Multi-time Scale Joint Scheduling Method Considering the Grid of Renewable Energy

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Abstract. Renewable new energy power generation prediction error like wind and light, brings difficulties to dispatch the power system. In this paper, a multi-time scale robust scheduling method is set to solve this problem. It reduces the impact of clean energy prediction bias to the power grid by using multi-time scale (day-ahead, intraday, real-time) and coordinating the dispatching power output of various power supplies such as hydropower, thermal power, wind power, gas power and. The method adopts the robust scheduling method to ensure the robustness of the scheduling scheme. By calculating the cost of the abandon wind and the load, it transforms the robustness into the risk cost and optimizes the optimal uncertainty set for the smallest integrative costs. The validity of the method is verified by simulation.

1. Introduction

Wind power, photovoltaic, small hydropower and other renewable energy output power is susceptible to climate, altitude, topography, temperature and other natural factors, so has randomness and volatility. Currently under the condition of satisfying the safe operation, renewable energy adopts full internet access to stabilize its output fluctuations by thermal power, larger hydropower and other conventional power. However, the adjustment capacity of conventional power is limited. When the deviation between the output of renewable energy and forecast value is large, system active power is imbalance and trend is overload. And there will be abandon wind, abandon light, abandon water etc. In the field of operation control, it has been a point that how to improve renewable energy consumptive through the multi-time scale joint dispatch of renewable energy [1].

In the paper [2], based on the difference in corresponding adjustment ability of power grid and wind power error at different time scales, a multi-time scale coordinated flexible load response scheduling model of “multi-level coordination, step-by-step refinement” is set to divide the whole process into day-ahead plan (24h), intraday 4h rolling plan and real-time 15min plan and automatic power generation control. In the paper [3], wind power and load prediction value are expressed by fuzzy parameters. Based on the credibility theory, the traditional deterministic system constraint is transformed into fuzzy chance constraints, and dynamic economic dispatch model following that is established, which includes several fuzzy parameters at the multi-time scale. In the paper [4], the stochastic programming is used to reflect the probability of wind power. The unit commitment problem is described as a two-stage stochastic
programming model with chance constraints, so a mixed sampling average approximation algorithm is carried out to solve it.

The current operation scheduling mainly focuses on the model of the economic scheduling problem and the day-ahead dispatching problem of unit commitment. Due to the randomness of renewable energy, some methods have practical difficulties, such as more generated scenes and large computation; the probability distribution of wind power prediction error is complex and the chance constraint is difficult to get robustness. In this paper, considering the prediction error of renewable energy, a multi-time scale robust scheduling is proposed to deal with various possible wind prediction errors without increasing reserve capacity of the system. It is a useful attempt to economically solve abandon wind and add the proportion of renewable energy.

2. Multi-time scale coordination process for grid dispatching

Power system scheduling is the core of the entire, and the Along with large-scale clean energy grid and green scheduling concept, scheduling method will also be replaced. Traditional grid scheduling is generally based on accurate power prediction. The low accuracy of clean energy prediction and a large volatility of output power bring new challenges to grid scheduling. In general, the accuracy of clean energy prediction is inversely proportional to the time span. Adopting the active scheduling model with multi-time scale can gradually reduce the impact of the clean energy’s uncertainty on the power grid.

The key to the multi-time scale robust scheduling techno-logy including clean energy is that the scheduling chart is divided into three time-scales: day-ahead plan, intraday rolling plan and real-time plan. Using multi-time scale can gradually reduce the influences on power grid, which is caused by the uncertainty of clean energy [5-6].

1) Day-ahead plan. The traditional scheduling is mainly day-ahead plan, which based on the initial state of the known unit, the tie-line exchange plan and the switch state in the day, it is carried out according to the next day load and short-term forecast data of clean energy. Due to the large fluctuations of clean energy, the key to day-ahead plan is to optimize a strong robustness unit start-stop plan and power distribution. Robustness here is abilities to cope with power fluctuation.

