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METHODS
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Research on China's New Energy Cross-Provincial Marketization Mechanism Under the Background of "Double Carbon"

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In the past decade, China's new energy has experienced a prosperous development and has become an important main power supply in China. With the promotion of China's power market–oriented reform, the market-oriented transaction mechanism will play an essential role for China to achieve a large-scale and efficient national allocation of new energy. This study systematically analyzes and designs the principle of China's new energy cross-provincial marketization mechanism, including those for a compound system such as an interprovincial medium and long-term transaction and spot transaction. The proposed mechanism is validated by its implemental results on a prototype power system with new energy.

Keywords: wind power, new energy, electric power dispatch, electricity market, power consumption, dual carbon

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INTRODUCTION

Building a new power system with new energy is a major strategic decision to promote the transformation and dispatching of clean energy in China. In the past decade, China's new energy has experienced a prosperous development, and the installed new energy ranks one in the world. By December 2021, the total installed wind power and photovoltaic power has reached 600 million kW. In 2021, the commercially trading power is about 3.5 trillion kWh, with a year-by-year increase of 15.7%, taking more than 40% of the total power consumption of the whole society. The installed wind and photovoltaic powers in China and their proportion in the world from 2004 to 2020 are shown in **Figure 1**; **Figure 2** respectively. As a result, the large-scale application of new energy has brought a series of challenges to a new power system in both technologies and applications.

To address the challenges faced by an integrated power system with new energy, different efforts are reported in literature. To investigate the effect of energy storage systems on automatic generation control of interconnected traditional and restructured energy systems, a method based on a two-area non-reheat thermal power system with extra generation from a wind turbine system and dish stirling solar thermal system is proposed and validated (Arya, 2019). To improve wind power quality and stability, a closed-loop active power control of wind farm based on frequency domain is introduced in Chen et al. (2019). An environment-friendly and economical scheduling optimization for an integrated energy system considering power to gas technology and a carbon capture power plant is implemented in Zhang and Zhang (2020). A robust optimization approach for the integrated community energy system in energy and ancillary service markets is presented in Zhou et al. (2018). A deep reinforcement learning–based approach for optimizing energy conversion in an integrated electrical and heating system with renewable energy is investigated in Zhang et al. (2019). A general

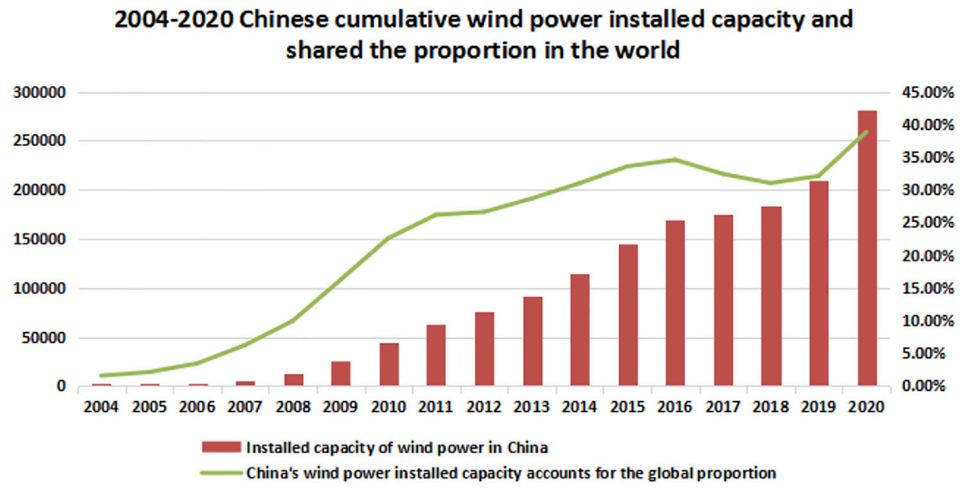

FIGURE 1 | Installed wind power in China and its proportion in the world from 2004 to 2020 (unit: MW).

