



Evolution Logic and Comparative Advantage of China's Power System Reform—A Comparative Study on Transmission Management Between China and the United States

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This paper examines the differences of power systems between China and the United States from the perspective of transmission management, and finally summarizes the institutional advantages of China's power system reform. The research shows that there are significant operation and supervision differences between China and the United States in transmission management. China has always maintained a unified management in transmission management, while the United States has adopted a decentralized management model in transmission. The implementation of centralized unified management in transmission links cannot only ensure the timely and effective allocation of national power energy, but also be helpful to concentrate all kinds of resources to develop large-scale power projects.

Keywords: power systems reform, transmission management, institutional advantages, China, the United States

INTRODUCTION

Every leap of productivity in human society is accompanied by the improvement and replacement of energy. "Electric power revolution" has greatly improved the efficiency of social operation, and also tends to industrialization with the rising social demand (Rothe, 2019). Power industry has natural monopoly, and monopoly always leads to low efficiency. In the 1990s, the United States, Japan and some European developed countries have carried out the market-oriented reform of power system, trying to break the low efficiency of monopoly through the reform of system and mechanism, and further optimize the allocation of power resources, so that the power system can better serve the social and economic development (Michaels, 2006). But things were ordered otherwise. The power outage in Texas in 2021 reflects the significant security risks brought by the segmented grid management to the stable operation system under the market-oriented reform.

In the early days of the founding of new China, the Chinese central government found that there were various drawbacks in the decentralized management of power grid, which seriously affected the stability and development of the power industry. Thus, the long-term centralized management of China's power system has become a feature of the economic planning. With the advancement of China's socialist market economic system reform, the problems of unclear management responsibility and inefficient operation of enterprises caused by the "integration of government and enterprise" in the power system are gradually exposed, so the central government has issued a series of policy documents

aimed at giving full play to the power's role in ensuring social and economic development. In 2002, the State Council issued the *Power System Reform Plan*, marking the formal opening of the power system reform of "separation of power plant and power grid," in order to introduce competition in the generation side to improve the efficiency of the power system. In 2015, the State Council issued *Several Opinions on Further Deepening the Reform of Power System*, focusing on solving five major problems, such as the lag of legislative amendment law, the lack of trading mechanism, the perfection of coordination mechanism, incomplete pricing mechanism and imperfect development mechanism. Both the vertical historical experience and the horizontal comparison between countries have proved that China's power system has its unique advantages in transmission management.

This paper analyzes the differences of power transmission management between China and the United States from the perspective of historical evolution (Figure 1), and finally summarizes the institutional advantages and optimization measures of China's power system reform.

THE EVOLUTION OF POWER SYSTEM REFORM IN CHINA AND THE UNITED STATES

In the 1980s-1990s, with the development of market economy, the incompatibility of power system policies originated from the planned period has become increasingly prominent in the market economy. Under the planned economy, the "un-separation of government and enterprise" cannot guarantee the effective management of the power system by government departments, and it is difficult to improve the market efficiency of the power industry, which hinders the further development of the power industry. Moreover, the experience from other countries shows that the power industry does not need the integration of generation, transmission, distribution and sales (Chawla and Pollitt, 2013). Based on the consideration of enhancing the effective management of power system and improving the market efficiency of power industry, China's power system reform is imminent (Bai, 2019).

In January 1997, the State Council decided to establish the state power company, which marked the transition of China's power management system from planned economy to socialist market economy, and laid the foundation for the reform of China's power system. In February 2002, the *Power System Reform Plan* was issued by the State Council, marking the official opening of China's power system reform. In March 2003, the State Electricity Regulatory Commission (SERC) was established, whose responsibility is to supervise and manage the operation order of the power market. In March 2013, the State Council decided to integrate the responsibilities of the National Energy Administration (NEA) and SERC to further improve the energy management system. In April 2015, the State Council issued *Several Opinions on Further Deepening the Power System Reform*, which started a new round of China's power system reform, focusing on solving such important problems as the lack of power system market trading mechanism, imperfect power

system planning coordination mechanism, and difficulties in the development and utilization of emerging energy. In November 2017, the National Development and Reform Commission (NDRC) and NEA issued the notice on *Accelerating the Pilot Reform of Incremental Distribution Business*, and clearly defined the goal of deepening the reform focusing on the marketization of incremental distribution and direct transactions between power plants and power users. In a word, the reform of China's electric power system not only strengthens the management of the state in the transmission link, but also improves the market allocation efficiency of power generation and sales, and realizes the unity of power system stability and efficiency to a certain extent (Table 1).

