Microgrid Comprehensive Economic Dispatch Based on Generation-load Interaction

Hongxia Yu¹, Hongze Fu

School of Information Science and Engineering, Shenyang University of Technology, Shenyang 110870, China

¹hongxiayu08@sut.edu.cn
31937683@qq.com, hirofhz@163.com

Abstract. The generation-load interaction is an effective way to utilize the generation and load side resources. Aiming at the uncertainty of the schedulable range of incentive-based DR’s load reduction, the upper limit of capacity reduction is determined by baseline load and forecast load based on the economic scheduling model, and the load reduction cost model of incentive-based DR is established. Considering the influence of the electricity price on electricity consumption, a load guidance cost model of price-based DR is established. According to the incentive load reduction cost and price load change cost and each unit model, a comprehensive model of day-ago microgrid dispatch is established. The example analysis verifies the validity of the comprehensive model. The scheduling accuracy can be guaranteed by modifying the reduction range of the incentive-based DR, and the rationality of the guided price load can be guaranteed by adjusting the price-based DR.

1. Introduction

With the continuous development of intelligent microgrids, demand-side resources become schedulable resources. The generation-load interactive scheduling mode has great benefits for the security and economy of the microgrid and the environment.

Scholars at home and abroad have done a lot of research on microgrid scheduling under generation-load interaction. Reference [2] on the premise of open sales side, the load is regulated by the incentive-based DR, which shows that the incentive-based DR can reduce the amount of wind and light discarded, and reduce the operating cost of the system. Reference [3] designed an incentive-based DR that combines rigid constraints and elastic constraints to optimize the incentive-based DR and conventional units on different time scales to enhance the generation-load interaction effect. When considering the scope of the reduction of incentive-based DR, the above references refer to the maximum reduction in the contract, and not refine the reduction for different time periods. Reference [4] analyses the uncertainty of price-based DR affected by the electricity price, and establishes an active dispatching network optimal dispatch model based on chance-constrained programming. Reference [5] considers the load response deviation under the time-of-use the electricity price, and constructs a "day-ago-day-real-time" multi-time scale rolling scheduling plan model. When analysing the effect of the price-based DR, the above-mentioned references adjust the load curve through the price elasticity coefficient when the price is known, and schedules the adjusted price-based load. The price-used is not necessarily the best price when price-making is not integrated into the dispatch model.
In view of the existing problems, this paper uses the baseline load as a characteristic of historical data, and introduces it into the determination of the incentive-based DR reduction range; Based on the price-guided characteristics of price-based DR, the electricity price is used as an optimization target to establish a price-based DR cost model. Combine the established DR cost model with the cost model of each unit to establish a microgrid day-ago integrated scheduling model on generation-load interaction, which is solved by genetic algorithm. The effect of DR in microgrid scheduling is verified by an example.

2. Microgrid Structure Considering DR and DR Model

2.1. Microgrid Structure Considering DR

From the perspective of generating and using electricity, the microgrid is divided into two parts: the grid side and the load side. Introducing DR on the load side, the microgrid structure is shown in Figure 1.

![Microgrid Structure](image)

Figure 1 Microgrid Structure

After DR is implemented on the user side, the characteristics of load resources can be fully mobilized. Interruptible load cuts off power consumption according to DR's subsidy policy and reduces the voltage generated by microgrid. Transferable load changes power consumption time and load curve according to the electricity price. Reducible load adjusts electricity consumption according to the DR signal, it can not completely cut off the electricity, only reduce the power.

2.2. DR Model

2.2.1. Incentive-based DR Model. Incentive-based DR is carried out through microgrid and user agreement, the agreement stipulates capacity reduction, compensation method, etc. The load reduction cost model of the incentive-based DR is as shown in formula (1).

\[
C_{l,m,t} = a_{l,m,t} q_{l,m,t}^2 - b_{l,m,t} q_{l,m,t}
\]

\[
a_{l,m,t} = e_{l,m}
\]

\[
b_{l,m,t} = e_{z,m} + r_{p,t}
\]

In the formula, \(q_{l,m,t}\) means the load reduction; \(e_{l,m}\) and \(e_{z,m}\) mean the quadratic term coefficient and the primary term coefficient of compensation function; \(r_{p,t}\) means the microgrid electricity price.

