Optimal configuration of distributed generation based on sparrow search algorithm

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Abstract: Aiming at the problem of how to effectively configure distributed generation (DG) in the distribution network, an optimization configuration model of DG with the lowest total system operating cost as the objective function, system power flow, node voltage, branch current and distributed power capacity as constraints is established. In this paper, a new technique based on the sparrow search algorithm (SSA), is used to solve the optimal configuration model of DG for the first time. Finally, the IEEE 33 distribution system is used as an example to perform simulation, which verifies the rationality of the optimal configuration model and the effectiveness and superiority of the SSA, which can more efficiently solve the problem about optimal configuration of DG.

1. Introduction

In recent years, with the development of economy and society, the demand for electricity has been increasing. Distributed generation\cite{1}can increase system capacity to meet load demand, while reducing power losses, improving voltage profile. The Connection of DG could change the power flow of the distribution network, causing changes in power losses and voltage profile. The degree of changes is affected by the location and capacity of DG. Therefore, it is of practical significance to study how to scientifically configure the location and capacity of DG in the distribution network.

At present, scholars have conducted research on the optimal configuration of DG from different perspectives, mainly focusing on the establishment of optimal configuration models and solution algorithms. Chen\cite{2}took the minimum voltage deviation as the optimization goal, and established the optimal configuration model of photovoltaic generation multi-point access to the distribution network from the perspective of voltage management. Wang\cite{3}introduced a voltage weighting factor on the basis of the voltage deviation to reflect the user' requirements of voltage quality,which enhanced the practicability of the optimal model. Yang\cite{4}took the lowest power losses as the optimization goal, established the optimal configuration model of DG.

Recently, many intelligent algorithms were proposed by researchers in the power systems field to address the planning of DG, such as particle swarm algorithm\cite{5}and harmony search algorithm\cite{6}. Mahmoud\cite{7}applied a newly proposed Manta Ray Foraging Optimization Algorithm to the optimal configuration of DG. The number of iterations of the algorithm was greatly shortened and the efficiency of model solving was improved. Hassan\cite{8}utilized the global search superiority of the crow algorithm and the local search superiority of the particle swarm algorithm to solve the configuration model of DG based on the lowest investment and power losses. Although the hybrid intelligent algorithm has improved the accuracy and efficiency of the solution, the algorithm principles and parameter setting will...
be more complicated.

In this paper, a new Intelligent algorithm Sparrow Search Algorithm (SSA) has been applied for the first time to determine the best location and size of DG to minimize the total operating cost of distribution network. Simulation of SSA based the optimal configuration model of DG is conducted on IEEE 33 distribution network. The results show that the SSA is highly performing for the minimization of the total operating cost, power losses and the improvement of the voltage profile.

2. Optimal configuration model of distributed generation

2.1. Objective function

In this paper, the main objective function (C) to be minimized is the total annual operating cost of distribution system, which includes the investment and maintenance cost of DG, the power losses cost and the annual electricity purchase cost.

\[
\min C = C_{in} + C_{loss} + C_b
\]  

2.1.1. The cost of investment and maintenance of DG.

\[
C_{in} = \sum_{i=1}^{n} P_{DG} \left( \frac{r(1+r)^t}{(1+r)^t-1} c_i + c_m T_{max} \right)
\]  

Where \(n\) is the total number of bus in the distribution system, \(P_{DG}\) is the active power of DG connected to the bus \(i\), \(r\) is the investment discount rate, \(t\) is the payback period of the DG investment, \(c_i\) is the installation investment of per unit capacity of the DG, and \(c_m\) is the maintenance cost per unit capacity of the DG, \(T_{max}\) is the annual operating time of DG.

2.1.2. Power losses cost of distribution system.

\[
C_{loss} = c_{sell} P_{loss} T_{max}
\]  

Where \(c_{sell}\) is the electricity price, \(P_{loss}\) is the total power losses of distribution system, \(T_{max}\) is the annual load operating time of distribution system.

2.1.3. The annual electricity purchase cost.

\[
C_b = c_b \left( P_{load} T_{max} - \sum_{i=1}^{n} P_{DG} T_{max} \right)
\]  

Where \(c_b\) is the purchase price of electricity, \(P_{load}\) is the total load of distribution system.

2.2. Operational Constraints

The optimization model is subjected to some constraints. In this work, we have four constraints introduced as follows:

2.2.1. Power flow constraint

\[
\begin{align*}
P_i - P_{DG_i} &= U_i \cdot \sum_j U_j (G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}) \\
Q_i - Q_{DG_i} &= U_i \cdot \sum_j U_j (G_{ij} \sin \delta_{ij} - B_{ij} \cos \delta_{ij})
\end{align*}
\]  

Where, \(P_i\) and \(Q_i\) is the active and reactive power of the load at bus \(i\), \(P_{DG_i}\) and \(Q_{DG_i}\) is the active and reactive power of the DG at bus \(i\).
reactive power of DG connected to bus $i$, $U_i$ is the voltage of node $i$, and $U_j$ is the voltage of node $j$, $G_{ij}$ is the conductance between bus $i$ and $j$, $B_{ij}$ is the susceptance between bus $i$ and $j$, and $\delta_{ij}$ is the phase angle difference between bus $i$ and $j$.

