An Optimal Decision-Making Method for Power Market Transaction Based on Renewable Energy Multi-Scenario Forecast

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Abstract. In order to improve the adaptability of power market transaction to the uncertainty of renewable energy, the multi-scenario forecast model of renewable energy is studied and an optimal decision-making method for power market transaction based on renewable energy multi-scenario forecast is proposed. Multi-scenario forecast of renewable energy is a forecast result composed of multiple forecast curves, which is an uncertain forecast model in nature. The optimal power market transaction decision-making method takes the lowest expected cost and the lowest loss of renewable energy as the optimization objectives and comprehensively considers the constraints including power balance, power network transmission capacity and so on. Finally, a case study based on IEEE-30 buses system shows that this method can fully consider the impact of renewable energy uncertainty on trading results and has a significant effect on improving the efficiency of power market transaction results.

1. Introduction

The optimal decision of power market transaction is the core technology in power market transaction, whose main function is to formulate the optimal operation schedule according to the boundary data such as load demand forecast, comprehensively consider the constraints such as power balance and power network transmission capacity and define the power market clearance results. Under the traditional power supply structure, as the output of coal power, hydropower and other power sources is more controllable, the optimal decision of power market transaction usually adopts the deterministic model. In recent years, with the rapid development of wind power, photovoltaic and other renewable energy, the traditional optimal decision-making method of power market transactions, which is characterized by deterministic model, is facing severe challenges.

The ref. [1-2] introduces the traditional optimal decision-making method for market transactions, which is based on deterministic model and does not consider the generation output uncertainty of wind power, photovoltaic and other renewable energy. Some research shows that if the uncertainty of renewable energy is not taken into account in the power market transaction decision-making process,
when the actual output of renewable energy deviates from the forecast curve in the actual operation process, it may not only affect the economy of market operation, but also affect the safety of power grid operation [3-4]. Therefore, considering the uncertainty of renewable energy forecast, the optimal decision-making method of power market transactions has become a research hotspot in this field. At present, relevant researches in this field mainly focus on two ideas. The first idea is to build a robust optimization model of power market transactions that takes into account the uncertainties of renewable energy [5-6], and the second idea is to build a stochastic optimization model of market transactions [7-8]. The biggest difference between the two idea is that the robust optimization model focuses more on system security, and the optimization results will meet the system operation requirements under different scenarios as much as possible.

It can be seen that the traditional optimal power market transaction decision-making method based on the deterministic model is difficult to take the uncertainty of renewable energy generation output into account, which cannot meet the requirements of power market transaction decision-making under the rapid development of renewable energy. Considering the safety requirements of the power system, the robust optimization model is more in line with the needs of the current power system optimization decision.

To this end, this paper will study the optimal decision-making method of power market transaction based on multi-scenario forecast of renewable energy. First, the basic concepts of multi-scenario forecast for renewable energy will be introduced. Then an optimal decision-making method for power market transaction based on renewable energy multi-scenario forecast is proposed with the aim of minimizing the operating cost and new energy loss and considering the operation constraints such as the power balance. Finally, a case study based on IEEE-30 buses system is used to prove the effectiveness of the proposed method.

2. Basic conception of renewable energy

The so-called multi-scenario forecast for renewable energy refers to the renewable energy generation output forecast results under different operation scenarios in the future obtained through data analysis according to the historical operation data of renewable energy and meteorological data. Multi-scenario forecast of renewable energy is just a representation of current uncertainty forecast of renewable energy. In addition to the multi-scenario forecast method, there are also interval prediction, probability prediction and other forms of representation. The above expressions can be converted from one another without essential difference.

Under different forecast scenarios, the forecast generation output of renewable energy at different time periods could be expressed in a matrix form as follows:

\[
P_{ne}^F = \begin{bmatrix}
P_{ne,1,1}^F & P_{ne,1,2}^F & \cdots & P_{ne,1,NT}^F \\
P_{ne,2,1}^F & P_{ne,2,2}^F & \cdots & P_{ne,2,NT}^F \\
\vdots & \vdots & \ddots & \vdots \\
P_{ne,NS,1}^F & P_{ne,NS,2}^F & \cdots & P_{ne,NS,NT}^F 
\end{bmatrix}
\]  

(1)

where \( P_{ne}^F \) represents the multi-scenario forecast matrix of renewable energy \( ne \). \( P_{ne,s,t}^F \) represents the power generation output forecast value of the renewable energy \( ne \) under the forecast scenario \( s \) at the time interval \( t \). \( NS \) and \( NT \) is respectively the number of forecast scenario and the number of time interval.

