Clearing approach for day-ahead electricity spot market based on fast calibration of conditional section constraints

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Abstract. With the expansion of the pilot area of the electricity spot market in China, how to consider the conditional section to clear the spot market is a new problem faced by dispatching operators. This paper first analyses the impact of conditional section constraints on the clearing of the spot market. Secondly, in order to improve the efficiency of spot market clearing calculation, based on the mode of posterior addition, a fast method of checking condition section is proposed. Thirdly, this method is incorporated into the framework of day-ahead spot market clearing. Finally, the validity of the method is verified by an example analysis of the IEEE118-node system.

1. Introduction
With the development of electricity market reform in China, more and more provinces have entered the stage of electric power spot market construction[1-3]. Under the spot market mode, the connection between power system operation and the market transaction is closer. The clearing results of the day-ahead and real-time market determine the generation plan of market-oriented units to a certain extent. This situation requires the adaptive transformation of scheduling operation process[4].

The clearing of the day-ahead electricity spot market includes three parts: determining the boundary conditions, calculating security-constrained unit commitment (SCUC) and security-constrained economic dispatch (SCED), and releasing the clearing results meeting the constraints[5-6]. Among them, the setting and treatment of grid security constraints will directly affect the market-clearing results and clearing calculation efficiency[7-8]. In the current simulation operation of spot market pilot[9], the grid security constraints are mainly the typical section security constraints (regular section). In all periods of power generation planning, the limit value of the same section is fixed. Through the approximate linear expression relationship between node power injection and section transmission power, it can be included in the SCUC and SCED model.

There are differences in the settings and expressions of grid security constraints. Among them, due to the close electrical coupling relationship between some large-scale hydropower units and AC/DC tie lines, the limit of section transmission in operation control is corresponding to the start/stop status and output of generators[10]. This kind of section is called the conditional section in dispatching management. If the unit related to the conditional section has been included in the scope of the market subject, then there will be the problem of how to determine the generation plan of the unit and the
corresponding section limit in the clearing process. How to consider the influence of conditional cross-section and deal with it pertinent in the process of power generation plan optimization or market clearing is a problem to be studied in academia and industry. Reference [11-12] proposed a method of conditional section model processing and analyzed the effect of model processing on spot market clearing results and calculation efficiency. The above research provides a useful reference for how to consider the impact of conditional sections in the process of power generation plan optimization. It is necessary to explore further how to deal with the conditional section in the process of clearing the electricity spot market.

The rest of the paper is organized as follows: Section 2 analyzes the influence of the conditional section on spot market clearing and the means of conventional model processing. In section 3, a parallel processing method based on condition constraint checking and section constraint checking are proposed for the relationship between control condition constraint and section constraint coupling. Section 4 analyzes the influence of different processing methods on the scale of clearing model, the optimization of clearing results and the calculation efficiency based on an example, and verifies the applicability of condition-based quick checkout clearing. Section 5 gives some suggestions.

2. Conditional sections and its treatment in spot market clearing

2.1. Definition of conditional control section
In most models of generation plan optimization and spot market clearing, the limit value of section security constraint is constant in the whole period of generation plan preparation, and there is no matching relationship between the size of section limit-setting and optimization decision variables (unit startup and shutdown, output)[13-14]. In the actual operation of the power grid, the limit capacity of some sections has a one-to-one correspondence with the decision variables, which is called the conditional control section in the industry. The limit value of section security constraint changes with the change of conditional expression. When determining the enabling and disabling conditions of the section constraint, which contains only a single control variable $K$, there is a correspondence between the variable $D$ of the section constraint expression and the control variable $K$:

$$D \in \left[ D_{i,\min}, D_{i,\max} \right], K \in \left[ K_{i,\min}, K_{i,\max} \right]$$ (1)

Where, $n$ represents the number of possible value ranges of the conditional control section; $i$ represents the range identification of the value range of the conditional control variable $K$, with $1 \leq i \leq n$; $K_{i,\min}$ and $K_{i,\max}$ represent the lower and upper bounds of the variable $K$ in interval $i$ respectively; $D_{i,\min}$ and $D_{i,\max}$ represent the lower and upper bounds of the variable $D$ in interval $i$ respectively. It is worth noting that for the range of $K$ and $D$ in formula (1), it is possible to express it in the form of an open interval. In the practical application of market clearing, the minimum value is superposed on the boundary of the open interval, which is simplified to a closed interval for processing.

