Medium and long-term power quantity check and adjustment method based on power quantity margin

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Abstract. Medium and long-term power trade is increasing, and the adjustable margin of power grid is reducing. Therefore, medium and long-term power quantity security check is necessary. Firstly, a power quantity margin model is constructed, and power quantity constraints and the future state grid model are considered. The power quantity limits of principal parts such as unit and line section are calculated, and quantity adjustment method is given. Then the medium and long-term power quantity check and adjustment are realized through the correlation coefficient matrix. Finally, the actual provincial power grid is taken as an example to verify the effectiveness of the proposed model and method. Through the calculation of the quantity margin by power, the verification of medium and long-term transactions and the control of the safety margin of the power grid are realized.

1. Introduction

In recent years, with the steady advancement of market-oriented reforms and the orderly liberalization of power generation plans in China, the scale of market trading power has been expanding, the volume of power quantity in the medium and long-term has been increasing, and the requirements for rigid execution have become higher and higher, causing grid regulation space and safety margin reduced [1-2]. Due to the long time span and the uncertainty of the grid boundary, it lacks an effective, comprehensive and standardized check adjustment method for medium and long-term power trade [3]. Therefore, in order to ensure the safety of the grid and the smooth execution of power trade, it is necessary to provide effective and feasible medium and long-term power quantity check and adjustment methods.

In foreign countries, there are many medium and long-term financial contracts. In the short-term, the spot market is considered and unified by SCUC (security constrained unit Commitment) and SCED (security constrained economic dispatch) [4-6]. In China, the trading and dispatching institutions are relatively independent, and there are many researches on medium and long-term and short-term power grid dispatching [7-9]. There are few studies on medium and long-term power quantity safety check. Generally speaking, there are two current solutions: It is a method of power quantity check, which converts power-related constraints into power quantity constraints, and checks medium- and long-term...
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power quantity in month and year. Based on the transaction power and planned quantity, the literature [3] considers three safety check indicators for peak shaving, energy saving, and blockage, and checks the medium and long-term quantity through annual and monthly safety checks. The reason for the failure to pass the check is given. In [10], the annual and monthly contract transaction power is used as the check object, and a safety division is established. The power consumption of the winning electricity and the transmission contact section is determined as a decision variable, and the safety calibration optimization model is determined. In [11], based on the power generation plan, a monthly quantity check model is constructed. Considering the constraints of system power, unit power and line power, the transmission capacity of the line is evaluated, and the monthly power trade plan is checked and adjusted. The power quantity check is performed from the quantity level to the overall analysis of the power transmission. It does not involve the power quantity decomposition and power flow calculation. It is simple and fast, but in the case that the current power grid structure becomes more complex and the AC-DC coupling becomes more and more tight, it is more and more difficult to analyze and calculate the section blockage and transmission limit from the power quantity point. In addition, when power quantity check is passed, there will be certain requirements for the start and stop of the unit and the output. If the transaction volume is relatively large, although the power quantity check can pass, there may be no feasible solution when the unit is dispatched.

The second is the power check method, which decomposes power quantity into power, and then performs power balance and network security check. The literature [12] conducts a safety check on the monthly power generation plan during peak load hours with one 6 time slot per day. In [13], considering the monthly 720 unit combination, three typical load sections of peak load, waist load and valley load are selected, and the power flow safety check and optimization correction are carried out with the optimal power flow model. In [14], the monthly power quantity decomposition and safety check are refined to the peaks, flats and valleys of each day to improve the safety check accuracy. Most of the existing power calibration documents have already determined the amount of power quantity, and then develop the unit combination and conduct safety check. However, in the process of medium and long-term electricity check, it is necessary to decompose the power quantity into power and check it again. Although this power check is more accurate, as the time scale is refined, the amount of calculation will inevitably increase, and the principle of power decomposition is also difficult to determine.

