Research on Trans-province Security Green Dispatch Pattern, Model and Assessment Method

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Abstract: The condition of resource distribution and power consumption differs between provinces. Resource will be wasted when dispatched only within province, and trans-province dispatch will be an ideal solution to optimize the allocation of resources. A trans-province security green dispatch pattern, which collaborates with province dispatch, is proposed. Trans-province optimal resource dispatch is attained to improve the new energy accommodation and mutual power aid between provinces. Based on dispatch model, trans-province security green index is designed and used to guide the optimization, and then assess the optimization effect. Taking simplified model of an area power grid for example, the simulation result shows that the proposal method is feasible and effective. The safety level and new energy accommodation of area power grid are obviously improved through trans-province dispatch.

1. Introduction
China's new energy industry has developed rapidly, and the total installed capacity of wind power and solar PV has leaped to the top of the world. However, China's power system has a complex structure and unbalanced resource distribution. Energy endowment and the contrary distribution of energy supply and consumption make it difficult to relocate resources. Therefore, the attributes of China’s energy industry necessitate the utilization of large-scale cross-provincial electricity transaction. The greater the scope of resource optimization configuration, the greater the benefits that can be harvested [1]. By constructing a large number of UHV transmission lines in China, the links between provincial power grids have become increasingly close, and the trans-province capacity has been significantly enhanced [2][3].

With the continuous improvement of the management mechanism, the duties and division of work between the provincial regulator and grid regulator are distinguished. The provincial regulator is mainly responsible for the dispatching management in the province, while the grid regulator focuses on the management of the inter-provincial transmission line, the provincial adjustment within the scope of coordination and regulation, and promoting consumption of renewable energy. Literature [4] simplifies the dispatching optimization scenario to improve the efficiency of optimization by estimating the upper limit of wind power consumption. Literature [6] proposed a DC transmission line optimization decision model considering operating cost and accommodation of wind power. The paper also constructed an optimizing operation process aim at promoting new energy consumption. Literature [7] established a transmission line scheduling optimization model for different scenarios to guide the dispatching plan. Literature [8] researched the multi-regional wind-fire coordination
optimization scheduling problem by considering the power balance along with the positive and negative standby constraints within each region, but it only studied the active power transmission constraints.

The above-mentioned literature have done some research on the optimal allocation of power and trans-provincial dispatching, but there is often a lack of overall planning in inter-provincial scheduling management. Dispatching plans evaluate the result through post-event evaluation, but this process is relatively independent, which is not conducive to reflecting the scheduling optimization process and adjusting the optimization results.

Based on the actual structure of provincial power grids, this paper proposes a trans-provincial green safety dispatching model which guides the optimization of dispatch operation following an optimizing adjusted green safety scheduling index. The paper also shows an example of a regional power grid to verify the correctness and effectiveness of the proposed model.

2. The intension and goals of trans-provincial security green dispatching

2.1 The intension of trans-provincial security green dispatching
The security green dispatching is different from traditional dispatching. Conventional power dispatching considers the safety, stability, quality and reliability of power grid operation. However, on the basis of improving the intrinsic safety level of the power grid, security green dispatching preferentially dispatches renewable energy to promote the maximization of new energy sources, and improve the new energy level of the power grid.

Combined with provincial-level dispatching, trans-provincial safety green dispatching maintains the safety and stability of provincial power grids and inter-provincial power transaction while promoting and optimizing the cross-provincial consumption of renewable energy.

2.2 The goals of trans-provincial security green dispatching
The security green dispatching initiates from optimizing dispatching, and the theory aiming at approaching a safe, green, fair and efficient system.

Safe: Safety and stability are the most basic and most important requirements for power system operation. Security green scheduling must first ensure the safety level of a power grid.

Green: Trans-provincial security green dispatching aims to promote cross-regional consumption of surplus renewable energy through a large-scale resource optimization.

