Power transaction security check optimization model and system of AC / DC hybrid power grid applied in China Southern Power Grid

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Abstract. With the continuous and in-depth promotion of China electric power reform, the annual and monthly trading volume of electric power is increasing, the power transaction security check is mainly based on the artificial experience to add and subtract the power components that is difficult to analyse the unit group with member coupling and the power restriction relationship between transmission sections. China Southern Power Grid has developed a set of power transaction security check system using improved SCUC optimization model. The system is able to effectively locate the reason for the power transaction security check exceeding the limit and give the optimization and adjustment suggestions. The efficiency and calculation speed of the power transaction security check optimization algorithm for large scale of AC / DC hybrid power grid are successfully improved. The IEEE RTS 96 system and CSG power system are used to test the efficiency of the algorithm under different grid scales. The calculation time is proved to be reduced about 50% and generation cost is almost the same as the conventional algorithm. The construction and application of the system helps CSG to solve the surplus hydropower consumption problem.

Keywords: power transaction; security check; AC / DC hybrid power grid; security constrained unit commitment model.

1. Introduction

With the continuous and in-depth promotion of China electric power reform, especially the issuance of China Development No.9 document in 2015, a new round reform was started. Medium and long-term market and spot market construction are two key points of this reform [1]. The traditional way of power generation based on agreement plan has gradually changed to a multi transaction medium and long-term power trading market with annual bilateral negotiation, monthly centralized bidding and power generation right transfer. The frequency of transactions and the amount of electricity traded have increased significantly. By the end of 2018, 29.5 billion kWh of cross-provincial and cross-regional market trading electricity has been completed, accounting for 13.6% of the total amount of China West-to-East electricity transmission. In addition, 33.32 billion kWh of intra provincial market trading has been completed, accounting for 35% of the total electricity consumption of the China Southern Power Grid. The following problem is that the security check of electric power transaction depends on the judgment of artificial experience to increase or reduce the amount of transaction contract [2], and lacks the guidance of objective rules and technical support system. At the same time, it is difficult to get the optimal unit output combination by considering the related unit groups or cross-section transaction
contracts as a whole, and it is also unable to effectively locate the reason for the power check exceeding the limit and give optimization adjustment suggestions. The paper [3] analysed the mode and method of power generation planning in the advanced foreign power market represented by the United Kingdom and the United States, and expounds the key technical content of power generation planning under the support of marketization, including the system structure with the basic characteristics of source network load interaction and the optimization idea with the operation economy as the goal. The paper [4] proposed the solution that the dispatching department determined the feasible space of the market transaction result in advance through the security pre-check and provided the results to the trading organization for organizing the market transaction. The paper [5-6] proposed a computing method and its mathematical model for the outwards transmission section electric energy limit based on the medium and long-term unit commitment. A monthly security constrained unit commitment (SCUC) model with minimum energy deviation as the objective is developed by the paper [7]. However, the models proposed in papers [4-7] are not suitable to different kinds of transactions and are difficult to meet the need of increasingly complex power grid operation mode. In the paper [8], a power market transaction model considering generation side and user side strategy is established, but the transaction security check is not involved. In addition, all electric power transactions are without load curve. In order to carry out security check, it is necessary to decompose electric power transactions into electric power curve [9-11], coordinate with power flow and stability calculation of power grid, and check key transmission sections. Therefore, it is urgent to build a set of power transaction security check system applied in AC/DC hybrid power grid, that could be suitable to different transaction security check with high efficiency, to assist power grid operators to analyse and make decisions.

In order to solve the problem, a set of power transaction security check system has been initially established by China Southern Power Grid. It supports the variety kinds of trade including annual long-term bilateral negotiation trading, monthly centralized bidding and power generation right transfer trading represented by the right transfer between Yunnan Province’s hydropower and Guizhou Province’s thermal power, etc. The system is able to effectively locate the reason for the power transaction security check exceeding the limit and give the optimization and adjustment suggestions. The efficiency and calculation speed of the power transaction security check optimization algorithm for large scale of AC / DC hybrid power grid are successfully improved. The IEEE RTS 96 system and CSG power system are used to test the efficiency of the algorithm under different grid scales. The calculation time is proved to be reduced about 50% and generation cost is almost the same as the conventional algorithm. The construction and application of the system helps CSG to solve the surplus hydropower consumption problem.

2. Function design of security check system
The system consists of four functional modules, including data interface, data management, annual electricity security check, monthly electricity security check, etc. Function structure of power transaction security check system is shown as figure 1.

2.1. Data interface
Data interface interacts with market trading system, integrated defense system, DMIS, EMS and other systems.

