Research on Energy Storage Capacity Planning Model Considering Peak Regulation Gap

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Abstract. Establishing a clean energy-based power supply model and realizing energy structure adjustment are currently important directions for energy development in various parts of China. Realizing the cleanliness of urban energy structures depends on large-scale energy storage technologies. Therefore, the rational planning of long-term and short-term energy storage plans in the region is of great significance to guide the development of urban energy storage and further realize the cleanliness of urban energy structure. In this context, this paper considers the peak shaving gap and establishes a wide range of energy storage capacity planning models. Urumqi is used as an example city to develop a regional planning plan using the above model. An example validates the effectiveness of the model.

1. Introduction
The application of the energy storage system in the power grid can delay the upgrade of the power grid, reduce transmission congestion, provide auxiliary services and improve the reliability of power supply, thus bringing corresponding benefits. At the same time, under the peaking and valley price mechanism, the energy storage system can realize arbitrage through low storage and high output [1-2]. Therefore, there are a variety of objective functions in energy storage planning, which can be as follows: the maximum return of the investment body, the lowest unit power generation cost of the city, the best emission reduction effect, the improvement of power supply reliability, or meeting the requirements of clean energy permeability [3-5]. Different cities should focus on different aspects of planning according to their own conditions. For the regions with severe curtailment of wind and light, effective measures should be taken to solve the problem of consumption of clean energy. Literature [6] pointed out that the lack of peak shaving capacity was the main factor restricting the consumption of new energy, and analyzed how to improve the peak shaving capacity of power grid through the auxiliary peak shaving means of thermal power plants to improve the consumption level of renewable energy. According to literature [7], through the pre-start and stop plan of load and the rolling adjustment within a day, load is brought into the coordinated control of the power system as an adjustable object, which can realize the joint peak regulation between the power grid and the demand side. The evaluation models of peak load capacity, peak load gap quantization model and effect evaluation model of electrolytic aluminum, silicon carbide and ferroalloy participating in large-scale new energy interconnection are established. Due to the limited sending capacity of the power grid, the insufficient peak adjusting capacity of conventional power, and the lack of large-scale energy storage technology, the absorption capacity of wind power...
needs to be improved [8-10]. On the premise that the installed capacity of wind power continues to expand and the scale of high-load energy enterprises continues to expand, the feasibility and effect quantification study on the involvement of demand-side resources in large-scale new energy peak regulation can effectively realize the complementary advantages and coordinated development of large-scale wind power and high-load energy enterprises, so as to reduce the peak regulation pressure of the power grid [11-13].

Based on the above considerations, combined with the application status of energy storage system in Chinese cities, this paper establishes an energy storage capacity planning model considering the peak shaving gap, and provides a practical method for cities to formulate energy storage planning schemes. The energy storage planning scheme of urumqi in recent years is obtained through the application of an example in urumqi, which verifies the practicability of the model and provides a reference for the formulation of energy storage planning scheme in other regions.

2. Another section of your paper

Generally in the experimental environment, energy storage planning uses optimization theory to select the location and volume of the energy storage system. For example, taking the lowest cost per unit of power generation as the goal, and considering the system supply and demand balance, energy storage charging/discharging power, safety and other constraints, the heuristic algorithm is adopted for optimization. The installation location of energy storage is selected and planned with the goal of minimizing network loss, and the optimal capacity is determined by particle swarm optimization algorithm. The location and capacity of distributed power supply and energy storage are optimized with the goal of minimizing the emission of pollution gas. The multi-objective site-selection and configuration model of energy storage system for active distribution network is established from the aspects of peak load clipping and voltage quality. With the goal of minimizing the sum of the investment cost of a day battery energy storage system and the operating cost of micro grid, the site selection and capacity model was constructed, etc. [14-15]. To sum up, at present, the research on site selection and capacity determination of energy storage system is mainly aimed at technical and economic indicators and based on various optimization algorithms for optimization. However, such methods have high data requirements and low efficiency, and the results are easy to fall into the local optimum. They are applicable to the experimental environment where various parameters are easy to obtain, and they are not operable in practice.

Therefore, a more practical planning method should be adopted. Combined with the application status of energy storage system in Chinese cities, the availability of data and the scientific and reasonable planning results are ensured. This paper establishes a peak-shaving gap energy storage capacity planning model, which is more practical and has a greater reference value.

