Research on Market Mechanism and Scheme Design of Yunnan Demand Response

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Abstract. In order to cope with the changes of participants, working mechanism and business model after the deregulation of power sales side under the new situation, and to improve the current situation of seasonal and periodic power shortage in Yunnan Province, the implementation scheme of Yunnan demand response is sorted out and its characteristics are analysed from the aspects of participation mode, implementation form and response type. Based on the lack of basis for the demand response subsidy price and the imperfect transaction mechanism in Yunnan demand response market mechanism construction, this paper proposes a price mechanism design scheme of charging seasonal peak electricity price for peak shaving demand response, collecting funds according to the grid electricity of power generation enterprises during valley filling period, and dynamically adjusting the price according to the change of supply side cost caused by demand response. Additionally, the trading mechanism of demand side response participating in day ahead market and real-time market is also proposed.

1. Introduction
Since the 13th Five-Year Plan, with the rapid growth of new energy power generation and power transmission from the province outside, the proportion of coal-fired power has been continuously reduced, and the structural contradiction of power supply in Yunnan Province has become increasingly prominent. In addition, with the commissioning of hydropower aluminium and hydropower silicon projects, power consumption has maintained a rapid growth, and the power supply in the whole province has changed from the surplus in the whole year to surplus in abundant period and tense in dry season. There is seasonal and periodic power shortage in some regions. In 2015, the National Development and Reform Commission proposed to actively implement demand response and make the market mechanism function fully, so as to promote the balance of power supply and demand side of the system, and maintain the safe and reliable operation of the power grid [1-3]. Based on that, Yunnan Province has successively issued “The Letter of Yunnan Provincial Energy Administration on Soliciting Opinions on Carrying Out Electric Power Demand Response Market Pilot Work” and “Yunnan Provincial Energy Bureau's Notice on Carrying Out DSM Work in 2019” to explore market mechanism, which can guide demand side to actively participate in peak load regulation, and promote optimal allocation of power resources. At present, there is still no optimal scheme for the market-oriented mechanism of Yunnan's demand response [4-7].
In view of this problem, domestic and foreign research shows that using market mechanism to guide power users to actively cut peak and fill valley can alleviate the contradiction between supply and demand, improve the level of power user load management, effectively promote demand response to participate in auxiliary service market and power spot market [8]. The United States and Europe are relatively early in implementing demand response, and mature in project allocation, pricing mechanism, incentive mechanism and policy. In the PJM market of the United States, demand response resources can participate in the main energy, auxiliary services and capacity markets, to compete fairly with other generation resources. On this basis, from the national and government levels, the special fund subsidy mechanism, incentive mechanism, benefit sharing mechanism, separation mechanism of revenue and electricity sales for power companies are proposed, as well as discount incentive, free installation incentive and special incentive for power saving [9]. The Ecogrid EU provides balanced services required by the system in a short period of time. Operators set the real-time price, and the distribution network resources respond to provide balanced resources according to the electricity price [10]. Finland actively carries out power demand response. Almost all users who implement power demand response adopt time of use tariff, and users can sign annual bilateral agreements with the power grid to participate in frequency modulation reserve and fast reserve [11]. The UK provides a variety of time of use tariff rates to encourage users to participate in demand response, and organizes demand side resources to participate in short-term operation reserve, fast reserve and stable grid frequency response through interruptible load contract [12]. However, there is still a lack in similar electricity price mechanism, incentive mechanism and supporting policies in domestic demand response market.

Since 2013, China has carried out the comprehensive pilot construction of power demand response in several cities, and the implementation of demand response has been expanding in China. Beijing, Jiangsu, Shanghai, Guangdong, Tianjin, Henan, Zhejiang and Jiangxi have been successfully implemented. At present, domestic demand response users are mainly for industrial and commercial users. Also, Jiangsu and Tianjin have taken measures such as peak electricity prices and demand response load subsidies, but they are still dominated by the active regulation of power grid companies and lack of market-oriented mechanism. With the improvement in the degree of electricity marketization, it is difficult to adjust the market interests of enterprises, mobilize the enthusiasm of participation, and cultivate the market consciousness of all kinds of subjects, if the orderly power consumption of power users is still arranged through the traditional mandatory management measures such as peak shifting power consumption, peak avoiding power consumption, power restriction and emergency switching off. In order to cope with the changes of participants, working mechanism and business model after the deregulation of power sales side under the new situation, and to improve the current situation of seasonal and periodic power shortage in Yunnan Province, it is urgent to study the design of market mechanism and scheme of demand response in Yunnan Province. Therefore, this paper analyses Yunnan demand response implementation plan and its characteristics from the implementation form, participation mode, response type and other aspects. Based on the problems existing in the construction of market-oriented mechanism of demand response in Yunnan, the design scheme about market-oriented mechanism of demand response in Yunnan is constructed.

