



The Balance Groups Mechanism for Improving the Operational Efficiency of Power System

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Abstract

The electricity market is of great significance for effectively balancing electricity supply and demand, promoting the consumption and utilization of new energy, and optimizing the allocation of electricity resources. It is a key carrier for the transition to clean and low-carbon energy system. This paper focuses on the research of the electricity spot market mechanism based on balance groups (BG). It analyzes the current development status of electricity spot markets in typical regions both at home and abroad. Considering the widespread participation of diverse market players such as distributed power supplies, energy storage systems, and virtual power plants, it designs a market operation mode and trading mechanism based on BG, and conducts example analysis based on actual operation data from power grids in typical regions. The research results show that the BG mechanism has significant advantages in reducing system operating costs and improving system operating efficiency, thus providing new ideas and methods for building a power grid that adapts to a high proportion of new energy access.

Keywords: New energy consumption; Spot market; Balance groups; Trading mechanism.

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1. Introduction

As we all know, there is a significant risk of decline in the utilization rate of new energy in China, due to the rapid development of new energy in different regions. By the end of 2023, China's installed capacity of wind and solar new energy reached 1.05 billion KW, accounting for approximately 36% of the total installed capacity; the power generation amounted to 1.43 trillion kWh, accounting for about 15.8% of the total electricity consumption of the entire society. It is expected that by 2030, the total installed capacity and power generation of new energy in China will reach 2.62 billion KW and 3.57 trillion kWh, accounting for 49% and 27% respectively. New energy will gradually become the main source of the power system in the future.^[1]

According to typical experiences from the international energy transition to clean and low-carbon energy, establishing a comprehensive electricity market system plays a crucial role in eliminating the uncertainties associated with high proportions of new energy sources. Currently, experts and

scholars are conducting in-depth research on the operation mechanisms of mainstream electricity markets in the United States, Europe and China, and analyzing the operation models and trading mechanisms of spot markets.^[2] Among them, the Pennsylvania-Jersey-Maryland(PJM) market in the United States and the National Electricity Market (NEM) in Australia adopt a combination of real-time clearing and post settlement to eliminate the deviation in electricity quantity; The Regulation Power Market (RPM) of Nord Pool in Northern Europe,^[3] the Energy Imbalance Market (EIM) of CAISO in the United States, and the Balancing Mechanism (BM) of the electricity market in the United Kingdom are specifically designed to eliminate the deviation in electricity quantity through balancing markets.^[4] The previous research provides a detailed explanation of the background and operation mode of the German BG mechanism, and analyze it for reference value. In the German balancing market, the two-part bidding mechanism integrating capacity and electricity, as well as the unified price settlement method, can help improve the enthusiasm of market players.^[5-6] Some scholars focus on the imbalance electricity market in the UK, exploring the impact of seasonal factors on electricity balancing market prices. It proposes a BiLSTM model for predicting price imbalances, which effectively improves prediction accuracy.^[7] The previous research proposes a balancing market design system

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with three levels of indicators, including planning, operation, and settlement. It measures the market conditions, performance, and development of the European electricity market, indicating that factors such as the time scale and settlement methods of the balancing market have a significant impact on the incentives for power producers.^[8] Some scholars analyze the impact of a high proportion of wind and solar power on the mechanisms generating electricity price imbalance in the European balancing market. It also suggests that imbalance electricity price in the balancing market provide favorable support for the participation of flexible resources such as adjustable load and energy storage.^[9] The previous research finds that the Paraguayan company can improve the benefits of Paraguay's energy surplus in terms of income by installing an electricity marketer in Brazil.^[10] Some scholars point that the energy and electricity imbalance problem caused by uncertainty in demand response, and constructs a hierarchical autonomous electricity market balance model with energy autonomous units, achieving self-dispatching and self-balancing capabilities of energy and providing an effective path for multiple resources to participate in the electricity market.^[11] The risks faced by balance of electricity and energy in high-proportion new energy systems was analyzed based on actual operational data and historical statistical data from the northwest region's power grid. It establishes a market mechanism aimed at achieving regional supply and demand balance and proposes measures for balance of electricity and energy that take into account reliable electricity supply and efficient consumption of new energy.^[12] Some scholars analyze the causes of medium- and long-term monthly energy deviations and proposes three strategies for a monthly balance mechanism to eliminate these deviations. It also conducts a simulation example study to analyze the characteristics and adaptability of different methods.^[13] The previous research analyzes the generation mechanism of different imbalance costs and organizes the composition and allocation mechanism of imbalance costs that are applicable to China's current development situation.^[14] It can provide a reference for the design of settlement rules and market mechanism of the electricity spot market. However, there is still a lack of a balanced market mechanism at the distribution network at present, that can adapt to the coordinated participation of multiple types of new market entities. The traditional peak and valley time-of-use tariff mechanism with higher rates during the day and lower rates at night, making it difficult to align with the current situation of electricity supply and demand and the new energy consumption. Since the spot market in China has not yet been fully operational, the scale and variety of ancillary service markets are limited, it is difficult to fairly and reasonably transmit the costs of system adjustment.

Gradually optimizing and improving the electricity pricing mechanism, constructing an electricity market system that accommodates the extensive participation of diverse players, and enhancing the new energy consumption capacity will

become important directions for China's power system transition to low-carbon energy.^[15] This paper, based on the balancing market mechanisms in countries such as Europe and the United States, takes into account China's current supply-demand situation, source-load structure, and the current operation of the electricity market. It proposes a spot market trading framework and collaborative methods for diverse market players that are adapted to the development of high proportions of new energy, aiming to promote the efficient consumption of new energy and reduce the overall operating costs of the system.

2. Current situation of spot market trading mode

2.1 European BG market mechanism

In recent years, the proportion of new energy in Europe has been increasing year by year. To support the grid connection of a high proportion of new energy and ensure the balance between electricity supply and demand, Germany pioneered the electricity and energy balance model centered on Balance Groups (BG) in 1999, while the United Kingdom established the Balancing Mechanism (BM) in 2011. By the end of 2023, the proportion of new energy generation in Germany had approached 60%. However, the required capacity for balancing resources has been decreasing year by year, and the success of energy transition in Germany is closely linked to its BG mechanism.