2.1. Peak shaving demand

Under the condition that large-scale clean energy is connected to the power grid, the peak shaving demand of the power grid is based on the load peak-valley difference under normal conditions, and is also affected by the output characteristics of clean energy after grid connection, including wind power and photovoltaic power Inversion peak characteristics. The peak shaving needs assessment model is as follows:

$$\text{P}_{\text{req}} = \text{P}_{L_{\text{max}}} (1 + k) - \text{P}_{L_{\text{min}}} + \text{P}_{\text{wind}} - \text{P}_{\text{pv}}$$  \hspace{1cm} (1)

Where, $\text{P}_{\text{req}}$ represents Peak shaving demand; $\text{P}_{L_{\text{max}}}$ and $\text{P}_{L_{\text{min}}}$ are the maximum load and the minimum load respectively; $\text{P}_{\text{wind}}$ is the wind power output; $\text{P}_{\text{pv}}$ is the photovoltaic power output; $k$ is the system rotation reserve ratio (= load reserve 2% ~ 5% + accident reserve 4% ~ 10%, the case analysis 15% is calculated uniformly).
2.2. Peak Shaving Capacity before Energy Storage Construction

2.2.1. Regardless of user side participation in peak shaving. Regardless of the user-side participation in peak shaving, the peak shaving of conventional power plants in the power system mainly includes two aspects, namely the peak shaving capacity of thermal power plants and hydropower plants. The lower safety limit of thermal power plants is generally 60 ~ 70%. The adjustment capacity model of thermal power plants is as follows:

$$P_{th} = \sum_{i}^{NT} (P_{f_{\text{max}}}^i - P_{f_{\text{min}}}^i)$$

where, $P_{th}$ is the sum of peak shaving capacity of all thermal power units, $P_{f_{\text{max}}}^i$ is the upper processing limit of unit $i$, $P_{f_{\text{min}}}^i$ is the lower safety limit of unit $i$ output; $NT$ is the number of thermal power units.

Hydropower plants have strong regulation capabilities, low safety limits, and fast start-stop regulation without additional costs. Its regulating capacity model is as follows:

$$P_{hw} = \sum_{i}^{NH} (P_{w_{\text{max}}}^i - P_{w_{\text{min}}}^i)$$

where, $P_{hw}$ is the sum of peak adjusting capacity of all hydropower units; $P_{w_{\text{max}}}^i$ is the upper limit of unit $i$, $P_{w_{\text{min}}}^i$ is the lower limit of output safety of unit $i$; $NH$ is the number of hydropower units.

The calculation method is general and can be used to calculate the peak shaving capacity of clean energy systems in various cities. For the case where the hydropower unit is not included in the current installation, $P_{hw} = 0$ can be set in the calculation.

2.2.2. Consider user-side participation in peak shaving. According to the characteristics of high-load energy load, high-load energy user load can adjust its load power when the system has a peak shaving gap, thereby participating in the system's peak shaving. This report mainly considers the load regulation characteristics of three typical high-energy loads: electrolytic aluminum and silicon carbide and ferroalloys.

$$P = P_{N_{p}} \left( \frac{U}{U_{N}} \right)^{P_{U}} \left( \frac{f}{f_{N}} \right)^{P_{f}}$$

where $P$ is the active power of the load, $P_{N_{p}}$ is the initial value of the active power, $P_{U}$ is the voltage characteristic coefficient, and $P_{f}$ is the frequency characteristic coefficient. The values of $P_{U}$ and $P_{f}$ can be obtained by measuring multiple sets of load buses and their corresponding active power.

For electrolytic aluminum plants, the limit value of the load bus voltage adjustment is 0.1p.u. According to the electrolytic aluminum load regulation characteristics, its active power can be adjusted to a maximum of (100-a)% of its rated power, and the adjustment capacity is a%.

For silicon carbide plants, the limit value of the load bus voltage adjustment is 0.11p.u. Calculated, its active power can be adjusted up to its rated (100-b)% and the adjustment capacity is b%.

In the same way, according to the current voltage adjustment limit value of the ferroalloy load being calculated at 0.11p.u., its active power can be adjusted up to its rated (100-c)% and the adjustment capacity is c%.

Therefore, the day-to-day adjustment capacity of the three high-load energy loads can be expressed as:

$$P_{\text{regu}} = a\% * P_{AI} + b\% * P_{SI} + c\% * P_{Fe}$$

If the silicon carbide and ferroalloy load start-stop schedule is taken into account, the adjustment range of these two loads is 100%. Therefore, the day-ahead peak regulation capacity of high energy load is:
\[ P_{\text{reg}} = 100\% \times P_{\text{sl}} + 100\% \times P_{\text{fr}} \]  

(6)

Then, the total peak-regulating capacity of high energy load is the sum of intraday regulating capacity and day-ahead start-stop capacity. The expression is as follows:

\[ P_{\text{reg}} = P_{\text{regu}} + P_{\text{regf}} \]  

(7)

In the above formula, \( P_{\text{sl}} \), \( P_{\text{sl}} \) and \( P_{\text{fr}} \) are respectively the load adjustment capacity of electrolytic aluminum, silicon carbide and ferroalloy. In the case that no user participates in the peak-adjusting mechanism of demand response, \( P_{\text{reg}} = 0 \) can be set.

