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 he 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 generationhas 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 to simulate the uncertainty of wind power and photovoltaic power generation; second, the multi-objective programming model is solved by using the dynamic weighted particle swarm algorithm to achieve the Pareto optimal; finally, solve the problem of the 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 PLANING MODEL CONSIDERING THE UNCERTAINTY OF DG OUTPUT

A. Objective Function

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

$$\min C_1=\min[\sum\nolimits_{\forall_p} P_p+\sum\nolimits_{\forall_w} P_w+\sum\nolimits_{\forall_{ge}} P_{ge}+\sum\nolimits_{\forall_s} P_s] \quad (1)$$

P_p, P_w, P_{ge} and P_s are distributed photovoltaic, wind power, gas internal combustion generators and energy storage equipment costs.

$$\min C_2=\min[r_{grid}E_{grid}+\sum_{\forall_p} r_pE_p+\sum\nolimits_{\forall_w} r_wE_w+\sum\nolimits_{\forall_{ge}} r_{ge}E_{ge}+\sum\nolimits_{\forall_s} C_s] \quad (2)$$

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

$$U_{imin}\le U_i\le U_{imax} \qquad i=1,2,\ldots,n \quad (3)$$

U_i is the voltage of the node I; the upper and lower bounds of the node voltage are expressed asU_{imin} and U_{imax}.

2) Branch transmission power constraints

$$P_l\le P_{lmax} \qquad l=1,2\ldots,n \quad (4)$$

P_l is the transmission power of the branch l; P_{lmax} is the upper limit of the transmission power of the branchl.

3) Tidal current constraints

$$\begin{cases} P_i=V_i \sum_{j=1}^{n} V_j(G_{ij}\cos\theta_{ij}+B_{ij}\sin\theta_{ij}) \\ Q_i=V_i \sum_{j=1}^{n} V_j(G_{ij}\sin\theta_{ij}-B_{ij}\cos\theta_{ij}) \end{cases} \tag{5}$$

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 conductanceis; B_{ij} is the branchsusceptanceis; jis the voltage phase angle difference between the node I.

4) Power supply capacity constraints

$$\sum_{k=1}^{n} P_k\eta_k>l_e \tag{6}$$

P_k is the real time output of the generator group k; l_e is the real time electric load of the system; η_k is the variable between 0-1, expressing the start-stop status of the unit.

5) Energy storage output constraints

$$\begin{cases} R_{min}^{i}\le r_k^i\le R_{max}^{i} \\ SOC_{min}\le SOC_t\le SOC_{max} \\ r_{k,t}^{i}t\le(SOC_{t-1}-SOC_{min})S_{max} \\ r_{k,t}^{i}t_{i,t}\le(1-SOC_{t-1})S_{max} \end{cases} \tag{7}$$

SOC_{min} is the minimum state of charge of the energy storage device; R_{max}^{i} is the power rating of the energy storage device I; tis time period; SOC_{t-1} is the state of charge between the time period 0-1; $r_{k,t}^{i}$ is the charging and discharging power of the energy storage device i in time section; $t_{i,t}$ is the charge and discharge time of the energy storage device i in time section t.

6) Total access of distributed power sourcesconstraints

$$\sum_{\forall DG} P_{DG} \le 20\%\times P_{new} \tag{8}$$

$\sum_{\forall DG} P_{DG}$ 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[3].In the project, Weibull curve 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:

$$\begin{cases} f(P_w)=\frac{K}{bC}\left(\frac{P_w-a}{bC}\right)^{K-1}\exp\left[-\left(\frac{P_w-a}{bC}\right)^{K}\right] \\ a=\frac{P_w^{'}v_c}{v_c-v_c^{'}} \\ b=\frac{P_w^{'}}{v_c-v_c^{'}} \end{cases} \tag{9}$$

K and Care the shape and scale parameters of the Weibull distribution;$P_w^{'}$ is the rated power of the wind turbine;v_c and $v_c^{'}$ 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 distribution in a certain period of time. The probability density formula of the output power of the photovoltaic power generation is shown in the following formula:

$$f(P_p)=\frac{\Gamma(\rho+\lambda)}{P_{p,max}\Gamma(\rho)\Gamma(\lambda)}\times\left(\frac{P_p}{P_{p,max}}\right)^{\rho-1}\left(1-\frac{P_p}{P_{p,max}}\right)^{\lambda-1} \tag{10}$$