BG is a virtual basic unit for grid regulation and market trading in the German power system. Each BG has a balance responsible party (BRP) that is responsible for the supply and demand balance within its scope. BRP can be a power producer, large user, as well as electricity sales companies, virtual power plant, and other market player. BRP possesses metering equipment for generation and consumption, as well as control measures. It is responsible for forecasting the generation and consumption within BG and reporting the forecast results and power market trading plans to the Transmission System Operator (TSO). When there is a deviation between the actual generation and load within the BG and the planned values, BRP can adjust internal power output and consumption load, or call upon flexible resources to achieve supply-demand balance. If balance fails to be achieved in this way, BRP must engage in the spot market to buy or sell capacity or energy from a Balance Service Provider (BSP) to maintain supply-demand balance.

Compared to Germany, the proportion of new energy installed capacity in the UK is relatively low, and its electricity market primarily focuses on medium- and long-term trading, with spot trading as a supplement. The UK has Balancing Mechanism Unit (BMU) as market players, which respond to calls from the Electricity System Operator (ESO). In the UK electricity spot market, the responsible party for balance remains the ESO. When there is an imbalance in power supply, ESO achieves power balance by adjusting the source-load characteristics of BMU or purchasing balancing resources.

2.2 Market construction in China

The Chinese electricity market is primarily based on medium- and long-term market transactions. Through a deviation handling mechanism for medium- and long-term contracts, it effectively guides market players to reduce deviations and actively provides imbalance services to ensure the stable operation of the market. Since 2017, China has accelerated the reform of electricity marketization, and gradually launched eight pilot projects for the construction of spot markets. These pilots explore different market models, pricing rules, clearing models, and price mechanisms. As of the end of 2023, the number of regions that have started trial operations of the electricity spot market has reached 29.^[16] Among them, Shanxi is the first provincial-level electricity market in China to operate formally, while provinces such as Guangdong and Shandong have adopted advanced electricity market operation mechanisms and achieved significant implementation effects. In terms of pricing methods, Shanxi has developed differentiated pricing approaches for different market players. New energy enterprises are prioritized for power generation through the "declared quantity not quoted" mode. New market players such as energy storage systems and virtual power plants can participate in transactions using either the "quotation offer" or "declared quantity not quoted" modes, and users are encouraged to actively engage with adjustable resources on the user side. The electricity spot markets in Guangdong and Shandong adopt the mode of "quotation offer on the generation side and declared quantity not quoted on the user side," which helps to ensure the stability of market prices. In terms of clearing modes, the Shanxi power grid adopts a segmented pricing and centralized optimization clearing approach, which helps to better reflect the supply-demand relationship. Guangdong Power Grid employs a nodal price clearing mechanism, which effectively reflects the cost differences resulting from transmission congestion in various geographical locations. Shandong Power Grid utilizes a price difference settlement model to mitigate market risks and ensure the safe operation of the power grid.

Due to significant differences in electricity market mechanisms, it is challenging to directly apply the European electricity market mechanism. Some scholars have suggested implementing pilot projects for balance groups (BGs) in prefectural areas, with regional power grid dispatch serving as the responsible party for balance. They recommend continuously improving the spot market trading system, formulating reasonable methods for sharing balance responsibilities, and establishing imbalance settlement reward and penalty mechanisms to encourage broader participation in market trading by the responsible party for balance.^[17] By integrating regional markets, the capacity for cross-regional electricity mutual assistance can be strengthened, reserve demand can be reduced, and resource allocation efficiency can be enhanced.^[18] Based on the current trading structure of China's spot market and incorporating elements from the European BG mechanism, developing a market mechanism

that accommodates multiple market players can effectively enhance the overall operational efficiency of the system.

3. Trading framework for spot markets based on balance groups

3.1 Operation mode of electricity spot market based on balance groups

To establish a mechanism for balancing electricity and energy in China, it is essential to gradually develop this system based on existing mechanisms. The ultimate goal is to guide market players in assuming balancing responsibilities and to reduce the demand for system balance by creating an integrated market mechanism.^[19-23] In the BG trading mode, city and county-level power grid dispatch departments can function as TSOs. They organize various market players, including power sources, user loads, independent energy storage, virtual power plants, and microgrids, to engage in trading. TSOs utilize input information such as the next day's system load prediction curve, user-side declaration curve, interconnection line power transmission plan, each unit bidding, unit operating parameters, and line operating parameters. The primary goal is to minimize the total power generation cost across the entire grid. To achieve this, the operator must consider unit operating constraints, including maximum and minimum output and ramp-up limits, as well as grid operating constraints, such as line flow and area reserve requirements. The operator employs the Security Constrained Economic Dispatch (SCED) program for optimization calculations, resulting in clearing results for spot market trading. These results include unit start-stop plans, output curves, and nodal prices.

The Balance Group Responsible Party (BRP) is primarily responsible for predicting power generation and consumption within its management scope. It optimizes the operating characteristics of local conventional power and energy storage and reports the results to the TSO. In the event of an energy imbalance, TSOs can flexibly adjust the BRP's internal resources or purchase balancing resources through the spot market to achieve supply-demand balance in the electricity system. Balancing Service Providers (BSPs) supply balancing resources to TSOs and BRPs to address imbalances. These resources include energy, ancillary services, and reserve capacities. Electric energy resources are flexible resources that track the changes in supply and demand conditions by adjusting output to support the balance of electricity and energy in the system, involving both supply-side generating units and demand-side flexible resources. Regulation ancillary services include primary and secondary frequency regulation, which are necessary for maintaining frequency stability within the system. Reserves refer to backup power energy resources provided to the TSO to ensure the stability of the electricity system (see Fig. 1).