2. Materials and Methods
Firstly, based on “The Letter of Yunnan Provincial Energy Administration on Soliciting Opinions on Carrying Out Electric Power Demand Response Market Pilot Work” and “Yunnan Provincial Energy Bureau's Notice on Carrying Out DSM Work in 2019”, this paper adopts the method of experience summary to analyse the implementation schemes of demand response at home and abroad, including the United States, Finland, the United Kingdom, Beijing, Jiangsu, Shanghai and other countries and provinces. On this basis, it is proposed that in order to cope with the changes of participants, working mechanism and business model after the deregulation of power sales side under the new situation, as well as the current situation of seasonal and periodic power shortage in Yunnan Province, it is necessary to further study the design of market mechanism and scheme of demand response in Yunnan Province.
Secondly, according to the process of demand response market work, this paper introduces the specific content of Yunnan demand response implementation plan. Taking Jiangsu as a reference, this paper sorts out the implementation plan of demand response from the aspects of implementation form, participation mode, response type and market subjects, and analyses the characteristics of Yunnan demand response implementation plan.

Finally, based on the characteristics of Yunnan's demand response implementation scheme, this paper puts forward the problems existing in the construction of Yunnan's demand response market-oriented mechanism from two aspects of demand response price mechanism and transaction mechanism, and constructs the design scheme of Yunnan demand response market-oriented mechanism in view of the existing problems.

3. Results & Discussion

3.1. Implementation scheme of Yunnan power demand response

3.1.1. Contents of Yunnan power demand response implementation scheme

Yunnan electric power demand response implementation plan is committed to improving the level of power consumption refinement, cultivating the value-added service ability of subjects in the power sales side, forming a new mechanism for the demand side and the supply side to keep the power and electricity balance, so as to achieve the demand side mobile peak shaving capacity accounting for about 3% of the maximum power consumption load. When the reserve capacity of power grid is insufficient, local overload or the difference between peak and valley is too huge, the peak to valley difference can be reduced by guiding users to carry out demand response. The implementation process is as follows: (1) scientifically determine the annual response plan; (2) organize the unilateral market bidding; (3) sign the demand response agreement in time; (4) timely start the demand response; (5) implement the demand response; (6) standardize the response result evaluation; (7) approve and issue the response compensation fee.

Yunnan Power Grid Co., Ltd. will forecast the annual power supply and demand situation every year, and submit the annual demand response plan to the Provincial Energy Administration for approval before March 15. It will be released through Yunnan power demand side management platform and Kunming electric power trading centre platform, among which the demand response is divided into agreed demand response and real-time demand response. Later, in mid early May every year, Kunming electric power trading centre takes 150% of the response amount determined in the annual response plan as the response demand, and through the power trading platform, the power consumers or power sales companies conduct bidding transactions. The power users who have completed the transaction shall sign the Yunnan power demand response agreement with the energy bureaus and power supply bureaus of all states and cities before the end of May. The response time determined in the agreement shall be from June 1 of each year to May 31 of the next year. On this basis, Yunnan Power Grid Co., Ltd. timely puts forward response start-up request according to the grid operation situation, reports to the Provincial Energy Bureau for approval, and sends response invitation to participants through Yunnan power demand side management platform. Relevant entities can query their load baseline, agreed response amount and response time information through Yunnan power demand side management platform, and perform response execution and abort. Finally, the response results are evaluated and the response compensation fee is approved and issued.

3.1.2. Characteristics of Yunnan power demand response implementation scheme

Combined with the power demand response implementation plan in Jiangsu, the implementation plan of Yunnan demand response is sorted out, as shown in Table 1. According to table 1, the following characteristics can be obtained.
At present, the implementation form of demand response in various provinces and cities is still guided by policy, dominated by active regulation of power grid companies, and lack of market-oriented mechanism.

