Improved particle swarm optimization techniques to wind-thermal coordination

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ABSTRACT

There is strong randomness in wind power, and its output is not controllable. Large scale wind power grid-connection to dispatch system brings new uncertainty. This paper constructs the wind-thermal random optimal model based on improved PSO algorithm and achieves the coordination of power cost and pollution emissions of thermal power units. Aimed at drawback of basic PSO algorithm, the paper uses chaos optimization search process to speed up the search and convergence speed. This improved algorithm could improve the coordination between global and local searching ability and apt to search out global optimum quickly. Finally, multi-objective optimal scheduling is illustrated by using the thermal-10 node. The results show that the improved PSO arithmetic solution set uniform distribution, predict accuracy and qualified rate is out of the solution of the highest degree of coordination, get each time specific unit output of the plan, according to the calculation results make corresponding power generation plan, to access a fairly large wind power dispatch system has the actual reference value, so the proposed method is feasible and effective.

Key words: wind-thermal system; improved PSO; coordination; chaos

NOMENCLATURE

\begin{align*}
\text{d} & \quad \text{Percentage of maximum unit capacity per hour t} \\
P_{WT}(t) & \quad \text{Total available wind generation at hour t} \\
P_{i,r} & \quad \text{Lower generation limit of } i\text{th thermal unit} \\
DR_{i}^{\text{max}} & \quad \text{Maximum ramp-down rate and down reserve} \\
P_{i}(t) & \quad \text{System load demand at hour t} \\
DS_{i}^{\text{max}} & \quad \text{Maximum up reserve contribution of } i\text{th thermal unit at hour t} \\
P_{i}^{\text{max}}(t) & \quad \text{Maximum and minimum generation} \\
P_{i}^{\min}(t) & \quad \text{respectively of } i\text{th thermal unit} \\
P_{WT}(t) & \quad \text{Total actual wind generation at hour t} \\
P_{W,j}^{\text{max}} & \quad \text{Upper generation limit of } j\text{th wind unit} \\
\text{DRW} & \quad \text{Down spinning reserve requirement} \\
P_{jW}^{\text{max}}(t) & \quad \text{Available generation of } j\text{th wind unit at hour t} \\
\text{SR}_{i} & \quad \text{Startup ramp rate limit of } i\text{th thermal unit} \\
STC_{i} & \quad \text{Startup cost of } i\text{th thermal unit} \\
TDR(t) & \quad \text{System ramping down capacity at hour t} \\
T^{\text{OFF},i} & \quad \text{Minimum down time of } i\text{th thermal unit}
\end{align*}
Min Lu and Mi Zhao  

INTRODUCTION

Electricity is a kind of extremely clean energy, but in the use of the energy have the negative effects on the environment [1-3]. At present, our country still with thermal power is given priority to, Thermal power units are more than 70% of capacity totally[4], in the future for a long time still can't change the condition, therefore, consider the clean energy and firepower unit united cooperation is a kind of practical needs. Energy saving power is the dispatch according to the energy saving, environmental protection, economy of the principles of power dispatch under the premise of reliable power supply. Priority to scheduling wind energy, water, biomass energy and other renewable power generation resources, then scheduling coal and power resources is a very important and necessary problem [5].

In the specific scheduling, press unit as pollutant emission or energy consumption level from low to high arrangement online, minimize resource consumption and pollution emission. Compared with the traditional dispatching, energy saving dispatching is more attention to energy conservation and environmental protection [6]; reduce the unit in the production of electric energy emphasis on pollutants; tend more to schedule the renewable energy units and large environmental fire unit efficiency. Thus, which saves energy, reduces the pollution of the environment, and realizes the sustainable development of the power industry [7-10].

The wind-thermal unit commitment solution methods reported in the literature include Simulated Annealing [8], Hybrid Dynamic Programming [11], and Fuzzy Mixed Integer Linear programming techniques [12]. This paper improves algorithm to the coordination global and local searching ability and is apt to search out global optimum quickly.