2.2.2. Voltage permitted range constraint

$$\min U \leq U_{ik} \leq \max U$$  \hspace{1cm} (6)

Where, $\min U$ and $\max U$ is the minimum and maximum voltage magnitude of all buses.

2.2.3. Branch current constraint

$$0 \leq I_{ij} \leq I_{ij,\text{max}}$$  \hspace{1cm} (7)

Where, $I_{ij,\text{max}}$ is the maximum current value allowed by the system branch.

2.2.4. DG installation capacity constraint

$$\sum_{i=1}^{n} P_{DG} \leq \mu P_{\text{load}}$$  \hspace{1cm} (8)

Where, $\mu$ is the installation coefficient of DG.

3. Basic principles and steps of sparrow search algorithm

3.1. Basic principles of Sparrow Search Algorithm (SSA)

The sparrow search algorithm[9] is a new intelligent algorithm that simulates the process of sparrow searching for food. It updates the positions of the producers and the scroungers constantly to find the optimal solution by comparing the fitness value.

In SSA, the producers are responsible for searching food and guiding the movement of the entire population. The location of the producer is updated as below[9]:

$$X_{i,j}^{t+1} = \begin{cases} X_{i,j}^t \cdot \exp(- \frac{i}{\alpha \cdot \text{iter}_{\text{max}}}), & \text{if } R_2 < \text{ST} \\ X_{i,j}^t + Q \cdot L, & \text{if } R_2 \geq \text{ST} \end{cases}$$  \hspace{1cm} (9)

Where $t$ represents the current iteration, $j=1, 2, 3 \ldots d$. $\text{iter}_{\text{max}}$ is the maximum iteration number. $X_{i,j}^t$ indicates the value of the $j$th dimension of the $i$th sparrow at iteration $t$. $R_2 (R_2 \in [0,1])$ and $\text{ST} (\text{ST} \in [0.5,1])$ represent the warning value and the safety threshold respectively[9].

The scroungers immediately leave their current position to compete for food when they find that the producer has found good food. The position update formula of the scrounger is as follows[9]:

$$X_{i,j}^{t+1} = \begin{cases} Q \cdot \exp(- \frac{X_{i,j}^t - X_p^t}{i^2}), & \text{if } i > n / 2 \\ X_p^t + \left| X_{i,j}^t - X_p^t \right| \cdot A^+, & \text{otherwise} \end{cases}$$  \hspace{1cm} (10)

where $X_p$ is the optimal position occupied by the producer. $X_{\text{worst}}$ denotes the current global worst location [9].

Assuming that the dangerous sparrows account for 10%~20% of the total population, and their position expressions are as follows[9]:

[... remaining text...]
\[ X^t_{ij} = \begin{cases} X^t_{\text{best}} + \beta \left| X^t_{ij} - X^t_{\text{best}} \right| & \text{if } f_i > f_g \\ X^t_{ij} + \kappa \frac{X^t_{ij} - X^t_{\text{worst}}}{(f_i - f_g) + \epsilon} & \text{if } f_i = f_g \end{cases} \] (11)

Where \( X_{\text{best}} \) is the current global optimal location. \( f_i \) is the fitness value of the present sparrow. \( f_g \) and \( f_w \) are the current global best and worst fitness values, respectively.[9]

3.2. SSA solution process
The flow of DG optimization configuration based on SSA is shown below:

Step1: Input the original data of distribution system, including bus number, load, line impedance, voltage level, reference power, and set SSA sparrow population number, producer ratio, maximum number of iterations and safety threshold.

Step2: Initialize the position of each sparrow, representing the DG capacity of each node.

Step3: Substitute the initial sparrow position into the distribution network, then, perform power flow calculation. Obtain the fitness value of each sparrow according to the power flow calculation result, and determine the optimal position of the producer and the global worst position.

Step4: Update the positions of producers and scroungers.

Step5: Substitute the updated sparrow position into the distribution network to recalculate the power flow, and calculate the fitness value of each sparrow again, then update the best position of the producer and the global worst position.

Step6: Determine whether the maximum number of iterations is reached, if yes, output the optimal position as the target solution; if not, then return step 4 to continue running.

4. Example analysis

4.1. Basic data and parameter settings
The IEEE 33 distribution system is composed of 33 buses, 32 distribution lines branches with an nominal voltage of 12.66 kV as shown in Figure 1, the all data of the system are in[10]; The installation investment cost per unit capacity of distributed power is 10,300 yuan/kW, the operation and maintenance cost is 0.045 yuan/kWh, the payback period is 20 years, and the discount rate \( r \) is 0.1. The details are shown in literature[11]. The upper and lower limits of the system allowable voltage are (0.90~1.05) \( U \), and the installation coefficient of DG is 30%.

