Assessment of Distribution Network Planning Based on Dynamic Weighted Particle Swarm Algorithm with Distributed Generation and Energy Storage

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Abstract—The Coordination Planning of distribution network with distributed generation and energy storage is a hot research topic at home and abroad. This paper proposes a multi objective programming model with minimum investment cost and minimum annual operating cost as the objective function; the uncertainty of wind power and photovoltaic power generation is simulated by Monte Carlo sampling; the multi-objective programming model is solved by using the dynamic weighted particle swarm algorithm, and the optimal Pareto is achieved; the results show that the proposed method can meet the demand of regional power network load and the requirements of the network, at the same time, effectively reduce the economic costs of the distribution network.

Keywords—distributed generation; dynamic weighted particle swarm algorithm; assessment

I. INTRODUCTION

In recent years, the distributed generation has been rapid development. However, distributed wind power and photovoltaic power has great randomness, which is harmful to the stable operation of power system[1]. With the series of transformation and reform of China’s energy and electric power industry, it is expected that all kinds of distributed power and energy storage will gradually penetrate into the existing distribution network system[2]. Therefore, the research on the coordination planning method of distribution network with distributed generation and energy storage has become a hot research topic at home and abroad.

This paper puts forward a coordination planning method of distribution network with distributed generation and energy storage based on dynamic weighted particle swarm algorithm. First, a multi-objective programming model with the minimum investment and annual operating cost as the objective function is proposed, using Monte Carlo sampling; the multi-objective programming model is solved by using the dynamic weighted particle swarm algorithm, and the optimal Pareto is achieved; finally, solve the problem of transforming IEEE33 node system. The results show that the proposed method can meet the demand of regional power network load and the requirements of the network, and effectively reduce the economic costs of the distribution network.

II. A PLANNING MODEL CONSIDERING THE UNCERTAINTY OF DG OUTPUT

A. Objective Function

In this paper, the optimal planning model has two objective functions:

\[ \min C_1 = \min \left[ \sum P_p + \sum P_w + \sum P_{ge} + \sum P_s \right] \] (1)

\[ \min C_2 = \min \left[ r_{grid} E_{grid} + \sum r_p E_p + \sum r_w E_w + \sum r_{ge} E_{ge} + \sum r_s C_s \right] \] (2)

\( C_2 \) is annual operating cost; \( r_{grid} \) and \( E_{grid} \) are the price and quantity of electricity to the main network; \( r_p \) and \( E_p \) are electric power cost of distributed photovoltaic power generation and annual distributed photovoltaic power generation; \( r_w \) and \( E_w \) are electric power cost of distributed wind power and distributed photovoltaic power generation; \( r_{ge} \) and \( E_{ge} \) are the power cost and annual power generation of distributed small scale gas combustion engine, \( C_s \) is annual operation and maintenance cost of energy storage.

B. Constraint Conditions

1) Node voltage constraints

\[ U_{iMin} \leq U_i \leq U_{iMax} \quad i = 1, 2, \ldots, n \] (3)

\( U_i \) is the voltage of the node i; the upper and lower bounds of the node voltage are expressed as \( U_{iMin} \) and \( U_{iMax} \).

2) Branch transmission power constraints

\[ P_l \leq P_{lMax} \quad l = 1, 2, \ldots, n \] (4)

\( P_l \) is the transmission power of the branch l; \( P_{lMax} \) is the upper limit of the transmission power of the branch.
3) Tidal current constraints

\[
P_i = \sum_j V_j (G_{ij} \cos \theta_j + B_{ij} \sin \theta_j) \\
Q_i = \sum_j V_j (G_{ij} \sin \theta_j - B_{ij} \cos \theta_j)
\]  

(5)

\(P_i\) and \(Q_i\) are the active and reactive power injected by the node \(i\); \(V_i\) is the electric voltage amplitude of the node \(i\); \(G_{ij}\) is the branch conductance; \(B_{ij}\) is the branch susceptance; \(\theta\) is the voltage phase angle difference between the node \(i\).

4) Power supply capacity constraints

\[
\sum_{k=1}^n P_k \eta_k \geq l_c
\]

(6)

\(P_k\) is the real time output of the generator group \(k\); \(l_c\) is the real time electric load of the system; \(\eta_k\) is the variable between 0-1, expressing the start-stop status of the unit.

