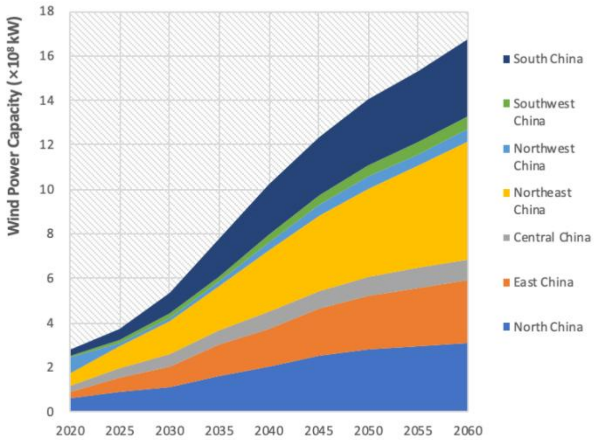

Fig. 4 Regional development trend of wind power

In terms of solar power, in medium and long term, with the completion of distributed PV power development in east and middle regions, construction of solar power generation bases, including CSP, will mainly expand in northwest region. It is expected that by 2060, installed capacity of PV power and CSP will reach 3.3 billion and 250 million kilowatts respectively, as shown in Figure 5. Among them, one third of installed PV power is distributed in Northwest China, which is 1.1 billion kilowatts. Distribution of CSP is mainly in Northwest China also, which reach 200 million kilowatts.

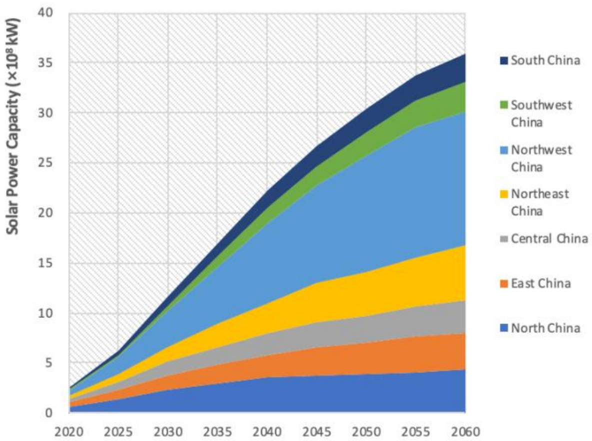

Fig. 5 Regional development trend of solar power

4. Development suggestions of new energy supply and consumption system

Firstly, China's distributed power supply mainly concentrated in East China, central China and North China, will maintain a rapid development trend, and should be developed as soon as possible considering power system absorbing capacity. Focusing on residential roofs, industrial and mining land roofs, railway and highways, shoal reservoirs and agricultural greenhouses, technology development potential of distributed PV power is higher than 1 billion kilowatts, and mainly in Henan, Shandong and Jiangsu provinces.

Secondly, large solar power bases in desert, gobi and wilderness areas will be the main mode of new energy bases in the future, and their supporting sources should be gradually adjusted from thermal power and electrochemical energy storage to CSP and long-period energy storage. With development of a large proportion of distributed new energy in east and central regions after 2030, large-scale new energy power bases will continue to expand in northwest region and other areas with conditions. In view of current technical path of large solar power bases in desert, gobi and wilderness areas is still unclear and its economy is still low, it is necessary to adhere new energy supply and consumption system construction.

Lastly, offshore wind power is related to whether eastern and central regions can safely and stably reduce carbon, and it is necessary to accelerate the expansion of scale and promote improvement of technical economy of offshore wind power, especially offshore wind power in deep sea. In addition, it is necessary to explore offshore energy islands with characteristics of offshore energy resource supply conversion hubs, as well as integrated facilities for conversion and utilization of various energy resources such as marine energy, energy storage, hydrogen production and seawater desalination, to improve utilization efficiency of offshore wind power.

Acknowledgments

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