Calculation and analysis of the storage capacity configuration of Shanxi power grid based on time series simulation

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Abstract. In recent years, with the energy transformation and the continuous innovation of new energy technology, the installed capacity of new energy continues to increase, the high proportion of new energy access increases the peak pressure of the power grid, but also increases the possibility of de-electric power. As a key solution, energy storage and wind power and other new energy in-depth integration, can effectively improve the power grid adjustment capacity, to ensure the benefits of new energy generation. Using the time series production simulation method, aiming at the utilization rate of new energy, this paper calculates the principle of energy storage configuration in different regions of Shanxi Province, and provides theoretical support for the analysis of energy storage configuration in Shanxi Province.

1. Introduction

In order to reduce carbon emissions and ensure energy security, China is setting off a new round of energy structure transformation and transformation, new energy installed capacity quickly leapt to the world's first. By the end of 2019, the proportion of new energy installed capacity had exceeded 20%, and in Gansu and Xinjiang provinces reached 40%. With the rapid progress of the "Shanxi energy revolution", it is expected that by the end of 2020 the province's new energy installed capacity will become the first in China, accounting for more than 40%.

New energy generation has the characteristics of intermittent and random, wind power also has the anti-tone[1]. The high proportion of new energy access leads to the increasing pressure of peak ingressing of the power grid. China's abandoned electricity consumption with the year-on-year reduction, but still a huge number, and mainly concentrated in the three northern areas. The provinces have taken a series of measures to promote the elimination of new energy sources, such as opening up new energy delivery channels, rational distribution of new energy field stations, and carrying out spot trading of new energy sources. With the development of technology, energy storage gradually entered the public's field of vision, and became a new way of thinking to solve the new energy abandonment limit[2]. As a key solution, the deep integration of energy storage and new energy can effectively enhance the power grid regulation capacity, to ensure the efficiency of new energy generation and the number of hours available[3].

At present, the research on electrochemical energy storage is also gradually deepening. Paper [4] analyzes the energy storage allocation scheme with the objective function of optimal economy, the maximum elimination of wind power and the consideration of both. Paper [5] expounds the analysis of energy storage power station to solve the problem of power grid operation in Shandong from 7 aspects, such as system peak ingesting and new energy reduction. Based on the time series scenario and
clustering method, paper [6] determines the capacity of energy storage capacity of a power grid in a northwest province.

2. Features of Shanxi power grid

Shanxi power grid is located in the western part of The North China Power Grid, which is an important part of the North China Power Grid. By the end of 2019, Shanxi's 500 kV power grid has formed a "three vertical and four horizontal" grid structure. "Three verticals" run through the north and south of Shanxi, Shanxi "North And South" is the main channel; Shanxi power grid power structure and electricity load is in verse distribution, the province's power flow is "north-south transmission" pattern.

By the end of 2019, Shanxi Province's new energy installed capacity reached 23.38 million kilowatts, of which 12.51 million kilowatts of wind power, 10.88 million kilowatts of photovoltaics, new energy accounted for 25.3% of the installed power capacity. Shanxi's maximum direct adjustment load is only 33 million kilowatts, direct transfer capacity of 11 million kilowatts, there is a huge peak pressure. In 2019, Shanxi Province's new energy consumption capacity of 276 million kilowatt-hours. The National Development and Reform Commission (NDRC) issued a Notice on Improving the Tariff Policy for Wind Power Feed-in Tariffs (No. 882 of the Price of The Reform (2019). The document stipulates that "projects approved by the end of 2018 will not be subsidized by the State if they are not connected to the grid by the end of 2020". If approved to be connected to the grid wind power projects to grab electricity prices, will appear in the second half of 2020 concentrated production situation, it is expected that in 2020 and 2021, Shanxi Province, new energy will usher in a peak.

Under different modes of operation, the peak load regulation capacity of Shanxi power grid will be different. In the summer mode of operation, because the wind power output is small and the thermal power unit does not need heating, Shanxi power grid basically meet the needs of new energy elimination, in the winter operation mode, due to the large power output, and heating unit by the heating power influence caused a serious difference in peak performance, thus bringing great pressure to the peak of Shanxi power grid."

