A multi-sequence method for monthly unit combination optimization using flexible resources

Dai Cui1,2, Fei Xu3*, Weichun Ge1,2, Yong Min3, Yunhai Zhou4,5, Xiaodong Chen2 and Pinchao Zhao4

1School of Electrical Engineering, Shenyang University of Technology, Shenyang, Liaoning, 100084, China
2Jinzhou Power Supply Company, Liaoning Electric Power Co., Ltd., Shenyang, Liaoning, 100084, China
3Department of Electrical Engineering, Tsinghua University, Beijing, 100000, China;
4College of Electrical Engineering & New Energy, China Three Gorges University, Yichang, Hubei, 443000, China
5Hubei Provincial Key Laboratory for Operation and Control of Cascaded Hydropower Station, China Three Gorges University, Yichang, Hubei, 443000, China;
*Corresponding author’s e-mail: xufei@tsinghua.edu.cn

Abstract. In order to solve the problem of renewable power curtailment, the authors put forward a multi-sequence monthly unit combination optimization method using flexible resources. In addition, an algorithm is proposed to estimate the capacity of peak load shifting of flexible resources in day-ahead or intraday scheduling. By optimizing various types of flexible resource scheduling in day-ahead or intraday scheduling, the maximum load of the system is lessened, and the limit on the capacity of thermal power units is reduced to improve the system's ability to accommodate renewable power. In the monthly unit combination optimization model, the total minimum output of thermal power units is introduced into the objective function, which can further reduce the thermal power start-up capacity in the monthly plan to increase the system's spinning reserve and to expand the renewable power accommodation capacity of the system. Various practical constraints are taken into account. The mixed integer programming and software GLPK are used to program and solve the model. Finally, an example of a provincial grid in north China is given to verify the effectiveness of the proposed method.

1. Introduction
In the previous unit combination optimization models, the implementation of planned electricity, the reduction of unit start-up times, the guarantee of a certain load rate of the unit, and the system security under the maximum load are mainly considered[1]. With the large-scale integration of renewable energy sources (RES) into the power grid, the consideration of the impact of RES in the monthly unit combination plan has gradually attracted the attention of scholars[2-6]. The volatility and randomness of RES output put forward more demands for flexible resources of the system[7]. And, the flexibility transformation of conventional units, such as the installation of electric boilers, or heat storage devices, as well as energy storage batteries and pumped storage power stations, also provides new flexibility resources for the power system[8-12].
In the power grid in northern China, there is generally a shortage of natural gas units that can start quickly, and large hydropower units with storage capacity and water resources guarantee. In order to ensure the power supply reliability of the system, a certain scale of thermal power unit start-up capacity needs to be maintained to provide reserve capacity to cope with the scenario of small renewable power output. However, the lower limit of output of thermal power units is usually 40%~50% of the installed capacity, and the heating units in the winter heating season generally do not participate in peak regulation, so that when the wind power output is large, the system has insufficient peak regulation capability, resulting in wind curtailment. In this article, the system's peak load shifting capability is considered as one of the optimization goals. Under the premise of meeting the system safety constraints, the monthly unit combination plan is reasonably formulated to improve the system's ability to accommodate wind power.

At present, provincial dispatching systems usually have short-term RES output forecasts for day-ahead scheduling; ultra-short-term forecasts for intraday and rolling scheduling. However, there are relatively few medium-term forecasts for RES output, and no meteorological department has reported wind forecasts on monthly time scales. Therefore, in the monthly unit combination, it is difficult to predict the RES output and apply it to the unit start-stop combination. The authors have done statistics on the total output of wind power at 96 points in a province from September 2018 to September 2019. The maximum wind power output is 6167 MW, and the minimum output is 2 MW, among which 11.96% is lower than 5% of the maximum output. Therefore, the duration and probability of low wind power output are not low. On the other hand, when there is a shortage of power supply capacity in the system, the power grid lacks technical means to effectively address the risk of power shortage: the power generation side lacks gas or hydropower units that can start quickly; the load side is currently restricted by policies. For example, there is no specific operational policy for interruptible loads, so it is difficult to ensure the reliability of power supply by orderly cutting off interruptible loads. Therefore, in combination with the actual practices of some provincial dispatching departments, the method in this paper is conservative and has not considered the use of stochastic optimization models to study the unit combination problem.