And the sum of occurrence probability under each forecast scenario should be equal to 1 to ensure that different forecast scenarios can cover all possibilities of the renewable energy, which could be expressed as:

\[
\sum_{s=1}^{NS} \rho_{ne,s} = 1
\]  

(2)
where \( \rho_{ne,s} \) represents the probability of renewable energy \( ne \) under the forecast scenario \( s \).

3. Optimal decision-making model and its solution of power market transaction

3.1. Optimization objective
In the optimal decision-making model, both the power grid operation cost and the energy lose expectation of renewable energy under different scenarios should be taken into consideration. The above optimization goals could be expressed as:

\[
\min F = \alpha_1 F_1 + \alpha_2 F_2
\]

where \( \min \) represents that the optimization problem is a minimization optimization problem. \( \Delta T \) is the time interval. \( F \) is the overall optimization objective. \( F_1 \) and \( F_2 \) respectively represent the optimization items of power grid operation cost and renewable energy loss energy. \( \alpha_1 \) and \( \alpha_2 \) are the weight coefficient values of the two optimization objectives, which are set by the trading operator according to the actual needs of the power market.

\[
F_1 = \sum_{g=1}^{NG} (u_g F_s + u_c F_c) + \sum_{g=1}^{NG} \sum_{s=1}^{NS} \rho_{ne,s} \sum_{t=1}^{NT} p_g (P_{g,s,t}) P_{g,s,t} \Delta T
\]

where \( NG \) is the number of traditional power units in the whole power network. \( F_s \) and \( F_c \) are the starting cost and stopping cost of the traditional power unit \( g \). \( p_g \) is the operation cost function of the traditional power unit \( g \) declared by the power supply. \( P_{g,s,t} \) is the generation output of the traditional unit \( g \) at the time interval \( t \) under the forecast scenario \( s \). \( u_g \) and \( u_c \) are the starting state variable and stopping state variable of the traditional power unit \( g \).

Renewable energy curtailment is different under different scenario. When evaluating the overall renewable energy curtailment power level, this paper adopts the expected value of renewable energy curtailment power under various scenarios, which can be expressed as:

\[
F_2 = \sum_{s=1}^{NS} \rho_{ne,s} \sum_{t=1}^{NT} PA_{ne,s,t} \Delta T
\]

where \( PA_{ne,s,t} \) is the loss energy of renewable energy \( ne \) at the time interval \( t \) under the scenario \( s \). \( \sum_{t=1}^{NT} \sum_{s=1}^{NE} PA_{ne,s,t} \) is the loss energy of all renewable energy in the operation day and the sum of loss energy under different forecast scenes is the expected value of loss energy.

3.2. Operation constraint
(1) Power balance constraint
The constraint of power balance requires not only that the power supply in each scenario should meet the requirements of real-time balance, but also that the system operation reserve in each period should meet the requirements, which can be expressed as:

\[
\sum_{s=1}^{NNE} P_{ne,s,t} + \sum_{s=1}^{NS} P_{g,s,t} = \sum_{b=1}^{NB} P_{b,t}
\]

\[
\sum_{s=1}^{NNE} P_{ne,min,s,t} + \sum_{g=1}^{NG} u_g PU_g - \sum_{b=1}^{NB} P_{b,t} \geq R_t
\]

where \( NB \) is the number of load bus in the whole power network. \( P_{b,t} \) is the load forecast of bus \( b \) at the time period \( t \). \( P_{ne,min,s,t} \) is the scene with the smallest forecast power value in each scene. \( PU_g \) is
the maximum technical generation output of the traditional generation unit $ g $ . $ R $ is the operation reserve capacity at the time period $ t $ . $ u_g $ represents the variable of the operation state of the traditional power unit $ g $ .

(2) Operation section constraint

The operation section constraint requires that the section power flow in each scenario should be within its limit value, which can be expressed as:

$$ PSI_s \leq \sum_{ne=1}^{\text{NNE}} G_{ne,s} P_{ne,s,t} + \sum_{g=1}^{\text{NG}} G_{g,s} P_{g,s,t} + \sum_{b=1}^{\text{NB}} G_{b,s} P_{b,j} \leq PSM_s $$

(8)

where $ PSM_s $ and $ PSI_s $ are the upper and lower limitation of the operation section respectively. $ G_{ne,s} $, $ G_{g,s} $ and $ G_{b,s} $ are the generation shift distribution factors between renewable energy $ ne $, traditional generation unit $ g $, load bus $ b $ and the operation section $ s $ respectively.

(3) Operation constraints of traditional power units

The operation constraints of the traditional power unit refer to the operation constraints that should be met during the operation of the traditional power unit, mainly including upper and lower limits of output and climbing ability, which could be expressed as:

$$ u_g P_{MU} \leq P_{g,s,t} \leq u_g P_{MU} $$

$$ u_g P_{PM} \leq P_{g,s,t} - P_{g,s,t-1} \leq u_g P_{PM} $$

(9)

(10)

where $ P_{MU} $ and $ P_{PM} $ are the maximum and minimum technical generation output of the traditional power unit $ g $ . $ P_{PU} $ and $ P_{PP} $ are the maximum and minimum generation climbing capacity of the traditional power unit $ g $ .