2.3. Peak adjustment gap.

The peak shaving gap is actually considering the difference between the peak shaving demand of clean energy grid connection and the conventional peak shaving capacity of the power system and the user-side peak shaving capacity. According to the above research content, the expression of the peak shaving gap can be obtained as:

\[ P_{\text{balance}} = P_{\text{reg}} - (P_{\text{bw}} + P_{\text{bf}}) - (P_{\text{regu}} + P_{\text{regf}}) \]  

(8)

2.4. Energy storage capacity.

Considering the role of energy storage for peak clipping and valley filling, the configured energy storage power is:

\[ P_{\text{Watt}} = \frac{P_{\text{balance}}}{2} \]  

(9)

The configured energy storage capacity is:

\[ P_{\text{capacity}} = \int_0^{24} P_{\text{balance}} dt, P_{\text{balance}} > 0 \]  

(10)

Typical daily charge / discharge duration is:

\[ h = \frac{P_{\text{capacity}}}{P_{\text{Watt}}} \]  

(11)

3. Empirical analysis

Combined with the planning data for the evolution of clean energy systems in the target year of Urumqi in Table 1, using the above planning method, the overall planning plan for the target year is calculated as shown in Table 2:

| Year | Installed type       | Capacity (MW) | Proportion |
|------|----------------------|---------------|------------|
| 2021 | Thermal power        | 12040         | 70%        |
|      | wind power           | 4300          | 25%        |
|      | Photovoltaic         | 860           | 5%         |
|      | Total                | 17200         | 100%       |
| 2023 | Thermal power        | 14664         | 65%        |
|      | wind power           | 5640          | 25%        |
|      | Photovoltaic         | 2250          | 10%        |
|      | Total                | 22554         | 100%       |
| 2025 | Thermal power        | 16700         | 60%        |
|      | wind power           | 7000          | 25%        |
|      | Photovoltaic         | 4100          | 15%        |
|      | Total                | 27800         | 100%       |
Table 2. Target annual energy storage allocation scale in Urumqi

| Scale                        | Year | 2021 | 2023 | 2025 |
|------------------------------|------|------|------|------|
| Energy storage power (MW)    |      |      |      |      |
| Energy storage capacity (MWh)|      |      |      |      |
| Typical daily discharge duration in winter (h) | 4.5  | 4.8  | 3.6  |

The three-phase plan for energy storage in Urumqi is as follows:

3.1. Planning stage (2019.11-2019.12)

3.1.1. Implement the energy storage planning plan and assume the main unit, and start to prepare the energy storage construction base planning plan;

3.1.2. The energy storage power station will be included in the planning of the autonomous region according to the first-phase 390MW scale;

3.1.3. According to the near and long-term 700MW energy storage power station and 1300MW energy storage power station included in the autonomous region plan (the "13th Five-Year Plan" and "14th Five-Year Plan" period)

Table 3. Urumqi energy storage configuration power and capacity list in 2021

| Energy storage side | Energy storage power (MW) | Energy storage capacity (MWh) |
|---------------------|---------------------------|------------------------------|
| Power side          |                           |                              |
| wind power plant    | 173                       | 792                          |
| Photovoltaic power station | 12           | 53                           |
| Grid side           | 150                       | 647                          |
| User side           | 50                        | 225                          |

3.2. Comprehensive start-up phase (2020.1-2021.1)

3.2.1. Put into operation a 190MW power-side energy storage power plant, a 100MW power-side energy storage power plant, and a 50MW user-side energy storage power plant;

3.2.2. According to the recent 700MW-scale energy storage power station included in the autonomous region's plan, the compilation of energy storage planning plans has begun;

3.2.3. Include the long-term 1300MW energy storage power station in the planning of the autonomous region;

Table 4. Three Scheme comparing.

| Energy storage side | Energy storage power (MW) | Energy storage capacity (MWh) |
|---------------------|---------------------------|------------------------------|
| Power side          |                           |                              |
| wind power plant    | 321                       | 1540                         |
| Photovoltaic power station | 21           | 100                          |
| Grid side           | 270                       | 1295                         |
| User side           | 90                        | 432                          |

3.3. Project commissioning and application stage ("Fourteenth Five-Year Plan" and long-term)

3.3.1. Put into operation a 342MW power-side energy storage power plant, a 180MW power grid-side energy storage power plant, and a 90MW user-side energy storage power plant;