In the pilot stage, Yunnan Province has not carried out real-time demand response. Compared with Jiangsu, which implements both agreed demand response and real-time demand response, the participation mode of demand response implementation in Yunnan is relatively single, and it is still in the initial stage of market-oriented demand response.

At present, the access threshold of market entities is low in the power demand response of provinces and cities. Jiangsu Province allows power users including residential load, load integrators, energy storage and other entities to participate in demand response. Similarly, Yunnan Province also encourages power users and power sales companies to participate in the pilot demand response market.

The formulation of demand response subsidy price needs to follow the basic principles of overall coordination and shared responsibility. The implementation of peak electricity price in Jiangsu Province has gradually reflected the operation principle of beneficiary burden. However, most of the funds for demand response in Yunnan Province come from special funds, and the principle of "who benefits, who bears" has not been realized.

| Pilot provinces and cities | Implementation form | Mode of participation | Response type | Market subject | Compensation standard | Source of funds | Corresponding ability |
|---------------------------|---------------------|-----------------------|---------------|----------------|----------------------|-----------------|----------------------|
| Yunnan                    | It is led by the government, organized by the grid company, and participated by load aggregators and power users | Agreed and real-time demand response | Power users and power selling companies | No more than 20 yuan / kW | Special funds | About 3% of the maximum power load |
| Jiangsu                   | It is led by the government, organized by the grid company, and participated by load aggregators and power users | Agreed and real-time demand response | Power users (including pilot residents), load integrator, energy storage and charging pile | No more than 15 yuan / kW | Peak tariff charged | About 5% of the average load at peak time |

3.2. Market-oriented mechanism of demand response in Yunnan

3.2.1. Problems in the construction of market-oriented mechanism of demand response in Yunnan

(1) Demand response price mechanism

Demand response subsidies in Yunnan lacks basis of formulation. At present, the funding source of demand response subsidies in Yunnan violates the principle of maintaining balance between revenue and expenditure as well as "who benefits, who pays". Power grid companies, users and power generation enterprises are both direct participants and beneficiaries of demand response. Demand response subsidies should be apportioned by all subjects through agreement under the supervision of the government, so as to clarify the funding source of demand response subsidies [14].

(2) Demand response trading mechanism

Yunnan demand response trading mechanism is not perfect. Yunnan power market is still dominated by medium and long-term trading, and the spot market is in the trial operation stage. There remains a question that whether the result of demand response should be reflected in the virtual power plant mode in auxiliary service market, regarded as the demand side resource reserve in medium and long-term trading, or solved by the self-adjustment of electricity consumption behaviour in spot market.
3.2.2. Scheme design of market mechanism for Yunnan demand response

(1) Demand response price mechanism

From the two aspects of "peak shaving" and "valley filling" demand response funding sources, the scheme design of demand response subsidy mechanism is proposed.

1) "Peak shaving" demand response

In the peak load period, in order to maintain the balance of power supply and demand, the peak price is charged to some power users who continue to use electricity during the peak period, so as to compensate the power users who are willing to participate in the "peak shaving" demand response during the peak period. That is to say, to collect funds from the power users who benefit during the peak period, so as to compensate the power users who sacrifice their electricity demand. Therefore, in view of the "peak shaving" demand response, the scheme of charging seasonal peak price to all industrial and commercial users is adopted. The charging of seasonal peak price can not only restrain the increase of peak load to a certain extent, but also can be used for "peak shaving" demand response compensation.

2) "Valley filling" demand response

In the low load period, in order to maintain the balance of power supply and demand, some power users increase the power load during the valley filling period, which ensures the increase of power generation capacity of power generation enterprises during the valley filling period, and reduces the start-up and shutdown of units and the abandonment of wind power and photovoltaic power. The beneficiary of "valley filling" demand response is the power generation enterprises, which need to collect funds according to the grid electricity of power generation enterprises during the valley filling period, so as to compensate the power users who effectively implement the "valley filling" demand response.

In addition, in view of the current situation of Yunnan Province, it is critical to build a more reasonable electricity price structure system. By adopting the pricing mechanism based on the cost accounting and supervision of the supply side, this paper distinguishes the difference of cost in different power consumption time and explores the establishment of dynamic price adjustment mechanism. The price is adjusted dynamically according to the change of supply side cost caused by demand response, so as to realize the balance between supply and demand side.