![Figure 1 The structure of IEEE33 distribution system](image)

The total number of sparrows in SSA is 100, the number of producers and sparrows aware of danger account for 20%, the safety threshold is 0.8, and the maximum number of iterations is 300.

4.2. Analysis of results

4.2.1. The schemes of DG configuration by SSA and particle swarm optimization (PSO) algorithm
The PSO and SSA are used to solve the optimal configuration model of DG on the IEEE 33-bus system. The schemes of DG configuration are shown in Table 1. The total capacity of DG by PSO and SSA is 1110kW, which is within the tolerance range of the distribution network.
Table 1 The schemes of DG configuration

| Algorithm | Bus number | Capacity (kW) |
|-----------|------------|---------------|
| PSO       | 13         | 370           |
|           | 27         | 370           |
|           | 32         | 370           |
| SSA       | 14         | 290           |
|           | 17         | 100           |
|           | 18         | 90            |
|           | 32         | 630           |

4.2.2. Analysis of configuration results of SSA and PSO algorithms
The results of total annual operating cost, power losses and voltage deviation are shown in Table 2. The voltage profile of each bus and power losses of each branch of distribution system are shown in Figure 2 and Figure 3.

Table 2 Optimization results of SSA and PSO distribution system

| Parameter                  | Without DG | With PSO | With SSA |
|----------------------------|------------|----------|----------|
| The total operating cost (million) | 10.90     | 9.06     | 9.02     |
| power losses (kW)          | 202.64     | 77.20    | 69.80    |
| voltage deviation          | 11.70      | 3.54     | 2.68     |

Figure 2 Voltage distribution of distribution network

Figure 3 Power loss of each branch of the distribution network

Figure 2 indicates that the voltage drop on the line reduced after connected DGs. The scheme obtained by the PSO algorithm and SSA reduced the voltage deviation of the original distribution system by 69.77% and 77.10%, respectively. SSA improved the voltage level of the distribution network better.

From Figure 3 and Table 2, the optimization scheme of the SSA algorithm can reduce the system power losses better, since the power losses of the system were reduced by 61.90% and 66.55% with DG connected by PSO and SSA, respectively.

4.2.3. Comparison of SSA and PSO performance
The convergence of PSO and SSA in the optimization process is shown in Figure 4. The total annual operating cost of the system is 9.06million and 9.02million with optimal configuration scheme obtained by the PSO and SSA respectively. Compared with PSO, SSA can converge to the optimal value faster.
5. Conclusion
This paper establishes an optimization configuration model of DG that considers investment and maintenance of DG, power losses and power purchase costs. A new Intelligent algorithm-SSA technology is used to solve the model for the first time. Through the example analysis, the SSA algorithm parameter setting is simple, and the optimal value can be found with lower iterations, and it has good adaptability to the optimization configuration problem of DG. The scheme of DG configuration obtained by the SSA algorithm can reduce system power losses and improve voltage profile more effectively with low operating costs. And the SSA algorithm can be extend to other power system optimization problems because of its superiority.

References
[1] Shen X, Cao M. (2015) Research on the impact of distributed power grid connection on distribution network. Journal of Electrotechnical Technology, 30(S1): 346-351.
[2] Chen C, Tan Y, Wang W, et al. (2019) Location selection method for distributed photovoltaic multi-point access to low-voltage distribution network. Automation and Instrumentation, (11): 198-201.
[3] Wang S, Deng X.F, Xie Q.Y, et al. (2020) Optimal configuration of distributed power distribution network considering voltage weight. Electrical Measurement and Instrumentation, 57(08): 38-44.
[4] Yang X.L, Yao J.F, Yao G.Q, et al. (2018) Optimal configuration of distributed power sources in distribution networks based on chaotic particle swarm optimization. Electrotechnical Technology, (22): 91-93+95.
[5] Ahmed A H, Hasan S. (2018) Optimal allocation of distributed generation units for converting conventional radial distribution system to loop using particle swarm optimization. Energy Procedia,153:118-124.
[6] Talaei K, Rahati A, Idoumghar L. (2020) A novel harmony search algorithm and its application to data clustering. Applied Soft Computing, 92:106273.
[7] Hemeida M, Ibrahim A, Al-Attar M, et al. (2020) Optimal allocation of distributed generators DG based Manta Ray Foraging Optimization algorithm (MRFO). Ain Shams Engineering Journal.
[8] Farh H M H, Al-Shaalan A M, Eltamaly A M, et al. (2020) A novel severity performance index for optimal allocation and sizing of photovoltaic distributed generations. Energy Reports, 6: 2180-2190.
[9] Xue J, Shen B. (2020) A novel swarm intelligence optimization approach: sparrow search algorithm. Systems Science & Control Engineering, 8:22-34.
[10] Zhang X.Z. 2019. Application of intelligent particle swarm algorithm in distributed energy planning. China University of Mining and Technology.
[11] Liang Y. 2016. Research on distributed generation planning considering demand-side response. North China Electric Power University (Beijing).