2.2. General treatment method of conditional section
In the existing generation planning optimization process, the section constraint is expressed as the linear expression of node injection (unit, load) using quasi-steady power transfer distribution factor (PTDF)[15], and treated as the linear constraint condition of the model.

The optimization of the Day-ahead spot market clearing mainly includes SCUC, SCED, and the calculation of node electricity price. Due to the large size of the day-ahead spot market, in order to ensure that the time limit for clearing calculation meets the operational requirements of the market, the
industry uses a "posterior addition" method to handle section safety constraints. After checking the previous SCUC results and DC power flow ground state, the overload/overrun section constraint is added to the SCUC model for an iterative solution. For the conditional section, the accurate analysis is that only when the conditional expression is valid, the limit corresponding to the section constraint will be valid. However, in the actual operation control of the power network, it is only necessary that the operation interval described by the equipment involved in the conditional expression corresponds to the operation interval of the section transmission power. Since each set of conditional sections not only involves multiple interval ranges but also needs to consider its condition part and section part separately, there are multiple adjustment strategies for the posteriorly added processing ideas. There are two common processing strategies:

1. According to the experience of manners to fix the interval range of conditional sections, set the conditional and sectional partial constraints of corresponding intervals;
2. Model the whole set of conditional control sections directly and add the transformed mathematical constraints.

Strategy (1) is developed based on manual experience, and there are no certain principles or methods to carry out. In this case, the manual verification operation may cause market players and other parties to doubt and affect the improvement of market transaction organization efficiency. Strategy (2) is the most direct way to deal with the conditional control section, and it also leads to the most complex model.

2.3. Modeling of conditional sections
For conditional section of the form (1), the direct way to deal with it is to model transformation according to strategy (2). That is, based on the clearing model without conditional section constraints, the 0-1 variable is introduced as the indicator of the interval of the conditional section, and an equivalent mathematical constraint is added directly in SCUC or SCED model, as shown in formula (2)-(6).

\[ K \leq \sum_{i=1}^{n} K_{i,\text{max}} \ast r_i \]  
\[ K \geq \sum_{i=1}^{n} K_{i,\text{min}} \ast r_i \]  
\[ D \leq \sum_{i=1}^{n} D_{i,\text{max}} \ast r_i \]  
\[ D \geq \sum_{i=1}^{n} D_{i,\text{min}} \ast r_i \]  
\[ \sum_{i=1}^{n} r_i = 1 \]  

Formulas (2) to (3) denote the constraints of the interval to which the conditional expression belongs; formulas (4) to (5) denote the constraints of the interval to which the section belongs, and formulas (6) denote that the sum of the relevant interval indicator variables for the conditional section is equal to 1. Among them, the state variable introduces a 0-1 variable \( r_i \) to represent the active state of the value interval of the conditional sections.

If 96 optimization periods are set, and \( p \) sets of conditional control sections are added, \( 96 \ast 5 \ast p = 480p \) treaty bundles and \( 96\ast n \ast p = 96np \) 0-1 variables will be added. The model size increases significantly. The increase in the number of 0-1 variables has a significant impact on the efficiency of solving mixed-integer programming problems.

3. Quick check method for conditional sections in spot market clearing
According to the one-to-one matching relationship between the condition formula and the section formula in the limit range, this paper presents a fast method for checking the conditional section. With
the "posterior addition" method currently used in spot clearing, conditional section constraints are handled through posterior checking and matching addition:

First, solve the clearing result without conditional section constraints. If the conditional section is beyond the limit, match the limit range of the selected section according to the range of conditional variables in the solution result. Then, replace the above section constraint limits with the original clearing model, and solve the clearing result that satisfies the conditional section constraints. The above method also uses the general section constraint "posterior addition" processing idea. However, in the feedback constraint link, there may be two direction adjustment strategies:

First, the feedback is made according to the current measurement value of the equipment involved in the condition section (group output, number of unit in operation, sectional flow). That is, the range identification variable \( i \) is fixed according to the value of the control variable \( K \). The interval limits of the control variable \( K \) and the section variable \( D \) corresponding to the identification variable \( i \) are fed back to the original clearance model for a second calculation in the form of constraints. This approach is referred to as the Conditional Constraint Check Processing.