2.2. Data management
Data management mainly includes basic information management, operation data management, constraint data management, etc. The function realizes the management of all kinds of transaction basic static data, implements the addition, deletion, modification and version management of these basic data, and supports the batch import of data in Excel and other file formats.
2.3. Annual electricity security check

The annual electricity security check is based on the Security Constrained Unit Combination (SCUC) technology, which is extended to the annual calculation time scale to calculate the limit electricity of the related subjects (must-on units, transmission section and whole grid, etc.) in the future power grid. This limit electricity is called the "barrel", and the electricity security check of each related subject is carried out based on the "barrel", simplifying complicated medium and long-term electricity security check problem to the intuitive process of calculating "barrel" and putting into "barrel". It contains four steps, Decomposition of annual transaction power, futuristic scene generation, security check of transactions and calculation of limit transmission power.

2.3.1 Decomposition of annual transaction power

Establish an annual safety constrained unit combination model with the minimum cross section limit as the goal, and comprehensively consider the system load constraints, system backup constraints, annual power plans of each power plant, grid power flow constraints, and unit operation constraints. According to the annual power decomposition model, the annual transaction power is decomposed into typical load level to obtain the unit's active output.

2.3.2 Futuristic scene generation

According to the unit's active output obtained from the annual transaction power decomposition and the maintenance plan and load forecast, the future state network topology and system operation mode are generated based on the basic operation mode.

2.3.3 Security check of transactions

AC power flow calculation is used to obtain the power flow of key transmission section. When the decomposition result of the power plan does not meet the grid operation requirements and there are transmission sections that exceed the limits, the power plan needs to be optimized and adjusted. Establish an annual power plan correction model with the minimum power plan adjustment amount as the goal, consider the system load constraints, transmission section limits constraints, unit operation constraints and other conditions, optimize the power plan and realize the safety correction of the power plan.

2.3.4 Calculation of limit transmission power

Based on the annual check and correction of the power plant output plan, establishing a SCUC optimization modelling with the maximum transmission power as the goal. The power plant electricity limit can be obtained, which can provide a specific quantitative trading space reference for the market power trading.
2.4. Monthly electricity security check
The monthly electricity security check realizes monthly bus load forecast, daily bus load forecast and daily curve forecast. Based on the monthly unit combination model, optimizing and calculating the future monthly operation mode, and automatically generating monthly security check results. According to electricity completion deviation, the system can give decision-making suggestions of monthly electricity congestion management and transaction plan adjustment.

3. Core algorithm and optimization model
The complexity of the medium and long-term electricity security check mainly includes: 1) the coupling adjustment between multiple periods of units output; 2) the coupling between grid security and generation plan; 3) the transformation between power and electricity. Therefore, the electricity security check technology based on the security constrained unit commitment (SCUC) technology is proposed. It takes the monthly unit commitment technology as the core, refines the electricity to the level of active output and power flow, and carries out the elaborate electricity security check.

3.1. Optimization model of AC / DC hybrid power grid
The objective of the model is to minimize the difference between the power plant and the power plan under various constraints. The objective function is:

\[
\min C = \sum_{m=1}^{M} \alpha_m (M_m + N_m) + \sum_{f=1}^{F} K_f C_f
\]

among,

\[
M_m = E_m - E_{m,e}, \quad E_m > E_{m,e}
\]
\[
N_m = E_{m,e} - E_m, \quad E_m < E_{m,e}
\]

Where: \( M \) is the total number of power plants with power contract; \( \alpha_m \) is the penalty coefficient of power plant power deviation, and realizes the priority control of power plant power deviation. When the power plant power is a higher priority, the value can take a larger value. The default value is 1; \( M_m \) is the positive power deviation of the power plant, \( M_m \geq 0 \); \( N_m \) is the negative power deviation of the power plant, \( N_m \geq 0 \); \( F \) is the total number of relaxation constraints; \( C_f \) is the relaxation amount of the \( f \)-th relaxation constraint; \( K_f \) is the penalty coefficient of the \( f \)-th relaxation constraint; \( E_{m,e} \) is the total electricity production of power plant \( m \) in the optimization period; \( E_{m,e} \) is the total planned electricity of power plant \( m \) in the optimization period, including the base electricity and all kinds of market trading electricity.

3.2. Constraints

3.2.1 Load balance constraints of district system

\[
\sum_{i \in A_a} P_{i,t} + \sum_{d \in A_p} P_{d,s} + \sum_{d \in A_p} P_{d,s} + P_{a,s} = L_{a,t}
\]

Where:
\( P_{d,s} \) is the equivalent load of DC line \( d \) at the sending end of the period \( t \); \( P_{d,r} \) is the equivalent generator power of DC line \( d \) at the receiving end of the period \( r \); \( A_a \) is the equipment set of the region \( a \); \( D \) is the total number of DC transmission lines in the system; \( I \) is the equipment set of generator units in the region \( a \); \( P_{i,t} \) is the active power of generator unit \( i \) in the period \( t \); \( P_{a,t} \) is the active power value of
AC equivalent metering point in the region $a$ in the period $t$; $L_{a,t}$ is the System load of region $a$ during the period $t$.