THE WIND-THERMAL POWER MATHEMATICAL MODEL

The objective function
(1) Economic Goals [13]
First consider the system of the unit cost of conventional fire power generation minimization (ignore the wind power generating cost)

\[
\text{minimize } F_T = \sum_{i=1}^{NT} \sum_{t=1}^{TF} \left[ I_{ON,i}(t) \times \frac{U_i(t)}{P_{iU}} + I_{OFF,i}(t) \times (1 - \frac{U_i(t)}{P_{iU}}) \times STC_i \right]
\]  (1)

Where subject to following constraints:

1) System constraints
a) Power balance constraint (losses are neglected)

\[
\sum_{i=1}^{NT} I_{ON,i}(t) \times P_{i}(t) + P_{w7}(t) = P_{i}(t)
\]  (2)

b) System up/down spinning reserve requirements

\[
\sum_{i=1}^{NT} I_{ON,i}(t) \times US_{i}(t) \geq USR_w + URW(P_{w7}(t))
\]  (3)

\[
\sum_{i=1}^{NT} I_{OFF,i}(t) \times DS_{i}(t) \geq DRW(P_{w7}(t))
\]  (4)
c) Minimum/maximum thermal plant output constraints

\[ P_i(t) - P_{WT}(t) \geq DR(t) + (P_{WT}(t) - P_i(t)) \]

\[ \sum_{i=1}^{NT} I_i(t) \times P_i^{\max}(t) + P_{WT}(t) \geq P_i(t) + USR_i + UR(t) \]

(5)

(6)

2) Thermal generator constraints

a) Unit’s maximum up/down reserve contribution constraints

\[ U^{\max}_i = d \times P_i^{\max} \quad \text{and} \quad D^{\max}_i = d \times P_i^{\max} \]

(7)

b) Unit’s up/down reserve contribution constraints

\[ U_i(t) = \min(U_i^{\max}, P_i(t) - P_i^{\min}) \]

(8)

\[ D_i(t) = \min(D_i^{\max}, P_i(t) - P_i^{\min}) \]

(9)

c) Unit’s ramping up/down capacity constraints

\[ U_i(t) = \min(U_i^{\max}, P_i(t) - P_i^{\min}) \]

(10)

\[ D_i(t) = \min(D_i^{\max}, P_i(t) - P_i^{\min}) \]

(11)

d) Unit generation limits

\[ P_i^{\min}(t) \times I_i(t) \leq P_i(t) \leq P_i^{\max}(t) \times I_i(t) \]

if \( I_i(t) = I_i(t-1) = 1 \)

\[ P_i^{\max}(t) = \min\{P_i^{\max}, P_i(t-1) + UR_i^{\max}\} \]

if \( I_i(t) = I_i(t-1) = 0 \)

\[ P_i^{\min}(t) = \min\{P_i^{\max}, P_i(t-1) + SR_i\}, \]

if \( I_i(t) = I_i(t-1) = 1 \)

\[ P_i^{\min}(t) = \max\{P_i^{\min}, P_i(t-1) - DR_i^{\max}\} \]

if \( I_i(t) = I_i(t-1) = 0 \)

\[ P_i^{\min}(t) = P_i^{\min} \]

(12)

(13)

e) Minimum up/down time constraints:

\[ [t_{ON,j}(t) - T_{ON,j}] \times I_i(t-1) - I_i(t) \geq 0 \]

\[ [t_{OFF,j}(t-1) - T_{OFF,j}] \times I_i(t-1) - I_i(t) \geq 0 \]

(14)

(15)

3) Wind generator constraints:

a) Wind generation fluctuation constraints:

\[ P_{WT}(t-1) - P_{WT}(t) \leq TDR(t) \]

\[ (P_{WT}(t-1) - P_{WT}(t)) \leq TUR(t) \]

(16)