Based on the spot market trading system, a two-tier trading mode consisting of day-ahead and real-time trading is implemented. In the day-ahead market, the TSO first coordinates various energy sources, loads, and storage

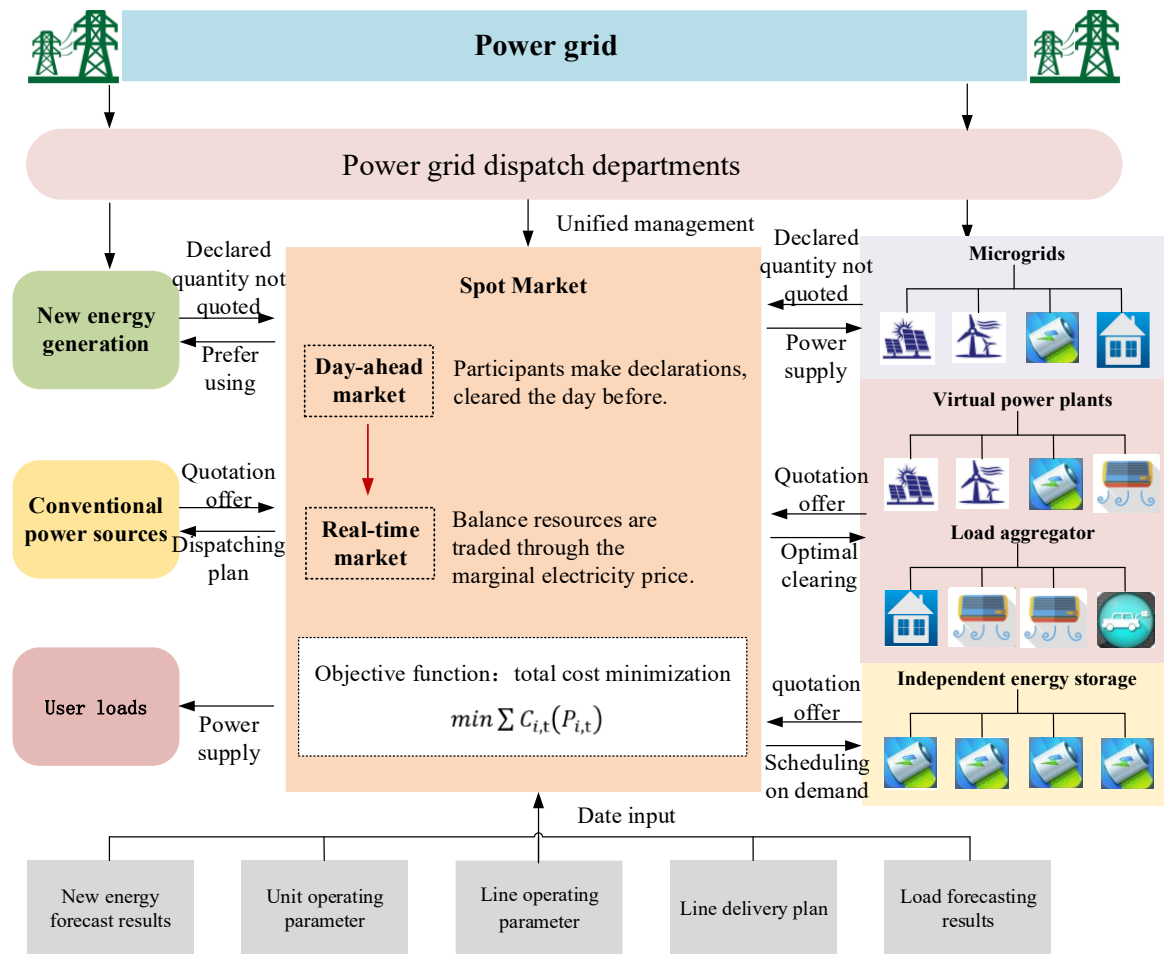


Fig. 1: Operation Architecture of Spot Market Based on BGs.

resources within the region. The TSO predicts the output characteristics and electricity load patterns of new energy sources, such as wind and solar power, for the next day. It then makes informed arrangements for the startup of conventional power sources and the charging and discharging plans of energy storage systems. To maintain a balance of electricity and energy, the TSO assesses the demand for reserve capacity for the next day. It organizes various flexible resources within the region and uses a "quotation offer" method to facilitate spot market trading. Based on the declaration results, the TSO will screen and sort the balancing resources according to their marginal capacity prices, determining which reserve units will

participate in the real-time market the following day for dispatching and allocation. In the real-time market, the TSO perceives the operating status of the system's sources, loads, and storage resources, making ongoing adjustments to the demand for balancing resources. When an imbalance occurs between supply and demand, the TSO dispatches and allocates reserve balancing resources in the market based on the actual differences in electricity generation and consumption while adhering to operational security constraints. The TSO clears these resources according to the marginal electricity price and fairly allocates the costs of balancing resources based on the supply and demand conditions of each BRP (see Fig. 2).

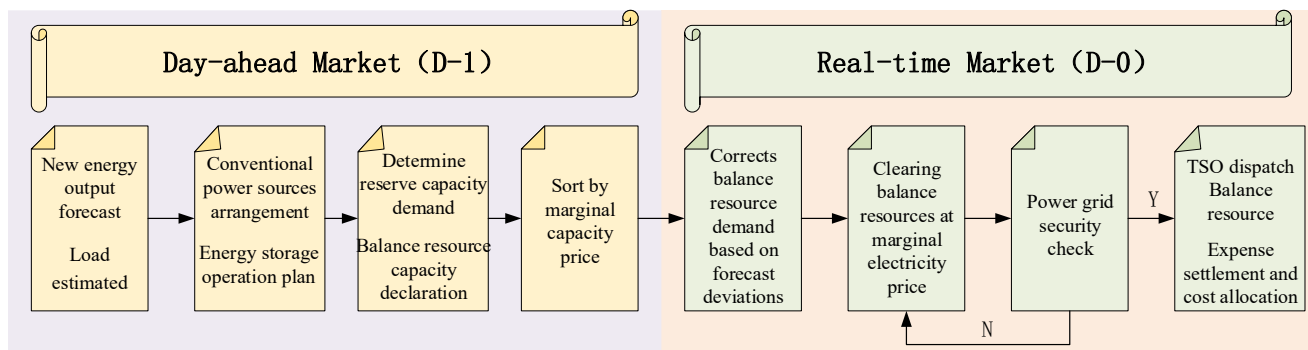


Fig. 2: Day-ahead - Real Time Two-Tier Spot Market Trading Process.