In addition, affected by the main variable capacity and line stability constraints, there are currently 6 new energy blocked sections in Shanxi Province, respectively, Yantong-Pingcheng main transformer in Datong area, Xinzhou-Shuozhou-Wuzhai-Minghaihu main transformer, Youyu main transformer, Hu-yu double back transmission line, Fenghuang main transformer and Wo-hu double back transmission line in Xin-Shuo area. Energy storage capacity configuration analysis is required for different characteristics within the section.

![Figure 1. Structure diagram of Shanxi Power Grid](image-url)

3. Energy storage configuration calculation

3.1. Analysis of wind power characteristics in Shanxi Province
Compared with light resources, wind resources are more volatile. The wind power characteristics of Shanxi Province correspond to the characteristics of wind resources, showing obvious daily characteristics and seasonal characteristics, and the daily characteristics are characterized by fluctuations and inverse characteristics.

Figure 2 is a day wind power curve, from the figure can be seen that the daily fluctuations of wind power reached 5.5 million kilowatts, accounting for 46% of the installed capacity of wind power at that time, day wind power output is significantly less than night, and the load characteristics of the opposite. Seasonal characteristics are reflected in the third quarter power than the first, second and fourth quarters, Figure 3 is the 2019 full-year wind power curve.

\[ W = EA_{WP,\min} + EA_{PV,\min} \]  

Here \( EA_{WP,\min} \) represents the abandoned wind power in the calculation period, \( EA_{PV,\min} \) represents the abandoned photoelectric quantity in the calculation cycle.

3.3. Constraints
Constraints include power balance constraints, system rotation reserve capacity constraints, upper and lower limit constraints of thermal power unit during heating and non heating periods, thermal power unit climbing rate constraints, interregional tie line power constraints, thermal power unit startup and shutdown constraints, new energy unit output constraints, energy storage charging and discharging power constraints, energy storage daily replay times constraints, energy storage state constraints

3.3.1. Power balance constraints

The power grid is in a state of constant balance, so the power output at a certain time should be equal to the current power load and tie line power, as shown in formula (2).

\[ P_{\text{load}}^i(t) + P_{\text{line}}^i(t) + \sum P_{LST}^i(t) = P_{T\rightarrow \text{load}}^i(t) \] (2)

Here, \( P_{\text{load}}^i(t) \) represents actual load of area \( i \) at time \( t \), \( P_{\text{line}}^i(t) \) represents tie line load of area \( i \) at time \( t \), \( P_{LST}^i(t) \) represents total switching power of area \( i \) with other areas at time \( t \), \( P_{T\rightarrow \text{load}}^i(t) \) represents equivalent load of area \( i \) at time \( t \).

The calculation of equivalent load is shown in formula (3).

\[ P_{T\rightarrow \text{load}}^i(t) = P_{\text{Th}}^i(t) + P_{\text{WF}}^i(t) + P_{\text{PV}}^i(t) + P_{\text{ES}}^i(t) \] (3)

Here, \( P_{\text{Th}}^i(t) \) represents output of thermal power unit of area \( i \) at time \( t \), \( P_{\text{WF}}^i(t) \) represents wind power output of area \( i \) at time \( t \), \( P_{\text{PV}}^i(t) \) represents photovoltaic output of area \( i \) at time \( t \), \( P_{\text{ES}}^i(t) \) represents energy storage output of area \( i \) at time \( t \).

3.3.2. Rotational reserve capacity constraint

In order to deal with the power imbalance caused by the output of interstitial power supply and other uncertain factors in the system, some thermal power units need to be kept in the rotating standby state, as shown in formula (4).

\[ S_p < \sum u(i,t) P_{\text{TP}}^i(t) - P_{T\rightarrow \text{load}}^i(t) < S_m \] (4)

Here, \( S_p \) represents positive rotational reserve capacity, \( S_m \) represents negative rotational reserve capacity, \( u(i,t) \) represents the state thermal power unit, start state is represented by 1, and stop state is represented by 0, \( N \) represents total number of thermal power units.