In this paper, the optimization of monthly unit combination and day-ahead scheduling are discussed from two aspects of power and electricity. In terms of power, since the start-up and downtime of the thermal power unit takes several hours, and the required cost is high, in the monthly plan, the adjustable output limit of thermal power units in operation need to be greater than the sum of system load and reserve capacity. In this way, the loss of load caused by the sudden reduction of RES output or the failure of units can be avoided. In terms of electricity, after considering the annual planned electricity of each power plant, market transaction, new energy accommodation and other factors, the relevant departments will issue the monthly planned electric quantity of the power plant. Because priority is given to the generation of RES in principle, under a certain load, the actual monthly power generation of a thermal power plant is greatly affected by the situation of renewable energy generation. At present, Renewable energy output forecasts are generally within 96 hours. When formulating a monthly plan, it is not possible to reliably predict the output of each day. If the power is decomposed into each day in the monthly plan, the deviation in actual implementation is often large. In this paper, according to the planned electricity of each power plant, the total online operation time of power plant units in the current month is allocated, and the economic scheduling, optimal scheduling of flexible resources and power completion of thermal power plants are considered in the day-ahead scheduling, so that the load rate and plan completion rate of units between power plants can be generally balanced.

It can be found from recent years' operating practices that although the thermal power plant's flexibility transformation and pumped storage power plants have strengthened the system's peak load shifting capability, the energy storage capacity of these devices and power stations is limited, and they cannot work in storage and discharge state for long time. Continuous wind conditions at night in winter will still cause wind curtailment. From the perspective of flexibility needs and optimization scheduling of flexible resources, the peak load with a short duration will be matched with flexible resources in short-term scheduling. Through peak cutting, the requirement of thermal power start-up capacity to meet
short-term peak load in monthly scheduling is reduced. This also reduces the total minimum output of thermal power, which can accommodate more new energy under continuous wind conditions.

2. Monthly unit combination model

2.1 Objective function

The monthly unit combination plan should be reasonably arranged to make the units run continuously and reduce the number of units start and stop[13]. Moreover, in order to improve the system's renewable power accommodation, the minimum total output of the thermal power unit should be as small as possible, so as to ensure that the system has enough spinning reserve capacity. At the same time, it is necessary to ensure the completion of the monthly planned electricity of each power plant and the load rate balance of each power plant. However, in the actual power grid, the monthly planned electric quantity of each power plant often varies greatly, even by two orders of magnitude, so the monthly planned electricity of each power plant can be completed and the load rate balance of each power plant can be ensured by introducing the minimum deviation of the maximum available electricity of each power plant in the objective function. In addition, the upper and lower limits of the maximum available power supply of each power plant are added in the constraints to ensure that each power plant is in a certain operating time. Based on the above factors, the objective function is the minimum start-up and shutdown costs, the minimum output of thermal power units in the system, and the minimum absolute value of the deviation between the actual value and the estimated value of the maximum available power supply. The objective function expression is show in equation (1).

\[
\min f = \sum_{t=1}^{T} \sum_{i=1}^{N} (\alpha_{it}^+ S_{ci}^U + \alpha_{it}^- S_{ci}^D) + M_1 \sum_{t=1}^{T} \sum_{i=1}^{N} \beta_{it} P_{it,\min} + M_2 \sum_{j=1}^{H} Q_{j,max} - Q'_{j,max}
\]

(1)

Where \(T\) and \(N\) are the total number of time periods and units, respectively. \(\alpha_{it}^+\) and \(\alpha_{it}^-\) are the starting and stopping variables of unit \(i\), respectively. They are both 0 or 1. When they are equal to 1, it means the unit is starting or stopping, otherwise the unit status is unchanged. \(S_{ci}^U\) and \(S_{ci}^D\) are the costs for unit \(i\) to start or stop once. \(M_1\) is the weight coefficient of the lowest output term. \(\beta_{it}\) is the starting and stopping state of unit \(i\) on \(t\) day, which is a 0-1 variable. When the value is 1, the unit is in the running state, otherwise the unit is in the shutdown state. \(P_{i,min}\) is the minimum output of unit \(i\). \(M_2\) is the penalty coefficient of the deviation term of the maximum power supply of power plants. \(H\) is the total number of power plants. \(Q_{j,max}\) and \(Q'_{j,max}\) are the actual value and the estimated value of the maximum available power supply of power plant \(j\), respectively. \(Q'_{j,max}\) can be calculated by estimating the average load rate of the system. First, set the daily starting capacity of \(t\) as \(B_t\), then \(B_t\) can be calculated by the equation (2).

\[B_t = L_{t,max} + RC_t\]

(2)

Where \(L_{t,max}\) is the maximum load of day \(t\); \(RC_t\) is the daily system reserve capacity of day \(t\).