3.2 Cost-benefit model for participants in the spot market

The main participants in the spot market include the TSO, BRP, and BSP. Various resource aggregates, such as small conventional units, distributed new energy sources, microgrids, virtual power plants, and load aggregators, can participate in electricity spot market trading as BRPs. Independent energy storage systems, virtual power plants, and load aggregators can act as BSPs, aggregating flexible resources on the demand side and providing support for system electricity and energy balance through spot market trading. Below, we outline the cost-benefit models for the various market roles.

As the TSO, the power grid dispatch department is responsible for the unified dispatch and management of various balance groups within the local area. It organizes different market entities to engage in spot market trading via the trading platform. The total revenue of the dispatch department includes electricity fees from supplying electricity to users. The total costs include the on-grid costs of internal power generation units and the expenses incurred from purchasing balancing resources through market-oriented mechanisms. The cost-benefit model for the power grid dispatch department is shown in Eq. (1) - (3):

$$C_{TSO} = \sum_{i=1} C_{L,i} - \sum_{i=1} C_{G,i} - C_{BSP} \quad (1)$$

$$C_{L,i} = Q_{L,v}P_{L,v} + Q_{L,f}P_{L,f} + Q_{L,p}P_{L,p} \quad (2)$$

$$C_{G,i} = Q_{G,v}P_{G,v} + Q_{G,f}P_{G,f} + Q_{G,p}P_{G,p} \quad (3)$$

where, $C_{L,i}$ is the cost of electricity consumption of the i th user, $C_{G,i}$ is the generation cost of the i th power source, and C_{BSP} is the total settlement cost of balancing resources. $Q_{L,v}, Q_{L,f}, Q_{L,p}$ are electricity consumption of users during peak, shoulder, peak, and off-peak periods, $P_{L,v}, P_{L,f}, P_{L,p}$ are unit electricity prices during peak, shoulder, peak, and off-peak periods. $Q_{G,v}, Q_{G,f}, Q_{G,p}$ are electricity generation during peak, shoulder, peak, and off-peak periods, $P_{G,v}, P_{G,f}, P_{G,p}$ are unit electricity prices for generation during peak, shoulder, peak, and off-peak periods.

The BRP is responsible for predicting the internal source, load and output status of its balance groups, arranging power generation efficiently, and engaging in electricity purchase or sales through market-oriented means to maintain the supply-demand balance. Its cost-benefit model is shown in Eq. (4) - (6):

$$C_{BRP} = \sum_{i=1} C_{L,i} + \sum_{t=1} C_{ex,t} - \sum_{i=1} C_{G,i} - \sum_{t=1} C_{R,t} \quad (4)$$

$$C_{ex} = Q_{ex}M_{ex} \quad (5)$$

$$C_R = Q_R M_{R,t} + P_{R,max} M_d \quad (6)$$

where, C_{BRP} is the total revenue of BGs, $C_{ex,t}$ is the income from energy exchange between BGs at the moment of t , Q_{ex}

is the net energy exchange, M_{ex} is the unit revenue of energy exchange. $C_{R,t}$ is the expenditure of external balancing resources purchased by BGs at the moment of t , Q_R is the total purchased energy of balancing resources for the day, $P_{R,max}$ is the maximum reserve capacity provided for the system on the day, $M_{R,t}$ is the unit marginal electricity price for providing balancing resources at the moment of t , M_d is the unit marginal price of reserve capacity.

The BSP aggregates and manages various flexible resources, such as power sources, adjustable loads, and energy storage, to support the balance of system supply and demand. It aims to obtain benefits through market-oriented means. The cost-benefit model is shown in Eq. (7) - (8):

$$C_{BSP} = \sum Q_S M_{S,t} + P_{S,max} M_d - C_e^{BSP} \quad (7)$$

$$C_e^{BSP} = \sum (Q_{G,i}^{BSP}) C_{G,i} + \sum (Q_{L,i}^{BSP}) C_{L,i} \quad (8)$$

where, C_{BSP} is the total revenue of BSP, Q_S is the total balancing resources provided for the day, $P_{S,max}$ is the maximum capacity provided for the day, $M_{S,t}$ is the unit marginal price of balancing resources provided at the moment of t , M_d is the unit marginal price of reserve capacity; C_e^{BSP} is the incentive cost for internal entities of BSP, $Q_{G,i}^{BSP}, C_{G,i}$ are the balancing energy and unit cost provided by various internal power sources, $Q_{L,i}^{BSP}, C_{L,i}$ is the balancing resource scale and unit cost provided by adjustable loads.

3.3 Collaborative optimization method for multiple market players

As digital and intelligent applications in the power grid continue to advance, microgrids, virtual power plants, and load aggregators are thriving, presenting new challenges to the balancing mode of the electricity system. While some electricity spot markets have established access conditions and trading rules that allow new market players to participate—such as through the "declared quantity not quoted" method—the overall participation of demand-side resources remains relatively limited. As a result, the full potential of market players has yet to be realized.

To promote the long-term stable development of the electricity market, it is increasingly important to coordinate the interests of various market players across the source, grid, load, and storage sectors. There is an urgent need to establish a flexible trading model and a reasonable cost-return mechanism for the electricity market. The BG model can facilitate the broader participation of new players, such as independent energy storage systems, virtual power plants, and microgrids. This approach aims to enhance the collaborative optimization of source, grid, load, and storage sectors, as well as improve the interconnection and mutual assistance capabilities of regional power grids. By ensuring a balance between supply and demand in the electricity system, it effectively promotes new energy consumption and

optimizes resource allocation.

In the BG model, the TSO manages electricity spot market trading to optimize the overall costs for multiple market players. The objective function for operation optimization is shown in Eq. (9).

$$C_g = \min \sum C_{i,t}(P_{i,t}^G) \quad (9)$$

where, C_g is the total cost of power generation, $C_{i,t}$ is the unit

cost of power generation of i th unit at the moment of t , $P_{i,t}^G$ is the power generation of i th unit at the moment of t .

