The research on power dispatching to improve clean energy utilization

Jianzhong Zhang¹, Jingwen Liu²,*, Xiang Shao¹, Xianwei Du¹

¹ School of Machine and Electric Engineering, Shandong University of Science and Technology, Taian, Shandong, China
² College of Electrical Engineering and Automation, Shandong University of Science and Technology, Qingdao, Shandong, China

*Corresponding author e-mail: liujingwen1228@163.com

Abstract. This study aims to improve the clean energy utilization in the system of multi-source joint power dispatching and control. This paper constructs a joint optimization dispatching model of complementary power generation. Taking the minimum power generation cost as the objective function and adding clean energy penalty items to the objective function so as to achieve the goal of improving clean energy utilization. At the same time, based on the basic cuckoo algorithm, an improved cuckoo algorithm with chaotic perturbation is proposed to solve this model. Finally, the dispatching model is validated by multi-source joint dispatching system. Dispatching test results show that the method proposed in this paper provides better overall performance than traditional joint dispatching method.

1. Introduction

In recent years, with the large-scale integration of wind power into the power grid, it has brought new challenges to the stability and security of power systems. Reference [1, 2] proposed a power dispatching model based on wind-solar hybrid power generation. Wind and solar hybrid power generation have significantly improved the stability of power supply. Later, reference [3, 4] has come up with a method of complementary power generation for wind power and pumped storage power stations to improve the efficiency of wind power utilization. However, none of the above methods can meet the capacity requirements for large-scale wind power integration.

For the joint dispatching of wind and water generation, although the problem of insufficient capacity can be solved in [5], the frequently adjustment of hydropower units can affect the efficiency of hydropower generation. The problems that arise in the joint dispatching process of wind power and thermal power have been reported in the literature [6], the probability scene method is used to solve the uncertainty of wind power output, and the rotation reserve constraint is used to enhance the stability of the unit's power generation. Among them, the random interval of wind power and the peak-to-valley difference of load are dealt with by hydropower, and the surplus hydropower generation capacity can bears part load.
2. Establishment of scheduling model

2.1. Objective function

This paper adds clean energy penalties to the goal of minimizing power generation costs to ensure the priority of clean energy.

\[ F = \sum_{i=1}^{N_h} \sum_{j=1}^{T} \left( a_i + b_i p_{i,j} + c_i p_{i,j}^2 \right) + \sum_{i=1}^{N_s} \sum_{j=1}^{T} \gamma_s Y_{i,s,j}^s V_{t,h} + \sum_{i=1}^{N_w} \sum_{j=1}^{T} \eta_w p_{i,w,j} V_{t,h} \]  

(1)

Where \( T \) is the total dispatching period, \( N_h, N_s, N_w \) are the number of thermal power units, hydropower units and wind turbines, however, \( a_i, b_i, c_i \) are the cost coefficient for thermal power units, \( p_{i,j} \) is the power generation of the thermal power unit, while \( \gamma_s \) is the coefficient of abandoned wind, and \( Y_{i,s,j}^s \) is the amount of discarded water, \( \eta_w \) is the abandoned wind penalty coefficient, \( V_{t,h} \) represents the number of hours included in a time period.

2.2. Model Constraints

The system power balance constraint is expressed as (2). Where \( p_{i,j}^h \) is the output of thermal power unit \( i \), \( p_{i,j}^s \) is the output of the hydropower station \( i \), and \( p_{i,j}^w \) is the output of wind power turbine \( i \), \( P_{dt} \) is the load of the system.

\[ \sum_{i=1}^{N_h} p_{i,j}^h + \sum_{i=1}^{N_s} (p_{i,j}^s - Y_{i,s,j}^s) - P_{dt} + \sum_{i=1}^{N_w} (p_{i,w,j}^w - V_{t,h}) = 0 \]  

(2)

