Source-load Dispatch Model for Electricity Day-ahead Market with Wind Power Penetration

Dai Cui1,2,*, Haiyang Cong2, Weichun Ge1,2, Di Jiang2, Wentao Sun2 and Miao Wang2

1School of Electrical Engineering, Shenyang University of Technology, Shenyang City, Liaoning Province, 110870, China
2State Grid Liaoning Electric Power Supply Co. Ltd, Shenyang City, Liaoning Province, 110004, China

*Corresponding author: cuidaitg@126.com

Abstract. Due to the intermittent and volatility of wind power output, the traditional power grid’s operation and dispatching mode and the adjustment capability of conventional units were unable to meet the demands of large-scale wind power penetration. Based on the characteristics of the day-ahead dispatching link in the spot power market, this paper combines the auxiliary service with the day-ahead power market transaction to form the day-ahead trading plan. At the same time, considering the conventional thermal power peak shifting and interruptible load peak shifting, a new market peak shifting optimization model reflecting the will of the source-load role is formed. On this basis, electricity day-ahead market dispatching model considering source-load and peak shifting is established, aiming at the maximum expected income of wind power plant. Through practical examples and scenario analysis, it is verified that the source-load peak shifting scheduling model will effectively improve the expected income and absorption rate of wind power plant.

Keywords: Wind Power Consuming, Day-Ahead Market, Peak Shifting, Source-Load Dispatching.

1. Introduction
In recent years, the scale of wind power installation in China has increased rapidly. China still takes coal and electricity as the main power generation resource, the power structure is lack of flexibility, and the system cannot fully adapt to the intermittent and volatility of wind power[1]. In addition, the reverse peak-shaving characteristics of wind power hinder the willingness of load side to absorb wind power. In the environment of new energy consumption facing many difficulties, the realization of renewable wind power and so on Large-scale energy absorption needs to be multiple angles, source-network-load triple-level participation [2].

The new round of power system reform in China continues to push forward, and the vitality of the power market continues to release [3-5]. In order to promote the large-scale optimal allocation of energy resources, the call to strengthen the absorption of new energy by means of the market has been
constantly issued. The market is the main trading platform of the spot market. Take one day as the time to promote the market, encourage market members to accurately predict their own power generation capacity or power demand, and form and system. Transaction plan suitable for system operation [6-8]. As the main link in the spot market, the market plays an important role in improving the optimal allocation of power resources, guiding the load response and interaction on the demand side, and improving the ability of the power grid to absorb new energy [9-10].

In the power market before the day, combining the peak shaving capacity of interruptible load with the peak shaving ability of thermal power units, the interruptible load users and thermal power units can participate in the unified coordinated dispatching of power grid as peak shaving resources, which is helpful to lighten the burden of the system in the real-time market and effectively improve the expected income of the system apoplectic electric field. Improve the wind power absorption rate.

2. Day-ahead Market Model of Source-load Peak shifting

2.1 Basic Premises and Assumptions

This paper is based on a wind-fire system in which the load demand curve is published by the trading center. The thermal power unit shall be output according to the medium and long-term contract, and shall be used as the peak regulation resource of wind power. The peak regulation capacity and its quotation shall be reported in the market, and if necessary, the output shall be reduced to the wind power generation space. Wind power expected output is load demand minus thermal power contract output, when wind power forecast output cannot meet. When expected to contribute, the wind farm will be punished to a certain extent.

2.2 Design of Power Market Mechanism for Source-load Peak shifting

The design of the market mechanism should be considered from the perspective of two main subjects.

(1) The thermal power units carry out peak shaving through the market mode. On the basis of its contract output, the thermal power unit continues to reduce the output to adjust the peak paid to transfer the power generation space for wind power. The thermal power unit declares the peak shaving quotation according to its own peak shaving cost and willingness, and classifies the quotation according to the peak shaving degree.

(2) The user side proactively declares the interruptible load service. Interruptible load is an important form based on incentive demand response, which refers to the user responding to the interrupt load request of dispatching center in a specific period of time according to the contract signed in advance, reducing or interrupting the power consumption, and obtaining the corresponding economic compensation.

3. Mathematical Model of Electric Day-ahead Market Clearing

3.1 Objective Function and Cost Model

1) Objective function

This objective function is formulated as follows:

$$\max \left( \sum \pi^w - \pi^o - C^w - C^i \right)$$

(1)

In the form: \( \pi^w \) represents the amount of wind power on the grid; \( \pi^o \) represents wind power clearing price; \( C^w, C^o, C^i \) are respectively the cost of thermal power peak shaving, interruptible load peak shaving, deviation penalty.

2) Cost Model of Peak shaving of Thermal Power Unit

The peak shaving cost of thermal power unit can be expressed as follows:

$$C^c = \sum \pi^w \pi^d$$

(2)
In the form: $\pi_{t}^{e}$ represents the peak shaving quotation. For thermal power units during the period $t$, $P_{t}^{e}$ represents the amount of peak shaving that won the bid.

3) Cost Model of interruptible load scheduling

Interruptible load scheduling costs can be expressed as follows:

$$C^o = \sum_{t} \sum_{s} \pi_{t,s}^{o} P_{t,s}^{o} I_{t,s}$$  \hspace{1cm} (3)

In the form: $\pi_{t,s}^{o}$ represents the unit interruption compensation quotation; $P_{t,s}^{o}$ represents the amount of interruption that won the bid; $I_{t,s}$ represents the call variable for an interruptible load.

4) Penalty cost model

The penalty cost can be expressed as follows:

$$C^+ = \sum_{t} P_{t}^{\pi} \pi_{t}^{\prime}$$ \hspace{1cm} (4)

In the form: $T_{t}$ represents the period when the predicted output of wind power is lower than the expected output of wind power; $\pi^{\prime}$ represents the difference between the expected output of wind power and the predicted output; $\pi^{\prime}$ represents the unit penalty price.

