Differential evolution algorithm based on entropy weight method to determine the weight to optimize the configuration of wind, solar, and diesel microgrid

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Abstract. In order to enhance the stable operation of the multi-energy complementary microgrid for wind, solar, and diesel storage, reduce operating costs, and solve the problems of large randomness, low accuracy, and slow convergence of traditional microgrid optimization multi-objective decision-making, a differential evolution based on the entropy weight method to determine the weight is proposed. Firstly, we establish a microgrid integrated energy model from the perspectives of system operation stability, economy and environmental protection; combined with the Pareto optimal solution set, multi-objectives are weighted according to the entropy weight method, and the multi-objective optimization problem is transformed into single-objective optimization. The problem is to avoid artificial setting of weight factors; the calculation example shows that this method is more economical and reasonable in optimization results, and provides an economic, reliable and environmentally friendly microgrid configuration strategy for users to increase power capacity.

1. Introduction
In the past few decades, the scale of the power grid has continued to expand and has gradually developed into a super-large interconnected network system for centralized power generation and long-distance transmission. On the one hand, with the continuous increase of long-distance power transmission, the dependence of the receiving-end power grid on external power continues to increase, the stability and safety of the grid operation tend to decline, and it is difficult to meet the diverse power supply needs. On the other hand, concerns about the gradual depletion of global conventional energy sources and environmental pollution have become increasingly prominent. In view of this, the optimization of environmentally friendly, efficient and flexible microgrid has gradually become a hot issue[1].

At present, many domestic and foreign scholars have made a lot of research results on the optimization of microgrid operation, mainly from the two aspects of environmental protection and economy. Literature [2] sets up a model to optimize the microgrid configuration with the goal of optimal economics of the combined heat, cooling and power system, but lacks consideration of pollution control costs; Literature [3] proposes multi-energy complementarity between solar thermal
power stations and electric heating systems, analyze the impact of different electricity prices on the configuration of electric heating power, but did not carefully analyze the independent operation of the microgrid; starting from the real-time control operation requirements, the literature [4] used the improved particle swarm algorithm to obtain the main energy storage configuration, and completed the previous Energy management and dispatch, but did not consider the complementarity of wind and solar.

Based on the above problems, this paper proposes a genetic algorithm based on the entropy weight method to determine the weight, combined with the Pareto optimal solution set, determines the weight between multiple indicators through the entropy weight method to solve the weight randomness problem, and converts the multi-objective problem into a single objective problem. The problem is to solve the problem of computational efficiency, so as to solve the problems of slow microgrid optimization and random multi-objective decision weights. The total cost of wind and diesel storage and diesel microgrid, environmental protection, microgrid reliability, and wind and solar complementarity are established as the objective function and optimization model of constraints. Finally, we take the microgrid data of a certain park as an example to compare the simulation examples. The simulation results show the effectiveness and superiority of the method in this paper.

2. Microgrid optimization model

2.1. Objective function

Taking into account issues such as economy and environmental protection, the objective function of the microgrid configuration optimization model established in this paper is composed of initial installation cost, operating cost, maintenance cost, governance cost and power generation subsidy:

\[
\min C_{\text{sum}} = \{ C_{\text{CP}}^j(t), C_{\text{OM}}(t), C_w(t), C_{pu}(t), C_{NF}(t) \}
\]

\[ C_{\text{CP}}^j(t) \] is the initial installed cost of the jth distributed micro source, \( C_{\text{OM}}(t) \) is the operating cost for microgrid, \( C_w(t) \) is the maintain costs for distributed micro-sources, \( C_{pu}(t) \) is the pollution control costs, \( C_{NF}(t) \) is the energy generation subsidies.

\[
C_{\text{CP}}^j(t) = \frac{r(1+r)^{n_j}}{(1+r)^{n_j} - 1} \times \frac{C_{\text{ins}}^j}{8760k_j} \times P_j(t)
\]

\( C_{\text{OM}}(t) \) is the operating cost of distributed micro-sources, including diesel fuel cost and the interaction cost between microgrid and grid, is determined by the following formula [5]:

\[
C_{\text{OM}}(t) = C_{\text{BP}}(t) + C_{pu}(t)
\]

\[
C_{\text{BP}}(t) = f_p(a \times P_{\text{dic}} - f(t) + b \times P_{\text{dic}}(t))
\]

\[
C_{pu}(t) = \sum_i P_{\text{cc}}(t) \times \text{price\_sell}(t)
\]

\( C_w(t) \) is the maintenance cost for distributed micro-sources is determined by the following formula [4]:

\[
C_w(t) = C_w^j(t) \times P_j(t)
\]

\( C_{pu}(t) \) is the governance cost for the distributed micro-source environment is determined by the following formula [5]:

\[
C_{pu}(t) = \sum_p \alpha_p \beta_p P_{\text{dic}}(t)
\]

\( C_{NF}(t) \) is the subsidy cost for wind and solar power generation is determined by the following formula [5]:
2.2. Restrictions