5) Energy storage output constraints

\[
\left\{ \begin{array}{l}
R_{min}^i \leq l_{t}^i \leq P_{max}^i \\
SOC_{min}^i \leq SOC_i \leq SOC_{max}^i \\
l_{t1}^i \leq SOC_{t1}^i \leq SOC_{min}^i S_{max} \\
l_{t2}^i \leq (1 - SOC_{t1}^i) S_{max}
\end{array} \right.
\]

(7)

SOC\(_{min}\) is the minimum state of charge of the energy storage device; \(R_{max}\) is the power rating of the energy storage device \(i\); \(l_{t}\) is the time period; SOC\(_{t1}\) is the state of charge between the time period 0-1; \(l_{t1}\) is the charging and discharging power of the energy storage device \(i\) in time section; \(l_{t2}\) is the charge and discharge time of the energy storage device \(i\) in time section \(t\).

6) Total access of distributed power sources constraints

\[
\sum_{DG} P_{DG} \leq 20\% \times P_{new}
\]

(8)

\(\sum_{DG} P_{DG}\) is the total installed capacity of the distributed power supply; \(P_{new}\) is the total amount of new load.

C. Processing of the output Uncertainty of Wind Power and Photovoltaic Units

1) Wind power output simulation

Statistics show that wind speed has statistical characteristics, which shows the partial normal distribution. In the project, the Weibull distribution is generally used to describe the wind speed distribution. On this basis, the probability density formula of the output power of the wind turbine is shown in the following formula:

\[
f(P_w) = \frac{K P_w^{K-1}}{\lambda^K} \exp \left(-\frac{P_w}{\lambda}\right)^K
\]

(9)

K and \(\lambda\) are the shape and scale parameters of the Weibull distribution; \(P_w\) is the rated power of the wind turbine; \(v_c\) and \(v_e\) are the cut in wind speed and rated wind speed of the wind turbine.

2) Output power simulation of photovoltaic power generation

The output power of the photovoltaic power generation is the product of the light intensity, the photovoltaic cell panel area and the photoelectric conversion efficiency. Statistics show that the light intensity is approximate to the beta area and the photoelectric conversion efficiency. The probability density formula of the output power of the photovoltaic power generation is shown in the following formula:

\[
f(P_p) = \frac{\Gamma(p+\lambda)}{\Gamma(p)\Gamma(\lambda)} \left(\frac{P_p}{\lambda}\right)^{p-1} \left(1 - \frac{P_p}{\lambda}\right)^{\lambda-1}
\]

(10)

\(P_{p,max}\) is the maximum output power of the photovoltaic power array; \(\rho\) and \(\lambda\) are the shape parameters of the beta distribution.

III. DYNAMIC WEIGHTED PARTICLE SWARM OPTIMIZATION

PSO (Particle Swarm Optimization) is a class of algorithm which starting from random solutions to find the optimal solution through Iterations [4]. Model in this article is a multi-objective optimization problem, however, the traditional PSO can only get one solution feedback, in order to solve the multi-objective optimization problem, we often find the solution through weighting each objective function into an overall objective function, then use the PSO.

Weighted dynamic multi-objective PSO algorithm used in this paper aggregates each objective function into an overall objective function \(C_o\) by assigning weights \(\omega\) to them. Calculate the value of the particles \(x_i\) in each iterative process \(N\):

\[
C_o(N) = \sum_{u=1}^n \omega_u (N) f_u [x_i(N)]
\]

(11)

The formulas for the weights is:

\[
\omega_u (N) = \frac{\cos (2 \pi N / u)}{\pi / u}
\]

(12)

The formula for the update velocity of the particle is:

\[
v_{i,N+1} = \xi (N) v_{i,N} + c_1 r_1 (P_{b,i} - X_i) + c_2 r_2 (P_{g,i} - X_i)
\]

(13)

\(v_{i,N}\) is iteration velocity of the particle, \(c_1\) and \(c_2\) are learning factors, their value is generally between 0-2; \(r_1\) and \(r_2\) are random numbers between 0-1; \(P_{b,i}\) is the best location that particle \(i\) experienced, \(P_{g,i}\) is the best location in the experience of the swarm. The inertia constant \(\xi (N)\) linearly decreases with iteration between 0-1, which making the searched volume of the whole algorithm reduce with the iteration.
\[ P_{L,N+1} = P_{L,N} + V_{L,N+1} \] (14)

By this calculation method, we can quickly exclude all infeasible system plan outside the feasible region, thus speed up the convergence rate. The process of the algorithm is shown in Figure I.