The development of the United States power industry is relatively mature, and its power system has undergone many rounds of reform. Its power reform mainly revolves around breaking the integration, liberalizing the control of power generation and distribution terminal, realizing free competition, and maintaining the monopoly of transmission terminal at the same time. The reform of the United States power system began with the *Energy Policy Act* of October 1992, which establishes the separation of power generation, transmission and distribution, to eliminate the monopoly of power industry and promote market competition and technological progress. In 1996, the Federal Energy Regulatory Commission (FERC) issued orders 888 and 889, requiring power companies with transmission facilities to open up the transmission network. In response to the FERC act, some power companies in the United States spontaneously joined forces and formed an Independent System Operation Company (ISO). In December 1999, FERC issued another order 2000, facilitating the establishment of Regional Transmission Organizations (RTO), and requiring all public utility companies with transmission networks to join RTO. Actually, the function of RTO is similar to ISO, but it adds the function of trans-regional transmission network planning and reliability maintenance on the basis of ISO. In 2003, ISO and RTO jointly established a power industry cooperation organization in most parts of the United States, called the ISO/RTO Committee (IRC).

In August 2005, the *Energy Policy Act 2005* of the United States was promulgated, which aimed to optimize the energy use structure of the United States and promote competition in the wholesale electricity market. Since then, FERC issued a series of decrees from 2006 to 2015, trying to further improve the level of power system marketization from the aspects of pricing, trading and management. However, due to the implementation of private ownership in the transmission sector in the United States, and the overlapping regulatory functions among different organizations, the unified centralized management of transmission has not yet been realized.

DIFFERENCES OF TRANSMISSION MANAGEMENT SYSTEM BETWEEN CHINA AND THE UNITED STATES

On the whole, the goal of power system reform in China and the United States is to establish a competitive power market, but the

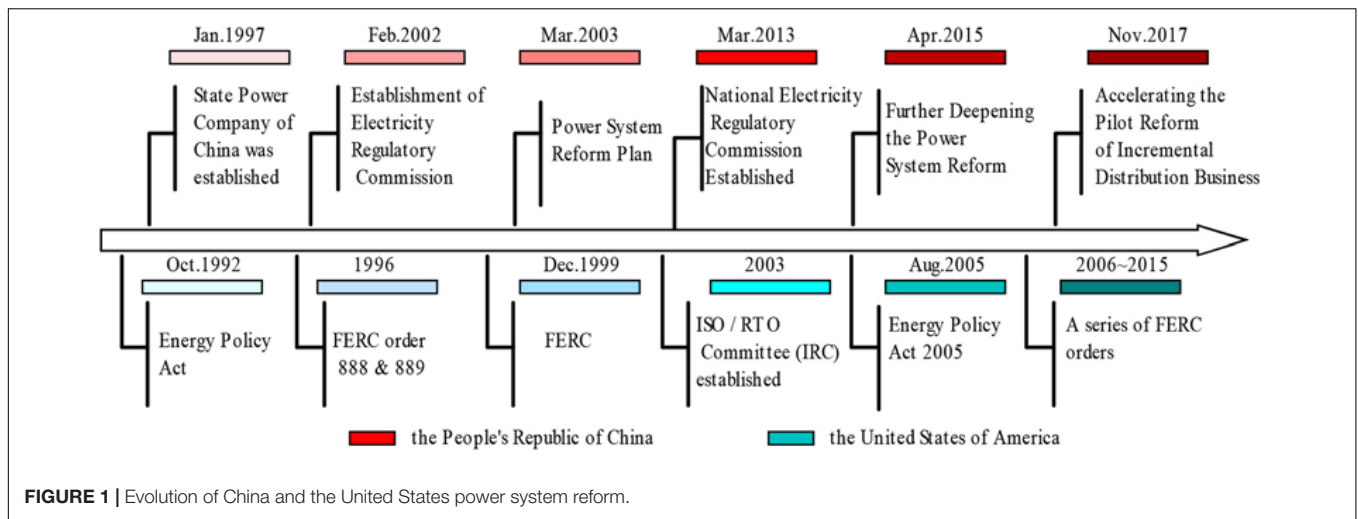


FIGURE 1 | Evolution of China and the United States power system reform.

TABLE 1 | Policies and contents of power system reform in China and the United States.