$P_{p,max}$ is the maximum output power of the photovoltaic power array, ρ and λ 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_{to} by assigning weightsω_u (u is the target number) to them. Calculate the value of the particles $x_i$in each iterative process N:

$$C_{to}(N)=\sum_{u-1}^{n}\omega_u(N)f_u[x_i(N)] \tag{11}$$

The formulas for the weights is:

$$\begin{cases} \omega_{c_1}(N)=|\cos(2\pi N/\xi)| \\ \omega_{c_2}(N)=1-\omega_{c_1}(N) \end{cases} \tag{12}$$

The formula for the update velocity of the particle is:

$$v_{i,N+1}=\xi(N)v_{i,N}+c_1r_1\left(P_i^k-X_i^k\right)+c_2r_2\left(P_g^k-X_i^k\right) \tag{13}$$

$v_{i,N}$ is iteration velocity of the particle,$c_1$andc_2 are learning factors, their value is generally between 0-2;$r_1$and$r_2$are random numbers between 0-1;P_i is the best location that particle i experienced,P_g is the best location in the experience of the swarm. The inertia constant ξ(N) linearly decreases with iteration between 0-1, which making the searched volume of the whole algorithm reduce with the iteration.

The formula of the particle position updating is:

$$P_{i,N+1}=P_{i,N}+V_{i,N+1} \quad (14)$$

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

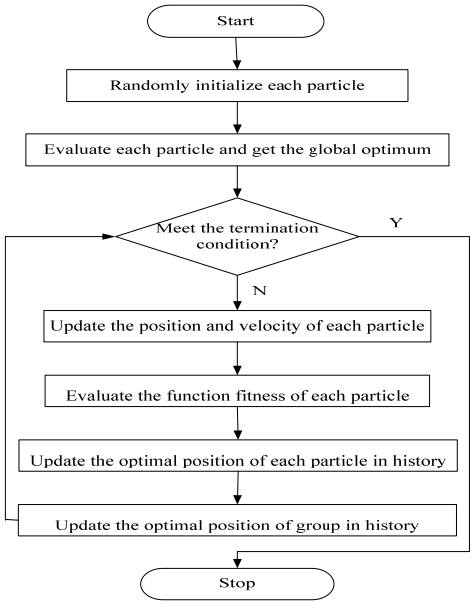

FIGURE I. DYNAMIC WEIGHTED PARTICLE SWARM ALGORITHM FLOWCHART

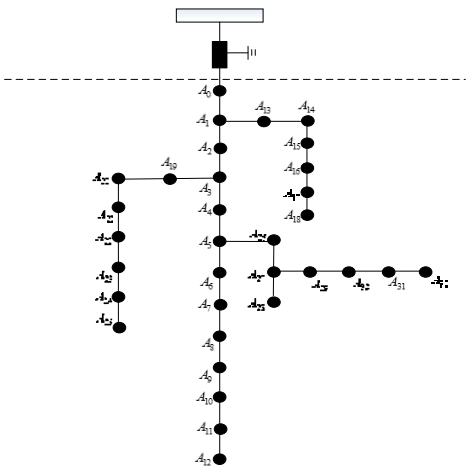

FIGURE II. IEEE33 NODE GRAPH

IV. CASE ANALYSIS

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 I. ANOTHER DATA NEEDED IN THE CASE

Parameter name	Value（unit）
Purchase price of the main grid power	0.5yuan/ KWh
The cost of the distributed wind power	0.1yuan/ KWh
The cost of the distributed solar power investment	27000yuan/ KW
The cost of the storage investment	1800yuan/ KW
The cost of the gas engine investment	15000yuan/ KW
The cost of the distributed solar power	1.15yuan/ KWh
The cost of the energy storage operation	1200（yuan/ KWh）/year
The cost of the distributed wind power investment	7200yuan/ KW
The cost of the gas engine power	0.4yuan/ KWh

TABLE II. PLANNING RESULTS

Number	Connecting node	Type	Parameter
1	A4	Solar power	300kW
2	A6	Energy storage	250kW·h
3	A8	Wind power	500kW
4	A9	Solar power	300kW
6	A12	Energy storage	250kW·h
8	A15	Solar power	250kW
11	A19	Solar power	250kW
12	A21	Wind power	300KW
13	A23	Solar power	300kW
14	A25	Energy storage	500kW·h
16	A28	Solar power	250kW
19	A32	Energy storage	500kW·h

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

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

	Cost of investment（ten thousand yuan）	The annual operation cost（ten thousand yuan）
Before planning	0	87
After planning	247	49

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.

ACKNOWLEDGMENT

This paper is supported by State Grid science and technology projects-Study on the Distributed Generation Development Applicability Strategy Analysis and Evaluation.

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