Mechanism and benefit analysis of resource optimal allocation of China's trans-provincial and trans-regional power trading

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Abstract. Trans-provincial and trans-regional power transactions can optimize the allocation of power resources in China, which has important value. However, due to the lack of in-depth and accurate understanding of the mechanism of resource optimal allocation of trans-provincial and trans-regional power trading, the application effect of trans-provincial and trans-regional power trading is not ideal. This paper analyzes the types and channels of trans-provincial and trans-regional power transactions, then analyzes the mechanism of resource optimization allocation of trans-provincial and trans-regional power transactions. Finally, taking the East China power grid as an example, the paper analyzes the benefits of the optimal allocation of trans-provincial and trans-regional power transaction resources.

1. Introduction
The reverse distribution of power resources and load in China determines the important value of trans-provincial and trans-regional power transactions in optimizing power resource allocation[1]. In recent years, China has increased the construction of western energy base on the one hand, on the other hand, it has increased the construction of trans-provincial and trans-regional power channels with the UHV power grid construction as the core[2]. The rapid growth of trans-provincial and trans-regional power trading volume has directly promoted the optimization of power production and consumption structure and the solution of the problem of abandoning light and wind[3].

However, due to the lack of accurate understanding of the mechanism of trans-provincial and trans-regional power trading promoting the optimal allocation of resources, the role of trans-provincial and trans-regional power trading in the general optimal allocation of resources is not enough, which leads to the insufficient utilization efficiency of power resources[4]. The phenomenon that the scale of trans-provincial and trans-regional power trade has increased significantly, while the amount of wind and electricity has been abandoned, and the channel utilization is insufficient also exists nationwide.

In view of the above problems, this paper analyses the transactions channels of trans-provincial and trans-regional power transactions based on the theory of optimal resource allocation with equal marginal substitution rate of economic factors; combined with the realization process of trans-provincial and trans-regional power transaction, the mechanism of resource optimization allocation of different kinds of power transactions is analysed and revealed; finally, taking the trans-provincial and trans-regional power transactions of China Central power grid as an example, the optimal allocation benefits of trans-provincial and trans-regional power resources are calculated and analysed.
2. Analysis of varieties and channels of trans-provincial and trans-regional power trading

2.1. Types of trans-provincial and trans-regional power trading

There is no unified standard for the classification of trans-provincial and trans-regional power trading varieties in China. Considering the actual situation of trans-provincial and trans-regional power trade[5], the classification of trans-provincial and trans-regional power trade in China is shown in Figure 1.

![Varieties of trans provincial and trans regional power trading](image)

Figure 1. Classification of trans-provincial and trans-regional power trade in China.

First of all, according to the classification of trading mechanism, China's trans-provincial and trans-regional trading can be divided into planned trading and market trading. At present, China's trans-provincial and trans-regional power trading is mainly planned trading, supplemented by market trading. According to statistics, in 2017, 776.8 billion kWh of electricity is planned to be traded trans-provincial and trans-regional, accounting for 72.2% of the total amount of trans-provincial and trans-regional transactions.

There are two kinds of planned transactions in the actual implementation, one is the nationally planned transaction, the other is the inter-provincial electricity transactions arranged by the two power grid companies using the UHV power grid transmission channel. There are two kinds of electricity market transactions, one is the medium and long-term market transactions. With the deepening of power market reform, the number of direct transactions dominated by power selling companies will increase significantly, and gradually realize network to network power transactions. In addition, contract transfer transactions will also develop rapidly in replacing the traditional way of administrative coordination.

The other is the temporary and short-term transaction, which mainly refers to the transactions between provincial power grid enterprises or between power generation enterprises and provincial power grid enterprises in the form of market competition to solve the problem of power shortage or potential water, wind, and light abandonment.

2.2. Trans-provincial and trans-regional power trading channels

2.2.1. Physical channel. Based on the consideration of channel constraints and security constraints, trans-provincial and trans-regional power transactions are transmitted by specific transmission lines. According to the different geographical locations and physical paths of the main power buyers and sellers, the physical channels of trans-provincial and trans-regional power transactions can be divided into special line transmission and cross-network transmission.

In reality, the physical channel of trans regional power transactions is often a complex combination of cross grid mode and special line mode. Taking the photoelectric transactions from Qinghai to Jiangsu as an example, the trading power is sent from Qinghai power grid to Shanxi power grid through the northwest power grid, then to Sichuan power grid through Debao DC line, and then to Jiangsu power grid through Jimping DC line. It realizes the trans-regional power transactions of northwest power transmission to East China.
2.2.2. Property rights channel. There are many market players in trans-provincial and trans-regional power trading. Under different types and modes of market trading, the market trading channels formed by trading players are relatively complex, as shown in Figure 2.

