Optimal configuration of distributed power sources based on Fruit Fly optimization algorithm

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Abstract. Based on the fuzzy membership technology to optimize the configuration of distributed generation access to the distribution network, a multi-objective optimization model is established that comprehensively considers the investment benefits of DG, polluting gas emissions and voltage quality. The chaotic sequence of Tent mapping is quoted in the fruit fly optimization algorithm (FOA) to improve it, increase the diversity of the population, and reduce the possibility of the algorithm falling into a local optimum. The simulation results of the PG&E33 node system verify the effectiveness and rationality of the model and the improved algorithm.

1. Introduction

In recent years, with the emergence of environmental pollution, energy crisis and other problems, distributed power generation with its advantages of energy saving, pollution reduction, safety and reliability, diverse structures, peak shaving and valley filling can not only meet the needs of special occasions, but also save investment and enrich It has played an important role in the power market and promoted economic development. It has received extensive attention from domestic and foreign scholars and has achieved rapid development [1]. However, the output of renewable energy resources such as wind and light is uncertain. Access to the distribution network will bring about problems such as reduced power quality, two-way flow of power flow, increased fault current, and islanding benefits [2]. Therefore, it is necessary to make reasonable planning for the distributed power sources connected to the distribution network.

At present, domestic and foreign researchers have conducted research on the location and capacity of DG and have achieved certain results. Literature [3] uses a single objective function optimization method for the optimization of distributed power generation, which is difficult to meet the needs of the actual power grid. Literature [4] uses a heuristic immune genetic algorithm to solve the problem of generalized power access to the distribution network based on the goal of network loss, but does not consider the planning of multiple goals such as voltage indicators. Literature [5] solves a multi-objective programming model that comprehensively considers investment costs and network losses, and uses linear weights to convert multiple objectives into single objectives for processing, and does not take into account the impact of different evaluation indicators on the optimization results. Literature [6] established a multi-objective optimization model for investment costs, network loss costs and power outage losses, but ignored the impact of environmental factors on distributed power planning. Literature [7] uses an improved genetic algorithm to solve the installation location and capacity of distributed
power in the distribution network, but the parameter selection is too complicated, the convergence speed is slow, and it is easy to fall into the local optimum, or even fail to converge.

In response to the above problems, this paper proposes a multi-objective optimization problem for distributed power generation in distribution network considering the investment benefits of distribution network DG, polluting gas emissions and voltage stability. Fuzzy membership processing technology is used to establish multi-objective fuzzy distribution network planning model. The improved algorithm is used to simulate the proposed model, and the reliability and practicability of the proposed model and algorithm are proved through the analysis of numerical examples.

2. Multi-objective fuzzy programming mathematical model with DG

2.1. Objective function

1) DG investment benefits

The annual income obtained by unit DG investment is [8]:

\[ f_1 = C_{PS} = \frac{C_{TPF}}{C_{INF}} \]  
(1)

In the formula, CTPF stands for the annual income after DG is connected to the grid, including the income from selling electricity and national policy subsidies; CINF stand for the investment which DG is converted to the annual investment cost, including land occupation cost, installation cost and operation and maintenance cost.

\[ C_{TPF} = 8760 \sum_{i=1}^{M} (C_{gpi} + C_{api}) S_{i}^{\text{rated}} \lambda_{efi} \]  
(2)

\[ C_{INV} = \sum_{i=1}^{M} \alpha_{dgi} S_{i}^{\text{rated}} C_{i}^{\text{fixed}} + 8760 \sum_{i=1}^{M} C_{i}^{op} S_{i}^{\text{rated}} \lambda_{efi} \]  
(3)

In the formula, \( C_{gpi} \) and \( C_{api} \) are the policy subsidized electricity price and feed-in tariff of the i-th type of DG, respectively; M is the number of DG types; \( S_{i}^{\text{rated}} \), \( C_{i}^{\text{fixed}} \) and \( \alpha_{dgi} \) are the conversion factor, annual unit investment cost and rated installed capacity of the i-th type DG's annual investment cost; \( \lambda_{efi} \) is the i-th type DG's rated capacity coefficient; \( C_{i}^{op} \) is the i-th type Fuel cost and operation and maintenance cost of type DG unit output.

2) Pollutant gas emissions

Distributed power sources emit a large amount of COx, NOx, SO2 and other pollutant gases into the air during the power generation process. There is a certain functional relationship between the emissions of various pollutants and the active power output of the power supply. This article uses the following annual pollutant gas emission model [9]:

\[ f_2 = \sum_{i=1}^{N_p} \sum_{j=1}^{N_{DG}} \sum_{k=1}^{N_k} 8760 P_{DG}(ij) \alpha_k ER_{jk} \omega_k \]  
(4)

In the formula, NP - distributed power installation node collection; Nq-the number of polluted gas types; \( P_{DG}(ij) \)-the active power output by the j-type distributed power source at node i; \( \alpha_k \), \( \omega_k-k \) Class-pollution gas emission coefficient ratio and weight coefficient; K-type pollutant gas emission rate of \( ER_{jk} - j \) distributed power supply.