Then the average load rate \(R_{avg}\) of the system can be calculated by the equation (3).

\[\overline{R}_{avg} = \frac{\sum_{j=1}^{H} Q_{j}}{\sum_{t=1}^{T} 24 B_t}\]

(3)
Where $Q_j$ is the monthly planned electric quantity of power plant $j$. $24B_t$ is the maximum daily generating capacity of day $t$. Therefore, the online operation time of each power plant unit can be obtained from the equation (4).

$$w_i \sum_{i \in j} P_i = Q_j / \overline{R}_j$$  \hspace{1cm} (4)

Where $w_i$ is operation time of unit $i$. $i \in j$ represents unit $i$ belonging to power plant $j$. $P_i$ is the installed capacity of unit $i$.

Then the estimated value of maximum available power supply of power plant $j$ can be calculated by the equation (5).

$$Q'_{j,\text{max}} = \sum_{i \in j} w_i P'_{i,\text{max}}$$  \hspace{1cm} (5)

In addition, to simplify the calculation, $\left| Q_{j,\text{max}} - Q'_{j,\text{max}} \right|$ needs to be converted into a linear function. That is, let $x_j = \left| Q_{j,\text{max}} - Q'_{j,\text{max}} \right|$, and then set two non-negative controlled variables $u_j$, $v_j$. For any $x_j$, $u_j$, $v_j$ exist, satisfying $x_j = u_j - v_j$, $x_j = u_j + v_j$.

2.2 Constraints

2.2.1 Reserve capacity constraints. In order to ensure the safety and reliability of the system operation, the maximum output of the thermal power unit should be greater than or equal to the maximum value of the sum of the load, the selling power of the system and the minimum reserve capacity in the calculation cycle. In this way, under the most conservative circumstances, the system can also ensure no loss of load. On the other hand, the minimum total output of thermal power units should be less than or equal to the minimum value of the sum of load and the power sold in the calculation period. Otherwise, when the renewable energy generation are completely cut off, the power generation of the system is still greater than the load, and the power generation and load balance cannot be achieved. The specific constraint expression is as follows:

$$\sum_{i=1}^{N} \beta_{i,j} P_{i,\text{max}} \geq \max(L_{i,h} + Q'_{i,h}) + R_{i,\text{min}}$$

$$\sum_{i=1}^{N} \beta_{i,j} P_{i,\text{min}} \leq \min(L_{i,h} + Q'_{i,h})$$  \hspace{1cm} (6)

Where $P_{i,\text{max}}$ is the maximum output of unit $i$. $L_{i,h}$ is the load at time $h$ on day $t$. $R_{i,\text{min}}$ is the minimum reserve capacity on day $t$. $Q'_{i,h}$ is the selling power of the system at time $h$ on day $t$.

2.2.2 Start-stop logic constraints.

$$\beta_{i,j} - \beta_{i,j-1} = \alpha'_{i,j} - \alpha_{i,j}$$  \hspace{1cm} (7)

2.2.3 Maximum startup times constraints. This constraint indicates that the starting and stopping times of each unit are less than 2 times during the optimization period.

$$\sum_{i=1}^{N} \alpha'_{i,j} \leq 2$$  \hspace{1cm} (8)
2.2.4 Minimum start-stop duration constraints. These constraints indicate that the thermal power unit cannot be shut down within 3 days after starting up, and the unit is not allowed to start up within 3 days after stopping down[14].

\[
\begin{align*}
\sum_{t=1}^{T-2} (\alpha_{t,j}^+ + \alpha_{t+1,j}^+ + \alpha_{t+2,j}^-) & \leq 1 \\
\sum_{t=1}^{T-2} (\alpha_{t,j}^- + \alpha_{t+1,j}^- + \alpha_{t+2,j}^+) & \leq 1
\end{align*}
\]

(9)

2.2.5 The maximum available power supply constraints of power plants. Set the upper and lower limits for the number of hours of each power plant to ensure that the deviation between the actual completed power and the planned power is within a certain range.

\[
\delta_j^{\max} \leq Q_{j,max} \leq \delta_j^{\min}
\]

(10)

Where \( \delta_j^{\max} \) and \( \delta_j^{\min} \) are the upper and lower limits of the maximum available power of the power plant \( j \), which are calculated by multiplying the planned electricity of each power plant by the maximum and minimum coefficients.