The system backup constraint is expressed as (3). Where \( p_{i,j}^{\max,h}, p_{i,j}^{\max,s} \) are the maximum output power of thermal power units and hydropower station respectively, \( k_d \) is fluctuation coefficient of load, \( k_w \) is the wind power fluctuation coefficient.

\[ \sum_{i=1}^{N_h} (p_{i,j}^{\max,h} - p_{i,j}^h) + \sum_{i=1}^{N_s} (p_{i,j}^{\max,s} - p_{i,j}^s) \geq k_d P_{dt} + k_w \sum_{i=1}^{N_w} p_{i,j}^w \]  

(3)

The output limit and climbing rate constraint of wind and thermal unit is expressed as (4). Where \( p_{i,j}^{\min,h}, p_{i,j}^{\max,h} \) are the maximum and minimum output of wind turbines, \( u_{di} \) and \( u_{ji} \) are the load shedding and loading limit value of the thermal power, \( f_{di} \) and \( f_{ji} \) are the load shedding and load limit value of the wind turbine.

\[ \begin{align*} 
 p_{i,j}^{\min,h} &\leq p_{i,j}^h \leq p_{i,j}^{\max,h} \\
 p_{i,j}^{\min,w} &\leq p_{i,j}^w \leq p_{i,j}^{\max,w} \\
 -u_{di} Vt &\leq p_{i,j}^h - p_{i,j-1}^h \leq u_{di} Vt \\
 -f_{di} Vt &\leq p_{i,j}^w - p_{i,j-1}^w \leq f_{di} Vt 
\end{align*} \]  

(4)

The pumped storage power station unit constraints is expressed as (5). The pumped storage power generation mode is selected in the article. Where \( p_{i,k,j}^{\min,s} \) and \( p_{i,k,j}^{\max,s} \) are the upper and lower limits of the discharge, \( g_{i,j}^s \) represents the discharge state of the power station. \( p_{i,k,j}^{\max,s} \) is the discharge power of the unit in the power station, \( p_{i,k,j}^{\min,s} \) is the charging power of the unit in the power station, \( p_{i,j}^{\min,s} \) and \( p_{i,j}^{\max,s} \) are the upper and lower limits of the energy storage, \( p_{i,j}^{\max,s} \) is the starting energy of the power station, besides, \( \lambda^s \) is the conversion efficiency at the time of charge and discharge.

\[ \begin{align*} 
 p_{i,j}^{\min,s} &\leq p_{i,k,j}^s \leq p_{i,k,j}^{\max,s} \\
 p_{i,j}^{\min,s} &\leq p_{i,j}^s \leq p_{i,j}^{\max,s} \\
 -u_{di} Vt &\leq p_{i,k,j}^s - p_{i,k,j-1}^s \leq u_{di} Vt \\
 -f_{di} Vt &\leq p_{i,j}^s - p_{i,j-1}^s \leq f_{di} Vt 
\end{align*} \]  

(5)
3. The solution method of dispatching model

3.1. Cuckoo algorithm
The cuckoo algorithm is an emerging algorithm that combines the breeding mechanism of cuckoos with the Levy search principle [8]. For a $d$ dimensional optimization problem, it needs to have $d$ variables at this time. The location update formula based on Levy Flight is (7) and (8):

$$x = [x_1, x_2, \cdots, x_d]$$

$$x^{(t+1)}_i = x^*_i + \alpha \otimes L(\lambda) \quad i = 1, 2, \cdots, n$$

$$L(\lambda) \sim u = r^{-\lambda}, 1 < \lambda \leq 3$$

Where $x^*_i$ represents the location of the nest, $\alpha$ is the step size, $L(\lambda)$ is the path to search, $u$ obey the normal distribution of $u \sim N(0, \sigma_u^2)$.

3.2. Chaotic perturbation operator
In order to improve the search accuracy of the algorithm, we add chaos perturbation operator [9]. The calculation formula is as follows:

$$x_{b,d} = x_{b,d} + R_d (2 \cdot x_d (i) - 1)$$

Where $x_{b,d}$ is the location of the parasitic nest, $x_d (i)$ is the chaotic sequence, $R_d$ is the search radius.

