Dynamic reconfiguration of distribution network with new energy generation considering economic and reliability

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Abstract. The penetration rate of new energy power generation in the distribution network has gradually increased, and the traditional static reconfiguration for a certain time section will be difficult to meet the actual operation requirements of the distribution network. A dynamic reconfiguration model of the distribution network with network loss, voltage offset, and new energy abandonment rate as the optimization goals was established. An adaptive genetic algorithm was used to solve the dynamic reconfiguration optimization of the distribution network. By simplifying the traditional network, a large number of infeasible solutions generated during the encoding process are reduced, and the optimization ability of the algorithm is improved. Based on the IEEE33 node system, four different scenarios were set up for simulation analysis. The results show that the reconfiguration can significantly reduce the network loss and voltage offset of the system, and also significantly improve the utilization efficiency of new energy and effectively improve the operation level of the distribution network. The feasibility and correctness of this method were verified.

1. Instruction
Increasing the proportion of renewable energy in the power grid is a new direction for the development of future power systems. With the continuous development and maturity of wind power and photovoltaic power generation technology, its penetration rate in the distribution network has increased year by year, which has brought certain influence and challenges to the operation of the distribution network[1]. The rational use of wind power and photovoltaic power generation can not only improve the economics and reliability of the distribution network operation, but also absorb a large amount of renewable energy, which has positive practical significance for alleviating energy shortages.

Reconfiguration of the distribution network[2-3] is to change the opening and closing states of the contact switches and section switches in the network, so that certain operating indicators can be effectively achieved under the premise of meeting the power supply load requirements and ensuring the safe and stable operation of the system. Such as reducing system network losses, improving node voltage quality, increasing load balance, and increasing the network's ability to absorb renewable energy.

Scholars have done a lot of researches on the optimal operation of distribution networks with DG. Reference[4] aimed at the randomness of wind power and photovoltaic power output, using point estimation to deal with the randomness, and solved the problem of multi-objective reconfiguration with uncertain DG. Literature[5] found that the distribution network under the high penetration rate of renewable energy was reconstructed, and the minimum network loss during the reconfiguration period was the optimization goal. Literature[6] aimed at the characteristics of output power change of wind and solar power, and used dynamic reconfiguration of distribution network to realize flexible control of wind and solar resources. Reference[7] used multi-scenario simulation technology to restructure and
optimize the distribution network with electric vehicles and DG, and proposed a reconfiguration strategy suitable for active distribution networks.

Based on the above research, this paper considers the economic and social benefits of distribution network operation, and establishes a distribution network reconfiguration model with optimization goals of network loss, voltage offset, and abandonment rate of renewable energy. The concept of node degree is introduced to optimize the coding process and improve the algorithm's ability to find the best. The simulation analysis of the modified IEEE33 node system verifies the effectiveness of the method in this paper.

2. Reconfiguration model of distribution network considering DG consumptive capability

With the continuous advancement of the reform of the power system, a large number of power distribution companies have participated in market competition, which has brought new challenges to the operation of traditional power grid companies. At the same time, considering the country's gradual increase in environmental protection requirements, the access to clean and renewable energy (wind power, photovoltaic power) will reduce the demand for traditional energy and reduce the degree of environmental pollution. Therefore, the distribution network reconfiguration model mentioned in this paper mainly considers the economic and social benefits of distribution network operation.

2.1. Economic benefit indicator

Take the minimum system network loss in one day as the optimization goal I:

$$E_{\text{loss},t} = \sum_{i=1}^{24} \sum_{i=1}^{n} k_i \cdot r_i \cdot \frac{P_i^2 + Q_i^2}{U_i}$$

Where: $t$ represents the period of operation of the distribution network; $n$ represents the total number of branches in the distribution network; $k_i$ represents the operating state corresponding to switch $i$ in the system, 0 is open, 1 is closed; $r_i$ is the branch $i$ resistance; $P_i, Q_i$ are the active and reactive power flowing through branch $i$; $U_i$ is the voltage at the end node of branch $i$.