3.2 Constraints

1) System operation power balance constraint

$$P_{t}^{e} + P_{t}^{w} - P_{t}^{p} = P_{t}^{l}$$ \hspace{1cm} (5)

In the form: $P_{t}^{e}$ represents active output of conventional thermal power units; $P_{t}^{w}$ represents active power of wind power plant; $P_{t}^{p}$ represents active power output for interruptible load; $P_{t}^{l}$ represents the load active power.

2) Line active power flow constraint

$$-P_{l,max} \leq P_{l}^{e} G_{l}^{e} + P_{l}^{w} G_{l}^{w} - P_{l}^{p} G_{l}^{p} \leq P_{l,max}$$ \hspace{1cm} (6)

Of which, $P_{l}^{e}$ represents the total active power of wind power plant during the period $t$; $P_{l}^{w}$ represents the total active power output of conventional thermal power units during the period $t$; $P_{l}^{p}$ represents the total active power of interruptible load users during the period $t$; $P_{l,max}$ represents the maximum active power transmission capacity of the line; $G_{l}^{e}$ represents the transfer distribution factor of the node to the line at which the wind turbine is located, $G_{l}^{w}$ represents the transfer distribution factor of the node to the line at which the thermal power unit is located, $G_{l}^{p}$ represents the transfer distribution factor of the node to the line at which the interruptible load user is located.

3) Interruptible load constraint

$$P_{i,s}^{l,min} I_{t,s} \leq P_{i,s}^{l} \leq P_{i,s}^{l,max} I_{t,s}$$ \hspace{1cm} (7)

In the form: $P_{i,s}^{l,min}$, $P_{i,s}^{l,max}$ are respectively the minimum and maximum amount of interruption.

$$\sum_{s} I_{t,s} = T_{i,max}$$ \hspace{1cm} (8)

In the form: $T_{i,max}$ represents the total time of interruptions.

4. Example analysis

The expected return of wind power plant under different scenarios is verified in the day-ahead market model of source-load peak shifting.
4.1 Basic Parameters of Numerical Examples
A typical daily load demand curve, medium and long term contract output curve and wind power forecast output curve are selected. From those, the expected output curve of wind power can be obtained. Each output curve is as shown in figure 1. The penalty price for the deviation of the forecast output of wind power is as follows: the deviation penalty price of the forecast output of wind power does not meet the expected part is interruptible load compensation quotation reference Table 1.

![Figure 1. Demands and output curve](image)

Table 1. Interruptible load capacity compensation quotation

|       | <100MW | <200MW | <300MW | <400MW |
|-------|--------|--------|--------|--------|
| RMB   | 170/MW·h | 200/MW·h | 262/MW·h | 300/MW·h |

In order to verify the influence of four scenarios on the profit of wind farm in the power market with source load and peak shaving, the expected income of wind farm in the following four scenarios is calculated.

Scenario 1: wind farms only perform conventional power transactions in the recent market. At this time, there are a large number of abandoned winds and there is a period when the predicted output of wind power cannot meet the load demand. The period calculates the electric energy income according to the predicted output force and subtracts the penalty cost of insufficient output at the same time.

Scenario 2: The wind farm carries out the market clearing before the power of the interruptible load peak regulation. In the period of time, the purchase of the interruptible load service does not require the payment of the assessment fee, but the wind power still exists in the scene.

Scenario 3: The predicted wind power output meets the expected wind power output and has surplus. The wind farm will clear the warehouse before the peak load regulation of thermal power and purchase the peak load regulation service of thermal power units. At this time, the wind farm will calculate the power income according to the predicted power generation, and the assessment fee will be paid for the predicted shortage.

Scenario 4: The wind farm implements the market clearing before the power of the source and load peak regulation, and at the same time, the peak regulation service for the thermal power unit and the interruptible load is purchased, and the assessment fee is not required.

Table 2. Expected gains for each scenario

| Scenario     | scenario one | scenario two | scenario three | scenario four |
|--------------|--------------|--------------|----------------|--------------|
| Income/RMB   | 3925140      | 4011433      | 3930560        | 4016853      |

4.2 Analysis of Results
From scenario 1, 2 expected income, it can be seen that wind farm reduces the loss of revenue caused by output deviation punishment in the power market where interruptible load is involved in peak shaving.

From the expected earnings of scenario 1, 3, it can be seen that neglecting the insufficient forecast
output of wind power, the power market in which thermal power is involved in peak shaving will make use of thermal power transfer space to bring additional expected benefits to wind power. When the average price of peak shaving compensation in the market is lower than the grid price of wind power, the purchase of peak shaving service by wind power will get a higher expected return.

From scenario 3, 4 expected earnings, wind farms obtain higher expected returns by buying source load peak shaving services in the source load peak shaving market. In scenario 4, the wind farm maximizes the expected revenue and realizes the full absorption of wind power.

5. Conclusions
In this paper, under the spot market environment, the peak-load auxiliary service and the electric energy trade are combined to optimize the configuration of the peak-shaving resources with the premise of priority-eliminating wind power and the maximum expected return of the wind farm. The market model forms an optimized trading scheme in advance which is suitable for the actual operation of the power system and reflects the wishes of market members. And the peak regulation service is combined with the prior electric energy market transaction, and the peak regulation potential on the power supply side and the load side is effectively excited. The system adjusts the resources with the priority of the wind power, and calls the source-load peak-regulation resources to effectively reduce the wind-off rate and improve the pre-period benefit of the wind power plant.

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