Integrated scheduling method of intelligent distribution network DSR and renewable energy based on MCS algorithm

Fengkai Qiu¹,*, Cheng Fang¹, Ming Zeng¹, Shi Tian¹, Zhengxian Zheng²

¹North China Electricity Power University, School of economics and management, Beijing 102206, China
²State Grid Zhejiang Electric Power Company, Zhejiang 310007, China

*Corresponding author e-mail: 602514627@qq.com.

Abstract. In the intelligent distribution network environment, the demand side resources (DSR) are the electric vehicle, energy storage, controllable load and other resources located in different locations, showing the characteristics of small single capacity and decentralized layout. How to build a multi time scale integrated scheduling framework of demand side resources and renewable energy, to schedule the distributed demand side resources in an orderly manner, and to realize the efficient integration of demand side resources and renewable energy, are the key problems of demand side resources participating in grid scheduling. Based on this, this paper proposes a multi time scale integrated scheduling method based on hierarchical scheduling for DSR and renewable energy in intelligent distribution network, and uses the modified cuckoo search algorithm (MCS) to solve the problem. The effectiveness of the proposed model and algorithm is verified by the integrated scheduling of electric vehicles and renewable energy in intelligent distribution network.

1. Introduction

At present, there are three modes of distributed resource scheduling in power system, namely centralized scheduling, decentralized scheduling and hierarchical scheduling [1, 2]. Centralized scheduling means that the power grid dispatching center directly schedules the demand side resources scattered in different places. In this scheduling mode, the data transmission volume is large; the transmission speed is high; the reliability of the communication network is also high, and it will increase the calculation burden of the dispatching center. Sometime it will even cause "dimension disaster" and other problems. Decentralized scheduling means setting load agent in the region, which is responsible for the scheduling of demand side resources in the region. However, this scheduling mode makes the load agents unable to cooperate in depth, and it is difficult to ensure that the optimization objective of each agent is consistent with that of the whole system. The hierarchical scheduling mode integrates the above two scheduling modes, and establishes the response agent layer and the grid dispatching center layer based on the demand side resource layer. The centralized scheduling mode is adopted in the grid dispatching center layer, and the decentralized scheduling mode is adopted in the response agent layer. This scheduling model not only solves the problem of too much computation in centralized scheduling, but also can effectively play the cluster effect of demand side resources[3, 4].Therefore, this paper adopts hierarchical scheduling mode.
The hierarchical scheduling framework for the integration of demand side resources and renewable energy consists of grid dispatching center layer, response agent layer and demand side resources layer from top to bottom.

2. Rolling optimization scheduling strategy under multi-time scales

Renewable energy output prediction accuracy is different at different time scales. The shorter the time scale, the higher the accuracy of the prediction of renewable energy output, and the less the fluctuation of uncertainty caused by the operation of the system. Under the current technical conditions, the output error of a single wind farm in the first 24 hours is generally 20% to 40%, and the intra-day 1 hour output prediction error is generally within 5%. Similarly, different types of demand side resource response characteristics are different. The response time of demand side resources under the real-time electricity price mechanism is generally 24h, and the response time of demand side resources under the interruptible load mechanism is generally hour-level, and the demand under direct load control mechanism response time of the side resources can be up to the minute level. Therefore, the matching of the demand side resource response characteristics and the renewable energy output characteristics on the time scale can be utilized, and the adaptive demand side response implementation mechanism is adopted in the day, day and real-time different time scales [5, 6].