(4) Operation constraints for renewable energy

Renewable energy operation constraint refers to the constraint conditions that need to be considered during renewable energy operation, which can be expressed as:

$$ PA_{ne,s,t} + P_{ne,s,t} = PF_{ne,s,t} $$

$$ PA_{ne,s,t} = \sum_{ne=1}^{\text{NNE}} P_{PA_{ne,s,t}} $$

$$ PF_{ne,s,t} = \sum_{ne=1}^{\text{NNE}} PF_{ne,s,t} $$

(11)

(12)

where $ PF_{ne,s,t} $ is the generation output forecast of renewable energy $ ne $ under the scenario $ s $ .

Equation (15) is a relation of wind power, requiring that the loss energy and generation output are equal to their forecast power. Equation (16) is the constraint of loss energy distribution relationship, requiring renewable energy to allocate loss energy in accordance with the principle of equal proportion.

3.3. Solution

An optimal decision-making model for power market transaction considering multi-scenario renewable energy forecast could be constructed immediately by taking equations (3) as the optimization objective and equations (6)-(12) as the constraint conditions.

Mathematically, the model is essentially a mixed integer programming problem. When the unit operating cost function of the objective function is quadratic, the model is a mixed integer programming problem. Otherwise, it is a linear mixed integer programming problem. The above models can be solved by mathematical programming methods such as simplex method or commercial software packages such as CPLEX. References are available [9-10]. Considering that the above methods are more commonly used, the specific solution process is not repeated in this paper.
4. Case study

In this paper, a case study based on IEEE-30 buses system is used to verify the validity of the proposed method. The standard system has a total of 30 buses, 6 power sources and 41 power lines. The power sources are located at bus 1, bus 2, bus 5, bus 8, bus 11 and bus 13 respectively. The power source at bus 1 is set as a renewable power energy source, while the other buses are traditional power units. The operation information of traditional power units is shown in Table 1.

| name | bus | Generation output range/MW | Maximum climbing ability/(MW/min) |
|------|-----|----------------------------|----------------------------------|
| TP1  | 2   | [50,100]                   | 2                                |
| TP2  | 5   | [80,160]                   | 4                                |
| TP3  | 8   | [80,160]                   | 4                                |
| TP4  | 11  | [50,100]                   | 2                                |
| TP5  | 13  | [80,160]                   | 4                                |

According to the meteorological forecast, the daily output range of renewable energy source is within the range of 20MW to 50MW and the predicted generation curve can be obtained by using the multi-scene prediction method, as shown in figure 1. It could be seen that although the prediction trend of power generation output in each scene is basically the same, namely the power generation output at night is high, while the power generation output at day is low. However, there are still large differences between different scenarios, so the optimal operation scheme of market transactions under different scenarios of renewable energy power generation output is not the same.

In order to illustrate the effectiveness of the proposed method, the optimization results of the proposed method are compared with those of the traditional deterministic method. Traditional deterministic methods only consider the scenarios with the highest probability of occurrence. The optimal solution can be obtained that, the traditional power sources including TP1, TP2, TP3 and TP4 would be in the running state in the optimized result of the method proposed in this paper, while the traditional power sources including TP1, TP3, TP4 and TP5 would be in the running state in the optimization result of the traditional deterministic method.

Further comparison result could be seen in table 2. Although in the scenario with the highest probability, the operation cost of the traditional method is lower than the optimization result of the method proposed in this paper. However, if the actual operation is in other renewable energy operation scenarios, the expected operating cost of the traditional method will be significantly higher than the optimization results of the method proposed in this paper. The results show that the optimization
method proposed in this paper has a high adaptability to the uncertainty of renewable energy output and is helpful to improve the overall operation efficiency.

| Item               | Scenario 3 only/ $ | Other scenarios/ $ |
|--------------------|--------------------|--------------------|
| This paper         | 3562               | 3548               |
| Traditional method | 3412               | 3875               |

5. Conclusion
In order to improve the adaptability of market transaction clearing results to the uncertainty of renewable energy generation, an optimal power market transaction decision-making method based on multi-scenario renewable energy forecast was proposed. This method can comprehensively consider the requirements of safe operation of power grid under different renewable energy forecasting scenarios, and provide a market trading scheme that conforms to the coordination of operation economy and safety, which plays a significant role in improving the market operation efficiency.

Acknowledgments
This work was supported by the Guangdong Power grid information project (No. 037800HK42190023).

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