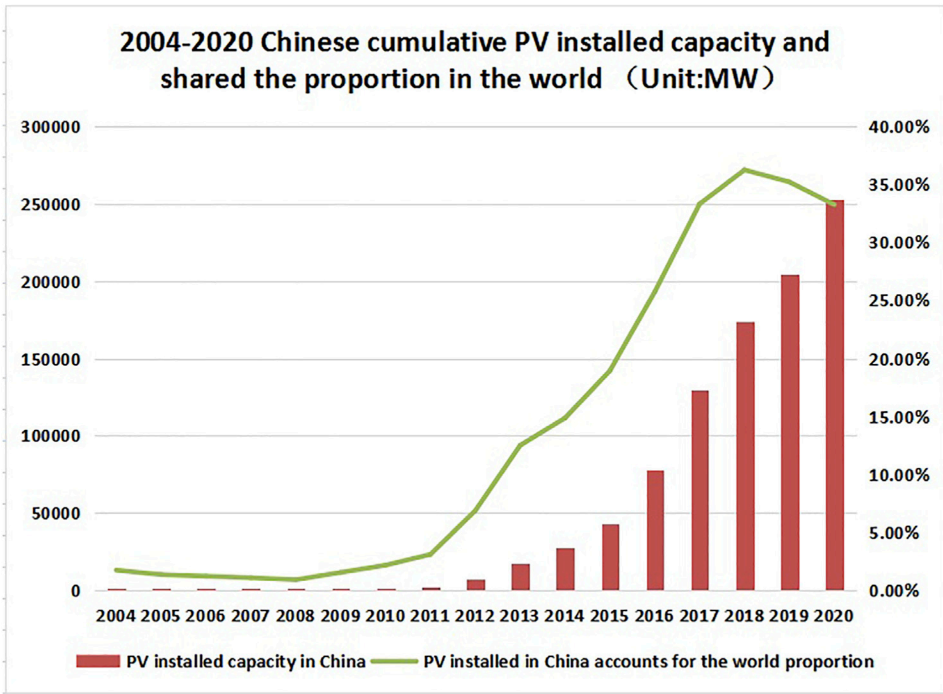

FIGURE 2 | Installed photovoltaic powers in China and its proportion in the world from 2004 to 2020 (unit: MW).

review on challenges faced by China compared with those by the US is detailed in Lu et al. (2016). A methodology for decentralized optimization of coordinated electrical and thermal generation in hierarchical integrated energy systems considering competitive individuals in developing wind power is proposed in Wang et al. (2018). The optimal operation of the integrated electricity–heat energy system considering flexible resources dispatch for renewable integration is comprehensively studied in Wang et al. (2021a). A study on energy management and optimization of vehicle-to-grid systems for wind power integration is conducted by Wang et al. (2020b). The socioeconomic viability of solar commercialization and electrification in South Asian countries is systematically assessed by Sun et al. (2021a). The role of technological innovation and knowledge spillover for energy efficiency utilization is investigated by Sun et al. (2021b).

From the aforementioned literature review it is obvious that there are a few literatures that are devoted to the commercialization of the new energy power system. In this point of view, this article studies China's new energy cross-provincial marketization mechanism, based on the integration unification of existing ones, under the background of "Double Carbon".

INTERPROVINCIAL TRANSACTION MODE

The general modes for the existing new energy cross-provincial transaction include the medium- and long-term physical contract and the cross-regional interprovincial incremental spot transaction. Cross-provincial and regional transactions of the new energy are mainly implemented through medium- and long-term transactions such as the forced annual priority power generation plan, interprovincial delivery transaction, and the power generation rights transaction.

Medium- and Long-Term Electricity Market Transaction Trading Mode

Annual Priority Generation Plan Mode

The annual priority power generation plan mode refers to the transaction of non-tradable electricity arranged in accordance with the national plan, intergovernmental agreements, and relevant policies and regulations.

Transaction Participants

It mainly includes large-scale wind power, photovoltaic power, and other new energy power generation enterprises covered by the national plan and the transmission and receiving end power grid companies.

Transaction Mode

It covers the medium- and long-term transactions and guarantees as secured in the contracts.

Electricity Pricing

Trans-provincial new energy transmission capacity shall be guaranteed in the annual trans-provincial priority power generation plan. The price will be set uniformly by the state government and approved for implementations.

Interprovincial Delivery Transaction

An interprovincial power transmission transaction refers to the tradable transaction of purchase and sale of power between power generation enterprises and power grids, or between the power transmission and receiving end power grids.

Transaction Participants

It consists of the wind power, photovoltaic power, and other new energy power generation enterprises and the transmission and receiving end power grid companies.