China		The United States	
Policies	Content	Policies	Content
Establishment of the state power company of China	<ul style="list-style-type: none"> Company system reform of Ministry of electric power industry set up a state-owned power company 	Energy Policy Act	<ul style="list-style-type: none"> Non-public companies are allowed to enter the wholesale electricity market Transmission companies provide transmission services at reasonable prices
The power system reform plan	<ul style="list-style-type: none"> The assets of the State Power Company were reorganized into 5 power generation companies and 2 transmission and distribution companies Establishment of a power dispatching and trading center implementation of electricity bidding online Electricity price is divided into feed-in price, transmission price, distribution price and terminal selling price 	Federal Energy Commission Decrees No.888 and No. 889	<p>Open and fair access for all utility companies through open grid</p> <ul style="list-style-type: none"> Promoting the competition in the wholesale electricity market.
SERC established	<ul style="list-style-type: none"> Power market regulation and operation supervision Put forward price adjustment suggestions to government price department 	Federal Energy Commission Decrees No.2000	<ul style="list-style-type: none"> All utility companies with transmission network join regional transmission organization (RTO)
SERC merged with NEA	<ul style="list-style-type: none"> Realizing the integration of power regulatory responsibilities Improve the energy management system 	IRC established	<ul style="list-style-type: none"> Coordinate and manage power systems in different regions
Further deepening the power system reform	<ul style="list-style-type: none"> Orderly deregulation of electricity price in competitive links other than transmission and distribution Promote the independent and standardized operation of trading institutions The profit model of electric power company is changed into the model combining cost and profit 	Energy Policy Act 2005	<p>Promoting competition in wholesale electricity market</p> <ul style="list-style-type: none"> Improve the competition level of power market
Accelerating the pilot reform of incremental distribution business	<ul style="list-style-type: none"> Increase the pilot scope of incremental distribution business reform Further deregulation of power distribution 	Federal Energy Commission Decrees No.681, 719, 768, 816, 890, 1000	<ul style="list-style-type: none"> Establish guidelines and operational rules for independent transmission organizations Improve the operation ability and market competition of wholesale electricity market Refine market pricing policies and procedures Optimization of transmission network open access control framework Improve transmission cost and cost allocation mechanism of power grid access

path choice to achieve the goal is very different, especially in the transmission management.

Operation of Transmission Network

The distribution of energy resources in China is unbalanced, and there is a large space gap between the power supply center and the power load center in China. This kind of spatial mismatch of power supply and demand objectively requires China to build cross regional UHV power grid. This has created conditions for the construction of the national unified power grid, and gradually formed the power grid pattern of UHV power transmission from west to East and north to south. In natural monopoly industries such as electric power, state-owned capital is dominant. In view of the disadvantages of domestic and foreign power systems in the decentralized management of transmission links, China has not implemented marketization in the transmission link. State Grid and China Southern Power Grid are the two central enterprises to manage and operate the transmission link, and the state-owned capital in the transmission link is centrally managed. Under this kind of management system, the power system puts more emphasis on the overall planning and operation stability. The control of state-owned capital also ensures that large-scale construction projects can get sufficient financial support, can realize the efficient allocation of cross regional power, and fully guarantees the integrity and stability of the power system. Under the public ownership, the power industry has made great achievements to meet the continuous and stable growth of power demand (Yu, 2014).

Transmission management in the United States is different from that in China. Its power system has four layers from top to bottom. The first layer is NERC, the second layer is FERC, the third layer is RTO and ISO, and the fourth layer is AEP. The transmission links in the United States are mainly managed by the third and fourth tier power companies. Under the privatization system, the United States has implemented the privatization of the whole process of power generation, transmission, distribution and sales, each power company is a local industry monopolist, and the power enterprises lack the overall dispatching. Due to the decentralization of transmission management functions and the lack of unified power transmission network, one of the hidden dangers is that in case of sudden power crisis, it is impossible to achieve timely and effective cross regional power allocation, which is unfavorable to the overall power stability of the country. In addition, because of the low return rate of power grid investment projects and long construction period, considering the return rate of investment, the private power companies are not willing to make large-scale investment in power grid construction, and even are not willing to upgrade the power grid. So the power supply system is facing a huge challenge of power supply reliability.

Supervision of Transmission Network

In terms of power regulation, after the first session of the 11th National People's Congress, the National Energy Commission, NEA and the Electricity Regulatory Commission are jointly responsible for China's power development planning and market operation regulation. In order to improve the

effectiveness of power regulation, in March 2013, the State Council integrated the functions of the former State Power Regulatory Commission into the NEA. Therefore, the national coverage of electric power supervision and unified electric power supervision standards are realized, which effectively avoids the overlapping of electric power supervision functions among different institutions, reduces the time lag of relevant policies in decision-making and implementation, improves the overall efficiency of electric power system.