(17)

b) Wind power curve constraints:

\[ v(t) \leq v_{i,j} \quad \text{or} \quad v(t) > v_{O,j} \]

\[ P_{W,j}^{\prime}(t) = 0, \quad v_{i,j} \leq v(t) < v_{R,j} \]

\[ P_{W,j}^{\prime}(t) = \varphi_j(v(t)), \]

\[ v_{R,j} \leq v(t) < v_{O,j} \]

\[ P_{W,j}^{\prime}(t) = P_{W,j}^{\max} \]

(18)

(19)

c) Total available wind generation

\[ P_{WT}^{\prime}(t) = \sum_{j=1}^{NW} P_{W,j}^{\prime}(t) \]

(20)

d) Total actual wind generation limit:

\[ 0 \leq P_{WT}^{\prime}(t) \leq P_{WT}(t) \]

(21)

(2) The Wind-Thermal Coordination Algorithm [14]

The wind model total actual wind generation at hour t is:

\[ P_{WT}(t) = \min\{P_{WT}(t), P_{WT1}(t), P_{WT2}(t), P_{WT3}(t)\} \]
Where \( P_{WT1}(t) = \frac{\sum_{i=1}^{NT} US_i(t) - USR_{\beta}}{\gamma} \)
\( P_{WT2}(t) = \frac{P_{L}(t) - \sum_{i=1}^{NT} I_i(t) \times P_{i}^{\min}(t)}{1 + \gamma} \)
\( P_{WT3}(t) = \frac{\sum_{i=1}^{NT} I_i(t) \times DS_i(t)}{\gamma} \)

\[ P_{WT}(t) = P_{WT}(t-1) + TDR(t) \]

**CHAOS OPTIMIZATION PSO ALGORITHM**

The basic PSO algorithm and its advantages and disadvantages

The basic PSO algorithm has two main aspects [15-19]:

1. Initial population randomly makes pbest, and Update gbest lose clear goals, the convergence of the algorithm is greatly restricted.
2. Individual speed and position update essentially relies on its own information makes the algorithm premature convergence is difficult to get the optimal solution.

The thought of Chaos optimization of PSO algorithm [16]

This paper through the fusion mechanism of chaos optimization, reduce strong dependence on initial value algorithm, the appropriate diversity of the algorithm, and also kept the PSO algorithm is easy to implement, fast speed, etc[20].

Specific ideas are as follows:

Firstly use the chaotic sequence to initialize the particle's position, select the location of the initial population positions in the amount of them, Then in particle update and imports the chaos optimization search, number of chaotic sequence are produced randomly and can get the location and the current particle optimal position, if it is better than the current particle, update the current particle optimal position, guiding the current particle jump out of local optimal point, to find the optimal solution quickly.

In this article use the improved particle swarm optimization algorithm to solve target model, which realize the wind-thermal power random multi-objective scheduling, obtains each time more close to the actual situation of the power generation plan, to access a fairly large wind power system scheduling plan has practical reference significance.

So based on improved PSO optimization steps are below:
1. Setting Parameters for the improved PSO;
2. Chaos Initialize 2*pop_size positions;
3. For each chaos initialized position i;
4. Calculate fit(i);
5. Select the top pop_size positions as the positions of the initial swarm;
6. For each particle i in the swarm, randomly in initialize the velocity(i);
7. Set pbest equals fit(i) and update p_best(i) using pos(i);
8. If fit(i) < g_best, update g_best using fit(i), update g_pos using p_best(i);  
9. While iter less than iter_max, calculate fit(i);
10. While iter_chaossearch less than iter_csmax,  
   If the result of chaos_search better than this particle, update the particle with the chaos_search position;
11. If fit(i) better than p_best(i), update pbest with Fit(i), update p_best(i) with pos(i);
12. If p_best better than gbest, update gbest with p_best(i), update g_pos with p_best(i);
13. Update the velocity (i), update the pos(i) over.