The microgrid needs to meet the power balance constraints during operation:

\[ P_{\text{load}}(t) = P_{\text{wind}}(t) \times N_{\text{wind}} + P_{\text{pv}}(t) \times N_{\text{pv}} + P_{\text{sto}}(t) + P_{\text{die}}(t) + P_{\text{cc}}(t) \]  

(9)

Microgrid power supply is random. In order to ensure the stability of microgrid power supply, the interactive power between microgrid and grid is limited to a certain range:

\[ \text{rate1} \times P_{\text{load}}(t) \leq P_{\text{cc}}(t) \leq \text{rate2} \times P_{\text{load}}(t) \]  

(10)

The micro-source equipment needs to meet the upper and lower limits of output when operating:

\[ P_{\text{min}} \leq P_j(t) \leq P_{\text{max}} \]  

(11)

In order to ensure that the energy storage equipment can be scheduled to operate periodically, the energy storage is required to be within the upper and lower limits of the equipment capacity, and the daily capacity must be kept consistent:

\[
\begin{align*}
0 \leq P_{\text{no}}(t) &\leq \beta_{\text{no}} \times c_e, \\
0 \leq P_{\text{nu}}(t) &\leq \beta_{\text{nu}} \times c_e, \\
\text{SOC}_{\text{min}} \leq \frac{E(t)}{c_e} &\leq \text{SOC}_{\text{max}}, \\
E(0) & = E(T)
\end{align*}
\]  

(12)

(13)

2.3. Evaluation index

A reasonable multi-energy and mutual benefit micro-grid configuration should be reliable, and the load shortage rate [5] that joins the grid interaction is measured:

\[ R_{\text{LPSG}} = \frac{\sum_{j=1}^{T} \left| \text{rate}_j \times P_{\text{load}}(t) - P_{\text{cc}}(t) \right|}{\sum_{j=1}^{T} \text{rate}_j \times P_{\text{load}}(t)} \]  

(14)

In the microgrid, wind and solar hybrid power generation can solve the problems of independent wind power generation and photovoltaic power generation with large volatility, and frequent charging and discharging of batteries. Therefore, the characteristics of wind and solar hybridization need to be considered:

\[ \lambda = \frac{1}{P_{\text{LPS}}} \sqrt{\frac{1}{T} \sum_{t=1}^{T} \left( P_{\text{wind}}(t) + P_{\text{pv}}(t) + P_{\text{die}}(t) + P_{\text{cc}}(t) - P_{\text{load}}(t) \right)^2} \]  

(15)

3. Our method

From equation (1)-equation (8), it can be seen that the multi-energy mutual benefit optimization problem of microgrid is mainly a multi-objective optimization problem, and the difficulty lies in the contradiction and dependence among the sub-objective functions. As in equations (6) and (7), increasing the power generation of diesel generators can reduce the operating costs in equation (6), but increase the environmental governance costs in equation (7). In response to this problem, literature [4] uses a linear weighting method to transform multiple goals into single-objective optimization problems. The weight selection of this method is subjective and random, which affects the optimization results.

In this paper, the Pareto optimal solution set [6] generated in the multi-objective optimization process is used to calculate the objective function values corresponding to the elements in the Pareto optimal solution set, and the entropy method is used to determine the weights of different evaluation indicators [7], using this The weights are multi-objective weighting, which makes the problem
converted to a single-objective problem, and then the differential evolution algorithm is used to optimize the problem \cite{8}. In the process of multi-objective optimization that generates Pareto optimal solution set, the algorithm has fewer iterations and less calculation, which ensures optimization while taking into account efficiency. The algorithm flow chart of the commission is shown in Figure 1.

4. Case analysis
This paper uses the load data of a small park, taking the typical day in winter as an example, in the calculation example, the service life of each micro source is set as 15 years; the price of diesel oil is 6.27 yuan / L; the equipment capacity and the installed investment cost of each micro source \cite{8}, the maintenance cost parameters are shown in Table 1, the pollution index of diesel generator is shown in
Table 2, and the wind and solar curve and user power load curve of typical day in winter are shown in Figure 2.

| Table 1. The relevant cost coefficient of each micro source |
|------------------------------------------------------------|
| Micro source type    | Equipment capacity(kW) | Installed cost (thousand yuan/kW) | Operation and maintenance coefficient (yuan/kWh) |
|----------------------|------------------------|----------------------------------|-----------------------------------------------|
| Fans                 | 0.3                    | 23.75                            | 0.0296                                        |
| Photovoltaic         | 0.2                    | 36.50                            | 0.0096                                        |
| Battery              | 1.5                    | 1.94                             | 0.0090                                        |
| Diesel generators    | 5.0                    | 16.00                            | 0.0880                                        |

| Table 2. Pollutant related cost coefficient |
|---------------------------------------------|
| Contaminant type    | Pollution emission factor (g/kWh) | Pollution control cost coefficient (yuan/kg) |
|---------------------|-----------------------------------|---------------------------------------------|
| CO2                 | 329                               | 0.041                                        |
| NOx                 | 6.150                             | 13.420                                       |
| CO                  | 3.520                             | 1.940                                        |
| SO2                 | 0.335                             | 5.422                                        |