To further reflect the cost difference among different units and the supply-demand situation of the power grid in different regions, the nodal pricing method is applied for clearing and settlement. Nodal price, based on the power output cost per unit, is subject to the system balance constraints, power output constraints and network congestion. Its objective function is shown in Eq. (10)-(11):

$$L(G, MCP, \lambda_{i,max}^G, \lambda_{i,min}^G, \lambda_{k,max}^S, \lambda_{k,min}^S) \quad (10)$$

$$= \sum_{i \in G} C_i(P_i^G) - MCP \left(\sum_{i \in G} P_i^G - \sum_{j \in L} P_j^L - \sum_{k \in S} P_k^S \right) - \sum_{i \in G} \lambda_{i,max}^G * (P_{i,max}^G - P_i^G) - \sum_{i \in G} \lambda_{i,min}^G * (P_i^G - P_{i,min}^G) - \sum_{k \in S} \lambda_{k,max}^S * (Z_{k,max}^S - Z_k^S) - \sum_{k \in S} \lambda_{k,min}^S * (Z_k^S - Z_{k,min}^S)$$

$$\rho_l = MCP \left(1 - \frac{\partial \sum P_k^S}{\partial P_i^G} \right) - \left(\sum_{k \in S} \lambda_{k,max}^S * \frac{\partial Z_k^S}{\partial P_i^G} - \sum_{k \in S} \lambda_{k,min}^S * \frac{\partial Z_k^S}{\partial P_i^G} \right) \quad (11)$$

where: ρ_l is the nodal price; MCP is the Lagrange multiplier of the system supply-demand balance equation; $\lambda_{i,max}^G$ and $\lambda_{i,min}^G$ are the Lagrange multipliers of the maximum and minimum output constraints of the i th unit, respectively; and $\lambda_{k,max}^S$ and $\lambda_{k,min}^S$ are the Lagrange multipliers of the maximum transmission capacity constraints of the k th line, respectively.

The system constraints include system balance constraints, power output constraints, line power flow constraints, etc.

1) System balance constraints: The balance unit should always maintain a balance between supply and demand. The total power generation of each balance unit plus the total injection of each line should be equal to the total power consumption load plus the total network loss of the system. Eq. (12)

$$\sum P_{i,t}^G + \sum Z_{k,t} = \sum P_{j,t}^L + \sum P_{k,t}^S \quad (12)$$

2) Power generation capacity constraint: The power output of each power source in the balancing unit should meet the upper and lower limit constraints of its rated output. Eq. (13) and Eq. (14)

$$P_{i,min}^C \leq P_{i,t}^C \leq P_{i,max}^C \quad (13)$$

$$0 \leq P_{i,t}^{DG} \leq P_{i,max}^{DG} \quad (14)$$

where: $P_{i,t}^C$ is the conventional power output of the system at time t ; $P_{i,max}^C$ and $P_{i,min}^C$ are the maximum and minimum conventional power output of the system; $P_{i,t}^{DG}$ is the distributed power output of the system at time t ; and $P_{i,max}^{DG}$ is the maximum distributed power output of the system.

3) Line power flow constraints: The power transmission of each line should not exceed the maximum transmission

capacity of that line. Eq. (15) and Eq. (16)

$$-Z_{k,max}^{TSO,in} \leq Z_{k,t}^{TSO,in} \leq Z_{k,max}^{TSO,in} \quad (15)$$

$$-Z_{k,max}^{BRP,in} \leq Z_{k,t}^{BRP,in} \leq Z_{k,max}^{BRP,in} \quad (16)$$

where: $Z_{k,t}^{TSO,in}$ is the power delivered to the TSO from the higher grid by k lines at time t ; $Z_{k,max}^{TSO,in}$ is the maximum power delivered by k lines; $Z_{k,t}^{BRP,in}$ is the power delivered to the balance groups by k lines at time t ; and $Z_{k,max}^{BRP,in}$ is the maximum power delivered by k th line.

4. Example analysis

4.1 Basic parameter setting

The IEEE42 node system is employed. It has a maximum annual load of 3,000MW and an installed capacity of 4,500MW, including 1,000MW of PV power, 1,200MW of wind power and 1,400MW of thermal power. The minimum operating output reaches 50% of the rated installed capacity. This system contains three balance groups BRP-A, BRP-B and BRP-C. There are five thermal power units (G1-G5), five wind power units (W1-W5), six PV power units (P1-P6) distributed in the system, and three power transmission lines connecting each BRP (Line1-Line3), as shown in Fig. 3. The rated installed capacity and unit generation cost of various power generation units are shown in Table 1. The examples compare and analyze the advantages of the BG market mode in new energy consumption level and the overall operation efficiency of the system by using the typical day with maximum new energy output hours and the typical day with maximum load, and utilizing the traditional dispatching mode and the BG market mode.

