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Site Selection and Capacity Determination of Multi-Types of DG in Distribution Network Planning

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Abstract: Site Selection and Capacity Determination of Multi-Types of Distributed Generation (DG) have a significant impact on the distribution network planning. Therefore, it is necessary to scientifically analyze the impact of the distributed generators on the distribution network. Considering the minimum sum of investment cost, network loss cost and power outage loss cost, the grid planning model is established by considering network constraints such as voltage constraint, line capacity constraint, power flow constraint and reverse power flow constraint.. The genetic algorithm is used to solve the optimal grid planning scheme for the distribution network with microgrid. Finally, the IEEE 14-bus Distribution Network is analyzed for the DG location and volume planning in Distribution Network to verify the validity and feasibility of the planning model.

1. Introduction

With the development of distributed generation (DG) technology, it has become a new and effective method to solve environmental pollution and energy problems. The distribution network structure, power flow distribution, short-circuit current and reliability of relay protection will be affected after the DG connected to the distribution network. These problems are directly related to the location and capacity of distributed generation to the distribution network. Therefore, the reasonable choice of the location and capacity of DGS is a very practical research direction.

Distributed power generation location and capacity planning is a multi-objective optimization problem. Different location and capacity planning schemes can be obtained based on different objectives or solutions. Documents [1-2] suggest that the distribution network model with distributed generation can be considered and planned from three perspectives: (1) investment perspective, with the minimum investment cost of the company as the optimization objective; (2) loss perspective, with the minimum distribution network loss as the optimization objective; (3) environmental protection perspective, with the goal of maximizing environmental benefits. Documents [3-5] adopt the objective of minimizing the annual cost of distribution network, establish relevant models and give the expansion planning of distribution network. Document [6-8] establishes a multi-objective model considering three objective functions, namely, the minimum investment cost of distributed generation, the minimum network loss and the static voltage stability. The constraints of the model include node voltage, maximum transmission power of line, the limitation of output of distributed generation, and the shortness of the model. The constraint of the first stage spinning reserve is constrained by the current and the constraints of the constraints are taken into account.

The maximum capacity of the distributed power supply to be built is determined according to the total load. In the case where the number of distributed power sources, location and single power



supply capacity, and the type of DG are uncertain, Establish an economic function with minimum network loss and minimum distributed power investment and operation and maintenance cost as the objective function of location and volume. The genetic algorithm is introduced into the location and volume of distributed power supply, and the IEEE14 node system is optimized to verify the rationality of the proposed site-fixed volume model.

2. the mathematical model of Distributed Generation

This paper includes four types of DG: MT (micro-turbine generator, MT), WG (wind turbine generator, WG), PV (photovoltaic, PV), BS (battery storage, BS). Based on the time-series characteristics of load and DG, a multi-type DG distribution planning model is established considering the environmental cost. This kind of DG has strong representativeness: MT capacity is rated and output is controllable; WG and PV represent a kind of DG whose capacity changes with time; BS capacity and power are rated, and can be supplied as long as there is electricity stored. This paper assumes that BS can operate continuously for 12 h at a certain power level, and 6 h full of electricity. According to the relevant calculation, the capacity of MT, WG, PV and BS was determined to be 45%, 20%, 10% and 25% respectively.

2.1. Power flow calculation for distribution network containing DG

The model of distributed generation connected to distribution network can be simplified as either PV node or PQ node. Because the location of distributed generation is generally close to the load center, this paper assumes that the location of distributed generation is on the load node. The introduction of distributed generation has changed the direction of power flow, but the traditional power flow method can still be used to solve the power flow. This paper assumes that the distributed generation is simplified to a negative load point. Newton-Raphson method is a very effective method for solving nonlinear equations at present. In most cases, this method has no risk of divergence, has strong convergence and can save computing time greatly. Therefore, the conventional Newton-Raphson method is used to calculate power flow of distribution network with distributed generators.