Fair: One of the key objectives of security green dispatching is to ensure fair participation of market members.

Efficient: Security green scheduling should improve the energy efficiency of power generation through optimizing dispatching mechanisms.

3. The trans-provincial security green dispatching scheme and model

3.1 The trans-provincial security green dispatching scheme
Provincial dispatching agency is responsible for the dispatching task. Considering the flexibility and effectiveness of trans-provincial transmission, the resource allocation is optimized by security green dispatching. The detailed process is shown in Figure 1.
The market participants join the trans-provincial dispatching by reporting the provincial dispatching plan, determining the provincial renewable energy consumption, as well as forecasting provincial electricity supply and demand. Following with the trans-provincial dispatching optimization, the provincial dispatching agency aggregates the provincial generation curves and operates the trans-provincial optimization model to have the optimal schedules. Then, an iterative safety check evaluates the safety of the optimal schedules. Eventually, the provincial dispatching agency announces the final dispatching schedule for energy suppliers.

3.2 The trans-provincial security green dispatching model

3.2.1 Objective function
The economic dispatching of power system considers energy cost of the unit output, and the factors such as power supply and demand and grid safety are taken as the hard constraints. This method is not able to illustrate the shortage of supply and demand, the specific consumption situation, and the renewable energy consumption cost. In addition to the essential goal of minimizing cost of power generation dispatching, grid safety and supply and demand are added to the objective function in the form of penalty fees, forming a comprehensive objective function that considers all aspects of the dispatching.

\[
\min \{ \sum_{i=1}^{T} \sum_{j=1}^{I} f(P_{ij}) + M_1 \sum_{n=1}^{N} \sum_{i=1}^{T} (\varepsilon_{n, i}^+ + \varepsilon_{n, i}^-) + M_2 \cdot Q_{\text{new}} \} \quad (1)
\]

In this equation, \( P_{ij} \) is the power output of generator \( i \) at time period \( t \), \( f(P_{ij}) \) is the variance of the generation cost of the generator \( i \) at time period \( t \) after the scheduling; \( \varepsilon_{n, i}^+ \) and \( \varepsilon_{n, i}^- \) are the positive and negative safety constrains of the \( n \)th transmission line, \( Q_{\text{new}} \) is the disposal renewable energy; \( M_1 \) is
the penalty caused by safety check. $M_2$ is the penalty caused by renewable energy curtailment. $T$ is the overall optimization period. $I$ is the total number of generators; $N$ is the total number of grid safety constrains

3.2.2 System constraints
In trans-provincial security green dispatch model, following constraints are considered:

1. Generator output constraints
   a. Generator output constraints
      Generators’ output should be scheduled within the rated range, where
      \[ P_{i,\text{min}} \leq P_{i,t} \leq P_{i,\text{max}} \quad (2) \]
      $P_{i,\text{max}}$ is the upper limit of the power output. $P_{i,\text{min}}$ is the lower limit of the power output.
   b. Output climbing speed constraints
      The output climbing speed constraint includes the output increasing constrain and output decreasing constrain, where
      \[ \Delta P_i \leq P_{i,t} - P_{i,t-1} \leq \Delta P_i \quad (3) \]
      $\Delta P$ is respectively represent the output increasing constrain and output decreasing constrain of generator $i$, $P_{i,t}$ is the output of generator $i$ at time period $t$; $P_{i,t} = P_{i,t}^{\text{pre}} + P_{i,t}^{\text{trans}}$ which is the aggregation of the provincial preliminary schedule and the trans-provincial market clearing result of generator $i$ at time $t$, $P_{i,t}^{\text{pre}}$ is the provincial preliminary schedule.