2.1. Day ahead scheduling strategy

The day ahead decision model of the dispatch center is as follows:

(1) Objective function

$$\min C_{\text{grid}}^{24h} = \sum_{t=1}^{T_{24h}} \left( \rho_{\text{pur}}^{24h}(t) \cdot P_{\text{pur}}^{24h}(t) + \sum_{k=1}^{N_{\text{agent}}} \left( \rho_{\text{dr,k}}^{24h}(t) \cdot P_{\text{dr,k}}^{24h}(t) \right) \right)$$

In the function, $C_{\text{grid}}^{24h}$ is the total cost of dispatching the grid before the demand side response; $T_{24h}$ is the total number of time periods scheduled by the distribution network; $\rho_{\text{pur}}^{24h}(t)$ is the electricity price for the time-of-day distribution network to purchase electricity from the main network; $P_{\text{pur}}^{24h}(t)$ is the power of the time-of-day distribution network to purchase electricity from the main network; $N_{\text{agent}}$ is the number of load agents; $\rho_{\text{dr,k}}^{24h}(t)$ is the response cost paid to the load agent for the time-of-day distribution network; $P_{\text{dr,k}}^{24h}(t)$ is the response adjustment power of the time-of-day load agent.

(2) Restrictions

a. Power balance constraint

In order to ensure the power balance of the distribution network system, the system's renewable energy output and external purchased power should be balanced with the power load of the system after the implementation of the electricity price response. After the electricity price is responded, the system's power load is the system baseline load and demand side. Responding to the difference in load reduction, that is:

$$P_{\text{load}}^{24h}(t) = \sum_{k=1}^{N_{\text{agent}}} P_{\text{dr,k}}^{24h}(t) = P_{\text{pur}}^{24h}(t) + P_{\text{re}}^{24h}(t)$$

In the function, $P_{\text{load}}^{24h}(t)$ is the forecast value of the daytime load of the time system; $P_{\text{pur}}^{24h}(t)$ is the forecast value of the renewable energy output of the time system.

b. Purchase power constraint

The distribution network purchases electricity from the large power grid. The purchased power is subject to the power purchase contract and the capacity of the transport channel. It can be expressed as:

$$P_{\text{pur}}^{\text{min}}(t) \leq P_{\text{pur}}^{24h}(t) \leq P_{\text{pur}}^{\text{max}}(t)$$

(3)
In the function, \( P_{\text{pur}}(t) \), \( P_{\text{pur}}^\text{min}(t) \), \( P_{\text{pur}}^\text{max}(t) \) are the upper and lower limits of the external purchase power.

c. Load agent adjustable amount constraint
For load agents, the adjustable amount is limited by the load characteristics and varies within a certain range. Can be expressed as:

\[
P_{\text{dr},k}^\text{min}(t) \leq P_{\text{dr},k}(t) \leq P_{\text{dr},k}^\text{max}(t)
\]  

(4)

In the function, \( P_{\text{dr},k}^\text{min}(t) \), \( P_{\text{dr},k}^\text{max}(t) \) are the load agent and can adjust the upper and lower limits respectively.

2.2. Intra-day scheduling strategy
The day-to-day decision model of the dispatch center is as follows:

(1) Objective function

\[
\min C_{\text{grid}}^{1h} = \sum_{t=1}^{T} \left[ \rho_{\text{pur}}^h(t) \cdot P_{\text{pur}}^h(t) + \sum_{k=1}^{N_{\text{agent}}} (P_{\text{dr},k}^h(t) \cdot P_{\text{dr},k}^h(t)) \right]
\]  

(5)

In the function, \( C_{\text{grid}}^{1h} \) is the total cost of intra-day 1h dispatching of the distribution network for the demand side response; \( T \) is the total number of time periods for intra-day dispatching of the distribution network; \( \rho_{\text{pur}}^h(t) \) is the electricity price for the distribution network from the main network during the intra-day time period \( t \); \( P_{\text{pur}}^h(t) \) is the power purchased by the distribution network from the main network during the intra-day time period \( t \); \( N_{\text{agent}} \) is the number of load agents; \( \rho_{\text{dr},k}^h(t) \) is the unit response cost paid to the load agent for the distribution network during the intra-day time period \( t \); \( P_{\text{dr},k}^h(t) \) is the response adjustment power of the load agent during the intra-day time period.