Where pop_size—the population size, fit(i)—fitness of number i, velocity(i)—the velocity of particle i, p_best(i)—the best place to particles i, pbest—individual extreme, pos(i)—current position, g_best—population extreme, gbest— Best fitness of populations, g_pos—the optimal location population, iter_max—the largest number of iterations,iter_csmax—Maximum chaos search times,

**TEST SYSTEM AND DISCUSSION**

Test System
To examine the effectiveness of the proposed algorithm, IEEE-10 nodes is considered. The system unit data and load demand are given in [21].
Tab 1 Set the parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Initial value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning factor</td>
<td>2.05</td>
</tr>
<tr>
<td>Inertial factor</td>
<td>0.729</td>
</tr>
<tr>
<td>Population size</td>
<td>20</td>
</tr>
<tr>
<td>Largest number of iterations</td>
<td>1000</td>
</tr>
<tr>
<td>Run number</td>
<td>50</td>
</tr>
<tr>
<td>Chaos control parameters</td>
<td>4</td>
</tr>
<tr>
<td>Number of Chaos optimization</td>
<td>5</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION

Through the improved PSO algorithm can get the follows:

Tab 2 The calculation results

<table>
<thead>
<tr>
<th>cost($)</th>
<th>Pollution emissions(ton)</th>
<th>Co-Ordination degree</th>
<th>solution Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>75971.33</td>
<td>2.2063</td>
<td>0.025103</td>
<td>X1</td>
</tr>
<tr>
<td>75978.67</td>
<td>2.2357</td>
<td>0.023500</td>
<td>X2</td>
</tr>
<tr>
<td>75981.00</td>
<td>2.2073</td>
<td>0.024169</td>
<td>X3</td>
</tr>
<tr>
<td>75974.74</td>
<td>2.1732</td>
<td>0.027613</td>
<td>X4</td>
</tr>
<tr>
<td>75983.33</td>
<td>2.1648</td>
<td>0.032116</td>
<td>X5</td>
</tr>
<tr>
<td>75991.42</td>
<td>2.1420</td>
<td>0.031005</td>
<td>X6</td>
</tr>
<tr>
<td>75971.67</td>
<td>2.0128</td>
<td>0.032310</td>
<td>X7</td>
</tr>
<tr>
<td>75975.03</td>
<td>2.1024</td>
<td>0.032115</td>
<td>X8</td>
</tr>
<tr>
<td>75993.33</td>
<td>2.0844</td>
<td>0.031295</td>
<td>X9</td>
</tr>
<tr>
<td>75993.13</td>
<td>2.0705</td>
<td>0.033772</td>
<td>X10</td>
</tr>
</tbody>
</table>

From table 2, we can know that the X10 non-inferior solution the coordination degree is the highest, about 0.033772, X10 each period of the output of generating unit as shown in Tab3

Tab3. The results of X10 non-inferior solution in each period of the output of generating unit