The strategy for generating chaotic sequences is as follows:

(1) Generating $d$ dimensional vectors $x(i) = (x_1(i), x_2(i), \cdots, x_d(i))$, the value of each component is a random number between $(0, 1)$.

(2) The $m$ iterations are performed according to equation (10) to generate corresponding chaotic sequences, so the sequence of the $m$ time iteration can be obtained $x(m) = x_1(m), x_2(m), \cdots, x_d(m)$.

In this paper, the chaotic mapping system is used to improve the randomness and universality of chaotic systems. The value $\alpha$ in the formula is generally 0.4, so it can be obtained:

$$x_n = \begin{cases} x_n / a, & 0 \leq x_n \leq a \\ (1-x_n) / (1-a), & a \leq x_n \leq 1 \end{cases}$$

This paper uses the solution of dimensional change to obtain the required chaotic perturbation radius. The specific method is as follows:

$$R_d = \beta \cdot \frac{1}{n} \cdot \sum_{k=1}^{n} x_{k,d} - x_{b,d}$$

Where $\beta$ is scale factor, $\frac{1}{n} \cdot \sum_{k=1}^{n} x_{k,d}$ is the average of the parasitic nest position, $x_{b,d}$ is the optimal position of the parasitic nest.
4. Simulation of examples

4.1. Example description

The system in this paper contains 6 thermal power units, 2 wind farms and 1 pumped storage power station. The calculation period of the example is 24 h and the time interval is 1 h. The basic parameters of the thermal power unit are shown in Table 1. The total installed capacity of each wind farm is 200W, and the maximum discharge power of the pumping station is 250W. Wind power and hydropower unit parameters in the system use Fang’s [10] data.

| Unit number | Rated power /MW | Maximum output /MW | Minimum output /MW | Climbing rate /(MW/h) |
|-------------|-----------------|---------------------|--------------------|-----------------------|
| G1          | 500             | 620                 | 460                | 70                    |
| G2          | 450             | 500                 | 350                | 65                    |
| G3          | 350             | 420                 | 300                | 55                    |
| G4          | 200             | 250                 | 160                | 48                    |
| G5          | 100             | 150                 | 50                 | 35                    |
| G6          | 100             | 150                 | 50                 | 35                    |

In order to ensure the economics of dispatching, some wind power will be dispatched preferentially. This will not only reduce the cost of power outages, but also make full use of renewable energy. The predicted values of the load are shown in Table 2.

| Time slot | Load value /MW | Time slot | Load value /MW | Time slot | Load value /MW |
|-----------|----------------|-----------|----------------|-----------|----------------|
| 1         | 1625.237       | 9         | 1787.315       | 17        | 1973.063       |
| 2         | 1501.162       | 10        | 1851.287       | 18        | 1987.615       |
| 3         | 1485.574       | 11        | 1986.952       | 19        | 1811.327       |
| 4         | 1528.387       | 12        | 1997.224       | 20        | 1765.971       |
| 5         | 1413.198       | 13        | 1932.866       | 21        | 1783.282       |
| 6         | 1584.713       | 14        | 1784.758       | 22        | 1635.133       |
| 7         | 1759.121       | 15        | 1793.379       | 23        | 1684.294       |
| 8         | 1776.549       | 16        | 1817.982       | 24        | 1626.336       |

4.2. Analysis of examples

In the case of the same optimization model parameters, the basic cuckoo algorithm and the improved cuckoo algorithm are used to optimize the above examples, and the population size is set to 200, and the maximum number of iterations is 600. The iterative process are shown in Figure 1, 2.
Figure 2. The improved cuckoo algorithm

Figure 3. Economic dispatch of thermal power unit output

Figure 4. The thermal power unit output of the paper

It can be seen from the above figure that the cuckoo algorithm based on chaotic perturbation algorithm has improved in both the optimization speed and the optimization ability for the introduction of chaotic operators. It makes the search efficiency and convergence speed of the algorithm changed under the same size.