3.3.3. Output constraint of thermal power unit

The starting mode of thermal power unit shall refer to the starting mode in 2019. The unit output in non heating period shall be considered as 50% of the lower limit and 85% of the upper limit. The upper and lower limits of the unit output in heating period shall be in accordance with the notice of jinjianneng market < 2018 > 144 on printing and distributing the calculation and prediction results of operation mode of heating unit in Shanxi Province (2018-2019). In order to simplify the calculation, the thermal power units with similar capacity are converted.

\[ \begin{align*}
W_{\text{NHP\rightarrow min}}^k &< \sum u(i,t) P_{\text{TP}}^i(t) < W_{\text{NHP\rightarrow max}}^k \\
W_{\text{HP\rightarrow min}}^k &< \sum u(i,t) P_{\text{TP}}^i(t) < W_{\text{HP\rightarrow max}}^k
\end{align*} \] (5)

Here, \( W_{\text{NHP\rightarrow min}}^k \) represents minimum technical output of thermal power unit with capacity \( k \) in non heating period, \( W_{\text{NHP\rightarrow max}}^k \) represents maximum technical output of thermal power unit with capacity \( k \) in non heating period, \( W_{\text{HP\rightarrow min}}^k \) represents minimum technical output of thermal power unit with capacity \( k \) in heating period, \( W_{\text{HP\rightarrow max}}^k \) represents maximum technical output of thermal power unit with capacity \( k \) in heating period.

3.3.4. Climbing rate constraint of thermal power unit

Due to the influence of boiler and steam turbine, the lifting load rate of thermal power unit is adjusted within a certain range, as shown in formula (6).

\[ \begin{align*}
P_{\text{TP}}^i(t) - P_{\text{TP}}^i(t-1) &\ll \Delta P_{\text{up}} \\
P_{\text{TP}}^i(t-1) - P_{\text{TP}}^i(t) &\ll \Delta P_{\text{down}}
\end{align*} \] (6)
Here \( \Delta P_{\text{up}} \) represents climbing rate of thermal power unit, \( \Delta P_{\text{down}} \) represents downward climbing rate of thermal power unit rate of thermal power unit.

### 3.3.5. Tie line power constraint between areas

The transmission capacity of the line is affected by material, sectional area, ambient temperature and other factors. Therefore, the real-time power between regions should meet the constraints of formula (7).

\[
P_{i,j}^{\text{line-min}}(t) < P_{i,j}^{\text{line}}(t) < P_{i,j}^{\text{line-max}}(t)
\]

Here \( P_{i,j}^{\text{line}}(t) \) represents the actual transmission power of area \( i \) and area \( j \) at time \( t \), \( P_{i,j}^{\text{line-min}}(t) \) represents lower power limit of area \( i \) and area \( j \) at time \( t \), \( P_{i,j}^{\text{line-max}}(t) \) represents upper power limit of area \( i \) and area \( j \) at time \( t \).

### 3.3.6. Start-Stop constraint of thermal power units

The start-up and shut-down action time interval of thermal power unit shall meet formula (8).

\[
\begin{align*}
S_{\text{on}}(i, t) + S_{\text{off}}(i, t + 1) &+ S_{\text{on}}(i, t + 2) + \cdots + S_{\text{on}}(i, t + \min \_\text{on}(i)) \leq 1 \\
S_{\text{off}}(i, t) + S_{\text{off}}(i, t + 1) &+ S_{\text{off}}(i, t + 2) + \cdots + S_{\text{off}}(i, t + \min \_\text{off}(i)) \leq 1
\end{align*}
\]

Here \( S_{\text{on}}(i, t) \) represents start-up action of unit \( i \) at time \( t \), action set 1, no action set 0; \( S_{\text{off}}(i, t) \) represents shut-down action of unit \( i \) at time \( t \), action set 1, no action set 0; \( \min \_\text{on}(i) \) represents the minimum starting time of unit \( i \); \( \min \_\text{off}(i) \) represents the minimum stopping time of unit \( i \).