3) Voltage stability index

Voltage quality is an important evaluation index for the operational reliability of the distribution network, and it plays an important role in the reasonable and optimal configuration of distributed power sources in the distribution network. This article uses the first type of voltage stability index of the distribution network Expected value [10]:

\[ f_3 = \max\{L_1, L_2, \ldots, L_b\} \]  
(5)

\[ L_{ij} = \left[ 4(P_j X_{ij} - Q_j R_{ij})^2 + 4U_i^2 (P_j X_{ij} + Q_j R_{ij}) \right]/U_i^4 \]  
(6)
In the formula, \( \{L_1, L_2, \cdots L_b\} \) - the set of the first type voltage stability index of all branches in the distribution network; \( L_{ij} \) is the annual expected value of the first type voltage stability index of the branch \( ij \), its value. The larger the value, the worse the system voltage stability; \( P_j \) and \( Q_j \) are the active load and reactive load of node \( j \) respectively; \( X_{ij} \) and \( Q_{ij} \) are the reactance and resistance of branch \( ij \) respectively; \( P_j \) is the voltage of node \( i \) Amplitude.

2.2. Fuzzy membership

Considering that the magnitude of each sub-objective function value is quite different, in order to avoid over-optimizing an evaluation index, fuzzy technology is used to establish the membership function of each evaluation index:

\[
\mu_i = \begin{cases} 
1, & f_i \leq f_{ibest} \\
\frac{f_{max}-f_i}{f_{max}-f_{ibest}}, & f_{ibest} < f_i < f_{max} \\
0, & f_i \geq f_{ibest}
\end{cases}
\]  \( (7) \)

In the formula, \( i = 1, 2, 3 \); \( \mu_i \) - the membership degree of the \( i \)-th objective function value, the closer the membership degree is to 1, the better the evaluation index is; \( f_i \), \( f_{max} \) - the \( i \)-th objective function value and maximum value; \( f_{ibest} \) - the optimal value when optimizing the \( i \)-th objective function separately.

Use the membership value of each evaluation index to establish a comprehensive satisfaction function:

\[ F = \beta_1 \mu_1 + \beta_2 \mu_2 + \beta_3 \mu_3 \]  \( (8) \)

In the formula, \( \beta_1, \beta_2, \beta_3 \) - are the weight coefficients of the membership degree of evaluation indicators constraints

2.3. Constraints

1) Equality constraints:

\[
\begin{align*}
P_i - P_{DGi} &= U_i \sum_{j \in j} U_j \left( G_{ij} \cos \theta_{ij} + B_{ij} \sin \theta_{ij} \right) \\
Q_i - Q_{DGi} &= U_i \sum_{j \in j} U_j \left( G_{ij} \sin \theta_{ij} + B_{ij} \cos \theta_{ij} \right)
\end{align*}
\]  \( (9) \)

In the formula, \( P_{DGi} \) and \( Q_{DGi} \) are the active power and reactive power injected into node \( i \) by the distributed power source respectively; \( j \) means that nodes \( i \) and \( j \) are connected; \( G_{ij} \) and \( B_{ij} \) are respectively the conductance and susctance of branch \( ij \); \( \theta_{ij} \) is the voltage phase angle difference between node \( i \) and \( j \).

2) Inequality constraints:

\[
\begin{align*}
U_i^{min} &\leq U_i \leq U_i^{max} \\
G_{DG, i} &\leq G_{DG, max} \\
I_{ij} &\leq I_{ij, max}
\end{align*}
\]  \( (10) \)

In the formula, \( U_i^{min} \) and \( U_i^{max} \) are respectively the upper and lower limits of the DG access capacity at node \( i \); \( G_{DG, max} \) are the nodes respectively the access capacity and the upper limit of the access capacity of the DG at \( i \); \( I_{ij} \) and \( I_{ij, max} \) are respectively the maximum value of the current of the branch \( ij \) and the allowable current.

3. DG optimization configuration method

3.1. Basic fruit fly optimization algorithm

Fruit fly optimization algorithm [11] proposes a novel bionic intelligence algorithm by imitating the foraging behavior of fruit flies. Drosophila has a sensitive sense of smell and vision. In the process of
foraging, it first collects the smell of food floating in the air through its sense of smell, then flies to the area, and then visually finds the food and the location of the gathering of partners to determine the final food position.