Figure 5. Economic dispatch of wind turbine output
The results of this paper are compared with those of economic dispatching method to verify its validity. Figures 4, 6, and 8 show the total output of fire, wind, and hydropower units obtained by this method, Figure 3, 5 and 7 are the result of economic dispatch. As shown in the above figures, the output...
of the thermal power unit obtained by the method of this paper is lower than that of the thermal power unit obtained by the economic dispatch method.

By comparison, it can be known that the wind power and hydropower output obtained by the optimization of this paper is significantly higher than the traditional optimization method.

| Dispatching method                  | Target value / ¥ | Thermal power cost / ¥ | The cost of wind power penalty / ¥ | The cost of Hydropower penalty / ¥ | Abandoned wind rate |
|-------------------------------------|-----------------|------------------------|-----------------------------------|----------------------------------|--------------------|
| Method of this paper                | 34780           | 2691                   | 4720                              | 315                              | 1.37%              |
| Economic dispatch method            | 35980           | 2965                   | 3620                              | 271                              | 1.58%              |

Table 3 shows the results of the optimized dispatch. It can be seen from the table that the dispatching method of this paper can reduce the total power generation cost and reduce the wind curtailment rate.

5. Conclusion

This paper introduces the clean energy penalty item to improve the clean energy utilization rate and reduce the overall operating cost. The joint power dispatching model is constructed, and the improved cuckoo algorithm is used to optimize the scheduling model.

(1) The dispatching strategy of this paper can fully mobilize the regulation of hydropower to reduce the intermittent and random effects of wind power generation. It can alleviate the frequency modulation and peaking pressure of thermal power, and improve the operating efficiency of thermal power units. Besides, the consumption of clean energy can be improved.

(2) The cuckoo algorithm has been improved in this paper, the improved cuckoo algorithm based on chaotic operator is beneficial to maintain the diversity of the population and improve the shortcomings of the cuckoo algorithm.

References

[1] Liu X. Economic load dispatch constrained by wind power availability: a wait-and-see approach [J]. IEEE Transactions on Power Systems, 2010, 1(3): 347-355.
[2] Koutroulis E, Kolokotsa D. Design optimization of desalination systems power-supplied by PV and W/G energy sources [J]. Desalination, 2010, 258(13): 171-18.
[3] Teleke S, Baran M E, Bhattacharya S, et al. Optimal control of battery energy storage for wind farm dispatching [J]. IEEE Transactions on Energy Conversion, 2010, 25(3): 787-794.
[4] Ortega-Vazquez M A, Kirschen D S. Estimating the spinning reserve requirements in systems with significant wind power generation penetration [J]. IEEE Trans. On Power Systems, 2009, 24(1): 114-124.
[5] Edgardo D, Castronuovo J A, Peças L. On the optimization of the daily operation of a wind-hydro power plant [J]. IEEE Transactions on Power Systems, 2004, 19(3): 1599-1606.
[6] Pappala V S, Erlich I, Rohrig K, et al. A stochastic model for optimal operation of a wind-thermal power systems [J]. IEEE Transactions on Power Systems, 2009, 24(2): 940-950.
[7] Jabr R A, Pal B C. Intermittent wind generation in optimal power flow dispatching [J]. Transmission & Distribution, 2009, 3(1): 66-74.
[8] Gandomi A, Yang X, Alavi A. Cuckoo search algorithm: A metaheuristic approach to solve structural optimization problems [J]. Engineering with Computers, 2013, 29(29): 17-35.
[9] Bakhshandeh A, Eslami Z. An authenticated image encryption scheme based on chaotic maps and memory cellular automata [J]. Optics & Lasers in Engineering, 2013, 51(6):665–673.
[10] Fang L, Pan Y, Junfeng Y. Unit commitment model for combined optimization of wind power-thermal power-pumped storage hydro [J]. Proceedings of the CSEE, 2015, 35(4): 258-8013.