However, the development process of power system in different regions of the United States is not the same. The power and obligation of power management in different departments are different, and the supervision mode of power wholesale market is also different. There are nine electricity markets in the United States. The management power of power transmission is distributed among RTO, ISO, and AEP, which are at the third and fourth levels of the United States power system. NERC and FERC, which are at a higher level of the power system, are mainly responsible for the work of macro nature, such as the formulation of power industry standards and the management of energy trade. The differentiation of power system regulators and their functions may lead to lack of supervision or overlapping of functions, which will have a negative impact on the efficiency of transmission management, increase the decision-making delay of relevant departments in case of transmission emergency, and may not be able to restore power transmission in time.

INSTITUTIONAL ADVANTAGES OF CHINA'S TRANSMISSION MANAGEMENT

Timely and Effective National Power Allocation

China can become one of the few countries in the world without large-scale blackouts for a long time. In 2018, China's average power supply reliability rate is 99.82%, the average outage time of users is 15.75 h per household, and the average outage frequency of users is 3.28 times per household. In the final analysis, it has a unified power grid management system, which makes the power grid planning, construction, operation, maintenance, dispatching and other links coordinate and operate efficiently, and ensures the long-term safe and stable operation of China's power system. In 2018, China's trans regional power transmission had reached to 136 million KW. Adhering to the integrated management of power grid is conducive to the optimal allocation of new energy in the whole country, the transformation of the energy resource advantages of the western region into economic advantages, and the promotion of the coordinated and balanced development of the national regional economy. Throughout history, in the process of dealing with major natural disasters, it is precisely because of the overall coordination of power grid management and dispatching that accidents can be timely and effectively handled, the losses caused by power accidents can be minimized, and the efficient post disaster reconstruction of power system can be guaranteed (She et al., 2020).

Concentrating Resources to Develop Large Power Projects

State Grid and its supporting facilities need to invest a lot of resources. Limited by their own resources, private enterprises are difficult to undertake the nationwide power grid construction. In addition, the profit orientation of private enterprises makes it difficult to maximize social benefits in the construction of power infrastructure. Therefore, in the important infrastructure construction related to the national economy and people's livelihood, the advantages of the Chinese government in concentrating on a large number of systems are fully reflected. Centralized management is conducive to the rational allocation of human, material, financial and intellectual resources, avoiding the negative impact of resource dispersion and excessive capital profit on social development under the privatization system, and improving the construction efficiency and social benefits of large-scale power projects to a large extent. In terms of the length of China's power grid lines, in 2018, the length of transmission lines with voltage level of 35 kV and above has reached 1.89 million kilometers, which is equivalent to 47 circles around the earth's equator, 291 times of that in the early days of China. In terms of power technology, the transmission line loss rate of power grid decreased from 23.35% in 1949 to 6.21% in 2018, and the coal consumption of power supply decreased from 1020 kgce/kwh in 1949 to 308 kgce/kwh in 2018.

CONCLUSION

After two effective power system reforms, China has basically achieved the vertical separation of power production, transmission and distribution, breaking the previous monopoly situation of the state power company on all aspects of power production, transmission and distribution, and making the power system more efficient. The centralized and unified management of transmission links and the market-oriented reform of both sides of power generation and distribution effectively realize the balance between power system security and efficiency. However, China still needs to further optimize its power system. Firstly, on the basis of centralized and unified management of transmission links, the competition of

different companies in generating and selling electricity is further standardized, so as to ensure the healthy development of power generation enterprises and the power accessibility of the public. Secondly, in terms of improving the functions of the power market, a complete power market integrating spot, long-term and auxiliary services should be established to reduce the impact of emergencies on the power system and improve the quality of power service supply. Thirdly, in terms of energy security, we should further optimize the power generation structure, reduce the dependence of China's power system on thermal power generation, increase the proportion of renewable energy power generation, reduce the potential safety hazard of single power generation mode to power stability, and fulfill China's international commitment of emission reduction and ecological environment protection.

AUTHOR CONTRIBUTIONS

WW: writing-original draft, methodology, and supervision. WZ: data curation, writing-review, and editing. LL: methodology, writing-review, and editing. ZC: conceptualization and software.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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