There are three BSPs in the region, *i.e.* A, B and C, which

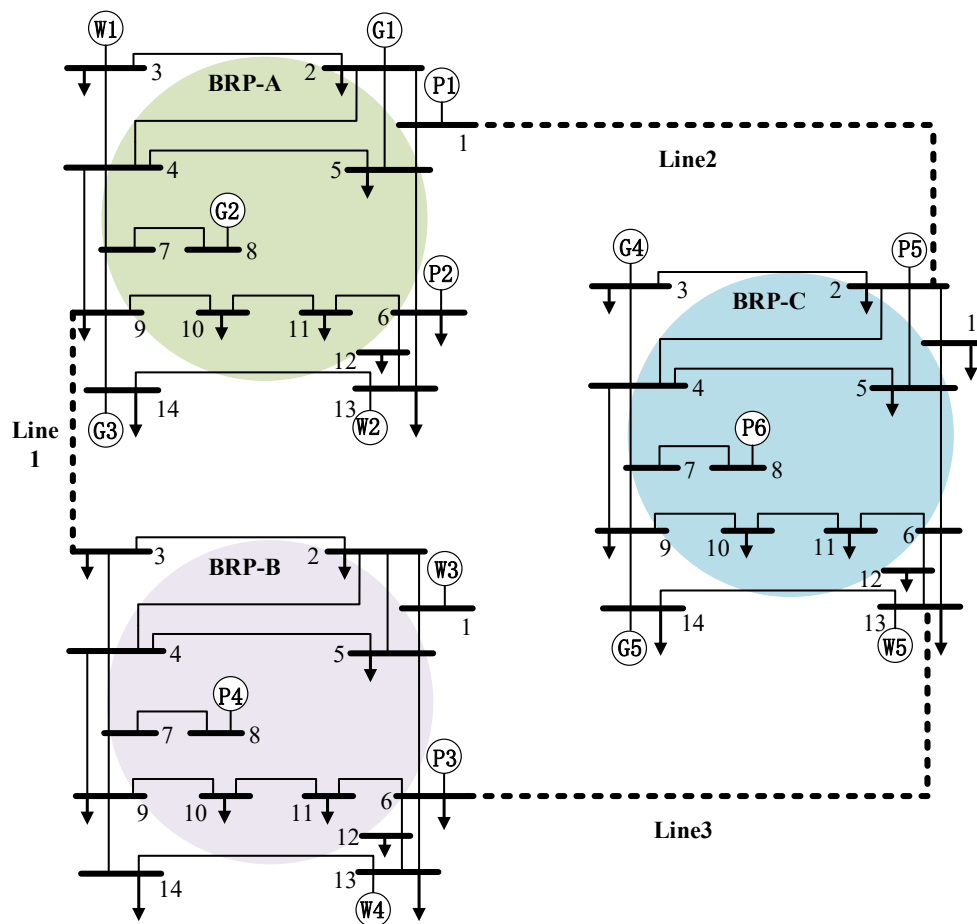


Fig. 3: Diagram of IEEE42 Node System Architecture.

Table 1: Rated Installed Capacity and Unit Generation Cost of Various Power Generation Units.

BG	Unit No.	Type of Power Supply	Installed Capacity (MW)	Cost of Energy (RMB/kWh)
BRP-A	G1	Thermal	400	0.46
	G2	Thermal	400	0.46
	G3	Thermal	200	0.46
	W1	Wind	300	0.39
	W2	Wind	300	0.39
	P1	PV	300	0.39
	P2	PV	300	0.39
BRP-B	W3	Wind	240	0.39
	W4	Wind	240	0.39
	P3	PV	100	0.39
	P4	PV	100	0.39
BRP-C	G4	Thermal	200	0.46
	G5	Thermal	200	0.46
	W5	Wind	240	0.39
	P5	PV	200	0.39
	P6	PV	200	0.39

offer three bands of prices from low to high based on their own balancing regulation costs. See Table 2 for the declaration data from the balancing capacity suppliers.

The real-time market usually determines the clearing order of BSPs based on the price of regulated capacity. During actual

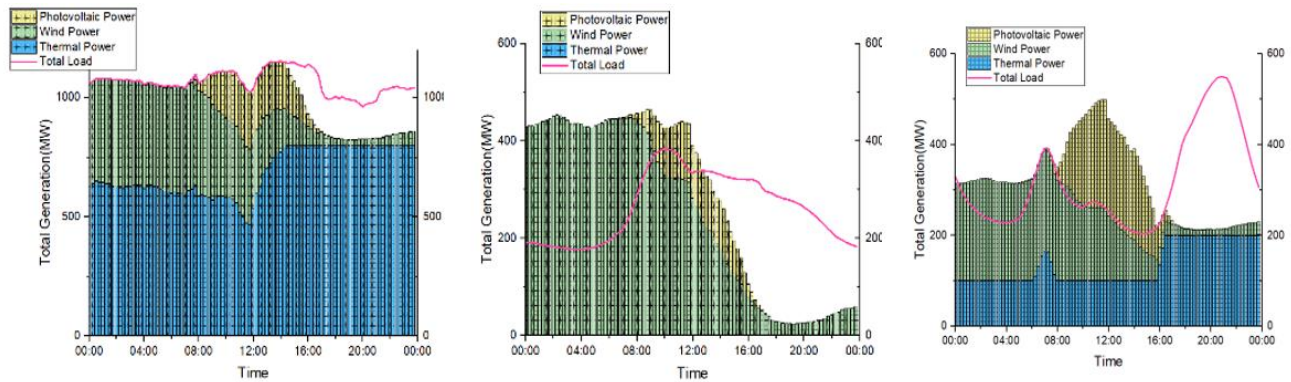
dispatching, the priority of cleared suppliers is decided according to the energy price.

4.2 Typical day with maximum new energy output hours

The system power output and electrical load data of a typical

Table 2: Declaration Data of BSP (RMB/kW, RMB/kWh, MW).

Supplier	1st Band			2nd Band			3rd Band		
	Capacity Price	Energy Price	Declared Capacity	Capacity Price	Energy Price	Declared Capacity	Capacity Price	Energy Price	Declared Capacity
BSP-A	8	4	100	12	5	50	16	6	100
BSP-B	10	3	50	12	4	100	14	5	50
BSP-C	12	3	100	14	4	150	16	5	100



(a) Supply and Demand Situation of BRP1

(b) Supply and Demand Situation of BRP2

(c) Supply and Demand Situation of BRP3

Fig. 4: Supply and Demand Situation of BRPs on the Typical Day with Maximum New Energy Output.

day with maximum new energy output hours are selected. In scenario 1-1, by using the unified dispatching operation mode and the clearing method of two-part price and marginal cost, the TSO purchases the corresponding balancing resources from the BSPs to achieve the system supply-demand balance. Based on the system 24-hour supply-demand curve and the offer from the BSPs, the maximum imbalance capacity on the same day is 700MW, the marginal capacity price is RMB 16/kW, and the total capacity balancing expenditure is RMB 11.20 million. In scenario 1-2, the BG market mode is applied. The BG supply and demand situation is obtained, as shown in Fig. 4, based on the internal power output and load curve of three BGs.

From the supply and demand situation of BGs on a typical day with maximum new energy output hours, during the maximum output period from 0:00-14:00, the wind power output remains high, which can fully cover the load demand of sub-systems, and the BRP2 and BRP3, which account for a high proportion of installed capacity for new energy generation, are in the state of power surplus, requiring curtailment of wind and PV power for the purpose of the regional supply-demand balance; after 15:00, new energy output declines significantly, and all systems are in a state of power shortage.