Transaction Mode

According to the transaction cycle, the transaction mode is generally divided into multiyear, annual, monthly, and monthly multi meat transactions. According to the transaction organization mode, it is generally divided into bilateral negotiation, centralized bidding, and listing to name a few.

Pricing

The trading power and price is determined by negotiation, declaration, and settlement by both parties.

Interprovincial Power Direct Transaction

An interprovincial power direct transaction refers to the transaction between direct participants of sending end new energy power plant, receiving end power users, and the power sales company. The power grid enterprises provide power transmission and distribution services according to the regulations. Generally, according to the release of the power generation and the consumption plan, some power is released in the annual interprovincial and regional annual power generation plan.

Transaction Participants

Transaction participants include the qualified sending end new energy power plants, the receiving end power users, the power sales companies, and the power grid enterprises.

Transaction Mode

There are mainly two applicable modes. The first is the bilateral negotiation mode between the sending end new energy power generation enterprise and the receiving end power users. The second is the commercially trading mode through the trading platform, including the centralized bidding, the listing trading mode, and so on. Power generation enterprises can choose to directly participate in the transaction or authorize their provincial power grid enterprises to participate in the market transaction.

Electricity Pricing

The region of the trans-provincial trading electricity is usually determined by the trading center in the annual trans-provincial power generation and utilization plan according to the liberalization of the trans-provincial power generation and utilization plan and national policies and regulations. The transaction price is determined through a bilateral negotiation, centralized bidding transaction, and listing transaction.

Interprovincial Power Generation Right Transaction

The interprovincial power generation right transaction, also known as the interprovincial contract transaction, refers to the paid transfer and purchase of the contracted electricity by the new energy power generation enterprises and other power generation enterprises through market-oriented approaches.

Transaction Participants

Transaction participants are the qualified new energy power generation enterprises and the thermal power generation enterprises.

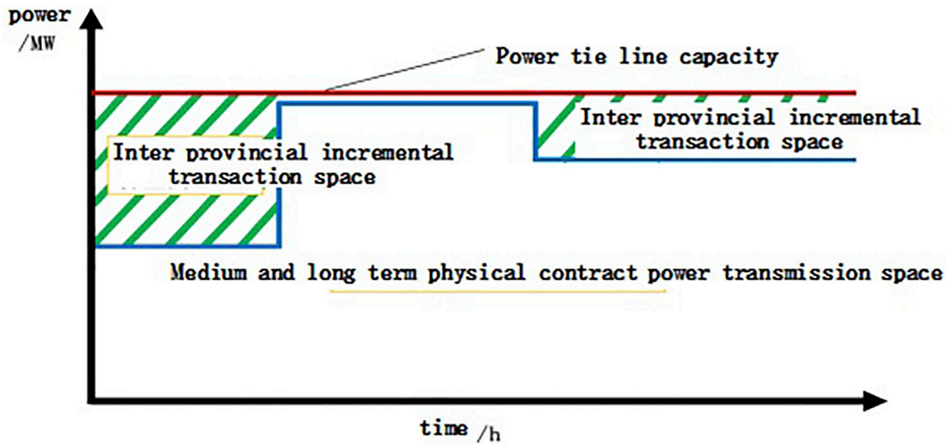

FIGURE 3 | Schematic diagram of interprovincial consumption under the mode of interprovincial incremental spot market.

Transaction Modes

The transaction is organized by the trading center, qualified new energy power generation enterprises, and thermal power generation enterprises by using the market-oriented approaches such as the bilateral negotiation and the centralized bidding through the trading platform.

Electricity Pricing

The transaction volume price of the power generation right is determined by both parties. In addition, at present, the transaction scale of the new energy power generation rights across provinces and regions is small.

Electricity Spot Trading Mode

The current cross-regional spot trading mainly refers to the cross-regional and interprovincial surplus renewable energy power spot trading.

Transaction Participants

The participants include the sending end new energy power plant, the hydropower plant, and the receiving end power grid company.

Transaction mode

Dispatching centers at all levels of the power grid company shall organize the sending end power generation enterprises and the receiving end power grid companies to apply for the centralized bidding and the unified clearing.

Pricing

Under the bidding mode, the volume and price before the day are uncertain, and the trading volume and price are determined according to the declaration and channel conditions of both parties. The intra-day price is determined according to the previous day price, and the trading volume is determined according to the declaration and channel conditions of both parties.