2.2.6 Minimum number of operating units.

\[
\sum_{i \in j} \beta_{i,j} \geq N_{j,\min}^s
\]

(11)

Where \( N_{j,\min}^s \) represents the minimum number of operating units of power plant \( j \) under the condition of ensuring the stable operation of the system.

2.2.7 Power plant manpower constraints. It indicates that due to the limitation of the power plant's human resources, the power plant can start or shut down at most one unit per day.

\[
\sum_{i \in j} (\alpha_{i,j}^- + \alpha_{i,j}^+) \leq 1
\]

(12)

3. Algorithm for estimating peak-shifting capability of flexible resources

One of the constraints of the monthly optimization model of thermal power units in this paper is to maintain a certain number of thermal power units in operation in order to satisfy the sum of the maximum load and the reserve capacity of the system. Considering that the pumping and energy storage devices can reduce the maximum load of the system during the short-term scheduling, that is, the peak shifting effect of the energy storage devices can relax the maximum load constraint in the monthly plan accordingly. Although the repeated charging and discharging of the energy storage device within a day can improve the efficiency of peak load shifting, it requires that the system has enough power generation capacity to meet the demand of both load and charging load during the two peak load periods. Therefore, in order to simplify the problem and ensure the reliability of system power supply, this paper does not consider the case of repeated charge and discharge within a day. On the other hand, although energy storage devices can accommodate more new energy by charging with new energy when the load is low, it has no direct impact on the minimum capacity of operating units of thermal power, so the charging effect is not considered in the calculation. After making the above assumptions, the peak-cutting effect of energy storage devices must satisfy two constraints: the maximum peak-cutting value is less than or equal to the maximum discharge power of the energy storage devices, and the cumulative peak-cutting energy is less than or equal to the capacity of the energy storage devices. The two constraints can be expressed as follows:
\[
\max \left\{ L(i) - L_{\max} \right\} \leq P_{\text{max}}^s \tag{13}
\]

\[
\sum_{i=1}^n (L(i) - L_{\max}) \Delta t \leq S_{\max}^s \tag{14}
\]

Where \( L_{\max} \) is the maximum load value of the system after peak cutting. \( n \) is the number of loads with a load value greater than \( L_{\max} \) before the peak load shifting. These loads are expressed as \( L(i), \ i = 1, 2, \cdots, n \). \( P_{\text{max}}^s \) and \( S_{\max}^s \) are the total maximum discharge power and the maximum capacity of the energy storage devices, respectively. \( \Delta t \) is the time interval.

Since \( L_{\max}, L(i) \) and \( n \) are all unknowns, the loads at 24 moments of the system are firstly sorted in descending order, and then the peak cutting starts from the maximum load value in turn. When calculating in step \( i \), assume \( L_{\max} \geq L^{(i+1)} \), and judge whether the constraint conditions are satisfied. If any constraints are not satisfied, the calculation stops, and the final \( L_{\max} \) is obtained.

4. Case study

The data of the example are the actual operation data of a provincial power grid of north China in heating period. The system includes 58 thermal power plants and 138 units in total. The flexible resources include the pumping power stations and energy storage devices, with a total capacity of 2000 MW·h and a maximum discharge power of 1000 MW. The optimal scheduling model is a mixed integer linear programming model, with a total of 10423 variables, of which 10262 are 0-1 integer variables, and the number of constraints is 13481. The mixed integer programming (MIP) is adopted in this article. The GLPK, which is a mature open source software package, is used to solve the example. The GLPK uses the method of proximity search, which has the capability of quickly improving the first MIP incumbents and improves the solution speed significantly[15].