In the BG market operation mode, considering the power mutual support among three BGs, the BRP firstly takes into calculate the supply-demand balance by reducing the thermal power output in case of power surplus, and if the power surplus continues to exist, curtailment of wind and PV power should be implemented; in case of power shortage, the BRP purchases the corresponding balancing resources from the

BSP in the balancing resource market to achieve the power balance, and the marginal capacity price and the energy price for clearing the balancing resources are calculated according to the total demand of three BGs at that moment. See Fig. 5 for new energy power curtailment in two scenarios.

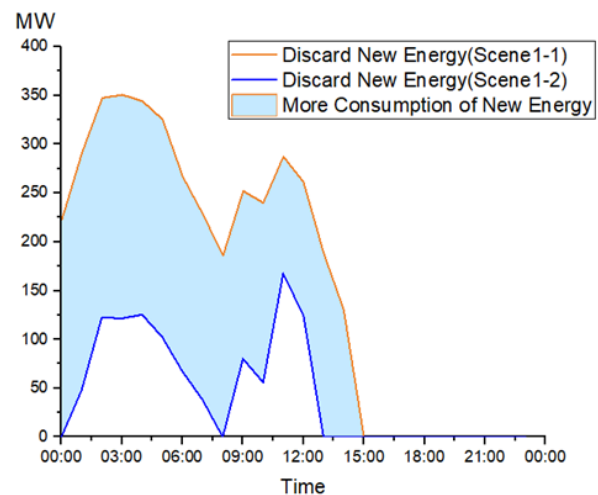


Fig. 5: New Energy Consumption Improvement Effect.

See Fig. 6 for the total system balancing cost in scenario 1-1, the total system balancing cost in scenario 1-2, and the balancing costs of BGs.

The analysis reveals that during the 0:00-15:00 period, all BRPs experience power surplus, resulting in minimal electricity exchange between BRPs, mainly consisting of new energy power, which can significantly reduce the curtailment of new energy power, but has little impact on the system cost. From 15:00 to 17:00, the renewable energy output experiences

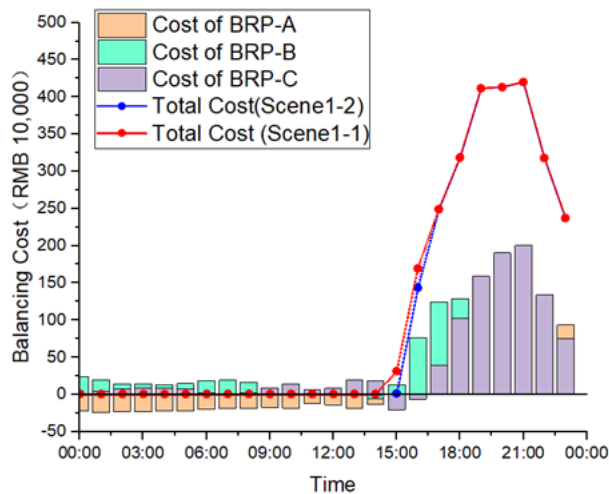


Fig. 6: Comparative Diagram of Costs before and after the Typical Day with Maximum New Energy Output.

a rapid decline, creating a substantial supply-demand gap in BRP-B. The electricity exchange between BRPs during this period effectively reduces system costs. After 17:00, all BRPs experience a load gap, and mutual assistance among BRPs is no longer possible.

Table 3 shows that, during the maximum new energy output period, the BG trading mode can effectively facilitate the mutual support among the subsystems and optimize the

power structure in a wider range, thus to reduce the power curtailment during the maximum new energy output period, resulting in the reduction of overall new energy power curtailment of the system from 3,931MWh to 1,053.2MWh, equivalent to about 73%. However, after 15:00, due to the reduction of new energy output, all sub-systems are in the state of power shortage, causing a limited effect on the demand optimization of balancing regulation resources of the system.

4.3 Typical day with maximum load

The system power output and electrical load data on the typical day with maximum load are used. With the high load supply demand on that day, all units in the region are started up. In scenario 2-1, by using the unified dispatching operation mode and the clearing method of two-part price and marginal cost, the TSO purchases the corresponding balancing resources from the BSPs to achieve the system supply-demand balance. The maximum imbalance capacity on the same day is 439.5MW, the marginal capacity price is RMB 14/kW and the total capacity balancing expenditure is RMB 6.153 million based on the 24-hour supply-demand curve and the offer from the BSPs. In scenario 2-2, the BG market mode is applied. The BG supply and demand situation is obtained, as shown in Fig. 7, based on the internal power output and load curve of three BGs.

Table 3: System Operation Optimization Effect on the Typical Day with Maximum New Energy Output Unit: RMB 10,000, MWh.

Parameter Comparison		Scenario 1-1	Scenario 1-2			
			BRP1	BRP2	BRP3	Total
Generation cost	Thermal	903.5	624	0	154.8	778.8
	Wind	599.2	239.7	239.7	119.8	599.2
	PV	139.7	55.9	27.9	55.9	139.7
	Total capacity expenditure	1120	251.7	334.9	533.4	1120
Balancing resource expenditure	Total energy expenditure	2567	711.1	900.4	899.6	2511.1
	Total balancing cost	3687	962.8	1235.3	1433	3631.1
	Transaction cost of BGs	/	-276.78	188.59	88.18	0
Total cost		5329.4	1605.62	1691.49	1851.68	5148.8
New energy power curtailment		3931	0	651.5	401.7	1053.2