As shown in channel ①, in the trans-provincial and trans-regional power transaction, the subject of the transaction is the provincial power grid companies of the two places, while the power grid companies that do not do the subject of the transaction in the physical channel provide transmission services and charge transmission fees. It can be seen that the mode of taking power sales companies or large users as the main body of transactions in channel ② and ③ can not only reduce the transactions' links but also gradually transform the original "many to one" and "one to one" monopoly mode to "many to many" competition mode. The contract transfer transactions indicated by channel ④ is the improvement and supplement of direct transaction. Through the contract transfer transaction, the transactions and power supply risk brought by the power market reform will be significantly reduced.

3. Analysis of the mechanism of optimal allocation of trans-provincial and trans-regional power trading resources

3.1. Formation mechanism and benefit analysis of mutual standby

To ensure a safe and reliable power supply, the power system must retain a certain proportion of reserve capacity, such as 20%. In general, the peak load time of the two provinces is different, so the reserve capacity will be lower than the sum of the reserve capacity of the two provinces when the total maximum load of the two provinces is taken as the basis for backup.

The total economic benefit of mutual standby can be calculated by multiplying the total reserve capacity reduced by its reserve compensation. Take the electricity load of Hunan and Hubei Province on a certain day as an example, \( P_1 \) and \( P_2 \) are the maximum loads of the day in the two areas, so the total reserve capacity of the two places should be \( 0.2(P_1+P_2) \). Due to the overall load, \( P_1 \leq P_1 + P_2 \), The difference in reserve capacity due to alternate exchanges shall be \( 0.2(P_1 + P_2 - \max P_i) \), After the introduction of the standby compensation cost, the economic benefits are as follows: \( V_e = 0.2(P_1 + P_2 - \max P_i) \times P_b \), Where \( P_b \) is the average unit reserve compensation price of the two places.
3.2. Power substitution formation mechanism and benefit analysis

Power supply to replace mainly reflects in the outsourcing of hydropower, wind power, photovoltaic power generation and nuclear power instead of provincial thermal power electricity purchasing power, to realize low resource consumption and reduce environmental pollution, at the same time, considering our country existing renewable energy subsidies, renewable energy electricity market price is relatively low, so the power supply alternative trading with triple benefits of economy, resources, and environment.

(1) Economic benefit: The benefit can be measured by the difference between the transaction price and the on-grid price of coal-fired power purchased by the power purchasing power multiplied by the transaction amount of clean energy. The calculation formula is as follows:

\[ V_i = p_{jh} \times Q_i - p_j \times q_i \times (1 + \eta_j) \]  

Among them,

- \( p_j \) —— The electricity purchase price of trans-provincial and trans-regional electricity purchase transactions in the electricity purchase region;
- \( p_{jh} \) —— Thermal power feed-in price;
- \( \eta_j \) —— Line loss suggestions;
- \( q_i \) —— Of the electricity purchased, renewable energy electricity;

(2) Resource efficiency: by provincial thermal power instead of provincial thermal power, can result in resource savings, is its resource benefits:

\[ C_i = \mu_i \times Q_i \]

\[ \mu \] is the average unit coal consumption of thermal power units. When standard coal price is introduced, resource benefit can be transformed into an economic index for evaluation.

(3) Environmental benefits: Similarly, the reduction of greenhouse gas and environmental pollutant emissions due to the reduction of power generation by thermal power units is the environmental benefits generated by the transaction. Under the premise of known coal saving amount, the greenhouse gas and pollutant emission unit factor is multiplied by the coal saving amount to obtain the result:

\[ C_m = \theta_m \times C_i \]

\[ \theta_m \] is the emission coefficient of the \( m \) type of coal emission.

3.3. Formation mechanism and benefit analysis of replacing small with large

Through trans-provincial and trans-regional transactions, the units with low energy consumption and low cost in the same power supply type can generate more electricity, while the units with high energy consumption and high cost can generate less electricity. This way usually includes the benefits of economic, resource, and environmental triple resource allocation.

(1) Economic benefit: the calculation method is the same as that of the power substitute type.