INTERPROVINCIAL AND REGIONAL SPOT TRANSACTION CONSUMPTION MODEL

By using the time series production simulation method and taking the maximum consumption of new energy as the optimization objective, the new energy delivery capacity in the surplus region in each period of the tie line channel is optimized to determine the optimal trading volume of new energy in each period in the interprovincial incremental spot market, as shown in **Figure 3**.

The optimal objective of this model is to maximize the new energy consumption of the system. Mathematically, it is formulated as follows:

$$\boldsymbol{max}\, J = \sum\nolimits_{t=1}^{T} \sum\nolimits_{n=1}^{N} \left(P_{w}^{t,n} + P_{pv}^{t,n} \right), \tag{1}$$

where T is the number of the scheduling cycle periods, N is the number of partitions of the whole system, $P_{w}^{t,n}$ is the generation power of the wind turbine in area n at time t, and $\mathrm{P}_{\mathrm{pv}}^{\mathrm{t,n}}$ is the generation power of the photovoltaic unit in area n at time t.

In the optimization, different constrains are also applied. The details are given as follows:

(1) Regional load balancing constraint

$$\sum_{j=1}^{S_{kind}} P_{j}^{t,n} + P_{p,v}^{t,n} + \sum_{u=1}^{U} P_{u}^{t,n} + \sum_{r=1}^{R} \left(P_{r,g}^{t,n} + P_{r,p}^{t,n} \right) + \sum_{i=1}^{N} L_{i,n}^{t} = d^{t,n} + P_{out}^{t,n} + \Delta P_{out}^{t,n}, \tag{2}$$

where $\mathrm{P}_{\mathrm{j}}^{\mathrm{t,n}}$ is the generation power of the j^{th} thermal power unit in region n at time t, $L_{i,n}^{t}$ is the generated power transmitted by region i to region n over period T, $\mathrm{p}_{\mathrm{out}}^{\mathrm{t,n}}$ is the medium- and long-term physical contract power for external n transmission to the system, $\Delta p_{out}^{t,n}$ is the surplus power in the interprovincial incremental transaction transmitted by region n to the outside of the system, $\mathrm{d}^{\mathrm{t,n}}$ is the load demand at time t in area n, U is the number of types of the hydropower units, R is the number of types of pumped storage units, $\mathrm{p}_{\mathrm{u}}^{\mathrm{t,n}}$ is the generating power of hydropower units in area n at time t, $\mathrm{p}_{\mathrm{r,g}}^{\mathrm{t,n}}$ is the generation power of the pumping and the storage unit r in area n at time t, and $\mathrm{p}_{\mathrm{r,p}}^{\mathrm{t,n}}$ is the pumping power of the pumping and the storage unit r in area n at time t. This constraint enforces that the load demand in each region should be balanced at all times.

(2) Rotate alternate constraint

$$D^t + P_{re}^t + \sum_{n=1}^{N} P_{out}^n \le \sum_{n=1}^{N} \sum_{j=1}^{S_{kind}} P_j^{\max} S_j^{t,n} + \sum_{u=1}^{U} P_u^{\max} S_u^{t,n} + \sum_{r=1}^{R} \left(P_{r,g}^{t,n} + P_{r,p}^{t,n} \right) + \sum_{i=1}^{N} C_{i,n}^t + \sum_{i=1}^{N} C_{p_w}^{t,n} + \sum_{i=1}^{N} C_{p_w}^{t,n}, \tag{3}$$

$$\sum_{n=1}^{N} \sum_{j=1}^{S_{kind}} P_j^{\min} \times S_j^{t,n} + \sum_{u=1}^{U} p_u^{\min} S_u^{t,n} + \sum_{r=1}^{R} \left(p_{r,g}^{t,n} - p_{r,p}^{t,n} \right) \le D^t + \sum_{n=1}^{N} p_{out}^n - N_{re}^t, \tag{4}$$