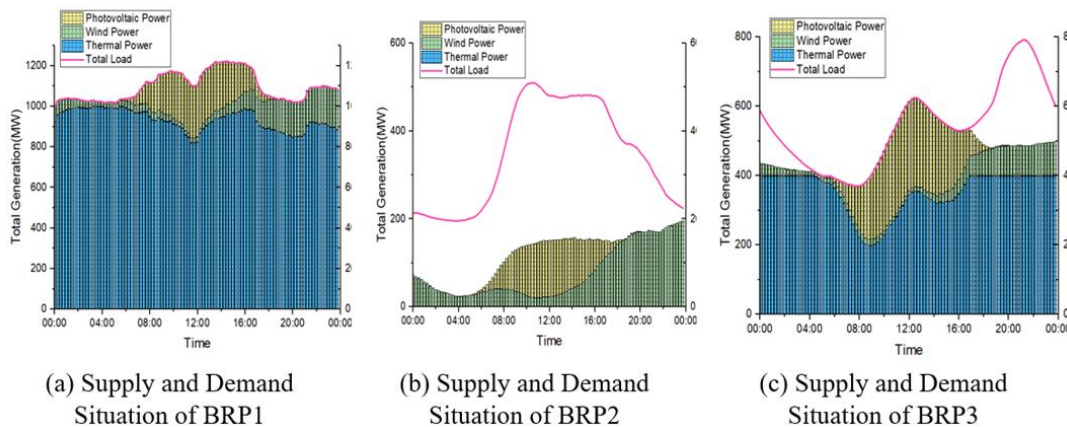


Fig. 7: Supply and Demand Situation of BRPs on the Typical Day with Maximum Load.

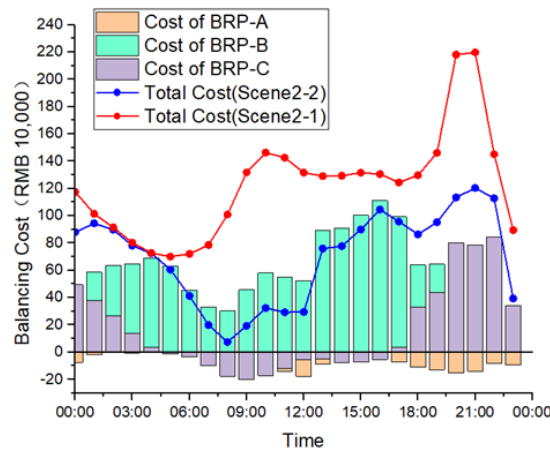


Fig. 8: Comparative Diagram of Costs before and after the Typical Day with Maximum Load.

Table 4: System Operation Optimization Effect on the Typical Day with Maximum Load Unit: RMB 10,000, MWh.

Parameter Comparison		Scenario 2-1	Scenario 2-2			
			BRP1	BRP2	BRP3	Total
Generation cost	Thermal	1399.1	1104	0	441.6	1545.6
	Wind	181.4	70	70.1	41.3	181.4
	PV	213.1	79.5	39.8	93.8	213.1
Balancing resource expenditure	Total capacity expenditure	615.3	0	166.3	194.8	361.1
	Total energy expenditure	2930.5	0	1234.4	439.6	1674
Total balancing cost		3545.8	0	1400.7	634.4	2035.1
Transaction cost of BGs		/	-161.8	224.2	-62.4	/
Total cost		5339.4	1091.7	1734.8	1148.7	3975.2
New energy power curtailment		0	0	0	0	0

From the supply and demand situation of BGs on a typical day with maximum load, BRP1 can achieve supply-demand balance by thermal power, BRP2 is in a state of shortage throughout the day due to insufficient output of purely new energy units, and BRP3 can achieve supply-demand balance due to high PV output during the day but is in a state of shortage at night.

The BG market mode firstly considers the power mutual support among three BGs on an hourly basis. Based on this, the BRP purchases the corresponding balancing resources from the BSP to achieve the power balance in case of power shortage, and the marginal capacity price and the marginal energy price for clearing the balancing resources are calculated according to the total demand of three BGs at that moment. See Fig. 8 for the total system cost in scenario 2-1, the total system cost in scenario 2-2, and the balancing cost curve of BGs.

It can be seen that the supply and demand situations of each BRP in this scenario vary significantly. Due to the power shortage of BRP2 throughout the day, electricity exchange between BRP1 and BRP3 during their surplus periods from 0:00 to 16:00 can significantly reduce the system balance cost.

After 16:00, as BRP3 experiences a supply-demand gap, the system cost rises sharply, but BRP1 still has the capacity for mutual assistance. Due to the tight supply and demand situation, all new energy is fully consumed, and the amount of abandoned new energy does not change before and after electricity exchange.

Table 4 shows that, during the peak load period, the BG trading mode can effectively guide the BRPs to tap the low-cost top resources within the BGs, participate in the overall system regulation, and effectively reduce the system cost, resulting in the revenue by the trading. During the peak load period, the optimized overall system cost decreases from RMB 53.394 million to RMB 39.752 million, equivalent to about 25.5%.

5. Conclusion

The construction of a sound electricity market system is the critical development path for clean and low-carbon energy transition. It plays an important role in promoting the consumption of new energy, improving the operation efficiency of the system, and realizing the fair and reasonable cost sharing. This paper discusses the operation mode and

trading mechanism of the BG market in major European countries, and describes the BG-based trading mechanism of electricity spot market according to the construction experience of the international mainstream electricity markets and based on the current spot market operation system in China. At the initial stage of construction, the electricity spot market is operated by the dispatching organization in an unified manner to ensure the safe and stable operation of the power grid, and to guide the participation of virtual power plants, load aggregators, microgrids and other multiple market players.

The project employs actual operation data, selects the typical day with maximum new energy output hours and the typical day with maximum load, and compares the differences between the BG market mode and the traditional dispatching operation mode in terms of system operation cost and new energy consumption level, and verifies by example analysis that the BG-based market trading mode is useful to achieve the demand-side source-grid-load-storage synergistic and optimal operation, which can effectively reduce the system operation cost and improve the new energy consumption capacity. The next step is to study the equilibrium game methods of different market players based on their operation characteristics, so as to further realize the reasonable transmission and fair sharing of market costs and strengthen the power system's ability to optimally allocate resources.

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Conflict of Interest

There is no conflict of interest.

Supporting Information

Not applicable.

CRedit Statement

Ninghui Han: Investigation, Writing - Original Draft, Visualization. **Jinghan He:** Supervision. **Xuankun Song:** Writing - Review & Editing.

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