2) Intraday rolling plan. Based on the load super short-term prediction and clean energy with higher accuracy, it can revise the day-ahead power generation plan. Day rolling plan mainly adjusts the unit output, but not change unit start-stop program in general. However, when the start-stop program can’t meet the peak demand, it is necessary to recalculate it from the current time to the final time, based on the latest clean energy and load forecast data.

3) Real-time plan. It is to make an adjustments to the power generation plan after 5min. On the basis of intraday rolling plan, the real-time planning based on the super short-term power forecast data is carried out, and the scheduling program is further refined to correct the deviation between scheduling plan and the forecast result. It is generally believed that clean energy fluctuations are small so that the deterministic scheduling can meet the requirements in real-time planning.

The day-ahead plan and the intraday rolling plan adopt a robust scheduling method. Its concept is to consider the uncertain factors (such as clean energy power) as a fluctuation interval, so that the scheduling results are adaptable to the uncertainties’ changes in this uncertainty set. Here is the first question about how to select the uncertainty set. At present, most of the research is based on a fixed uncertainty set, such as setting the clean energy power fluctuation between 0.8 and 1.2 times the predicted value.

3. Robust scheduling method considering renewable energy

Renewable energy similar to loads, is uncontrollable power, which must firstly get output curve of load and renewable energy by the power forecast, and then develop a conventional power generation plan by scheduling calculation to ensure the power balance in system. At present, the predictive accuracy of renewable energy can’t fully meet the engineering needs. Taking the wind power as an example, the short-term power prediction error is about 20%, which is far less than the load forecast accuracy. This is a big trouble to the traditional scheduling system based on accurate power prediction.
In the mid-long term, organize the clean energy trade, which is matched with the surplus delivery, and add the proportion of clean energy in outside transmission. In the short-term level, considering the uncertainty of renewable energy power generation, establish inter-provincial spot market and match the actual power generation capacity of renewable energy to realize renewable energy consumption.

3.1. Objective function

Assuming the number of thermal power units in a grid is \( N \), the number of hydropower is \( M \), the number of gas turbine units is \( R \), the number of wind farm is \( J \). In addition to wind power and photovoltaic, other units mentioned as conventional units, thus the total is \( G = N + M + R \); Scheduling cycle is \( T \). The economic model is as follows:

Objective function. It is the minimum sum of the various types of power generation costs, which meets the balance of electricity in the predicted scene. \( F_{g}(n,t) \) and \( F_{N}(r,t) \) are represent the generation cost function of conventional units \( n \) (such as the thermal power and the nuclear) and new energy generating unit \( r \) within the time \( t \). The cost function is the quadratic function, which sets the actual units output as a decision variable. The variable coefficients are obtained by the actual operation or experiment.

\[
\text{Min}: F = \sum_{n=1}^{N} \sum_{t=1}^{T} F_{g}(n,t) + \sum_{r=1}^{R} \sum_{t=1}^{T} F_{N}(r,t) \tag{1}
\]

Constraint equations:

\[
\sum_{n=1}^{N} P_{g}(n,t) + \sum_{m=1}^{M} P_{m}(m,t) + \sum_{r=1}^{R} P_{r}(r,t) + \sum_{j=1}^{J} P_{j}(j,t) = P_{t}(t) \tag{2}
\]

\[
\sum_{g=1}^{g} (P_{\text{max}}(g) - P(g,t)) \geq P_{t}(t) \times L\%
\]

\[
P_{\text{min}}(g) \leq P(g,t) \leq P_{\text{max}}(g) \tag{3}
\]

\[
-R_{g}(g) \times T_{60} \leq P(g,t) - P(g,t-1) \leq R_{g}(g) \times T_{60}
\]

\[
\sum_{t=1}^{T} P_{m}(m,t) \leq W_{m}(m) \tag{4}
\]

\[
\sum_{t=1}^{T} P_{r}(r,t) \leq W_{r}(r) \tag{5}
\]

\[
\left| \sum_{g=1}^{G} \gamma_{g}(g,l) P(g,t) + \sum_{j=1}^{J} \gamma_{j}(j,l) P(j,t) \right| \leq L(l) \tag{6}
\]