In this case, the maximum monthly total renewable energy accommodation capacity can be used as a quantitative indicator to measure the renewable energy accommodation capacity. It is the cumulative value of the daily 24-hour load value of the month minus the minimum output value of the thermal power unit at the corresponding time, reflecting the system's peak load adjustment capacity and the maximum accommodation capacity of the system. It is the estimated value of the accommodation capacity. The actual value of the accommodation capacity is related to the actual value of wind power and photovoltaic output. To calculate it, a large number of simulations need to be performed after the scenery probability model is established to obtain statistical indicators. Such statistical indicators are more important for long-term program. Due to the limitation of ability and energy, this paper has not done further research on this issue.

The algorithm in the Section 3 is used to cut the peak of daily load in the optimization period. One day's load is selected as the case, and the peak cutting diagram is shown in Figure 1. The comparison of daily load before and after peak cutting is shown in Figure 2. Then, in the two scenarios of peak cutting and no peak cutting, the monthly optimal scheduling model in Section 2 is used to optimize the monthly unit combination plan. The obtained optimization results are compared with the historical actual scheduling results, as shown in Figure 3, Figure 4 and Table 2.

From the perspective of power, it can be seen from Figure 3 that when the optimal scheduling model is not using flexible resources, the daily maximum total available power generation output is less than the historical actual scheduling results, but greater than the daily maximum load and reserve demand of the system. The daily minimum available power generation output is less than the historical actual dispatch result, which improves the system's ability to accommodate renewable energy. As can be seen from Figure 4, after the use of flexible resources, the sum of the daily maximum load and the reserve of the system decreases after peak cutting. This relaxes the limit of monthly start-up capacity, making the daily minimum available power output smaller. In this way, the system's renewable energy
accommodation space becomes larger than when no flexible resources are used, which makes the system's renewable energy accommodation capacity further enhanced.

Figure 1. The peak cutting diagram

Figure 2. The comparison of daily load before and after peak cutting

Figure 3. Optimization results without flexible resources

Figure 4. Optimization results with flexible resources

From the perspective of electricity, it can be seen from Table 1 that when the flexible resources are not used, the maximum amount of renewable energy that can be accommodated per month has increased by 560.05 million kWe, an increase of 14.48%. The total monthly power supply deviation has decreased by 3.6%. The total number of monthly start-ups has been reduced by 4 times, and the average monthly load factor has increased by 14.72%, which means that the unit's economical efficiency has been enhanced. After the use of flexible resources, the total monthly renewable energy accommodation is further increased, an increase of 1162.25 million kWe, 30.04% higher than before the optimization, and the system's accommodation capacity has been significantly enhanced. In addition, the monthly total startup times are reduced by 2 times, and the average monthly load rate is increased by 17.48%, which means the units’ economical efficiency is further improved. However, in the actual power system, the monthly planed electricity between power plants varies greatly, even by two orders of magnitude, and the deviation between the actual value and the estimated value of the maximum available power supply
having the smallest absolute value was considered in the objective function, resulting in an increase in the monthly load rate standard deviation.

| Table 1. Comparison of optimization results |
|--------------------------------------------|
| Before optimization | Optimization results |
| Without using flexible resources | Using flexible resources |
| Maximum monthly accommodation of new energy /×10^6 kWh · h | 3868.54 | 4428.59 | 5030.79 |
| Monthly units start-up times | 12 | 8 | 10 |
| The absolute value of the deviation of the monthly available power supply /×10^6 kWh · h | 6141.97 | 5918.53 | 6731.52 |
| Monthly load rate average | 71.88% | 86.60% | 89.36% |
| Monthly load rate standard deviation | 0.3008 | 1.149 | 1.6926 |
| Maximum monthly power supplya/×10^6 kWh · h | 25726.26 | 21353.34 | 20692.23 |

a The planned amount of electricity for the month was 16574.68 million kWh · h.

5. Conclusions
The key to improve the accommodation of renewable energy is to improve the flexibility of power system and to enhance the regulation ability of system. This paper proposes a multi-sequence monthly unit combination optimization method using flexible resources. The objective function is to minimize the start-up and shutdown costs, the minimum output of the thermal power unit of the system, and the minimum deviation between the actual value and the estimated value of the maximum available power supply of power plants. An algorithm is proposed to estimate the peak shifting capacity of flexible resources in day-ahead or intraday scheduling. By optimizing various types of flexible resource scheduling in day-ahead or intraday scheduling, the maximum load of the system is reduced, and the limit on the capacity of thermal power units is reduced to enhance the system's ability to accommodate renewable energy. The actual data of a provincial power grid in China are taken as an example, and the obtained optimization results are compared with the historical actual scheduling results. The results show that the optimization method in this paper can effectively improve the renewable energy accommodation capacity and improve the economical efficiency of the system.