Incentive-based DR should consider not only the maximum reduction range stipulated in the contract but also the forecast reduction when determining the maximum reduction, restrictions of incentive-based DR:
\[ 0 \leq q_{l,m,t} \leq \min \left( q_{l,m,max}, B_{l,m,t} - B_{A,m,t} \right) \]  \tag{2} \\
\[ U_{l,m,t} + \sum_{i=1}^{T} U_{l,m,t} (1 - U_{l,m,t-1}) \leq I_{l,m,max} \]  \tag{3} 

Form (2) means the upper limit constraint for load reduction, \( q_{l,m,max} \) means the maximum load reduction capacity, \( B_{l,m,t} \) means the base load, \( B_{A,m,t} \) means the forecast load; Form (3) means the frequency constraint, \( U_{l,m,t} \) means the state variable, \( I_{l,m,max} \) means the maximum number throughout the scheduling cycle.

2.2.2. Price-based DR Model. Users of price-based DR project adjust their load based on the electricity price of current time period. The load-guided cost model of price-based DR is as follows (4).

\[
\begin{align*}
C_{p,n,t} &= a_{p,n,t} q_{p,n,t}^2 + b_{p,n,t} q_{p,n,t} + c_{p,n,t} \\
a_{p,n,t} &= \frac{D \cdot r_{p,t}}{\gamma_t \cdot B_{A,n,t}} \\
b_{p,n,t} &= D \cdot r_{p,t} \cdot \frac{\gamma_t - 1}{\gamma_t} \\
c_{p,n,t} &= (1 - D) \cdot r_{p,t} \cdot B_{A,n,t}
\end{align*}
\]  \tag{4} 

In the formula, \( q_{p,n,t} \) means the transferable load, \( B_{A,n,t} \) means the forecast load, \( D \) means the electricity discount, \( \gamma_t \) means the electric elasticity.

Restrictions of price-based DR:

\[
\begin{align*}
\Delta r_{p,t} &= \frac{q_{p,n,t} r_{p,t}}{B_{A,n,t} \gamma_t} \\
\Delta r_{p,min} &\leq \Delta r_{p,t} \leq \Delta r_{p,max} \\
\sum_{i=1}^{T} q_{p,n,i} &\leq \Delta q_p \\
\sum_{i=1}^{T} (r_{p,t} + \Delta r_{p,t}) (B_{A,n,t} - q_{p,n,t}) &\leq \sum_{i=1}^{T} r_{p,t} B_{A,n,t}
\end{align*}
\]  \tag{5} \tag{6} \tag{7} 

Form (5) means the price adjustment constraint, \( \Delta r_{p,t} \) means the price change, \( \Delta r_{p,min} \) and \( \Delta r_{p,max} \) mean the minimum change and maximum change; Form (6)(7) mean the users’ satisfaction constraints, \( \Delta q_p \) means the maximum transfer load remaining.

3. Day-ago Scheduling Model

According to the DR model and the mathematical models of each unit, the integrated dispatch objective function is constructed with the lowest operating cost of the microgrid, as follows (8):
\[
\begin{align*}
\min F &= \sum_{t=1}^{T} \left( \sum_{i=1}^{I} C_{i,t} + \sum_{j=1}^{J} C_{g,j,t} + \sum_{m=1}^{M} C_{m,t} + \sum_{n=1}^{N} C_{p,n,t} + C_{m,t} + C_{p,n,t} - C_{cr,t} \right) \\
C_{i,t} &= a_{i} P_{i,t}^2 + b_{i} P_{i,t} + c_{i,1} \\
C_{g,j,t} &= \frac{c_{\text{gas}} P_{g,j,t}}{\eta_{g,j} L_{G}} \\
C_{m,t} &= \sum_{i=1}^{I} d_{i,t} P_{i,t} + \sum_{j=1}^{J} d_{g,j} P_{g,j,t} + \sum_{k=1}^{K} d_{w,k} P_{w,k,t} \\
C_{p,n,t} &= R P_{p,n,t} \\
C_{cr,t} &= d_{cr} \left( \sum_{k=1}^{K} P_{w,k,t} + \sum_{m=1}^{M} q_{m,m,t} \right)
\end{align*}
\]