Figure 2. Typical winter wind and solar curve and consumer power load curve

Assuming that the unit wind turbine, unit photovoltaic, unit diesel generator and unit energy storage configuration are all rated values, the objective function is to obtain a set of optimal solutions \( (N_{\text{wind}}, N_{\text{pv}}, N_{\text{sto}}, N_{\text{die}}) \) make the objective function value the lowest.

\[
\min C_{\text{sum}} = f(N_{\text{wind}}, N_{\text{pv}}, N_{\text{sto}}, N_{\text{die}})
\]  

(16)

In order to verify the pros and cons of microgrid configuration under this algorithm, two other algorithms are selected as the comparison algorithm in this paper:

- **Algorithm 1**: Multi-objective differential evolution algorithm with Pareto dominance \([6]\)
- **Algorithm 2**: Multi-objective differential evolution algorithm with artificial weighting \([4]\)

In the three algorithms, the mutation scaling factor \( F \) is selected as 0.5, the recombination probability is selected as 0.9, the population size is 100, and the number of iterations is 500. Algorithms 1 and 2 are the above two algorithms, and algorithm 3 is determined by the entropy method proposed in this paper. The weighted differential evolution algorithm; the optimization results are shown in Table 3.
Table 3. Microgrid configuration optimization results

| Algorithm | Fans | Photovoltaic | Battery | Diesel generators | $\lambda$ | $R_{LPSP}$ |
|-----------|------|--------------|---------|------------------|---------|----------|
| 1         | 291  | 488          | 9       | 23               | 0.015   | 0.172    |
| 2         | 371  | 304          | 5       | 15               | 0.053   | 0.089    |
| 3 (ours)  | 319  | 302          | 3       | 18               | 0.007   | 0.087    |

Comparing Algorithm 1, Algorithm 2 and Algorithm 3, Algorithm 1 uses Pareto dominance differential evolution algorithm, which cannot balance the results of various indicators in the optimization process. The optimization results are easily affected by the initial value, and the algorithm shows instability. Algorithm 2 uses the artificially weighted differential evolution algorithm. Since the optimization objectives are all costs and the unit is unified, this paper uses a proportional method to weight. The artificial weight affects the optimization results, making its wind-solar complementary characteristics ($\lambda$) and load The power shortage rate ($R_{LPSP}$) is weaker than algorithm 3.

5. Conclusion

In this paper, a differential evolution algorithm based on entropy weight method is proposed to solve the problems of stability, cost and environmental protection of wind, solar, diesel and multi energy complementary microgrid, as well as the traditional optimization algorithm is easy to fall into local optimization and multi-objective optimization has randomness optimization problem, to a certain extent, solves the problem of randomness of multi-objective optimization algorithm; the example results show that the algorithm has certain advantages, and the optimization results make the example have better stability, wind solar complementarity, and lower total cost of microgrid, which has certain reference significance for the establishment of economic, environmental protection, stable and safe microgrid capacity allocation optimization.

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References

[1] ZIA M, ELBOUCHIKHI E, BENBOUZID, et al. Microgrids energy management systems: a critical review on methods, solutions, and prospects[J]. Applied Energy, 2018, 222: 1033-1055.
[2] KONG X Q, WANG R Z, HUANG X H. Energy optimization model for a CCHP system with available gas turbines[J]. Applied Thermal Engineering, 2005, 25(2): 377-391.
[3] Murty V V S N, Kumar A. Optimal DG integration and network reconfiguration in microgrid system with realistic time varying load model using hybrid optimization[J]. IET Smart Grid, 2019, 2(2): 192-202.
[4] HONG Y Y, LIAN R C. Optimal Sizing of Hybrid Wind/PV/Diesel Generation in a Stand-Alone Power System Using Markov-Based Genetic Algorithm[J]. IEEE Transactions on Power Delivery, 2012, 27 (2): 640-647.
[5] BELFKIRA R, HAJJI O, NICHTA C, et al. Optimal sizing of stand-alone hybrid wind/PV system with battery storage[C]/ 2007 European Conference on Power Electronics and Applications. Aalborg, Denmark: 2007 European Conference on Power Electronics and Applications, 2007: 1-10.
[6] E. Zitzler, L. Thiele. Multiobjective evolutionary algorithms: a comparative case study and the strength Pareto approach[M]. IEEE Press, 1999.
[7] Das S, Suganthan P N. Differential evolution: A survey of the state-of-the-art[J]. IEEE transactions on evolutionary computation, 2010, 15(1): 4-31.
[8] Storn R. On the usage of differential evolution for function optimization[C]. Proceedings of North American Fuzzy Information Processing. IEEE, 1996: 519-523.