The implementation steps of the fruit fly optimization algorithm can be summarized as:

1. Set the population size $M_{\text{pop}}$ and the maximum number of iterations $n_{\text{max}}$, and randomly initialize the population positions $X_{\text{axis}}$ and $Y_{\text{axis}}$ within the feasible range.

2. Calculate the random direction and distance of individual fruit fly search

   \[
   \begin{align*}
   X_i &= X_{\text{axis}} + D_{\text{randvalue}} \\
   Y_i &= Y_{\text{axis}} + D_{\text{randvalue}}
   \end{align*}
   \]  

   In the formula, $X_i$ and $Y_i$ are the position of fruit fly $i$; $D_{\text{randvalue}}$ is the random search distance.

3. Since the food location is the quantity to be determined, first estimate the distance $D_{\text{list},i}$ between the individual fruit fly and the origin, and then calculate the individual odor concentration judgment value $c_i$.

   \[
   \begin{align*}
   D_{\text{list},i} &= \sqrt{X_i^2 + Y_i^2} \\
   c_i &= 1/D_{\text{list},i}
   \end{align*}
   \]  

4. Each individual odor concentration judgment value is substituted into the odor concentration function (or objective function), and the current individual odor concentration value is calculated.

   \[c_{\text{smell},i} = f(c_i)\]

5. Sort the individual odor concentration values of Drosophila to find the individual with the best odor concentration (suitable for solving the minimum value problem).

   \[
   \left[ c_{\text{smell},\text{best}}, c_{\text{index},\text{best}} \right] = \min(c_{\text{smell},i})
   \]  

   In the formula, $c_{\text{smell},\text{best}}$ is the contemporary best taste concentration value; $c_{\text{index},\text{best}}$ is the contemporary best individual position index.

6. Record and save the optimal odor concentration value and group location.

   \[
   \begin{align*}
   c_{\text{smell},\text{history}} &= c_{\text{smell,best}} \\
   X_{\text{axis}} &= X(c_{\text{index},\text{best}}) \\
   Y_{\text{axis}} &= Y(c_{\text{index},\text{best}})
   \end{align*}
   \]  

   In the formula, $c_{\text{smell},\text{history}}$ is the best taste concentration value in history.

7. Enter iterative optimization, repeat steps (1)-(5), and judge whether the current iteration number is less than the maximum iteration number and whether the best odor concentration value of each iteration is better than the last best taste concentration value. If so, proceed to step 3.2.

3.2. Improved fruit fly optimization algorithm

The Fruit fly optimization algorithm randomly initializes the position of the group at the beginning of the optimization, which easily causes the algorithm to fall into a local optimum, and thus cannot obtain the optimal solution of the problem. Chaotic motion is a universal phenomenon in nonlinear systems. It has randomness and ergodicity, and can traverse all states in a certain range according to its own laws without repeating. Therefore, this paper combines the chaos operator with the FOA algorithm, and uses the chaotic sequence of the Tent map to assign values to the initial population to ensure the diversity of the initial population. The expression of Tent mapping is [12]:

\[
x_{t+1} = \begin{cases} 
2x_t, & 0 \leq x_t \leq 0.5 \\
2(1 - x_t), & 0.5 < x_t \leq 1
\end{cases}
\]

The Tent map is represented by the Bernoulli shift transformation as follows:
\[ x_{t+1} = (2x_t) \mod 1 \]  

(17)

The flow chart of solving the DG multi-objective programming model using the improved Fruit fly optimization algorithm is shown in Figure 1.

4. Calculation example analysis

4.1. Calculation example parameter setting

In the MATLAB software compilation environment, the IEEE33-node distribution network system is taken as a simulation example. The total active load of the system is 3715kW, the total reactive load is 2300kvar, and the reference voltage is 12.66kV. The network topology is shown in Figure 2. The detailed parameters of the system can be found in literature [13].

DG type wind turbines include wind power, photovoltaics, fuel cells, and micro gas turbines. To simplify calculations, the DG connected to the distribution network is treated as a negative PQ node. The candidate installation nodes for DG wind turbine (WT) and photovoltaic (photovoltaic, PV) are 10, 18, 21, 24, 32, Fuel cell (FC) and micro-turbine (micro-turbine).

![Figure 2. PG&E33 node distribution network topology diagram](image)

The candidate installation nodes for turbine (MT) are 3, 13, 17, and 30. Assuming that the power factor of the four types of DG is constant at 0.8, the total output of the DG does not exceed 25% of the...
system load, and the unit installed capacity is all 10kw. The algorithm parameters are set as follows: Drosophila population size is $M_{pop}=50$; the maximum number of iterations is $n_{max}=300$; the random initialization interval of fruit flies population position is $[0, 100]$; the random search direction and distance of fruit flies are $[-15, 15]$.