In the formula, \( C_{i,t} \) means the thermal power component, \( P_{i,t} \) means the generating power, \( a_{i}, b_{i}, c_{i,1} \) mean the coefficient of cost function; \( C_{g,j,t} \) means the gas turbine component, \( P_{g,j,t} \) means the generating power, \( c_{\text{gas}} \) means the gas price, \( \eta_{g,j} \) means the generation efficiency, \( L_{G} \) means the calorific value; \( C_{m,t} \) means the maintenance cost, \( P_{w,k,t} \) means the wind power, \( d_{i,t}, d_{g,j}, d_{w,k} \) mean the maintenance cost coefficient; \( C_{p,n,t} \) means the extranet purchase cost, \( P_{p,n,t} \) means the purchase power, \( R \) means the external the electricity price. \( C_{cr,t} \) means the benefit from energy-saving and emission-reducting, \( d_{cr} \) means the subsidy coefficient.

The ionization balance and the constraints of each unit are as follows:

\[
\begin{align*}
\sum_{i=1}^{I} P_{i,t} + \sum_{j=1}^{J} P_{g,j,t} + \sum_{k=1}^{K} P_{w,k,t} &= \text{P_load} - \sum_{m=1}^{M} q_{m,m,t} - \sum_{n=1}^{N} q_{p,n,t} \\
\text{P}_{\text{min}}^{g,j} &\leq P_{g,j,t} \leq \text{P}_{\text{max}}^{g,j} \\
-P_{\text{down}}^{g,j} &\leq P_{g,j,t} - P_{g,j,t-1} \leq P_{\text{up}}^{g,j} \\
\text{P}_{\text{min}}^{f,i} &\leq P_{f,i,t} \leq \text{P}_{\text{max}}^{f,i} \\
-P_{\text{down}}^{f,i} &\leq P_{f,i,t} - P_{f,i,t-1} \leq P_{\text{up}}^{f,i} \\
0 &\leq P_{w,k,t} \leq P_{z,k}
\end{align*}
\]

Form (9) means the power balance constraint of the microgrid, \( \text{P_load} \) means the load of the microgrid; Form (10) (11) mean the output and climb constraints for gas turbines, \( \text{P}_{\text{min}}^{g,j} \) and \( \text{P}_{\text{max}}^{g,j} \) mean the minimum and maximum output power, \( P_{\text{down}}^{g,j} \) and \( P_{\text{up}}^{g,j} \) mean the maximum downward and upward climbing constraints; Form (12) (13) mean the output and climb constraints of the thermal power unit, \( \text{P}_{\text{min}}^{f,i} \) and \( \text{P}_{\text{max}}^{f,i} \) mean the minimum and maximum output power, \( P_{\text{down}}^{f,i} \) and \( P_{\text{up}}^{f,i} \) mean the maximum downward and upward climbing constraints; Form (14) means the wind power output constraint, and \( P_{z,k} \) means the maximum output power of the wind power system.

4. Example Analysis

4.1. Example Parameters

Assume that the data predictions for the microgrid on typical days are shown in Figure 2. Assume that the peak-valley period and initial the electricity price of the microgrid are shown in Table 1, and the rate
of change of the electricity price in price-based DR is 40%. The parameters of the incentive-based DR are shown in Table 2. GA is used to solve the problem.

| Time Period Division | The Electricity Price/Y |
|----------------------|--------------------------|
| Peak                 | 10:00—13:00;16:00—21:00 | 627 |
| Flat                 | 5:00—10:00;13:00—16:00  | 408 |
| Valley               | 0:00—5:00;21:00—24:00   | 283 |

### Result Analysis

In order to compare and analyze the impact of DR on the results of optimal scheduling, the following two operating modes are set up to analyze it.

**Method 1:** Excluding DR scheduling, all load is traditional load.

**Method 2:** Including incentive-based and price-based DR scheduling, the load includes reducible load and transferable load in addition to the traditional load.