3.2.2 Partition alternate constraint
Positive reserve capacity constraints:

$$
\sum_{i \in A_a} (P_{i,max} - P_{i,t}) \geq R_{a,t,u}
$$

(3)

Negative reserve capacity constraint:

$$
\sum_{i \in A_a} (P_{i,t} - P_{i,min}) \geq R_{a,t,d}
$$

(4)

Where: $R_{a,t,u}$ is the lower limit of the positive reserve capacity of the region $a$ in the period $t$; $R_{a,t,d}$ is the lower limit of the negative reserve capacity of the area in the period; $P_{i,max}$ is the maximum technical output of the generator $i$; $P_{i,min}$ is the minimum technical output of the generator $i$.

3.2.3 Grid security constraints

$$
-p_i \leq \sum_{n \in N} [P_{n,t} - L_{n,t}] S_{n,t} \leq p_i
$$

(5)

Where: $p_i$ is the upper and lower limit of the power flow of the $l$-th transmission section; $N$ is the set of grid calculation nodes; $P_{n,t}$ is the generation unit power of the grid calculation node $n$ in the period $t$; $L_{n,t}$ is the load power of the grid calculation node $n$ in the period $t$; $S_{n,t}$ is the sensitivity of the injected power of the grid calculation node $n$ in the period $t$ to the $l$-th transmission section.

3.2.4 Generator set operation constraints

$$
P_{i,min} u_{i,t} \leq P_{i,t} \leq P_{i,max} u_{i,t}
$$

(6)

$$
-\Delta_i \leq P_{i,t} - P_{i,t-1} \leq \Delta_i
$$

(7)

$$
\sum_{r = t - UT_i + 1}^t y_{i,r} \leq u_{i,t}, \quad \forall i, t \in \{UT_i, ..., T\}
$$

(8)

$$
\sum_{r = t - DT_i + 1}^t z_{i,r} \leq 1 - u_{i,t}, \quad \forall i, t \in \{DT_i, ..., T\}
$$

(9)

$$
y_{i,t} - z_{i,t} = u_{i,t} - u_{i,t-1}
$$

(10)

Where: $u_{i,t}$ is the start and stop status of the unit $i$ in the time period $t$; $P_{i,min}$ is the lower limit of the unit $i$ output power; $P_{i,max}$ is the upper limit of the unit $i$ output power; $\Delta_i$ is the maximum value of the climbing speed of the thermal power unit $i$ in each time period; $UT_i$ and $DT_i$ is the minimum start-up time and the minimum stop time of the unit $i$ respectively; $y_{i,t}$ is the flag of unit $i$ status changing from stop to start in the time period $t$; $z_{i,t}$ is the flag of unit $i$ status changing from start to stop in the time period $t$.

3.2.5 Unit fixed plan constraints
\[ u_{i,t} = 1, \quad (i,t) \in \Phi_{on} \quad (11) \]
\[ u_{i,t} = 0, \quad (i,t) \in \Phi_{off} \quad (12) \]
\[ P_{i,t} = p_{i,t}, \quad (i,t) \in \Phi_{plan} \quad (13) \]

Where: \( \Phi_{on} \) is the time set of the unit that must be started; \( \Phi_{off} \) is the time set of the unit that must be stopped; \( p_{i,t} \) is the fixed output plan of the unit \( i \) in the time period \( t \); \( \Phi_{plan} \) is the time set of fixed output plan of the unit \( i \).

3.2.6 Regional exchange capacity constraint
\[
\frac{\beta}{60} \sum_{t=1}^{T} \left( \sum_{d \in A_n} P_{d,t}^n + \sum_{d \in A_s} P_{d,t}^p + P_{d,t}^a \right) = Q_a
\]

Where: \( Q_a \) is the contract electricity of cross region transaction in the dispatching period; \( \beta \) is the number of minutes contained in the dispatching period; \( T \) is the total number of periods for optimization calculation.

3.2.7 Power plant capacity constraints
\[
\frac{\beta}{60} \sum_{t=1}^{T} \sum_{i \in A_m} P_{i,t} = E_m
\]

Where: \( A_m \) is the set of units included in the power plant \( m \); \( I_m \) is the number of units in the power plant \( m \); \( E_m \) is the total generating electricity of the power plant \( m \) in the optimization period.