3. Distribution network planning model with DG

3.1. objective function

The equipment investment cost, operation and maintenance cost, fuel cost, and environmental protection conversion cost are mainly included in the objective function, so that the annual investment cost is the lowest, and the power supply reliability required by the user is satisfied. The economic mathematical model (CF) is described as follows:

$$\min C = C_{DG} + C_f + C_{loss} - C_e - C_b \quad (1)$$

1) C_{DG} : The total cost of MT, WG, PV and BS is:

$$C_{DG} = \sum_{i=1}^{n_{DG}} (r_{1_i} \times CRF + r_{2_i}) \times P_{DG_i} \quad (2)$$

$$CRF = \frac{a \times (1+a)^m}{(1+a)^m - 1} \quad (3)$$

In the formula: n_{DG} is the number of nodes for installing distributed generators; r_{1_i} is the unit capacity cost (converted according to the proportion of various types of distributed generators) (10,000 yuan/k W); CRF is the coefficient factor for converting initial investment into annual equivalent value; r_{2_i} is the operation and maintenance cost of DG per unit capacity (converted according to the proportion of

various types of distributed generators) (10,000 yuan/kW).take $r_{2_i} = r_{1_i} \times 5\%$, P_{DG_i} is the rated power of station I(kW); α is the discount rate, take $\alpha = 0.01$; m is the useful life of DG.

2) C_f : Annual cost of fuel. Only MT needs to use natural gas as fuel in the DG considered in this paper. Fuel cost is MT annual operating cost.

$$C_f = C_{unit} \sum_{t=1}^{8760} \sum_{i \in N_{mt}} G_{mt,i}(t) \quad (4)$$

In the formula: C_f is the annual cost of fuel, (10,000 yuan); $G_{mt,i}(t)$ is the MT i access node time t output, MW; C_{unit} is the unit MT hourly fuel cost, 0.06 million yuan/MWh.

3) C_e : environmental benefits.

$$C_e = \left(\sum_{i=1}^{n_{DC}} P_{DG_i} \times T_{DG_i} \right) \times C_{pe} \quad (5)$$

In the formula: C_{pe} is the environmental cost for thermal power units (yuan /k Wh).

4) C_b : saving the cost of purchasing electricity from the higher power grid.

$$C_b = \left(\sum_{i=1}^{n_{DG}} P_{DG_i} \times T_{DG_i} \right) \times C_{pb} \quad (6)$$

In the formula: T_{DG_i} is the maximum annual utilization hours (H) of station I, and C_{pb} is the unit price per unit (yuan /kWh).

3.2. constraint condition

1) power flow equation

$$\begin{cases} P_{DG_i} - P_{Li} = e_i \sum_{j \in i} (G_{ij} e_{ij} - B_{ij} f_j) + f_i \sum_{j \in i} (G_{ij} f_j + B_{ij} e_j) \\ Q_{DG_i} - Q_{Li} = f_i \sum_{j \in i} (G_{ij} e_j - B_{ij} f_j) - e_i \sum_{j \in i} (G_{ij} f_j + B_{ij} e_j) \end{cases} \quad (7)$$

In the formula: P_{DG_i} and Q_{DG_i} are active and reactive power injection of node i , node i and j are connected directly, $e_i + jf_i$ is node voltage, G_{ij} and B_{ij} are real and imaginary parts of node admittance matrix, respectively.

2) Voltage constraint

$$V_{\min} \leq V_i \leq V_{\max} \quad (8)$$

In the formula: U_{\min} and U_{\max} are the lower and upper limit of voltage of node i .

3) Branch current constraint.

$$I_{ij} \leq I_{ij_max} \quad (9)$$

In the formula: I_{ij} is the current through line ij ; I_{ij_max} is current limit for line ij .

4. Solving algorithm

Flow chart of genetic algorithm shown in Figure 1.

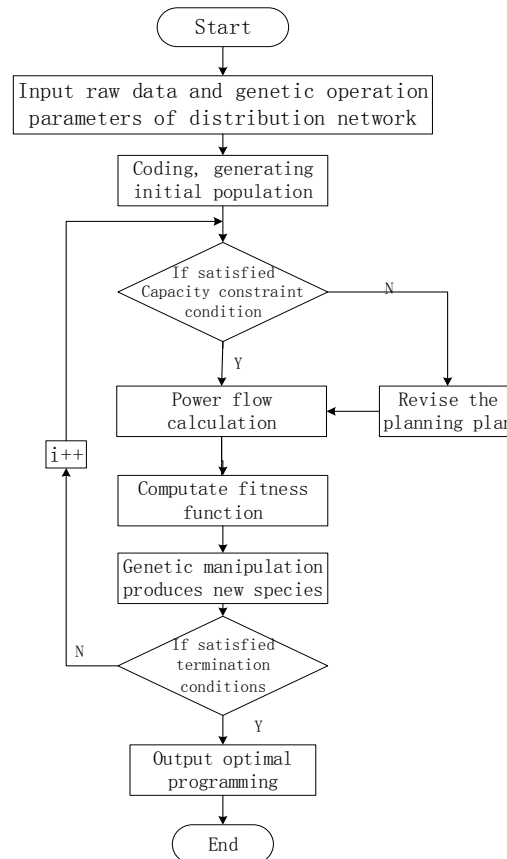


Figure 1. Flow chart of genetic algorithm

The steps of solving the location and sizing problem of distributed generation based on genetic algorithm are as follows:

- (1) Input the original data and the operation parameters of genetic algorithm, obtain the node information and branch information of distribution network, obtain the parameters of distributed generation, and initialize the parameters of the algorithm;
- (2) generating random initial population according to the prescribed coding mode.
- (3) it is proposed that individuals who do not meet the constraints should be amended.
- (4) power flow calculation;
- (5) calculate the objective function values and fitness function values of each individual and evaluate them.
- (6) genetic manipulation produces new populations.
- (7) Check whether the current result satisfies the termination condition

5. Example analysis

5.1. Grid structure and DG access point

The rationality of the algorithm is verified with the 14 node radial microgrid. The microgrid structure is shown in Figure 2.

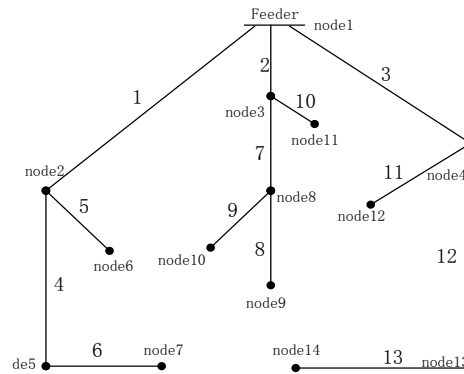


Figure 2. IEEE14 distribution network

In Figure 2, 1-14 is the node number, where bus 1 can be regarded as a balanced node, and the remaining 13 nodes are PQ nodes. In order to simplify the calculation, a preliminary selection of the access location range of distributed generation is made before planning the optimal installation capacity of distributed generation. This simplification method has a certain theoretical basis, for example, from the perspective of environmental impact, wind turbines are usually installed in areas with rich wind resources; from the perspective of load reduction, distributed power generation is generally considered near heavy-duty nodes. This paper focuses on the role of distributed generation in improving node voltage quality and load-bearing capacity of distribution network. Therefore, nodes with low voltage stability index and some overloaded nodes are selected as the feasible access points of distributed generation. An improved voltage stability index calculation method [13] based on the existence of power flow solution is proposed. After calculation: for (2, 5, 6, 7) branches, select node 7; for (3, 8, 9, 10, 11) branches, select node 9; for (4, 12, 13, 14) branches, select node 14. At the same time, consider the heavy load problem, choose the 4 nodes with the largest load 3, 6, 8, 9. To sum up, the candidate nodes of the distributed generation are nodes 3, 6, 7, 8, 9 and 14 respectively.

5.2. Optimal plan for comprehensive investment

The optimal plan of location and capacity of distributed generation based on economy is shown in Table 1.

Table 1. Location and capacity of distributed generation

DG access node number	DG capacity /MVA
3	1.3
6	0.5
7	0.3
8	1.7
9	1.6
14	0.8

As shown in Table 2, considering all aspects, the total cost without DG is 934,200 yuan, and the total cost of DG is 577,200 yuan.

Table 2. Cost comparison of distribution networks with or without distributed generation

Cost item	contain DG/ million yuan.	not contain DG/ million yuan
DG investment cost	149.363	0
MT fuel cost	33.717	0
Loss of net	62.64	93.42
environmental benefit	52	0
Economical purchasing cost of superiors	136	0

It can be seen that after the DG is connected to the distribution network, the cost of purchasing electricity, the cost of network loss and the total annual cost of the distribution network are significantly reduced, which shows that the planning scheme obtained by the study is better, economic improvement effect is obvious of the DG.

6. Conclusion

This paper establishes a distribution network planning model including DG, which not only considers economic factors, but also introduces the environmental benefits of distributed power sources. The genetic algorithm based on implicit coding and optimal preservation strategy is used to solve the location and volume of the distributed power supply. The results of the example verify the feasibility of the proposed algorithm. At the same time, it shows that although the investment cost of distributed power supply is still relatively high, by optimizing the location and capacity of the distributed power supply, the network loss can be effectively reduced and the cost of purchasing electricity can be saved. Obtain environmental benefits, and thus improve the economic and environmental benefits of the system as a whole.

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