2. Grid safety constraints
   a. Load balance constraints
      In the trans-provincial security green optimization, the load in the grid should be balanced, where
      \[ \sum_{j=1}^{I} \sum_{t=1}^{T} P_{i,t} - D_t + \varepsilon_t^+ - \varepsilon_t^- = 0 \quad (4) \]
      $D_t$ is the system load at time $t$, $\varepsilon_t^+$, $\varepsilon_t^-$ are positive numbers which respectively represent the positive deviation and negative deviation of the system load.
   b. Transmission capacity constraints
      \[ \overline{P}_{j,t}^{\text{tie}} \leq P_{j,t}^{\text{tie}} + \varepsilon_{j,t}^+ - \varepsilon_{j,t}^- \leq \underline{P}_{j,t}^{\text{tie}} \quad (5) \]
      $\overline{P}_{j,t}^{\text{tie}}$, $\underline{P}_{j,t}^{\text{tie}}$ are the transmission upper limit and transmission lower limit of the $j$th transmission line: $P_{j,t}^{\text{tie}}$transmission capacity of the $j$th transmission line at time $t$; $\varepsilon_{j,t}^+$, $\varepsilon_{j,t}^-$ are positive numbers which respectively represent the positive exceeding power and negative exceeding power. The DC power flow in the grid can be expressed in the following, where
      \[ P = B_0 \quad (6) \]
      \[ P_1 = Y_B A_0 \quad (7) \]
      $P$ is the raw matrix of input power at each joint; $B$ is the digestion matrix at each joint; $\theta$ is the phase vector at each joint; $P_1$real power vector in by-pass lines ; $Y_B$ is a diagonal matrix of the by-pass vector; $A$ is the grid topology matrix.

      From equations (6) and (7), the input load at joints can be relate to power flow, where
      \[ P_1 = Y_B A_0 P \quad (8) \]
      The power flow in each transmission line can be calculated from equation (8).
3.2.3 Evaluation of trans-provincial security green index

The trans-provincial security green index indicates the safety, sustainability, fairness and effectiveness of the objective function where

\[
\text{Index} = \sum_{t=1}^{T} \sum_{j=1}^{J} f(P_{tj}) + M_1 \sum_{n=1}^{N} \sum_{t=1}^{T} (e_{n,t}^+ + e_{n,t}^-) + M_2 \cdot Q_{\text{New}} \quad (9)
\]

The Index in equation (9) refers to the trans-provincial security green index. In general, the cheaper the allocation cost, the higher the safety level and the smaller the renewable energy curtailment, therefore the lower the index value.

The safety index is \( M_1 \sum_{n=1}^{N} \sum_{t=1}^{T} (e_{n,t}^+ + e_{n,t}^-) \). \( e_{n,t}^+ \) and \( e_{n,t}^- \) are scheduled transmissions that exceed the safety constraints. \( M_1 \) is a penalty, the optimization need to be adjusted if the safety index does not equal to 0.

The green index is determined by renewable curtailment \( Q_{\text{New}} \) and curtailment penalty cost \( M_2 \). The higher the renewable consumption requirement, the higher the curtailment penalty.

The fairness and effectiveness index work as a whole to promote the optimization of the resource allocation, which can be indicated by the overall generation cost \( \sum_{t=1}^{T} \sum_{l=1}^{L} f(P_{lt}) \).

4. Case study

A regional power grid is simplified to form an interconnected four provinces power grid to illustrate the robustness of the model. The topology is shown in Figure 2. Multiple transmission lines are interconnected at different locations in a province. The case study analyzes the scheduling plan of the regional power grid at a certain time \( T \) (time interval is 1 hour), and the penalty parameter \( M_1 \) is set to 10000, and \( M_2 \) is taken as 1000.

| No. | Transmission line | Remaining capacity/MW |
|-----|-------------------|------------------------|
| 1   | Transmission line #1 | 400                    |
| 2   | Transmission line #2 | 500                    |
| 3   | Transmission line #3 | 250                    |
| 4   | Transmission line #4 | 500                    |
| 5   | Transmission line #5 | 600                    |

The transmission capacity of interconnected transmission line are as follows.

\[ \text{Figure 2} \text{ Simplified power system structure of the area grid} \]

The optimization process is a Mixed Integer Programming problem which is calculated by utilizing the MIP package in CPLEX 12.6.
At peak hours, some provinces experience the electricity shortage. In the case that the power supply is generally sufficient while some provinces’ load are unbalanced, each province has the preliminary schedule as shown in Table 2.