<table>
<thead>
<tr>
<th>Time</th>
<th>P1(MW)</th>
<th>P2(MW)</th>
<th>P3(MW)</th>
<th>Time</th>
<th>P1(MW)</th>
<th>P2(MW)</th>
<th>P3(MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>247.9</td>
<td>298.5</td>
<td>376.9</td>
<td>15</td>
<td>263.3</td>
<td>251.6</td>
<td>254.3</td>
</tr>
<tr>
<td>2</td>
<td>225.6</td>
<td>275.0</td>
<td>312.3</td>
<td>14</td>
<td>236.9</td>
<td>212.7</td>
<td>238.6</td>
</tr>
<tr>
<td>3</td>
<td>286.1</td>
<td>301.2</td>
<td>332.1</td>
<td>15</td>
<td>165.6</td>
<td>173.5</td>
<td>153.7</td>
</tr>
<tr>
<td>4</td>
<td>323.5</td>
<td>332.6</td>
<td>375.9</td>
<td>16</td>
<td>143.2</td>
<td>157.3</td>
<td>142.6</td>
</tr>
<tr>
<td>5</td>
<td>385.6</td>
<td>398.2</td>
<td>415.3</td>
<td>17</td>
<td>159.0</td>
<td>146.2</td>
<td>157.3</td>
</tr>
<tr>
<td>6</td>
<td>408.7</td>
<td>432.5</td>
<td>450.1</td>
<td>18</td>
<td>201.3</td>
<td>156.7</td>
<td>172.0</td>
</tr>
<tr>
<td>7</td>
<td>432.4</td>
<td>424.4</td>
<td>467.8</td>
<td>19</td>
<td>256.4</td>
<td>203.7</td>
<td>193.5</td>
</tr>
<tr>
<td>8</td>
<td>524.2</td>
<td>510.3</td>
<td>531.4</td>
<td>20</td>
<td>275.9</td>
<td>243.6</td>
<td>208.1</td>
</tr>
<tr>
<td>9</td>
<td>432.8</td>
<td>479.8</td>
<td>432.6</td>
<td>21</td>
<td>308.5</td>
<td>312.4</td>
<td>206.7</td>
</tr>
<tr>
<td>10</td>
<td>376.2</td>
<td>354.6</td>
<td>321.7</td>
<td>22</td>
<td>328.6</td>
<td>321.7</td>
<td>258.9</td>
</tr>
<tr>
<td>11</td>
<td>334.5</td>
<td>321.4</td>
<td>302.7</td>
<td>23</td>
<td>336.7</td>
<td>356.9</td>
<td>324.8</td>
</tr>
<tr>
<td>12</td>
<td>289.5</td>
<td>265.9</td>
<td>271.4</td>
<td>24</td>
<td>336.1</td>
<td>376.8</td>
<td>298.7</td>
</tr>
</tbody>
</table>

Algorithm analysis

From the above results of test system, we can find that using the improved PSO algorithm can obtain the highest coordination in the whole system and on the basis of coordination degree of the highest to determine the corresponding output plans can get the optimal benefits, including economic and environmental benefits, specific algorithm analysis indicators are as follows:

(1) The Distribution of Solution

The basic PSO algorithm solution of distribution coefficient is 0.7013, improved PSO algorithm solution of distribution coefficient is 0.9129, more close to 1, so the distribution of improved PSO algorithm is better.

(2) The Rate of Convergence

The convergence rate of the two algorithms is shown in figure 1 and figure 2
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From Fig 1 and 2, we can see that the improved PSO’s convergent ratio is better than basic PSO, and improved PSO tends to have less iteration ultimately. It means that improved PSO algorithm has better convergence properties than basic PSO.

(3) Solution of the coordination degree
The improved algorithm can get the highest coordinate under the global optimal, then determined by the coordination degree of the highest solution generation schedule can get the best economic benefits.

The Discuss of Optimal Solution
Through the improved PSO algorithm obtain the highest coordination degree solutions and according to the pareto solutions available to the corresponding period of the output value. Because of the wind farm output has strong randomness, the actual power system needs to reserve to deal with the output of the upper and lower volatility and spare capacity also increases [22]. At this point, the thermal power unit can't completely according to the generating cost or pollution emissions of the optimal scheduling, and must be appropriate to consider its spare capacity increase. The costs of two algorithms are $75993.13 and $76829.37 respectively. It means the improved algorithm has better economic benefits.

Considering the wind power forecasting error of scheduling plan, the result already contains random effect of wind power will be more close to the actual state - thermal power scheduling, to the actual scheduling plan is more practical reference value.

CONCLUSION
This paper uses the improved PSO algorithm to solve the wind multi-objective coordinated problem of thermal power. Wind power output and power load are the main random factors in the power system. This paper modeling considering wind power to improve the algorithm search speed. Based on improved algorithm, the coordination of the solution of the highest degree can be calculated. Simulation results verified that the chaos optimization PSO algorithm has good practical value and practical guiding significance in real wind-thermal power system.

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