### 3.3.7. Power constraints of charge and discharge in energy storage system

The charging and discharging power of the energy storage system is affected by the rated power and efficiency of the energy storage system, and the energy storage system cannot be charged and discharged at the same time.

\[
\begin{align*}
P_i^+(t) &\leq \eta^+ P_i^\

P_i^-(t) &\leq \eta^- P_i^-

P_i^+(t)P_i^-(t) &= 0
\end{align*}
\]

Here \( P_i^+(t) \) and \( P_i^-(t) \) are the charging and discharging power of area \( i \) at time \( t \), \( \eta^+ \) and \( \eta^- \) are the charge and discharge efficiency for energy storage, \( P_i^+ \) and \( P_i^- \) are the charge and discharge rated power for energy storage, when the stored energy is in charging state, \( P_i^-(t) \) set to 0, otherwise, \( P_i^+(t) \) to 0.

### 3.3.8. State of charge constraint of energy storage

\[
\begin{align*}
\text{SOC}_{i}(t) &= \text{SOC}_{i}(t-1) + \Delta t P_i^+(t) \eta^+ - \Delta t P_i^-(t) \eta^- \\
\max [\text{SOC}_{i}(t)] &\leq \text{SOC}_{max} \\
\min [\text{SOC}_{i}(t)] &\geq \text{SOC}_{min}
\end{align*}
\]

Here \( \text{SOC}_{i}(t) \) represents State of charge of energy storage system in area \( i \) at time \( t \), \( \text{SOC}_{max} \) and \( \text{SOC}_{min} \) are the upper and lower limits of the state of charge.

### 4. Simulation and analysis

In order to improve the utilization rate of new energy channel and Shanxi Province, this part uses time series production simulation method to calculate the energy storage demand.

This section uses time series production simulation method to simulate the energy storage configuration in Youyu area, Datong area and Xin-Shuo area respectively, aiming at the utilization rate of new energy. Then, aiming at the utilization rate of new energy in the whole province, we optimize the allocation and storage of energy in different regions, and get the power and capacity of the allocation and storage of energy in Shanxi power grid.

Style and spacing

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4.1. Improve the utilization rate of new energy channels

The blocking of cross section is the main component of new energy in Shanxi Province. This section takes Youyu area and Datong area as examples to calculate the configuration requirements of energy storage system to improve channel utilization.

Figure 4 shows the power curve of new energy in two regions in 2020.

![Figure 4. The power curve of new energy in two regions in 2020 (MW)](image)

Figure 5 shows the abandoned power of new energy due to the limited cross-section when the two regions are equipped with different power storage. With the increase of energy storage power, the waste power of new energy due to the limited cross-section decreases gradually, and the reduced waste power slows down.

![Figure 5. Energy storage power consumption in different power configurations (twh)](image)

4.2. Improve the utilization rate of new energy in Shanxi Power Grid

In consideration of the impact of the limit of the transmission channel, the energy storage configuration should also be reasonable in each region. Figure 6 shows the new energy utilization curve of the whole network when the ratio of energy storage power to capacity is set 1:4. When Shanxi power grid is equipped with 3 million kilowatts of energy storage, the utilization rate of new energy can reach 95%.
5. Conclusion

(1) Considering the channel utilization ratio, the allocation of 2 million kWh energy storage in Datong area can reduce the new energy consumption by 540 million kWh due to the blocked section. When 500000 kWh of energy storage is allocated in Youyu area, 180 million kWh of new energy waste can be reduced due to blocked cross section.

(2) When the Shanxi power grid is equipped with 3 million kilowatts of energy storage, the waste energy of new energy will be reduced by 1.84 billion kilowatt hours, and the utilization rate will be increased by 3.9 percentage points to 95%.

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