where D^{t} is the load demand of the system at time t, P_{re}^t is the positive standby demand of the system at time t, $\mathrm{N}_{\mathrm{re}}^{\mathrm{t}}$ is the negative standby demand of the system at time t, $P_j^{\max}$ is the maximum output level of thermal power unit J, $\mathrm{C}_{\mathrm{p_w}}^{\mathrm{t,n}}$ is the minimum output level of thermal power unit J, $\mathrm{C}_{\mathrm{p_{pv}}}^{\mathrm{t,n}}$ is the trusted capacity of the wind turbine unit in the area n, $\mathrm{S}_{\mathrm{j}}^{\mathrm{t,n}}$ is an integer variable representing the number of operating units of thermal motor unit j in region n at time t, $\mathrm{p}_{\mathrm{u}}^{\max}$ is the maximum output level of u of the hydro generator set, $\mathrm{p}_{\mathrm{u}}^{\min}$ is the minimum output level of u of the hydro generator set, and $\mathrm{S}_{\mathrm{u}}^{\mathrm{t,n}}$ is an integer variable indicating the number of operating units of the water motor unit u in region n at time t.

(3) Generation power constraint of the thermal power units

$$P_j^{\min,n} \times S_j^{t,n} \le P_j^{t,n} \le S_j^{t,n} \times P_j^{\max,n}. \tag{5}$$

(4) Climbing rate constraint of the thermal power unit

$$P_j^{t,n} - P_j^{t-1,n} \le \Delta P_{j,up} \times S_j^{t-1,n} + P_j^{\max} \times \left(S_j^{t,n} - S_j^{t-1,n} \right), \tag{6}$$

$$P_j^{t-1,n} - P_j^{t,n} \le \Delta P_{j,down} \times S_j^{t,n} + P_j^{\max} \times \left(S_j^{t-1,n} - S_j^{t,n} \right), \tag{7}$$

where $\Delta P_{j,up}$ is the climbing rate of thermal power unit, $P_j^{\max}$ is the maximum climbing rate of thermal power unit J in 1 hour, and $\Delta P_{j,down}$ is the maximum climbing rate of the generating power of the thermal power generator set J within 1 hour.

(5) Power constraint of wind power and photovoltaic power generation

$$0 \le P_w^{t,n} \le N_w^n P_w^{t,n^*}, \tag{8}$$

$$0 \le P_{pv}^{t,n} \le N_w^n P_{pv}^{t,n^*}, \tag{9}$$

where P_w^{t,n^*} and P_{pv}^{t,n^*} are the theoretical normalized output sequences of the wind power and the photovoltaic powers, respectively.

(6) Inter area transmission line capacity constraints

$$-P_{i,n}^{\max} \le L_{i,n}^t \le L_{i,n}^{\max}, \tag{10}$$

where $L_{i,n}^{\max}$ is the maximum secure transmission capacity of the tie line between regions I and n, and $L_{i,n}^t$ is the power transmitted by region I to region n through the tie line at time t. This constraint means that the transmission power on the tie line between any two regions should be within the safe capacity of the tie line. In the implementation, one sets the current reference direction as follows: the inflow region is in the positive direction, and the outflow region is in the negative direction.

(7) System scheduling instruction constraints

$$0 \le Y_t + Z_t \le 1, \tag{11}$$

$$\sum_{t=1}^{T} (Y_t + Z_t) = SCH_{num}, \tag{12}$$

where the variable is a 0–1 discrete variable. $Y_t = 1$ means that the system issues the start instruction at time t; otherwise, it means that the system does not issue the start instruction at time t. $Z_t = 1$ indicates that the system issues a shutdown command at time t; otherwise, it means that the system does not issue a shutdown command at time t. $\mathrm{SCH}_{\mathrm{num}}$ indicates the maximum number of the start-up and the shutdown scheduling allowed by the system in the scheduling cycle. Considering the actual dispatching situation, it is necessary to restrict the start-up and shutdown times of the units in the network in the whole dispatching cycle.

(8) Tie line transmission security capacity constraint

$$P_{out}^{t,n} \le \Delta P_{out}^{t,n} \le P_{out}^{n,\max}. \tag{13}$$

This constraint means that the transmission power of the interprovincial tie lines cannot exceed the safe transmission capacity of the tie lines, and the surplus volume behind the medium- and long-term physical contract curve of the interprovincial tie lines can only be used to organize the interprovincial incremental spot transactions.

SIMULATION VERIFICATION

Based on the power system of the Gansu province in Northwest China in 2020, considering the development of the interprovincial incremental spot market on DC transmission lines, this study analyzes the effect of the medium- and long-term physical contract interprovincial incremental spot market mode on the new energy consumption.