Among them, equation (2) is a power balance equation. \( P_{g}(n,t), P_{m}(m,t), P_{r}(r,t) \) and \( P_{j}(j,t) \) are represent the output of thermal power units \( n \), hydropower stations \( m \), gas generating units \( r \) and wind farm \( j \) within the time \( t \). \( P_{t}(t) \) is the load for the period \( t \); Equation (3) is rotation reserve constraints, and \( L\% \) is the load’s demand on the rotation reserve. \( P_{\text{max}}(g) \) is the upper limit of conventional units \( g \). Equation (4) and equation (5) are represent the upper and lower bounds and climbing speed constraints of the conventional unit. \( R_{g}(g) \) and \( R_{g}(g) \) are represent down and climbing speed of the conventional unit \( g \), and scheduling time \( T_{60} = 60\text{min} \). The adjusting speed of hydropower units and pumped storage units is fast so that climbing speed constraint can be not considered. Equation (6) and equation (7) are
represent the total power constraints of the hydropower station and the gas power plant. Due to the limitation of the amount of water and gas, the allowable power generation capacity of the hydropower station $m$ and the gas power plant $r$ in the dispatching cycle are $W_m(m)$ and $W_r(r)$. Equation (8) is a line flow constraint. $g l (g l)$ and $j l (j l)$ are represent power distribution factors of conventional units $g$ and wind power farms $j$ on the line $l$. $L(l)$ is line flow control.

3.2. Day-ahead joint scheduling
In day-ahead timing, clean energy situation is assessed using the latest clean energy output forecast results. Then organize and develop a wealthy clean energy spanning market, and adjust the cross-regional transmission plans and provincial generation plans. The specific steps include the following.

(1) A day-ahead new energy basic curve forming channel by sub-center, which co-ordinate the province. According to the next day load forecast and the minimum technical output (under established thermal power mode), arrange the new energy power that has been determined in the monthly transaction with the “reduction does not increase” principle. Calculate and decompose to the cross-regional channel according to the sectional limit in the district, and then form the day-ahead new energy base curve of each channel. Finally, submit it to the state and split into new energy enterprises.

(2) The sub-center at sending ends lets new energy generation enterprises organize surplus new energy power generation capacity to participate in the day-ahead cross-regional spot market price.

(3) In the national scheduling inter-provincial spot market, carry out a centralized auction, clear and form the day-ahead new energy spot curve, and then get the day-ahead new energy plan curve superposed by spot curve and basic curve.

![Figure 1. Day-ahead spot market trading space](image)

Day-ahead spot market trading space as shown in Figure 1. In accordance with the principle of not adding the thermal power-on, national dispatch center put the monthly trading amount of thermal power into the trading curve, and form the day-ahead initial curve of the DC plan. Due to the uncertainty of new energy, supplementary sent by the thermal power may not match the monthly rate of electricity. In this moment, the transaction should support flexible power adjustment. National center checks the safety for cross-regional channel day-ahead plan curve, and adjusts in turn following the principle of the thermal power > new energy spot > new energy base, to form the final day-ahead transmission plan curve. The maximum power transmission capacity curve of the cross-zone DC is calculated by the sending-end sub-center, and the maximum power receiving capacity of trough and the minimum DC
power receiving demand are provided by the receiving-end sub-center. After overall sending-end and receiving-end demand, the state optimizes and forms cross channel curve, so as to include the curve of day-ahead new energy delivery plan.

3.3. Intraday joint scheduling
In principle, intraday markets mainly carry out for the actual new energy output and day-ahead new energy plan curve. Mainly divided into the following two cases:

(1) While the actual output of the new energy < the day-ahead new energy plan curve, sub-center applies to the state for reducing delivery plan. Beginning is to reduce the day-ahead new energy spot curve, and then reduce the day-ahead new energy basic curve. At the same time, to maintain the stability of the DC cross-zone transmission, thermal power output is increased moderately.

