Differential evolution algorithm based on PCA to determine the objective function to optimize the configuration of microgrid

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Abstract. Recently, microgrids are increasingly used in our lives. The purpose of this paper is to solve the uncertainties of multi-objective decision-making and the instability of algorithms in the optimal configuration of traditional microgrids. This paper proposed a differential evolution algorithm based on PCA to determine the objective function. Firstly, a multi-objective optimization model of the microgrid was established on the basis of fully considering the economy, environmental protection and stability of the microgrid. Next, the first principal component of the multi-objective was extracted based on PCA combining innovatively the Pareto optimal solution set, and the multi-objective optimization problem was transformed into a single-objective optimization problem. Finally, the experimental simulation result shows that the algorithm proposed in this paper can comprehensively consider the economy, environmental protection and stability of the microgrid on the basis of ensuring the efficiency and stability of the algorithm to realize the optimized configuration of the microgrid.

Keywords: PCA; differential evolution algorithm; Pareto optimal solution set; microgrid

1. Introduction

With the continuous expansion of the scale of the power grid, while bringing convenience to people, some problems are caused. For example, the stability of the power grid is no longer sufficient for large-scale power supply. In addition, traditional power grids are difficult to absorb green energy. The optimized operation of the microgrid contributes to functions such as clean energy consumption and multi-energy complementation. Therefore, a stable, safe, and green microgrid optimized configuration has become a good way to solve these problems [1].

In recent years, many scholars have conducted researches on microgrids, but they are relatively one-sided, failing to take into account the efficiency, stability, environmental protection, and economy of microgrid operations. An optimal economic dispatch model was established which considered the combined cooling, heating and power microgrid of energy storage power stations [2]. However, the combined cooling, heating and power microgrid generates pollutant gas during its operation. Environmental protection was not considered. An optimized configuration of solar-storage micro-grid energy storage was proposed [3], which could reduce the power loss of the micro-grid system, but did not take into account the instability of wind and solar power generation. Clean energy was considered such as wind energy, solar energy, and small hydroelectric power generation equipment to improve
economy and environmental protection \cite{4}, but the traditional multi-objective optimization is random and unstable.

Therefore, this paper proposes a PCA-based differential evolution algorithm to determine the objective function method. Through the establishment of a multi-objective optimization operation model of the microgrid, and a simulation comparison with other algorithms, it is proved that the method studied in this paper is completely feasible.

2. Multi-objective Optimization Model of Microgrid

2.1. Objective function

This study comprehensively considers the economy and environmental protection of microgrid operation. A total objective function was established that minimizes the power generation cost and environmental cost of the optimal operation of the microgrid. The objective function is as follows \cite{5}:

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

(1)

In the equation: \(t\) is the time series. \(C_{CP}^j(t)\), \(C_{OM}(t)\), \(C_w(t)\) and \(C_{pu}(t)\) represent the initial installed cost of the \(j\)-th distributed micro-source, the operating cost of the microgrid including the cost of diesel fuel \(C_{BP}(t)\) and the interaction cost between the microgrid and the grid \(C_{pc}(t)\), the maintenance cost of micro-sources and the cost of pollution control. Their equations are as follows:

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

(2)

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

(3)

\[
C_{BP}(t) = f_{j}(aP_{\text{dis}} - j(t) + bP_{\text{dis}}(t))
\]  

(4)

\[
C_{pc}(t) = \sum_{i} P_{ac}(t) \text{price}_{\text{sell}}(t)
\]  

(5)

\[
C_w(t) = C_{w}^j(t)P_j(t)
\]  

(6)

\[
C_{pu}(t) = \left(\sum_{k} \alpha_k \beta_k\right)P_{\text{die}}(t)
\]  

(7)

2.2. Restrictions

In this paper, the constraints of microgrid configuration optimization mainly included power balance constraints, interaction stability constraints, equipment output constraints and energy storage capacity constraints \cite{5}. Their restriction equations are as follows:

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

(8)

\[
\text{rate}_1P_{\text{load}}(t) \leq P_{ac}(t) \leq \text{rate}_2P_{\text{load}}(t)
\]  

(9)

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

(10)

\[
\begin{cases}
0 \leq P_{\text{die}}(t) \leq \beta_{\text{dis}} c_v \\
0 \leq P_{\text{cha}}(t) \leq \beta_{\text{cha}} c_v
\end{cases}
\]  

(11)

\[
\begin{cases}
SOC_{\min} \leq E(t)\left(c_v\right)^{-1} \leq SOC_{\max} \\
E(0) = E(T)
\end{cases}
\]  

(12)

2.3. Evaluation index

The evaluation indicators of microgrid generally include reliability, wind and solar complementarity, environmental protection, etc. In this paper, the load shortage rate \(R_{LPSP}\) was used to evaluate the
reliability of the microgrid, and the fluctuation rate of battery charging and discharging $\lambda$ was used to evaluate the wind and solar complementarity of the microgrid. Both are used to assist in the analysis of microgrid configuration optimization results. Their equations are as follows:

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

$$\lambda = \frac{1}{P_{LV}} \left( \frac{1}{T} \sum_{i=1}^{T} \left[ P_{\text{wind}}(t) + P_{\text{pv}}(t) + P_{\text{dis}}(t) + P_{\text{cc}}(t) - P_{\text{load}}(t) \right]^2 \right)^{1/2}$$

3. Methodology

3.1. Differential evolution algorithm
Diffenential evolution algorithm is an evolutionary algorithm for solving optimization problems. It is a multi-objective optimization algorithm proposed on the basis of genetic algorithm [6]. The individual generated after the mutation operation of the differential evolution algorithm is different from the previous one, which can solve the problem of the traditional genetic algorithm that is easy to fall into the local optimum. This paper used the classic single-objective differential evolution algorithm [7]. The calculation equation of the variation vector is as follows:

$$v_{ij} = x_{p1,j} + F (x_{p2,j} - x_{p3,j})$$

In the equation: $x_{p1,j}$, $x_{p2,j}$, and $x_{p3,j}$ are three individuals randomly selected from the population in the t-th iteration and $p1 \neq p2 \neq p3 \neq i$, parameter $F$ is the variation scaling factor.

3.2. Pareto-optimal set
In multi-objective optimization, it is difficult to find an optimal solution, therefore in this article firstly the Pareto-optimal set of the multi-objective optimization problem was found. Pareto-optimal set embodies the dominant thought. The dominant thought is as follows.

Given a multi-objective optimization problem: $\min f(x), x_1, x_2 \in \Omega, \forall k, f_k(x_1) \leq f_k(x_2)$, then $x_1$ is dominant over $x_2$.

After obtaining a solution, if there is no solution dominating it in the Pareto-optimal set, this solution is added to the Pareto-optimal set.

3.3. Determine the objective function by PCA
After obtaining the Pareto-optimal set, the value of each objective function of each solution is used as the sample data for PCA to determine the objective function. Then extract the first principal component through PCA, and transform the multi-objective optimization problem into a single-objective optimization problem [8].

Suppose the number of Pareto-optimal set is n; according to the data model of microgrid configuration proposed in this paper, the four cost values of $C_{CP}, C_{OM}, C_w, C_{Pu}$ for each solution can be calculated. The algorithm flow is as follows:

1) There were n samples and 4 indicators, then $x_{ij}$ was the value of the j-th indicator of the i-th sample: $x_{i1} = C_{CP}^i, x_{i2} = C_{OM}^i, x_{i3} = C_w^i, x_{i4} = C_{Pu}^i$.