Table 1. DG investment operating parameters

| type | cost of investment (Ten thousand yuan/kW) | Operation and maintenance costs (Yuan/kW) | Conversion factor | Capacity factor | Feed-in tariff [Yuan/(kW⋅h)] | Government subsidies [Yuan/(kW⋅h)] |
|------|--------------------------------|--------------------------------|------------------|----------------|-------------------------------|----------------------------------|
| PV   | 4.56 | 0.012 | 0.0842 | 0.30 | 0.56 | 0.28 |
| WT   | 1.32 | 0.033 | 0.1005 | 0.36 | 0.56 | 0.28 |
| MT   | 0.95 | 0.198 | 0.1008 | 1.00 | 0.45 | 0.00 |
| FC   | 1.85 | 0.350 | 0.9750 | 1.00 | 0.45 | 0.00 |

Table 2. DG pollution gas emission indicators (kg⋅(kwh)-1)

| type | NOx | SO₂ | PM₁₀ | CO | CO₂ |
|------|-----|-----|------|----|-----|
| PV   | 0   | 0   | 0    | 0  | 0   |
| WT   | 0.092 | 0.001 | 0.020 | 0.245 | 0.73 |
| MT   | 0.005 | 0.011 | 0    | 0.003 | 0.48 |
| FC   | 0.005 | 0.011 | 0    | 0.003 | 0.48 |

4.2. Analysis of results

In order to verify the effectiveness of the improved fruit fly optimization algorithm (IFOA) in solving such problems, IFOA and FOA are respectively used for optimization calculations. The parameter settings of FOA are consistent with this article. Figure 3 shows the convergence curve of the fruit fly optimization algorithm before and after the improvement. It can be seen from the figure that both FOA and IFOA tend to converge, but the convergence speed is quite different.

Table 1 shows the optimal configuration of DG obtained by the Drosophila optimization algorithm before and after the improvement. From the data in the table, it can be seen that the environmental pollution indicators of IFOA have been improved to a certain extent, which is 27.9% lower than before the improvement, and the voltage indicator is the best, which is 41.0% lower than before the improvement, but its investment efficiency is poor. Combined with the analysis of Figure 3, it can be seen that although the three sub-objectives obtained by the IFOA optimization calculation are not all optimal, the comprehensive membership degree is significantly better than the FOA algorithm. This also
shows that the improvement of the voltage quality and environmental pollution indicators of the distribution network is at the cost of the investment benefits of DG. Therefore, when optimizing the configuration of DG, the proportion of each indicator should be integrated.

Table 3. DG optimization configuration of different optimization methods

| Optimization | DG configuration capacity(Install node) | Evaluation index |
|--------------|----------------------------------------|------------------|
|              | PPV/kW | PWT/kW | PMT/kW | PFC/kW | DG investment benefit | Pollutant gas emissions×105/kg | Voltage stability index /pu |
| Not optimized | -      | -      | -      | -      | -                    | -                           | 1.9050                      |
| IFOA         | 280    | 220    | 200    | 220    | 0.8465               | 6.9258                      | 1.1246                      |
| (18)         | (24)   | (30)   | (13)   |        |                      |                             |                             |
| FOA          | 300    | 200    | 180    | 240    | 0.9142               | 9.5960                      | 1.1824                      |
| (21)         | (32)   | (30)   | (17)   |        |                      |                             |                             |

Figure 4 shows the voltage curve obtained by the Drosophila optimization algorithm before and after the improvement.

It can be seen from the figure that the curves optimized by IFOA and FOA algorithms have been significantly improved, and the voltage curve optimized by IFOA is the most ideal. The lowest voltage of the system before optimization is 0.9040pu, and the average voltage is 0.9521pu. The lowest voltage obtained by IFOA optimization is 0.9425pu, the average voltage is 0.9812pu, the lowest voltage and the average voltage are increased by 0.0385pu and 0.0291pu respectively compared with before optimization. Based on the above analysis, it can be seen that reasonable and optimized configuration of DG can effectively improve the voltage quality and increase the reliability of power supply of the distribution network.

Figure 4. Voltage curves of different optimization methods

5. Conclusion
(1) Evaluate the feasibility of DG's optimal configuration from multiple perspectives such as economic benefits, environmental pollution and voltage quality, making the planned configuration plan more convincing. Modeling with fuzzy technology overcomes the over-optimization problem caused by the different magnitudes of each sub-objective, and provides convenience for decision-makers to more intuitively evaluate the pros and cons of each planning scheme.
(2) The chaotic sequence of Tent mapping is quoted into the fruit fly optimization algorithm to assign values to the initial population, which increases the diversity of the population and effectively reduces the possibility of the algorithm falling into the local optimum.

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