3.3.2. According to the recent 1300MW scale energy storage power station, it is included in the planning of the autonomous region;
3.3.3. According to the power supply planning plan and the operation of the completed energy storage power station, proceed to develop the "15th Five-Year Plan" energy storage plan for Urumqi Autonomous Region;

| Table 5. Urumqi energy storage configuration power and capacity list in 2025 |
|---------------------------------------------------------------|
| **Energy storage side** | **Energy storage power (MW)** | **Energy storage capacity (MWh)** |
|------|------------------|------------------|
| Power side | | |
| Wind power plant | 595 | 2140 |
| Photovoltaic power station | 40 | 147 |
| Grid side | 503 | 1808 |
| User side | 167 | 603 |

4. Conclusion
This article adopts a more practical planning method. Based on the current application status of energy storage systems in Chinese cities, and taking into account the conditions for data availability, to ensure the scientificity and rationality of planning results, a planning model for energy storage capacity that takes into account the peak shaving gap is established. Then, based on the case analysis of Urumqi, a specific energy storage planning plan for the region with the time nodes of 2021, 2023, and 2025 was developed. On the one hand, the operability and effectiveness of the energy storage capacity planning model are verified. On the other hand, the formulated energy storage planning plan also has certain reference value for Urumqi and other regions. In the current energy context, actively considering the peak shaving gap to plan energy storage capacity and formulate a planning plan is to actively develop energy storage, and to take full advantage of energy storage technology and practical advantages to promote the transition to clean energy. However, in the context of the ubiquitous electric power Internet of Things, a series of issues such as how to achieve efficient energy storage and effectively promote the transition to a clean energy city need to be further studied.

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Research on Urumqi clean energy city and energy storage development.

References
[1] D.W Zhao, W.T Zhang, X.N Liu, etc. Planning of integrated energy system in the park with photovoltaic and hybrid energy storage J. Journal of Electric Power System and Automation, 1-8 [2019-03 -28].
[2] Y ZHANG, S REN, Z.Y DONG. et al. Optimal placement of battery energy storage in distribution networks considering conservation voltage reduction and stochastic load composition J. In IET Generation, Transmission & Distribution, 2017.11(15) : 3862 - 3868: 3869 - 3840.
[3] W Xiong, Y.Q Liu, W.H Su, et al. Multiple energy storage optimal configurations for regional integrated energy systems with multiple complementary energies J. Power automation equipment,2019,39(1): 118-123:124-125.
[4] X.S Zhang, Zhou xuan,Lli zhuo, et al. Optimization planning of future distribution network oriented to energy Internet J. Power construction,2017.38(2) :45-51.
[5] L Guan, P Chen. Z.S Tang, et al. Optimization design method of regional integrated energy station considering cold, heat and electricity storage. 0. Power System Technology, 2016.40 10): 2934-2943.
[6] Y Zhang, G.L Wu, G.S Fu, X.G Liu, Y.J Meng. Impact of Auxiliary Peak Shaving in Thermal Power Plants on Power Systems Containing High Proportion of Renewable Energy J. Electric Power and Energy, 2018, 39 (03): 373-376.
[7] G.H Xie, Q.H Li, C.Z Gao, et al. Research on wind power dissipation capacity based on Balmoral
model [J]. Energy Technology & Economy, 2012, 23 (5): 29-33.

[9] H Yang, J.X Liu, J.S Yuan. Study on the negative peak regulation capability of conventional units in wind power systems J. Chinese Journal of Electrical Engineering, 2010, 30 (16): 26 -31

[10] H.Z Zhang, S.H Yin, H Shen, et al. Evaluation of peak shaving margin of wind power grid-connected system based on sequential Monte Carlo method J. Automation of Electric Power Systems, 2012, 36 (1): 32-37.

[11] J.M Lu. Research on the Model Method and Implementation Mode of China's Power Demand Side Response D. Beijing: North China Electric Power University, 2009.

[12] Q Lu, W Wang, S Han, et al. Evaluation method of power grid abandonment based on peak shaving capacity analysis J. Power System Technology, 2013 (7): 1887-1894.

[13] N Zhang, T.R Zhou, C.G Duan, et al. Impact of large-scale wind farm access on power system peak regulation J. Power System Technology, 2010, 34 (1): 152-158.

[14] J.H Duan. Research on planning and operation decision model of microgrid energy storage system D] Beijing; North China Electric Power University, 2016.

[15] B Liu. X.Y Qiu. Optimized Energy Storage Planning for Active Distribution Networks J. Journal of Instrumentation, 2016, 37 (5): 1180-1186.