(2) While the actual output of the new energy > the day-ahead new energy plan curve, the state opens the intraday spot market according to the process. For achieving the daily increase in new energy delivery, the cross-regional DC power is added and the cross-zone thermal power is reduced. Priority to increase the cross-regional DC curve, and thermal power is adjusted after reaching the limit of DC.

4. Case Studies
The proposed tie-line plan is based on the variable direction multiplier method about multi-regional interconnected power grid. The decomposition, coordination and solution algorithms of this method are tested to verify the feasibility and the solving efficiency. The case runs the intraday rolling plan, and the setting as follows: scheduled time window 4h, the time granularity 15min, and the total executed points 16. The short-term power forecast data for load and clean energy is adopted in day-ahead plan. the average permeability of clean energy in this case is 24.5%, which is like the reverse peaking characteristic. Assuming that the output clean energy in each period meeting the mean value u is the expected value, and the standard deviation is normal distribution of σ=0.15u.

Comparison is carried out between the proposed method and the fixed tie-line plan method for two zones. The fixed tie line plan selects transmission power, which can ensure that the full period of regional power grid run safely. In this case, the zone 2 delivers 350MW to zone 1. Results are shown in Table.1.

|                           | Scheduling cost |            |        |
|---------------------------|-----------------|------------|--------|
|                           | New method      | Traditional method |
| Zone 1 Conventional unit power generation costs | 510005 | 594259 |
| Zone 2 Conventional unit power generation costs | 510005 | 477584 |
| Abandoned power costs of new energy | 508176 | 926566 |
| **Total costs**            | 1528186         | 1998408    |

Table 1 shows that the proposed method in this paper is better to accept new energy than traditional method so that new energy costs decreases by 41.2%. And total operating costs decrease by 23.5% through the coordination of different zones.

Table 2 shows the economic comparison of day-ahead plan and intraday rolling plan, which show the economy of dispatching plan has been improved after the intraday rolling correction. By using the proposed method, the convergence is obtained after 8 iterations. The solution time of the optimal scheduling in zone 1 is 0.3267s, and the zone 2 is 0.3419s. Total time is 0.7190s. Results show the algorithm is efficient.
### Table 2. Economic comparison of day-ahead plan and intraday scrolling plan (unit: RMB)

| Scheduling plan          | Day-ahead plan | Intraday scrolling plan |
|--------------------------|---------------|------------------------|
| Generation costs (including start-stop costs) | 6581766       | 6578266                |
| Environment costs        | 1591213       | 1590215                |
| Total costs              | 8172979       | 8168482                |

The maximum new energy output in different period and the actual output power curve of two methods is shown in Figure 4, which is clear that the proposed method can improve the new energy consumption. In the scheduling window, this method can effectively suppress the fluctuation of renewable energy and improve the new energy by 8.7% compared with the traditional fixed line planning method.

The robustness of traditional scheduling method is poor. Total costs of abandon wind and cutting load is high so that there is no way to ensure that the actual line flow don’t exceed the limit, even if there is enough reserve. The multi-time scale scheduling method can reduce the impact of clean energy uncertainty on the system. And the total cost of the two-time scale robust scheduling framework is the lowest, and the trend of the line is safe. All of these reflect the strategy in dealing with the clean energy Uncertainty is superior.

![Figure 2. The trend of different scheduling method for each time](image)

#### 5. Conclusion

The method in this paper reduces gradually the impact of clean energy prediction bias on the grid by using multi-time scale (day-ahead, intraday, real-day) and coordinating various power sources such as hydropower, thermal power, wind power and gas power. And its effectiveness is analyzed by a practical case. The simulation results show that the proposed method is aimed at the current situation of large-scale access to clean energy, which can provide a reference solution clean energy consumption in a wide range, considering the security of grid and the coordination of supply and demand.

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