In summary, the power quantity check is too primitive, not fine enough. The power check is difficult to use due to dimensional disasters and computational speed, and the point-by-point check of the medium- and long-term scale refinement to power is not significant. This paper proposes a method based on the power quantity margin, which takes the power quantity limit of key components such as unit and section as the target, and implements safety check by means of power calculation and power quantity check. In addition, the current literature does not consider future grid topology changes, this paper will be based on the future grid model for power calibration.

2. Power quantity margin model

Based on the future grid model, the verification method proposed in this paper takes the calculation of the maximum monthly power generation of the main subjects (unit, unit group, line, section) as the target, and considers the constraints of unit operation, grid balance, and network security to establish a grid margin solution model to determine the amount of power quantity, which is used as the basis for power quantity check. If the quantity exceeds the limit, quantity adjustment is performed according to the correlation matrix. In the process of solving the power quantity margin of the subjects, the constraints of other subjects and grid operation are considered. The planned trade is considered to be viable only after passing all the power quantity check of the associated subjects.

In the process of calculation, this paper uses electric power to calculate, and selects 3 points [15] according to the load peak, flat and valley time, and then accumulates and converts into power quantity.
2.1. Objective function

The maximum monthly power generation of the unit, the unit group, the line and the section is the target:

\[ \text{max } f(p_{i,t}) = \sum_{t=1}^{T} p_{i,t} \times \alpha_{i} \]  

(1)

Where: \( p_{i,t} \) represents the active power value of the subject during the \( t \) period, \( T \) represents a monthly period, which can take one hour, more hours or one day as a time slot according to the calculation requirement, and \( \alpha_{i} \) represents the power-quantity conversion coefficient of the device \( i \), according to the time period choiced.

2.2. Mandatory power quantity

In the actual dispatching of the power grid, due to the need of safe operation, many units have mandatory power quantity. In the process of calculating the power quantity margin of each subject, these power quantity must be used as boundary conditions. Mandatory power quantity at least have the following types:

1. Constrained quantity generated by voltage support, short circuit capacity, etc. Local voltage support and DC short-circuit capacity cause the unit to start up, thus forming the amount of electric quantity.
2. The network security constraint power quantity refers to the amount of quantity that the generator set must turn on due to the ability and limit of the section.
3. The amount of electric quantity generated by the accident reserve capacity after the DC blocking of the area. Considering cross-region DC blocking, the DC floor-end power grid should maintain a reasonable scale unit turned on, and the necessary accident reserve capacity should be left. The part that needs to be turned on beyond the local balance is regarded as the mandatory power quantity.
4. The minimum boot mode required for phased protection. The power quantity is generated by the minimum technical output of the unit in order to ensure the sensitivity and phase protection cooperation.

2.3. Constraints

The model is based on the SCUC model. In addition to the conventional constraints [16], the unit group constraints and power quantity constraints are added. The unit group power constraints and unit constraints are similar, so they are listed together. The specific constraints are as follows:

1. Power balance constraint:
   \[ \sum_{i=1}^{T} p_{i,t} = P_{t} \]  

(2)

Where \( P_{t} \) represents the system load forecast for the \( t \) period.

2. Unit(unit group) limit constraint:
   \[ p_{i,\text{min}} \leq p_{i,t} \leq p_{i,\text{max}} \]  

(3)

Where \( p_{i,\text{min}}, p_{i,\text{max}} \) respectively represent the lower limit and upper limit of the active output of the unit (unit group) \( i \).

3. Unit turn on and off time constraint:
   \[ \begin{cases} t_{i,\text{on}} \geq t_{i,\text{up}} \\ t_{i,\text{off}} \geq t_{i,\text{down}} \end{cases} \]  

(4)

Where \( t_{i,\text{on}}, t_{i,\text{off}} \) are the continuous on and off time of unit \( i \), \( t_{i,\text{up}}, t_{i,\text{down}} \) are the minimum on and off time of unit \( i \).