Load

The power consumption is 112.6 billion kWh in 2020. The maximum load is 17.23 million kW in 2020.

TABLE 1 | Comparison of new energy consumption in the Gansu province before and after the interprovincial incremental spot market mode.

	No interprovincial incremental spot market	With interprovincial incremental spot market
Abandoned wind power rate (%)	12.53	3.9
Abandoned photoelectric rate (%)	9.63	3.2
New energy consumption (100 million kwh)	346.32	389.56
Direct current transmission net power value (100 million kwh)	179.21	216.51

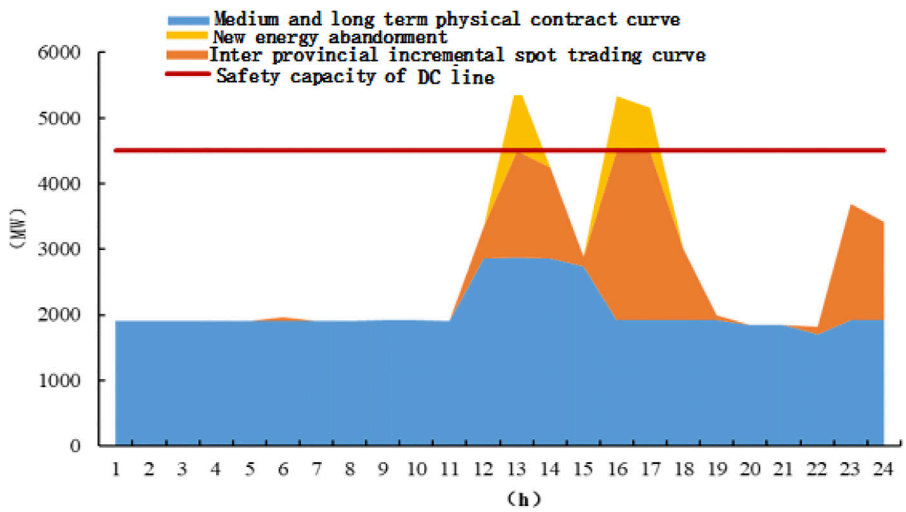

FIGURE 4 | Transmission power of the Gansu Qishao DC transmission line.

Exchange of Electricity With Other Provinces

The exchange of electricity with the neighbor provinces is considered. In 2020, the exchange power of connecting lines between Gansu and other provinces is considered as the net transmission of 36 billion kWh, of which the net transmission of DC medium- and long-term physical contract is 18 billion kWh, and the maximum transmission/receiving capacity of DC is 5.5 million kW.

Thermal Power Installed Capacity

The total installed capacity of thermal power units is 20.86 million KW in 2020.

Hydropower Installed Capacity

The installed capacity of the adjustable hydropower is 2.95 million kW, the installed capacity of the runoff hydropower units is 6.95 million kW, and there is no pumped storage unit in 2020.

Wind Power

The total installed capacity of the centralized wind power in the province is 14.17 million kW, and the annual theoretical power generation utilization hours of the wind power is 2,100 h in 2020.

Photovoltaic Power

The total installed capacity of the centralized photovoltaic in the province is 9.84 million kW, and the theoretical utilization hours of the photovoltaic power generation in the whole year is 1,480 h in 2020.

The production simulation method is used to solve the annual consumption of new energy in the Gansu province after the implementation of the incremental spot market. **Table 1** compares the annual consumption of new energy in the Gansu province before and after the implementation of the interprovincial incremental spot market transaction mode.

It can be seen from **Table 1** that after the interprovincial incremental spot market transaction mode is implemented between the two provinces, the consumption and utilization level of new energy in the province has been significantly improved. When the interprovincial incremental spot market was not activated, the new energy power rationing rate of the province was 11.62%. After the interprovincial incremental spot market was activated, the new energy power rationing rate of the province decreased to 3.9%. Due to the interprovincial incremental spot market transaction, the consumption of new energy in the province increased by 3.111 billion kWh, and the increased power of new energy was sent out through the DC channel.

Figure 4 shows the transmission power of the Gansu Qishao DC interconnection line and the power limitation of new energy in the Gansu province on a special day after the implementation of the interprovincial incremental spot market.