(2) Constraints

a. Energy balance constraint
In order to ensure the power balance of the distribution network system, the system's renewable energy output and external power purchase should be balanced with the power load of the system after the excitation response.

\[
P_{\text{load}}^h(t) + \sum_{k=1}^{N_{\text{agent}}} P_{\text{dr},k}^h(t) = P_{\text{pur}}^h(t) + P_{\text{pv}}^h(t)
\]  

(6)

b. Purchase power constraint
The distribution network purchases electricity from the large power grid. The purchased power is subject to the power purchase contract and the capacity of the transport channel. It can be expressed as:

\[
P_{\text{pur}}^\text{min}(t) \leq P_{\text{pur}}^h(t) \leq P_{\text{pur}}^\text{max}(t)
\]  

(7)

In the function, \( P_{\text{pur}}^\text{min}(t) \), \( P_{\text{pur}}^\text{max}(t) \) are the upper and lower limits of the external purchase power.

c. Load agent adjustable amount constraint
For the load agent, the adjustable amount is constrained by the load characteristics and varies within a certain range, which can be expressed as:

\[
P_{\text{dr},k}^\text{min}(t) \leq P_{\text{dr},k}(t) \leq P_{\text{dr},k}^\text{max}(t)
\]  

(8)

In the function, \( P_{\text{dr},k}^\text{min}(t) \), \( P_{\text{dr},k}^\text{max}(t) \) are the upper and lower limits of the load agent.

3. Improved cuckoo algorithm
This paper improves CS from two aspects: (1) Introduce variation mechanism in the process of algorithm evolution to further increase population diversity by referring to the idea of genetic algorithm; (2) Embed
variation, crossover and selection operation in the algorithm to promote the competition and cooperation between groups, so as to increase the accuracy of optimization results by referring to the idea of differential evolution algorithm.

(1) Increase population diversity
The variation mechanism is as follows: when the CS algorithm iterates to the \( g \) generation, the current best nest \( x_{\text{best}}^g \) is selected, and the variation operation is continued instead of being directly inherited to the next generation, and the variation step size gradually decreases with the increase of evolutionary algebra.

\[
x_{\text{best}}^g = x_{\text{best}}^g + \{\alpha \cos[\pi \left( \frac{G_{\text{iter}}}{G_{\max}} - 1 \right) / 2 (G_{\max} - 1)] \} \otimes \tau
\]

(9)
Where, \( x_{\text{best}}^g \) is the position of bird's nest after mutation; \( \tau \in [0,1] \) is \( 1 \times D \) vector and obeys the standard normal distribution; \( D \) is the dimension of the optimization problem. \( G_{\max} \) is the maximum evolutionary algebra of the algorithm; \( G_{\text{iter}} \) is the current evolutionary algebra.

(2) Differential evolution operator
In view of the information sharing mechanism of the difference algorithm, this paper constructs the difference operator embedded in the multi-objective cuckoo algorithm as follows.

1) Mutation operation.
All bird nests are regarded as a population, and \( x_i^g \) is the individual that needed variation. In the current population, two individuals \( x_{\text{rand}1}^g \) and \( x_{\text{rand}2}^g \) are randomly selected, and the following differential strategy is adopted to generate the variation individual \( y_i^g \)

\[
y_i^g = x_i^g + M \left( x_{\text{rand}1}^g - x_{\text{rand}2}^g \right)
\]

(10)
Where, \( M \) is the scaling factor.

2) Cross operation.
The value of the \( \sigma \)-dimension component of individual \( z_i^g \) is generated according to the rule shown in equation (11):

\[
z_i^g = y_i^g, r < CR; \text{ or } \sigma = d
\]
\[
z_i^g = x_i^g, \text{ else}
\]

(11)
Where, \( r \) is a random number of \([0,1]\); \( CR \) is crossover probability; \( d \) is a randomly selected dimension to ensure that at least one dimension of component values are contributed by the individual variation.

3) Select operation. The rules of operation selection are shown in equation (12):

\[
x_i^{g+1} = z_i^g, x_i^g \text{ dominate } z_i^g
\]
\[
x_i^{g+1} = x_i^g, x_i^g \text{ dominate } z_i^g
\]
\[
x_i^{g+1} = \text{random}(z_i^g, x_i^g), \text{ else}
\]

(12)
Where, \( \text{random}(z_i^g, x_i^g) \) represents the random selection of an individual \( z_i^g \) and \( x_i^g \) with equal probability.