(2) Resource benefit: resource benefit is the difference between the coal consumption of two units, that is, the replacement of local thermal power by outsourcing power can produce resource-saving quantity, that is, its resource benefit:

\[ C = Q_i \times \left( \mu_j - \eta_j \right) \times \mu_i \]

\( \mu \) is the average unit coal consumption of a thermal power unit in a province.

(3) Environmental benefits: based on the resource benefits generated by the transactions and the number of greenhouse gases and pollutants emitted per unit of standard coal, the environmental benefits generated by the transactions can be obtained.

3.4. Formation mechanism and benefit analysis of mutual protection and mutual aid

Mutual protection and mutual aid can design a transactions portfolio with time constraints according to the time characteristics of each type of power generation, which not only realizes the optimal allocation of resources from the perspective of space but also improves the utilization efficiency of resources from the perspective of time. Mutual protection and mutual aid have realized the triple benefits of economy, resources, and environment in the optimal allocation of resources.
In terms of benefit measurement, the benefits of mutual protection and mutual aid are calculated and accumulated according to the rules of "power substitution" and "replacing small with large" respectively. At the same time, due to avoiding the waste of surplus power, they should be included in the resource benefits according to the principle of "solving surplus and deficiency".

4. Numerical examples
Taking the inter-provincial and inter-regional power transactions of Central China Power Grid in 2017 as an example, the benefits of resource optimal allocation of different transaction types are calculated and analysed.

4.1. Calculation results
Table 1. Trans-provincial and trans-regional power transactions efficiency measurement of Central China Power Grid in 2017.

| Configuration mode                  | Trading quantity (thousand kWh) | Economic benefit (thousand yuan) | Environmental benefit (thousand yuan) |
|-------------------------------------|---------------------------------|----------------------------------|--------------------------------------|
| The power supply to replace         | 174392859.2                     | 40318427.7                       | 27785491.1                           |
| With large generation of small      | 3159487.4                       | 165291.9                         | 4693.3                               |
| Mutual insurance in all aid         | 2723117.9                       | 680854.2                         | 459117.7                             |
| To solve the surplus and deficiency |                                 |                                  |                                      |
| Avoid abandoned electric            | 646733.1                        | 153487.0                         | 233704.1                             |
| Avoid the lack of electricity       | 353605.0                        | -1129.3                          | 198.7                                |
| Total                               | 181275802.7                     | 41316931.5                       | 28483204.9                           |

| Configuration mode                  | Safety benefit (thousand yuan)  | Comprehensive benefit (ten thousand yuan) | Benefit per unit (yuan/kWh) |
|-------------------------------------|--------------------------------|-------------------------------------------|----------------------------|
| The power supply to replace         | 55337584.0                     | 0.0                                       | 123441502.9               |
| With large generation of small      | 9347.2                         | 0.0                                       | 179332.4                  |
| Mutual insurance in all aid         | 914378.8                       | 0.0                                       | 2054350.6                 |
| To solve the surplus and deficiency |                                 |                                          |                          |
| Avoid abandoned electric            | 246479.4                       | 0.0                                       | 633670.6                  |
| Avoid the lack of electricity       | 395.8                          | 2475235.0                                 | 2474700.2                 |
| Total                               | 56508185.1                     | 2475235.0                                 | 128783556.6               |

4.2. Result Analysis
The power substitution transaction, which mainly absorbed the southwest hydropower, is the main source of the benefits of the optimal resource allocation in Central China, accounting for 95.85% of the total benefits. The second is the mutual insurance and mutual aid transactions, accounting for 1.60%. Although the large generation and small generation transactions account for 1.74% of the transaction size, the benefit ratio is only 0.14%. Trans-provincial and trans-regional power trading based on surplus and shortage problems have the highest unit benefit and the smallest transactions scale, so it should give priority to ensuring power supply safety and resource utilization, but should not be the main goal of trans-provincial and trans-regional power trading.

5. Conclusion
At present, there is a lack of scientific analysis on the mechanism of optimal allocation of resources in China's trans-provincial and trans-regional power trading system and related policies. The electric power
trading system mainly emphasizes the ways of avoiding power shortage and abandonment, and relatively ignores the other four ways. To a certain extent, this affects the development of trans-provincial and trans-regional power trading and is also the deep-seated reason for a large amount of abandoned wind, light and water, and the insufficient utilization of transmission channels. The example calculation results of the central China Power Grid show that the comprehensive benefits of the other four methods are greater. In order to play the role of the other four ways of resource allocation, the key is to establish a sharing mechanism of comprehensive benefits of resource allocation based on property rights channels.

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