We use the standard IEEE33 node system to test the case. IEEE33 Node system is shown in Figure II [6].

There are no power and energy storage in the current power distribution network system and all electricity needs are provided by the main network. All the nodes are allowed to configure the distributed power and energy storage except 1,3,5. The grid connected switch of the main network remains closed, which allowing the distribution network systems purchase power from the main network as long as there is power shortage, but the extra power should be grounded at the switch, and is not allowed to return to the main network. Other required data of the case is shown in Table I [7].

Substitute the above data and the basic parameters provided by IEEE Node system into dynamic Weighted PSO, the plan results are shown in Table II.

<table>
<thead>
<tr>
<th>Parameter name</th>
<th>Value (unit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchase price of the main grid power</td>
<td>0.5 yuan/ KWh</td>
</tr>
<tr>
<td>The cost of the distributed wind power investment</td>
<td>27000 yuan/ KW</td>
</tr>
<tr>
<td>The cost of the storage investment</td>
<td>1800 yuan/ KW</td>
</tr>
<tr>
<td>The cost of the solar power investment</td>
<td>15000 yuan/ KW</td>
</tr>
<tr>
<td>The cost of the gas engine investment</td>
<td>1.15 yuan/ KWh</td>
</tr>
<tr>
<td>The cost of the energy storage operation</td>
<td>1200 (yuan/ KWh) / year</td>
</tr>
<tr>
<td>The cost of the distributed solar power</td>
<td>1.15 yuan/ KWh</td>
</tr>
<tr>
<td>The cost of the gas engine power</td>
<td>0.4 yuan/ KWh</td>
</tr>
</tbody>
</table>

IV. CASE ANALYSIS

The comparison of the system cost before and after the panning is shown in Table III.

TABLE II. PLANNING RESULTS

<table>
<thead>
<tr>
<th>Number</th>
<th>Connecting node</th>
<th>Type</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A4</td>
<td>Solar power</td>
<td>300 kW</td>
</tr>
<tr>
<td>2</td>
<td>A6</td>
<td>Energy storage</td>
<td>250 kWh</td>
</tr>
<tr>
<td>3</td>
<td>A8</td>
<td>Wind power</td>
<td>500 kW</td>
</tr>
<tr>
<td>4</td>
<td>A9</td>
<td>Solar power</td>
<td>300 kW</td>
</tr>
<tr>
<td>6</td>
<td>A12</td>
<td>Energy storage</td>
<td>250 kWh</td>
</tr>
<tr>
<td>8</td>
<td>A15</td>
<td>Solar power</td>
<td>250 kW</td>
</tr>
<tr>
<td>11</td>
<td>A19</td>
<td>Solar power</td>
<td>250 kW</td>
</tr>
<tr>
<td>12</td>
<td>A21</td>
<td>Wind power</td>
<td>300 kW</td>
</tr>
<tr>
<td>13</td>
<td>A23</td>
<td>Solar power</td>
<td>300 kW</td>
</tr>
<tr>
<td>14</td>
<td>A25</td>
<td>Energy storage</td>
<td>500 kWh</td>
</tr>
<tr>
<td>16</td>
<td>A28</td>
<td>Solar power</td>
<td>250 kW</td>
</tr>
<tr>
<td>19</td>
<td>A32</td>
<td>Energy storage</td>
<td>500 kWh</td>
</tr>
</tbody>
</table>

TABLE III. THE COMPARISON OF THE SYSTEM COST BEFORE AND AFTER THE PANNING

<table>
<thead>
<tr>
<th></th>
<th>Cost of investment (ten thousand yuan)</th>
<th>The annual operation cost (ten thousand yuan)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before planning</td>
<td>0</td>
<td>87</td>
</tr>
<tr>
<td>After planning</td>
<td>247</td>
<td>49</td>
</tr>
</tbody>
</table>

Without considering the time value of money, it is expected to achieve static equilibrium after putting all devices into production in the first seven years. It is much shorter than the life of the new equipment. Therefore, it is believable that the proposal proposed in this paper improve the economic efficiency of the power distribution network system.

V. CONCLUSION

In this paper, a multi objective programming model of distribution network system considering wind power and photovoltaic output uncertainty is proposed. By using the basic data of IEEE33 node and relevant supplementary data, a
distribution network system planning and simulation are constructed. By using the model and algorithm constructed in this paper, the planning results of the distribution network system are obtained. Cost comparison shows that the proposed scheme can bring benefits to the distribution network system.

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REFERENCES