4. Study case

4.1. IEEE RTS 96 system
IEEE RTS 96 system is used to test the efficiency of the algorithm under different grid scales. The scale of the system is multiplied and the convergence precision is set to 0.001. The calculation period is 15min, that is, 96 optimization periods a day. The calculation performance and calculation results are compared as follows. Algorithm calculation performance and optimization results comparison of RTS standard calculation example system is shown as table 1 and table 2.

| Number of units | Calculation time of traditional algorithm / s | Calculation time of algorithm in this paper / s | Change rate of calculation time / % |
|-----------------|-----------------------------------------------|-----------------------------------------------|----------------------------------|
| 96              | 441.28                                       | 220.64                                       | 50.0                             |
| 192             | 979.28                                       | 489.64                                       | 50.0                             |
| 288             | 1804.4                                       | 789.425                                      | 56.3                             |

| Number of units | Generation cost of traditional algorithm / MBtu | Generation cost of algorithm in this paper / MBtu | Change rate of generation cost / % |
|-----------------|-----------------------------------------------|-----------------------------------------------|----------------------------------|
| 96              | 824400                                       | 826873                                       | 0.3                              |
| 192             | 1644000                                      | 1647288                                      | 0.2                              |
| 288             | 2460001                                      | 2462461                                      | 0.1                              |

4.2. CSG power system
The proposed algorithm is validated and analyzed by using the actual data of a CSG regional power system in China. The system consists of 805 generating units and 230 transmission sections. Monthly SCUC takes one hour as a calculation period, and the number of calculation periods is 720. The traditional standardized modeling direct solution method are used to calculate the test cases. The comparison results between traditional algorithm and the modeling method by this paper is shown as table3.

| Power system scale | Calculation performance | Optimization results comparison of CSG power system |
|-------------------|-------------------------|-----------------------------------------------|
|                   | traditional algorithm   | algorithm in this paper | traditional algorithm   | algorithm in this paper | change rate |
| 805 units         | 7650                    | 2648                      | 5.415                   | 5.426                   | 65.4%       |
| 230 sections      |                         |                           |                         |                         |

The traditional algorithm takes 7650 seconds to get the optimization result, and the running cost is 541.5 million RMB. In contrast, the algorithm proposed in this paper takes 2648 seconds to get the optimization result, and the running cost is 542.6 million RMB. Although the algorithm proposed in this paper is faced with a slight increase in the cost of optimization objectives, its execution time savings are very significant.

This paper analyzes the calculation process for many times. The grid includes 805 generating units that need to carry out state combination calculation, and the number of calculation periods is 720. Using the traditional standard model of safety constrained unit combination, the total number of discrete variables of generator state is 579600 (805 × 720), the number of constraints of transmission section is 165600 (230 × 720), and the average calculation time is more than 2 hours. Through the SCUC solution technology based on the multi strategy combination of model dimension reduction, 162 calculation periods of the optimal model after merging of similar periods are calculated. Through the dimension reduction preprocessing of the model, invalid network constraints and shaping variables are identified. The number of discrete variables of the unit state of the optimized model after dimension reduction is reduced to 231280, the number of constraints of the transmission section is reduced to 89830, and the average total calculation time is reduced Within 45 minutes. Through the SCUC fast calculation method based on the combination of model dimensionality reduction and multi strategy, the calculation time is reduced from more than 2 hours to less than 45 minutes, the solution efficiency is significantly improved, and the practical application requirements are met.

5. Conclusion
The security check model based on SCUC proposed in this chapter has the following characteristics:
1) Security constrained unit commitment (SCUC) is a good tool to solve the problem of power grid security and multi period generation plan optimization. Through the model transformation, the medium and long term electricity check optimization model is established, and the safe constrained unit commitment is transformed into a medium and long term electricity safety check optimization evaluation tool.
2) The power transaction security check model takes the trading electricity as one of the optimization constraints. Under various constraints such as power generation and consumption balance, power grid security, unit operation and so on, it carries out integrated security constraint checking calculation for all electricity plans, analyses whether all kinds of medium and long-term electricity contracts can be reasonably and safely allocated to each period, and realizes the refined security check of medium and long-term electricity quantity.
3) Considering the various boundary conditions of the medium and long term dispatching operation of the power grid, the overall optimization method of the unit startup and shutdown, unit output and section power flow is proposed and the power flow level check analysis of the annual monthly power plan, transaction and contract is realized.
4) The efficiency and calculation speed of the power transaction security check optimization algorithm for large scale of AC/DC hybrid power grid are successfully improved. The IEEE RTS 96 system and CSG power system are used to test the efficiency of the algorithm under different grid scales. The calculation time is proved to be reduced about 50% and generation cost is almost the same as the conventional algorithm.

6. References

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