(2) Demand response trading mechanism

Demand side response meeting the requirements can participate in day ahead market and real-time market, and can declare price and load in auxiliary service market. It can not only provide electric energy, but also provide frequency modulation and standby services.

In the day ahead market, the demand response can provide the capacity quotation curve of standby auxiliary service and the power quotation curve with decreasing power consumption. The unit commitment, unit output and auxiliary service are jointly optimized, and the optimization objective is to minimize the total social cost, which can be expressed as

\[
\begin{align*}
    \min & \sum_{t=1}^{T} \sum_{i=1}^{N} \left[ C_{\text{run},i} \left( P_{G,i}(t) \right) + C_{\text{start},i} x_{i}(t) \left( 1 - x_{i}(t-1) \right) \right] \\
    & + \sum_{t=1}^{T} \sum_{j=1}^{M} C'_{\text{res},j} \left( R_{\text{res}}(t) \right) - \sum_{t=1}^{T} \sum_{i=1}^{N} B_{k,i} \left( P_{k}(t) \right)
\end{align*}
\]

Where T is the number of time periods, N is the number of units, \( P_{G,i}(t) \) is the output of unit i, \( C_{\text{run},i} \left( P_{G,i}(t) \right) \) is the unit operation cost, \( C_{\text{start},i} \) is the unit start-up cost, \( x_{i}(t) = 0 \) is the unit shutdown, \( x_{i}(t) = 1 \) is the unit start-up, \( R_{\text{up},i}(t) \) and \( R_{\text{down},i}(t) \) are the amount of unit up regulation and unit down regulation, \( C'_{\text{up},j} \left( R_{\text{up}}(t) \right) \) and \( C'_{\text{down},j} \left( R_{\text{down}}(t) \right) \) are the up and down auxiliary service costs respectively, M is the number of demand response providers who provide auxiliary services, \( R_{\text{res}}(t) \) is
the reserve capacity of demand response, \( C'_{\text{res}, j} \left( \left( R_{\text{res}} \left( t \right) \right) \right) \) is the cost of ancillary services, \( S \) is the number of demand response providers that provide electricity quotation curve with decreasing electricity consumption, \( P_k \left( t \right) \) is the power of demand response providers who provide auxiliary services, and \( B_{k, j} \left( P_k \left( t \right) \right) \) is the electricity revenue.

In the real-time market, the demand response can provide the capacity quotation curve of standby auxiliary service and the power quotation curve with decreasing power consumption. The unit output and auxiliary service are jointly optimized, and the optimization objective is to minimize the total social cost, which can be expressed as

\[
\min \sum_{i=1}^{N} \left[ C_{\text{run}, i} \left( P_{G, i} \left( t \right) + \Delta P_{G, i}^0 \left( t \right) \right) \right. \\
+ C_{\text{up}, i} \left( R_{\text{up}, i} \left( t \right) \right) + C_{\text{down}, i} \left( R_{\text{down}, i} \left( t \right) \right) \\
+ \sum_{j=1}^{M} C_{\text{res}, j} \left( \left( R_{\text{res}} \left( t \right) \right) \right) - \sum_{k=1}^{S} B_{k, j} \left( P_k \left( t \right) + \Delta P_k^0 \left( t \right) \right) \\
\]

(2)

Where \( \Delta P_{G, i}^0 \left( t \right) \) is the deviation of the unit output between the real-time and the day ahead market, as well as \( \Delta P_k^0 \left( t \right) \) is the deviation of the power of demand response providers who provide auxiliary services between the real-time and the day ahead market.

The demand side response that does not meet the requirements to provide energy, frequency modulation and standby services can be regarded as an emergency demand response when the price of electricity rises. In an emergency, the demand side response can be compensated better than the market price to reward its contribution to reducing the overall price. Bettering the demand response trading mechanism can play the role of market mechanism to prevent individual power producers from trying to raise electricity prices to earn high profits in peak hours. Meanwhile, users will have more initiative and choice to reduce the negative impact of price fluctuations.