4. Unit(unit group) power quantity constraint:
\[ q_{i,\text{min}} \leq q_i \leq q_{i,\text{max}} \]  \hspace{1cm} (5)

Where \( q_i \) is the power quantity of unit (unit group) \( i \), \( q_{i,\text{min}} \) is the lower limit of power quantity, including mandatory power quantity, \( q_{i,\text{max}} \) is the upper limit of power quantity.

(5) Power grid security constraint:

\[ L_{k,\text{min}} \leq \sum_{t=1}^{M} l_i \cdot S_{i,k,t} \leq L_{k,\text{max}} \]  \hspace{1cm} (6)

\[ D_{j,\text{min}} \leq d_{j,t} \leq D_{j,\text{max}} \]  \hspace{1cm} (7)

Where \( L_{k,\text{min}} \) and \( L_{k,\text{max}} \) represent the lower limit and upper limit of the power flow of line \( k \), \( M \) is the number of system nodes, \( l_i \) is the net injection power of node \( i \) during \( t \) period, \( S_{i,k,t} \) is the sensitivity of node \( i \) injected power to branch \( k \) during \( t \) period, \( d_{j,t} \) is the power flow of the section (section of the branch) \( j \) during \( t \) period, \( D_{j,\text{min}} \) and \( D_{j,\text{max}} \) respectively represent the lower limit and upper limit of the power flow of line \( j \).

2.4. Future state grid model

Due to the future power grid involved in the mid and long-term power safety check, especially the changes in important power transmission and transformation equipment will have a greater impact on the power flow, the future power grid model is the foundation, and the current research is still less [17].

![Figure 1. Description of power grid model.](image)

This paper uses the CIM/E format [18-20] document to describe the grid model. The topology connection of the power grid model is based on the substation. The first step is to include multiple voltage levels. Each voltage level includes multiple equipments. The equipments are connected through terminals, and the terminals are connected through connectivity nodes. As shown in the Figure 1 above.

In view of the business needs of dispatch planning and safety check, this paper takes into account the current grid model and fully considers the commissioning, decommissioning and outage of plant stations with different time intervals and different voltage levels to form a future state grid model for medium and long-term electricity check. In the model construction and maintenance, the key issues are considered:

(1) Only 220kV and above voltage devices are considered, and the 220kV step-down transformer in the model is equivalently processed. At the same time, the scope of modeling equipment is mainly for all types that have an impact on grid power, such as plant stations, units, lines, transformers, loads, busbars, etc., but not for secondary equipment such as protection devices.

(2) For new investment equipment, it is necessary to increase the basic information such as the equipment name, the plant station, and the voltage level, and establish the logical relationship between the node and the existing model.
(3) For the maintenance equipment, according to the equipment outage and re-service time, combined with the timing requirements of the model generation, identify the status of equipment outage and commissioning.

(4) For decommissioning equipment, delete the equipment in the corresponding equipment table, and delete the relevant records in the connection node, voltage level, transformer, transformer winding, line end point table, transformer end point table, bus line and logic relationship table.

Based on the above-mentioned margin model and future grid model, a medium and long-term power quantity margin solution model is established, and then a mature cplex optimization calculation software package is used to solve the problem.

3. Power quantity check and over-limit adjustment

Through the above calculation, the monthly power quantity margin of each subject can be obtained, and then the planned power of each subject can be calculated according to the plan trade, and the two comparisons can determine the over-limit situation.

Calculate the planned power quantity of each subject by the following methods:

\[ F = K \cdot U \]  \hspace{1cm} (8)

Where \( U \) represents the medium and long-term trading quantity of the unit, \( F \) represents the planned quantity of subject, and \( K \) represents the correlation coefficient matrix.

For unit and unit group, the correlation coefficient matrix is shown as below, where \( k_{ij} \) represents the inclusion relationship between unit \( i \) and unit (group) \( j \), which is 0 or 1.

\[
K = \begin{bmatrix}
k_{11} & k_{12} & \cdots & k_{1n} \\
k_{21} & k_{22} & \cdots & k_{2n} \\
\cdots & \cdots & \cdots & \cdots \\
k_{n1} & k_{n2} & \cdots & k_{nn}
\end{bmatrix} \hspace{1cm} (9)
\]

For line and line section, the correlation coefficient matrix is shown as below, where \( k_{ij} \) represents the power transfer distribution factor for unit \( i \) and line (or section) \( j \), which needs to be solved according to the network model.