2) All samples were centralized. The equations are as follows:

$$x_{ij}^m = \frac{1}{n} \sum_{n=1}^{n} x_{ij}$$

$$x_{ij}' = x_{ij} - x_{ij}^m$$
3) The covariance matrix $XX^T$ of the sample was calculated.
4) Eigenvalue decomposition of matrix $XX^T$.
5) Feature vector $w = \begin{bmatrix} w_1, w_2, w_3, w_4 \end{bmatrix}$ was taken out corresponding to the first principal component.
6) The objective function of the single objective was obtained. The equation is as follows:

$$C = w_1(C_{cp} - x_1^m) + w_2(C_{om} - x_2^m) + w_3(C_w - x_3^m) + w_4(C_{pu} - x_4^m) + \sum_{j=1}^{4} x_j^m$$

(18)

3.4. Algorithm flowchart
Firstly, the Pareto-optimal set was obtained from the multi-objective optimization. The algorithm flowchart as shown in figure 1. Then the objective function was determined by PCA, and finally the optimal solution was obtained by differential evolution algorithm. The flowchart is shown in figure 2.

**Figure 1.** Pareto-optimal set algorithm flowchart.

**Figure 2.** PCA-based differential evolution algorithm flowchart.

4. Experiment and Result

4.1. Experimental data and parameter settings
This article used data from a microgrid in a park. The capacity, installed cost and operation and maintenance cost of each device are shown in Table 1.

Table 1. Related parameters of each device

| 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                                           |

The correlation coefficient of pollution control is shown in Table 2.

Table 2. The correlation coefficient of pollution control

| 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                                       |

The typical winter wind and solar curve selected in this study is shown as figure 3 and consumer electric load curve selected in this study is shown in figure 4.

Figure 3. The typical winter wind and solar curve.

Figure 4. Consumer electric load curve.

The purpose of the experiment is to find the number of devices with the smallest value of the objective function.

This study verified the feasibility of this experiment by comparing it with the other two algorithms. Algorithm 1 is a multi-objective differential evolution algorithm with Pareto dominance. Algorithm 2 is a multi-objective differential evolution algorithm using artificial weighting. Algorithm 3 is the differential evolution algorithm based on PCA to determine the objective function proposed in this paper. The constraints are used to determine the parameter encoding range and the encoding method is ‘RI’. The parameters of the differential evolution algorithm in the three algorithms are guaranteed to be the same. The value of parameter F is 0.5, crossover probability is set to 0.9, population size is 100, the number of iterations is 500.

4.2. Result

The results obtained after 500 iterations are shown in Table 3. Simulation experiment results showed that algorithm 1 was unable to balance the relationship between the various objective functions well, resulting in a very high number of wind and solar generators in the results obtained. Although the environmental protection was very good, the cost was too high and the reliability was very weak. Algorithm 2 used expert analysis to manually assign weights to each objective function, thereby
transforming the multi-objective optimization problem into a single-objective optimization problem, which had a relatively large subjective impact. The algorithm 3 used in this paper used PCA to determine the objective function, so it was more objective. And the simulation result of algorithm 3 is also better than algorithm 2. Therefore, the algorithm proposed in this paper is completely feasible.

| Algorithm | Wind Turbines | Photovoltaic generator | Energy storage equipment | Diesel generators | $\lambda$ | $R_{LPSP}$ |
|-----------|---------------|------------------------|--------------------------|------------------|--------|----------|
| 1         | 376           | 374                    | 12                       | 11               | 0.0432 | 0.1019   |
| 2         | 335           | 319                    | 4                        | 16               | 0.0706 | 0.1032   |
| 3         | 289           | 340                    | 4                        | 18               | 0.0264 | 0.0956   |

5. Conclusion
This paper proposes a differential evolution algorithm based on PCA to determine the objective function to optimize the configuration of the microgrid, and transform the multi-objective optimization problem into a single-objective optimization problem. By comparing with the experimental simulation results of the other two algorithms, it can be concluded that the algorithm proposed in this paper is completely feasible. On the basis of ensuring the efficiency and stability of the algorithm, the economy, environmental protection, and stability of the microgrid can be comprehensively considered to realize the optimized configuration of the microgrid.

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