### Table 2. Excess and shortage of power supply for each province

| Province   | Electricity Shortage (MW) | Remaining thermal capacity (MW) | Average generation cost (yuan/MWh) | Surplus renewable generation capacity (MW) | Average renewable generation cost (yuan/MWh) |
|------------|---------------------------|---------------------------------|-----------------------------------|------------------------------------------|------------------------------------------|
| Province A | -                         | 900                             | 350                               | 50                                       | 100                                       |
| Province B | -                         | 400                             | 300                               | 20                                       | 80                                        |
| Province C | -                         | 500                             | 270                               | -                                        | -                                         |
| Province D | 700                       | -                               | -                                 | -                                        | -                                         |

After the trans-provincial security green optimization, the variation of connection lines’ spare space are as follows

### Table 3. The variation of connection lines’ spare space

| No. | Transmission line | Before optimization/MW | After optimization/MW |
|-----|-------------------|------------------------|-----------------------|
| 1   | Transmission line #1 | 400                    | 357.9                 |
| 2   | Transmission line #2 | 500                    | 492.1                 |
| 3   | Transmission line #3 | 250                    | 0                     |
| 4   | Transmission line #4 | 500                    | 84.21                 |
| 5   | Transmission line #5 | 600                    | 315.79                |

Through the scheduling, the power gaps in province D are met by the inter-provincial power mutual aid. Including 650MW of thermal power from other provinces and 50MW of renewable energy, province A bid 50MW renewable energy, province B dispatched 20MW renewable energy and 380MW thermal power, and province C dispatched 250MW thermal power. The results of the market clearing showed that most of the dispatching favored the renewable energy and financial viability. However, due to the limitation of the transmission capacity of the transmission lines between the two provinces (see Table 3), the penalty fee for the limit of the transmission line #3 is much higher than the cost of the resource. Therefore, the relatively low-cost resources of the province C are only partially adapted, and other resources are dispatched instead. The fair and efficient scheduling requirements are met as a whole.

Before the optimization, there were 700MW power gaps in the preliminary schedule of the four provinces, and 70MW excess renewable capacity. The conventional network adjustment did not dispatch the units in each province. After the trans-province optimization, the power gap in province D was met, and the excess renewable power was consumed. The changes in the overall inter-provincial safe dispatch index are shown in Table 4.

### Table 4. Trans-province security green dispatch index

|                   | Safety index | Green Index | Fairness Effectiveness Index | Total index |
|-------------------|--------------|-------------|------------------------------|-------------|
| Before optimization | 7000000      | 70000       | -(no dispatch)               | 7070000     |
| After optimization | 0            | 0           | 188100                       | 188100      |
It can be seen from the above results that through the trans-provincial security green scheduling, it is possible to balance the supply and demand while improving the safety and stability level of the power grid. The overall security green index has significant improved.

5. Conclusion
In the context of the continuous establishment of inter-provincial power grids and the increasingly close inter-provincial grid connection, it is of great significance for trans-province transmission scheduling models and mechanisms to achieve inter-provincial resource assistance and coordination. This paper proposes a trans-provincial security green scheduling model which synergize with provincial scheduling to achieve a safe, green, fair and effective power dispatching. The paper also designed a trans-provincial index to dynamically evaluate and quantify the optimization result in an intuitive way. A case study is attached in the end of the paper to validate the robustness of the model which prove the operation principle of the model. In general, the trans-provincial security green dispatching model is able to effectively allocate the resource in each province to minimize the relocation cost, and it also expand the profitability of the generators by facilitating the renewable power curtailment.

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