4. Conclusions
With the gradual advancement of China's electricity market-oriented reform process, in order to cope with the changes of participants, working mechanism and business model after the deregulation of the power sales side under the new situation, and to improve the current situation of seasonal and periodic power shortage in Yunnan Province, it is necessary to further study the design of market mechanism and scheme of demand response in Yunnan Province. At present, the implementation process of Yunnan's demand response plan is to scientifically determine the annual response plan, organize the unilateral market bidding, sign the demand response agreement in time, timely start the demand response, implement the demand response, standardize the response result evaluation and issue the response compensation fee. Referring to Jiangsu Province's demand response implementation plan, this paper analyses Yunnan's demand response implementation plan from seven aspects: implementation form, participation mode, response type, market main body, compensation standard, fund source and response ability. It can be found that the implementation form of demand response in various provinces and cities is lack of market-oriented mechanism; the participation mode of demand response in Yunnan is relatively single; the access threshold of market entities in power demand response is low; the principle of "who benefits, who bears" has not been realized in the formulation of subsidy price.

In order to solve the problems of demand response subsidy price lack of basis and demand response transaction mechanism is not perfect in the construction of market-oriented mechanism of demand response in Yunnan Province, a price mechanism design scheme of charging seasonal peak electricity price for peak shaving demand response, collecting funds according to the grid electricity of power generation enterprises during valley filling period, and dynamically adjusting the price according to the
change of supply side cost caused by demand response is proposed. Additionally, the trading mechanism of demand side response participating in day ahead market and real-time market is also proposed.

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References
[1] Wang, L.K., Yang, S.C., Cao, Y., Yan, M.F., Yan, C.H., Fan, C. (2014) Research on international standard architecture of demand response. Journal of China Electrical Engineering, 22: 3601-3607.
[2] Xu, Z., Sun, H.B., Guo, Q.L. (2018) Review and Prospect of comprehensive demand response research. Chinese Journal of electrical engineering,38: 7194-7446.
[3] Wang, B.B., Tang, N., Zhao, S.N., Lin, K.Y., Wang, Y., Xiao, Y. (2017) Stochastic and adjustable robust mixed day ahead dispatching model for demand response in wind power. China Electrical Engineering Society,37:6339-6346.
[4] Ding, Y., Hui, H.X., Lin, Z.Z., Zheng, M.L., Qu, X.Y., Cui, W.Q. (2017) Business model and market framework design for power demand side active response. Power system automation,41: 2-9.
[5] Zhang, J., Wang, T., Li, B. (2014) Research on standardization of power demand response technology. Journal of China Electrical Engineering, 22: 3623-3629.
[6] Chen, Z.X., Zhang, Y.J., Chen, B.D., Lin, X.M. (2020) Day ahead optimal economic dispatch of regional energy centers under generalized price type demand side response. Chinese Journal of electrical engineering,40: 1873-1886.
[7] Xu, G.D., Zhang, L., Liang, J., Sun, D.L., Zhao, L., Han, X.S. (2020) Electricity demand price elasticity evaluation based on equipment power consumption characteristics. Power system automation,44: 48-60.
[8] Liu, X.L., Wang, Z.J., Gao, F., Wu, J., Guan, X.H., Zhou, D.M. (2014) Power generation and consumption response of high energy consuming enterprises under time of use tariff. Power system automation, 8: 41-49.
[9] Yang, W., Zeng, Z.J., Chen, H.Y., Wang, F., Guo, M.L. (2017) Research on demand side response trading mechanism of Guangdong power market. Guangdong electric power,30: 25-34.
[10] Pan, X.H., Wang, B.B., Li, Y. (2013) Foreign demand response technology and project practice. Power demand side management, 15: 58-62.
[11] Zhou, M, Li, G.Y., Ni, Y.X. (2012) Preliminary study on the implementation mechanism of DSM in power market. Power grid technology, 29: 6-11.
[12] Zhao, Y., Li, B.S., Jiang, C.W. (2016) Suggestions on the operation mechanism of China's demand side resources participating in the power market under the condition of open power sales side. Power construction, 3: 112-116.
[13] Chen, Y.G., Zhang, X., Luo, G., BAI, Y., Tan, Z.F., Zhong, H.W. (2019) Demand response mechanism and method of electricity spot market under the mode of non quotation of customer reported volume. Power system automation,43: 179-186.
[14] Zhang, W., Wang, X.L. (2017) Supply side demand response strategy based on block bidding. Power system automation,41: 24-29.