It can be seen from **Figure 4** that when the new energy abandonment occurs in the Gansu province, the new energy transmission capacity of the Gansu province can be improved by organizing an incremental spot transactions among provinces, to improve the utilization rate of new energy. Interprovincial incremental spot trading can make full use of the surplus capacity of the interprovincial transmission channels, which can not only improve the new energy utilization rate of transmission end provinces but also improve the channel utilization level.

CONCLUSION

Interprovincial incremental spot trading can make full use of the surplus capacity of the interprovincial transmission channels, which can not only improve the new energy utilization rate of transmission end provinces but also improve the channel utilization level. In case of new energy power abandonment, the incremental spot transactions between provinces can be organized to improve the export volume of new energy in the prototype province and also enhance the utilization rate of new energy in the province in question.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

QZ: conceptualization, methodology, and original draft. JL: reviewing, and editing. QL: reviewing, and editing. DW: reviewing, and editing. SY: reviewing, and editing.

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REFERENCES

Arya, Y. (2019). Effect of Energy Storage Systems on Automatic Generation Control of Interconnected Traditional and Restructured Energy Systems. *Int. J. Energ. Res* 43, 6475–6493. doi:10.1002/er.4493

Chen, Z., Liu, J., Lin, Z., and Duan, Z. (2019). Closed-Loop Active Power Control of Wind Farm Based on Frequency Domain Analysis. *Electric Power Syst. Res.* 170, 13–24. doi:10.1016/j.epsr.2019.01.003

Lu, X., McElroy, M. B., Peng, W., Liu, S., Nielsen, C. P., and Wang, H. (2016). Challenges Faced by China Compared with the US in Developing Wind Power. *Nat. Energ.* 1, 1–6. doi:10.1038/nenergy.2016.61

Sun, H., Awan, R. U., Nawaz, M. A., Mohsin, M., Rasheed, A. K., and Iqbal, N. (2021). Assessing the Socio-Economic Viability of Solar Commercialization and Electrification in South Asian Countries. *Environ. Dev. Sustain.* 23, 9875–9897. doi:10.1007/s10668-020-01038-9

Sun, H., Edziah, B. K., Kporsu, A. K., Sarkodie, S. A., and Taghizadeh-Hesary, F. (2021). Energy Efficiency: The Role of Technological Innovation and Knowledge Spillover. *Technol. Forecast. Soc. Change* 167, 120659. doi:10.1016/j.techfore.2021.120659

Wang, L., Jing, Z. X., Zheng, J. H., Wu, Q. H., and Wei, F. (2018). Decentralized Optimization of Coordinated Electrical and thermal Generations in Hierarchical Integrated Energy Systems Considering Competitive Individuals. *Energy* 158, 607–622. doi:10.1016/j.energy.2018.05.200

Wang, W., Huang, S., Zhang, G., Liu, J., and Chen, Z. (2021a). Optimal Operation of an Integrated Electricity-Heat Energy System Considering Flexible Resources Dispatch for Renewable Integration. *J. Mod. Power Syst. Clean. Energ.* 9, 699–710. doi:10.35833/mpce.2020.000917

Wang, W., Liu, L., Liu, J., and Chen, Z. (2020b). Energy Management and Optimization of Vehicle-To-Grid Systems for Wind Power Integration. *CSEE J. Power Energy Syst.* 7, 172–180. doi:10.17775/CSEEJPES.2020.01610

Zhang, B., Hu, W., Cao, D., Huang, Q., Chen, Z., and Blaabjerg, F. (2019). Deep Reinforcement Learning-Based Approach for Optimizing Energy Conversion in Integrated Electrical and Heating System with Renewable Energy. *Energ. Convers. Manage.* 202, 112199. doi:10.1016/j.enconman.2019.112199

Zhang, X., and Zhang, Y. (2020). Environment-Friendly and Economical Scheduling Optimization for Integrated Energy System Considering Power-To-Gas Technology and Carbon Capture Power Plant. *J. Clean. Prod.* 276, 123348. doi:10.1016/j.jclepro.2020.123348

Zhou, Y., Wei, Z., Sun, G., Cheung, K. W., Zang, H., and Chen, S. (2018). A Robust Optimization Approach for Integrated Community Energy System in Energy and Ancillary Service Markets. *Energy* 148, 1–15. doi:10.1016/j.energy.2018.01.078

Conflict of Interest: Authors QZ, JL, QL, and DW were employed by the company State Grid Gansu Electric Power Company.

The remaining 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.