Second, the feedback is made according to the current measurement value of the equipment involved in the section (section current, number of units on the section, group output). That is, the range identification variable \( i \) is locked according to the value of the section variable \( D \). The interval limits of the control variable \( K \) and the section variable \( D \) corresponding to the identification variable \( i \) are fed back to the original clearance model for a second calculation in the form of constraints. This approach is referred to as Section Constraint Check Processing.

Due to the different constraints of feedback, there will be differences in the optimization result and efficiency of the spot market-clearing model. Therefore, it is possible to calculate and compare the optimality and solution efficiency of the two checking methods at the same time to select the adjustment method of the conditional section. By SCUC calculation without the conditional section, the conditional and control section constraints can be fixed and re-iterated. At this time, it’s needed to compare the optimality or minimum time of SCUC solution after adding constraints (only one model is solved in a limited time) to complete the processing of this conditional section in the process of spot clearance. Based on those mentioned above two post-check processing methods, a fast check mode of conditional section constraints is formed, as shown in Figure 1.

![Figure 1. The quick calibration method of conditional sections.](image)

After solving the SCUC model without conditional section constraints, if the conditional section is out of bounds in DC power flow checking, the SCUC model is updated and solved by adding new constraints in the way of both conditional section checking and section constraint checking. Based on the optimization and efficiency of the calculation results, the adjustment strategies and clearing results of conditional sections are synthesized.
Within the set time range, if both methods can obtain the feasible solution, the better way to get the objective function is to enter the subsequent calculation process (SCED calculation); if there is only one method to get the feasible solution, it will naturally enter the subsequent SCED calculation and static security check.

4. Case study

4.1. Case illustration
This paper selects the IEEE118 node system to construct a test case for clearing the spot market. The optimization frequency is 15 minutes, and the optimization period is 96. Examples show that some conditional sections are out of bounds when clearing the spot market without the constraint of the unconditional control section. The processing mechanism designed in this paper is used to complete the spot market clearing in different situations.

4.2. Comparison of clearing results of different treatment methods for conditional sections
Selected conditional control section constraints are shown in Table 1. They are incorporated into the solution of SCUC problems using conditional constraint check processing, section constraint check processing, and modeling methods, respectively.

| Control objects and their limits | Section constraints and their limits |
|---------------------------------|-------------------------------------|
| #38, #39 unit output (MW)       | (150, 204] [0, 150]                |
| #131, #132 line flow (MW)       | [-100, 150] [-300, -100)           |

(1) Clearing results based on conditional constraint checking
SCUC is first cleared out (regardless of conditional control constraints), and then for conditional sections that exceed the limit, it will be cleared based on the conditional constraint check. The output curve of the control unit group and the flow of the controlled section are as shown in Figure 2(a) and Figure 2(b).

![Figure 2](image)

(a) Comparison of units schedules and section flow (correction based on sections)

When unconditional section constraint is not considered, the system clearing is mainly affected by unit #38 and #39 quotations. During several peak periods (period 46-56, period 76-81), the unit group should have output adjusted to around 200 MW, and the section flow composed of line #131 and #132 reaches about 200 MW. However, after checking based on the conditional constraint expression, the original interval (150, 204] where the group output is located in the conditional expression determines that the section current limit consisting of line #131 and #132 is [-100, 150], and the amplitude of the section reverse current is less than 100 MW.

During several valley periods (period 21-31), the pre-clearing results are as follows: The group should have exerted about 100 MW, and the local current consisting of lines #131 and #132 reaches about 50 MW. However, after checking and processing based on conditional constraint expressions, the
original interval \([0, 150]\) where the output of the unit group is located the section current limit range of the section consisting of lines #131 and #132 to be [-300, -100) so that the section current is adjusted from the original forward to the reverse, and the amplitude is more significant than 100MW. Within the full-time period, the power output of unit group #38, #39, and line #131, #132 section flow all meet the logic of the conditional control section constraint. Therefore, the checking method based on the conditional constraint expression can find feasible solutions that meet the requirements of security constraints.