Figure 3 shows the load curve change of the microgrid after DR implementation. It is proved that DR can make good use of user-side load to ensure the stable operation of microgrid and reduce the output of traditional units.

Figure 4 shows the change of microgrid the electricity price after the implementation of price-based DR. The adjusted time-of-use price can better guide the response time of transferable load, playing the role of clipping peaks and filling valleys.
Table 3 Changes of Microgrid Operating Cost Before and After DR

| Time (h) | Pre-DR cost ($10^5$/Y) | Post-DR cost ($10^5$/Y) | Time (h) | Pre-DR cost ($10^5$/Y) | Post-DR cost ($10^5$/Y) |
|---------|------------------------|-------------------------|---------|------------------------|-------------------------|
| 1       | 8.1025                 | 10.134                  | 13      | 1.2844                 | 1.1915                  |
| 2       | 6.5136                 | 6.2567                  | 14      | 6.9727                 | 6.1327                  |
| 3       | 5.6234                 | 7.4769                  | 15      | 8.0822                 | 9.7095                  |
| 4       | 0.22958                | 0.25177                 | 16      | 10.654                 | 6.6893                  |
| 5       | 0.24998                | 0.24567                 | 17      | 9.3401                 | 8.3883                  |
| 6       | 0.35935                | 0.43675                 | 18      | 8.0706                 | 10.499                  |
| 7       | 1.6762                 | 2.1438                  | 19      | 0.77274                | 0.75316                 |
| 8       | 5.0129                 | 6.9625                  | 20      | 1.3699                 | 1.7058                  |
| 9       | 6.9505                 | 2.7838                  | 21      | 1.4492                 | 1.6501                  |
| 10      | 0.69001                | 0.87317                 | 22      | 1.4309                 | 1.4108                  |
| 11      | 1.3822                 | 1.3995                  | 23      | 3.1522                 | 2.0386                  |
| 12      | 1.5262                 | 2.1216                  | 24      | 3.2323                 | 0.34470                 |
| Total   | Preis-DR 91.599         | Total Cost Post-DR 91.219 |

Under the generation-load interaction, DR is implemented on the demand side, and it can develop and utilize reducible load and transferable load, reducing the load during the peak period of microgrid and increasing the load during the valley period of microgrid. When price-based DR is added to the scheduling model, the electricity price can be adjusted based on cost, reducing the total cost of microgrid operation.

5. Conclusion
1) When determining the maximum reduction range of the incentive-based DR, the predicted reduction range is taken into consideration. The upper limit of the reduction at each moment combines historical data and predicted data, which can increase the accuracy of scheduling and enhance the effect of reducing load.
2) The price-based DR is included in the scheduling model, and the impact of the price-based DR on the operating cost of the microgrid is also considered while considering the user needs.
3) DR can increase the flexibility and diversity of microgrid, and help the system to adjust the peak load and reduce the operation cost of microgrid.

Acknowledgments
The authors are grateful for the financial support of the National Natural Science Foundation of China (No. 61803273), the Key Research and Development in Liaoning Provincial Department of Provincial Science and Technology Department of China (No. 2019JH8/1010068) and Liaoning Provincial Education Department Key Research Project (No. LZGD2017039).

References
[1] Guolong Ma, Zexiang Cai, Ping Liu. Optimization of multi-agent microgrid power supply capacity considering demand response of the electricity price incentives [J]. Electric Power Automation Equipment, 2019,39(05):96-102+108.
[2] Xianjun Qi, Qiao Cheng, Hongyue Wu, Shihai Yang, Zhixin Li. Impact of Excited Demand Response on Operation Reliability of Distribution Network [J]. Journal of Electrical Engineering and Technology, 2018, 33(22):5319-5326.
[3] Liangce He, Zhigang Lu, Lijun Geng, Jiufeng Zhang, Xueping Li, Xiaojing Guo. Environmental economic dispatch of integrated regional energy system considering integrated demand response[J]. International Journal of Electrical Power and Energy Systems, 2020, 116.
[4] Liangliang Hua, Wei Huang, Lijun Ge, Lifu, Liu. Double-layer optimal dispatch model of active distribution network considering demand response [J]. Electric Power Construction, 2018, 39(09):112-119.