After the occurrence of the limit, you can locate the over-limit subject, the over-limit month, and the corresponding power plant or unit according to the above formula (8). According to certain principles (such as minimum adjustment, minimum adjustment of new energy, minimum adjustment cost, etc.), the medium and long-term trading power quantity is adjusted.

4. Case analysis

Apply the above method to the power quantity safety check of Sichuan Power Grid. The main steps include establishing a future grid model, calculating quantity margins, quantity check, and quantity adjustment. Constraints include grid balance constraint, safety constraint, unit (group) power and quantity constraint, minimum on-off time constraint, and so on.

4.1. Establish future grid model

Sichuan is dominated by hydropower, and the power grid is complex. In addition to being connected to the outside through multiple tie lines and DCs, there are also a large number of power plants under the jurisdiction of the national dispatch and control center. These power plants are transported to East China through three DCs together with Sichuan local hydropower.

Based on the grid model on the last day of 2017, this paper establishes a 2018 monthly scale grid model, and considers the maintenance plan, new investment plan and decommissioning plan of key equipment, refines the monthly model, and forms multiple future state grid models. As shown in the following Table 1:
Table 1. Construction of power grid model.

| Grid model start time | Model change reason            |
|-----------------------|--------------------------------|
| 20180116              | Equipment outage               |
| 20180128              | Equipment outage               |
| 20180210              | Equipment outage               |
| 20180307              | Equipment outage               |
| 20180316              | Equipment outage, Equipment add|
| 20180406              | Equipment outage               |
| 20180425              | Equipment outage, Equipment add|
| 20180510              | Equipment outage               |
| 20180610              | Equipment add                  |
| 20180810              | Equipment outage, Equipment add|
| 20180910              | Equipment outage, Equipment add|
| 20181010              | Equipment outage, Equipment add|
| 20181111              | Equipment outage, Equipment add|
| 20181120              | Equipment outage               |
| 20181210              | Equipment outage, Equipment add|

4.2. Calculate power quantity margins

According to the above power margin calculation method, the monthly power margin of the main unit (plan unit), the unit group, the line and the section of the Sichuan power grid is calculated. All 336 plann units (units and power plants), 20 sections, and 21 units have been calculated in the province. The monthly power quantity margin of a section is shown in the following Figure 2:

![Figure 2. Power quantity margin of line section.](image)

It can be seen from the figure that during the wet season (May-October), due to the influence of power supply balance and network constraints, the power quantity margin is large; since the section has power outages and maintenance in February, the quantity space in February significantly less than other months.

The monthly power quantity margin of a plan unit is shown in the following Figure 3:
Figure 3. Power quantity margin of plan unit.
The planning unit is a new hydropower plant, which has been put into operation since March, so there is no quantity margin in January and February; in the wet season, the quantity margin is large. The monthly power quantity margin of a unit group is shown in the following Figure 4:

Figure 4. Power quantity margin of unit group.
The unit group consists of several units. It can be seen from the comparison of the above figure that the unit group is not necessarily equal to the accumulation of its member's quantity margin due to the constraints of the power and quantity of its own unit group. From May to October, the power quantity margin of the unit group is less than the accumulation of its member's quantity margin, which is also consistent with the actual situation.

4.3. Power quantity margin verification
(1) Hydropower plant annual power quantity margin comparison
In order to verify the accuracy of the power quantity margin calculation, the calculation result of a hydropower plant in 2018 is compared with the actual power quantity, as shown in the following Figure 5:

Figure 5. Comparison of hydropower quantity.
It can be seen from the figure that there is a certain deviation between the quantity margin of the power plant and the actual power quantity, and the deviation shows an increasing trend as the month increases. This is mainly because the forecast data and grid model were acquired at the end of 2017. As time increases, the accuracy of the underlying data decreases, resulting in increased bias.