(2) Clearing results based on section constraint checking

Similarly, after section constraint checking, the clearing is re-cleared, and the results of pre-clearing and post-checking are shown in Fig. 3(a) and Fig. 3(b), respectively.

(a)  
(b)  
Figure 3. Comparison of units schedules and section flow (correction based on sections)

During several peak periods (period 46 to 56, 76 to 81), after security validation based on the section constraint expression, the original section tide interval [-300, -100] where line #131 and #132 is located determines that the output of #38 and #39 groups is within a smaller limit \([0, 150]\), and the output of the groups is reduced to less than 150MW.

During several valley periods (period 6 to 31), after security validation based on the section constraint expression, the original section tide interval [-100,150] where lines #131 and #132 is located determines that the output limit range of this group is (150, 204], and the output of the group is raised to more than 150 MW.

Within the full period, the #38, #39 group output, and #131, #132 line section tidal current all meet the conditional control section constraints. Therefore, the method of security validation based on the section constraint expression is also able to find feasible solutions that meet the requirements of security constraints.

(3) Clearing results of conditional control section modeling

Further, instead of using the two constrained interval matching methods described above, the SCUC model is directly modeled by introducing a 0-1 variable. The output curve of the group of control units, and the flow of the controlled section is shown in Fig. 4(a) and Fig. 4(b), respectively.

(a)  
(b)  
Figure 4. Comparison of units schedules and section flow (conditional section constrains modeling)
Different from the two methods based on conditional constraint checking and section constraint checking, the model processing is to model the conditional control section directly. The output of the unit group and the line section flow have no obvious decisive effect. However, due to the existence of conditional section constraints, the coupling relationship between the #38, #39 unit group output and the section tidal current composed of line 131 #, 132 # will be automatically considered during the optimization of the algorithm, so that the conditional control section is included in SCUC Problem solving.

However, since the modeling method adds the coupling relationships of multiple conditional control intervals with conditional control section constraints to the original clearing model. Compared with the conditional constraint checking and section constraint checking methods, the modeling method increases the number of constraints and 0-1 variables of the clearing model. Thereby the clearing efficiency of the day-ahead spot market is affected.

|                          | New Constraints | New 0-1 variable | Calculation time (s) | Total Cost (yuan) |
|--------------------------|-----------------|------------------|----------------------|-------------------|
| Conditional Constraint Checking | 192             | 0                | 118.73               | 423,419,558       |
| Sectional Constraint Checking   | 192             | 0                | 154.86               | 423,530,527       |
| Modling Processing              | 864             | 192              | 1648.52              | 423,316,990       |

The comparison of the results of the three modeling methods is shown in Table 2. Considering conditional control, the front-end school process or post-school process will only bring up to 0.053% of the total cost of day-ahead scheduling optimization. However, the size of the clearing model is much smaller than that of conditional control section modeling, and the SCUC calculation time is much shorter. Therefore, it is feasible to solve SCUC problems with conditional cross-section constraints by considering both results of constraint-based and section-based checking, which significantly improves computational efficiency.

5. Conclusion and prospect
In this paper, based on the posterior addition processing mode of day-ahead spot market clearing calculation with conditional section constraints, a method for fast checking and processing of ground over-limit conditional sections is presented. The following conclusions and implications are obtained through an example analysis:

(1) Both methods based on conditional constraint check processing and section constraint check processing can ensure that the clearing results of the spot market meet the requirements of conditional section control. But due to the differences in constraints added by feedback, there are differences in the optimum and efficiency of the clearing.

(2) The checking and processing method of parallel computing for conditional sections described in this paper is conducive to improving the efficiency of clearing calculation and enhancing the optimality of results under the precondition of meeting the security constraints of the power network.

(3) Compared with the sectional constraint modeling method, there is a loss of optimality of dispatch costs in different time periods, but there is an advantage in computing the solution efficiency. The method described in this paper can be combined with the modeling method as one of the conditional sections in the clearing calculation of the spot market. For section constraints which have a great influence on dispatch economy, the modeled method is preferred, whereas the fast check method is used to improve the calculation efficiency of spot market clearance ahead of time and ensure that the organization of spot transactions ahead of time is carried out in an orderly manner.
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