Acknowledgments
Thanks to the State Grid Liaoning Electric Power Co., Ltd. Technology Project (NO. SGTYHT / 17-JS-199) for funding this research.

References
[1] Li, L.L.; Guan, Y.B.; Geng, J.; Yao, J.G.; Wang, G. (2011) Modeling and solving for monthly security constrained unit commitment problem. Autom. Electr. Power Syst., 35: 27-31.
[2] Chen, X.; Kang, C.; O'Malley, M.; Xia, Q.; Bai, J.; Chun, L.; Sun, R.; Wang, W.; Li, H. (2015) Increasing The Flexibility of Combined Heat and Power for Wind Power Integration in China: Modeling and Implications. IEEE Trans. Power Syst. 30: 1848–1857.
[3] Zhou, M.; Xia, S.; Li Y.; Li, G.Y. (2015) A joint optimization approach on monthly unit commitment and maintenance scheduling for wind power integrated power systems. Proc. CSEE, 35: 1-10.
[4] Yuan, Y.P.; Wang J.X.; Zhou, K.; Wang, X.L.; Wang, X.B.; Zhang, S.J. (2019) Monthly Unit Commitment Model Coordinated Short-term Scheduling and Efficient Solving Method for Renewable Energy Power System. Proc. CSEE, 18: 5336-5345+5580.
[5] LIU, Q.H.; Zheng, Y.X.; Yang S.C. (2015) A power and energy joint optimization model and its application for long-term large-range wind power accommodation. Autom. Electr. Power Syst., 39: 145-150.
[6] Luo, Y.H.; Yin, Z.X.; Yang, D.S.; Zhou, B.W. (2019) A New Wind Power Accommodation Strategy for Combined Heat and Power System Based on Bi-Directional Conversion. Energies, 12: 2458.

[7] Lu, Z.X.; Li, H.B.; Qiao, Y. (2016) Power System Flexibility Planning and Challenges Considering High Proportion of Renewable Energy. Autom. Electr. Power Syst., 40: 147-158.

[8] Su, C.G.; Shen, J.J.; Wang, P.L.; Zhou, L.A.; Cheng, C.T. (2018) Coordinated Dispatching Method for Wind-turbine-integrated Power System with Multi-type Power Sources Based on Power Flexibility Margin. Autom. Electr. Power Syst., 42: 111-122.

[9] Cui, Y.; Chen, Z.; Yan G.G.; Tang, Y.H. (2016) Coordinated Wind Power Accommodating Dispatch Model Based on Electric Boiler and CHP With Thermal Energy Storage. Proc. CSEE, 36: 4072-4081.

[10] Qi, Y.Z, Liu, Y.T. (2014) Output Power Rolling Optimization and Real-Time Control in Wind-PV-Pumped Storage Hybrid System. Transactions of China Electrotechnical Society, 29: 265-273.

[11] Yuan, X.M.; Cheng, S.J.; Wen, J.Y. (2013) Prospects Analysis of Energy Storage Application in Grid Integration of Large-scale Wind Power. Autom. Electr. Power Syst., 37: 14-18.

[12] Li, S.L. Dai, J.T.; Dong, H.Y.; Shen, W.C.; Ma, X.P. (2019) Optimal Operation of Wind Power-Photovoltaic-Pumped Storage Joint Power Generation System Considering Correlations. Proceedings of the CSU-EPSA, 31: 92-102.

[13] Xia, Q.; Chen, Y.G.; Chen, L. (2011) Establishment of mode and method for energy-conservation monthly unit commitment consideration dispatching[J]. Power Syst. Technol., 35: 27-33.

[14] Shi, L.; Geng, Z.W.; Zhang, J.; Song, J.X.; Chen, Q.X.; Guo, J.H.; Zhang, H. (2014) Risk-adaptable monthly generation scheduling mode. Power Syst. Technol., 38: 3384-3389.

[15] Zhou, Y.H.; Zhao, P.C.; Xu, F.; Cui, D.; Ge, W.C.; Chen, X.D.; Gu, B. (2020) Optimal Dispatch Strategy for a Flexible Integrated Energy Storage System for Wind Power Accommodation. Energies, 13: 1073.