4. Numerical examples validate
In order to verify the validity and correctness of the proposed model and algorithm, the actual distribution network in a certain region of China was used as the test system to conduct simulation analysis. The relevant parameters of renewable energy, electric vehicle load and other loads in the system are as follows: in terms of renewable energy, there are 40 wind power generating units in the region, with a total installed capacity of 40.5MW, a total distributed photovoltaic area of about 1.6
square kilometers, and a total installed capacity of 3.2MW. The typical daily maximum output of renewable energy is 34.1MW, and the minimum output is 12.5MW. In terms of electric vehicle load, there are about 3,200 charging piles in this region. The maximum daily charging load of electric vehicles is 8.1MW, and the minimum charging load is 0.4MW. Another load includes commercial load and residential load. The daily maximum load is 37.80MW and the minimum load is 10.5MW.

4.1. Scheduling policy validation
Typical daily actual output curve of renewable energy, EV charging load curve and other load curve prediction results are shown in Fig. 1:

![Renewable energy output and load forecast in day ahead at the typical load day](image1)

**Fig 1.** Renewable energy output and load forecast in day ahead at the typical load day

Fig. 2 shows the comparison of electric vehicle charging load curve after the implementation of demand side response.

![System charging load before and after response](image2)

**Fig 2.** System charging load before and after response.

As can be seen from the figure above, the load of the electric vehicle is transferred after the electric vehicle participates in the demand-side response. Before response, the charging load of EV was mainly concentrated from 17pm to 5am. After the response, the EV charging load was transferred to 14pm to 15pm and 0pm to 6pm, which happened to be the periods when the renewable energy output was higher than the load. The analysis shows that after the implementation of the response, when the output of renewable energy is higher than the load demand and the system has the risk of abandoning wind and
light, the electric vehicle will increase the charging load. When the output of renewable energy is lower than the load demand, and the electricity cost of online shopping is higher, electric vehicles can cut down the charging load, provide response quantity for the system, and reduce the operating cost of the system.

4.2. Verification of the effect of peak cutting and valley filling and absorption of renewable energy for electric vehicles

After guiding the electric vehicle to participate in the demand-side response of the system, the total load curve and abandon wind and light curve of the system are shown in Fig. 3 and 4 below.

![Fig 3. Total system load before and after response.](image1)

![Fig 4. Abandoned wind and light of the system before and after the response.](image2)

It can be seen from Fig. 3 and 4, after the demand side response, when the system load is higher than the output of renewable energy, electric vehicle charging load cuts, when renewable energy output is higher than the system load, increase electric vehicle charging load, the electric vehicle charging load from the load peak shift to renewable energy output peak, peak effective implementation of the peel and at the same time, system abandon the abandoned light conditions improve. However, it can also be seen that, although the implementation of demand side response enables electric vehicles to achieve peak cutting and valley filling to a certain extent, wind and light abandoning still exist due to the low access ratio of electric vehicles at present. Therefore, in order to completely solve the problem of wind and light abandoning, it is necessary to improve the access scale of electric vehicles or develop other types of demand-side resources.
5. Conclusion and Prospect

Firstly, this paper analyzes the typical centralized model of distributed resource scheduling. Combined with the characteristics of demand side resource decentralization, the hierarchical scheduling framework of demand side resource participation system scheduling is established, and the demand side resource layer, response agent layer and scheduling center layer are established from bottom to top. Then, using the matching of demand side resource response characteristics and renewable energy output characteristics in time scale, the demand side response scheduling model is established in the day ahead, day inside and real-time time multiple time scales, and the corresponding scheduling strategy is formulated. Finally, taking the demand side response of electric vehicles as an example, a three-tier scheduling framework of electric vehicles participating in power grid scheduling is established, which verifies the effect of electric vehicles participating in demand side response to reduce system operation cost, cut peak and fill valley, and improve renewable energy consumption.

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