In January-July, the monthly deviation rate is less than 10%, and the maximum deviation of the whole year is less than 15%, which is in line with the current medium and long-term quantity check demand, and the deviation will be corrected within the time scale of the monthly and the day ahead.

(2) Coupling analysis of correlation sections
In order to verify whether the power quantity margin calculation can handle the correlation section, consider two sections A and B with physical connection, and set two cases: Case 1, the limit of section B is the normal limit, 4000MW; Case 2, the limit of section B is 3000MW, which compares the power quantity margin of section A under two conditions. The result is shown in the following Figure 6:

![Figure 6. Comparison of power quantity margin for section.](image)

It can be seen that under the same conditions of other constraints, changing the limit of section B will affect section A. The power quantity margin of section A is reduced by 10.8% overall in Case 2, especially during the wet season, the power quantity margin of Section A drops significantly. It can be seen that the power flow of sections A and B in the wet season are large, and the decrease of section B limit has a greater impact on section A. This also shows that various constraints and coupling relationships are considered in the calculation of the power quantity margin.

4.4. Power quantity check and adjustment
After completing the power quantity margin calculation, specify a medium and long-term power plan for a part of the planning unit, and then perform the power check according to the above method. After the check, it was found that the power quantity plan of Sections 1 and 2 was greater than the quantity margin in July, and the limit was exceeded, as shown in the following Table 2:

| Section | Power quantity plan | Power quantity margin | Over limit quantity |
|---------|---------------------|-----------------------|---------------------|
| Section 1 | 169999 | 166725 | 3274 |
| Section 2 | 189197 | 182279 | 6918 |

According to the correlation coefficient, find the planning unit that causes the section to exceed the limit, and then adjust the power with the minimum adjustment function as the objective function, and finally eliminate the limit. The specific adjustment amount is as shown in the following Table 3:

| Plan unit | Eliminate over limit of section 1 | Eliminate over limit of section 2 | Eliminate over limit of both section |
|-----------|----------------------------------|----------------------------------|-------------------------------------|
| 1st plan unit | 8622 | 0 | 29838 |
| 2nd plan unit | 0 | 48831 | 74142 |
| 3rd plan unit | 0 | 2971 | 2971 |
|             | 4th plan unit | 5th plan unit | Total     |
|-------------|---------------|---------------|-----------|
| 4th plan unit | 0             | 28702         | 28702     |
| 5th plan unit | 0             | 5726          | 5726      |
| **Total**    | **8622**      | **86230**     | **141379**|

It can be seen from the above table that the total adjustment of the elimination of the two sections at the same time is greater than the cumulative elimination of each section, indicating that there is a coupling relationship similar to the “seesaw” in these two sections, so it is more expensive to eliminate the over-limit of the two sections at the same time.

5. Conclusion

Aiming at more and more medium and long-term power trading, this paper proposes a method based on the power quantity margin of key units such as unit and section. Considering the future state grid model, the safety check can be realized by means of power calculation and power quantity check. The actual and practical examples are used to verify the accuracy and feasibility of the algorithm. The method realizes the whole process of power quantity margin calculation, check and adjustment, and at the same time, it has a more quantitative and intuitive grasp of the grid operation boundary through the quantity margin. Further research is needed in the following areas:

(1) In the medium and long-term scale, due to the uncertainty of grid model and forecast data, the calculation results must have certain deviations. Therefore, it is necessary to coordinate the yearly, monthly and daily scales of quantity check calibration, and gradually roll to achieve fine calibration.

(2) In the medium and long-term power-to-quantity conversion, time selection is important. According to the selection of power at 96 points a day, the workload is large and unnecessary. According to one point per day, it is too rough. According to the typical power curve, different types of units and different seasons should be considered. Therefore, it is necessary to further deepen the research and improve the calculation accuracy in light of the actual situation.

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