Take the minimum voltage offset of each node within one day as the optimization goal II:

$$E_{uj,t} = \sum_{i=1}^{24} \sum_{j=1}^{n} \left| \frac{U_j - U_{jn}}{U_{jn}} \right|$$

Where: $t$ represents the period of operation of the distribution network; $n$ is the total number of nodes in the distribution network; $j$ is the node number of the distribution network; $U_j$ and $U_{jn}$ are the actual and rated voltages at node $j$.

2.2. Social benefit indicator

Takes the minimum renewable energy abandonment rate as the optimization goal 3:

$$E_{\text{New},t} = 1 - \frac{\sum_{k=1}^{N_{\text{wind}}} P_{\text{wind},k,t} + \sum_{k=1}^{N_{\text{solar}}} P_{\text{solar},k,t}}{\sum_{k=1}^{N_{\text{wind}}} P_{\text{windmax},k,t} + \sum_{k=1}^{N_{\text{solar}}} P_{\text{solarmax},k,t}}$$

Where: $t$ represents the period of operation of the distribution network; $N_{\text{wind}}$ and $N_{\text{solar}}$ represent the number of wind power and photovoltaic power in the system; $P_{\text{wind},k,t}$ and $P_{\text{solar},k,t}$ represent the actual output power of $k$-th wind and photovoltaic power at time $t$; $P_{\text{windmax},k,t}$ and $P_{\text{solarmax},k,t}$ represent the maximum output power of the $k$-th wind and photovoltaic power source at time $t$.

2.3. Reconfiguration model of distribution network considering DG dissipation capability

The distribution network reconfiguration model considering the economic and social benefits of operation is as follows:
\[
\min \{E_{\text{loss}, t}^*, E_{\text{U}, t}^*, E_{\text{New}, t}^*\}
\]  

3. Solution of Distribution Network Reconfiguration Model Based on Adaptive Genetic Algorithm

3.1. Simplified distribution network topology

For any node in the distribution network (excluding the first node and the last node), there is a flow in and out. Define the number of inflow branches of node \( i \) as \( \delta_{\text{in}}(i) \), if the inflow branch of this node is 2, \( \delta_{\text{in}}(i) = 2 \). Define the number of outgoing branches of node \( i \) as \( \delta_{\text{out}}(i) \), if the inflow branch of this node is 1, \( \delta_{\text{out}}(i) = 1 \). In Fig. 1, for node 1, \( \delta_{\text{in}}(1) = 0 \), \( \delta_{\text{out}}(1) = 1 \); for node 4, \( \delta_{\text{in}}(4) = 1 \), \( \delta_{\text{out}}(4) = 2 \). If the node satisfies \( \delta_{\text{in}}(i) + \delta_{\text{out}}(i) \leq 2 \), then all nodes on this branch can be merged. For the original structure in Fig. 1, according to binary coding, the number of feasible solution is \( 2^{17} \); the number of feasible solution of the simplified power distribution system is only \( 2^7 \).

![Fig.1 Original and simplified diagrams of system](image)

3.2. Adaptive genetic algorithm

The crossover rate \( P_c \) and the mutation rate \( P_m \) determine the optimization efficiency of the genetic algorithm. The traditional genetic algorithm sets the \( P_c \) and \( P_m \) to constants, which results in the algorithm's optimization efficiency is not high and affects the performance of the algorithm. In order to improve the algorithm's performance and optimizing ability. Literature [8] proposed that \( P_c \) should decrease according to the linear law, and \( P_m \) increase according to the exponential law. Therefore, when performing crossover and mutation operations on chromosomes, this paper sets \( P_c \) and \( P_m \) to dynamically adjust according to the following methods:

\[
P_c^{(k+1)} = P_{c, \text{initial}} + \frac{k+1}{T_{\text{max}}} (P_{c, \text{initial}} - P_{c, \text{end}}) + e^{-\Delta f(t)/\Delta t}
\]

\[
P_m^{(k+1)} = P_{m, \text{initial}} + \frac{k+1}{T_{\text{max}}} (P_{m, \text{initial}} - P_{m, \text{end}}) \cdot e^{-\Delta f(t)/\Delta t}
\]

Where: \( P_c^{(k+1)} \), \( P_m^{(k+1)} \) represents the crossover rate and mutation rate in the \( k+1 \)-th iteration; \( P_{c, \text{initial}} \), \( P_{c, \text{end}} \), \( P_{m, \text{initial}} \), \( P_{m, \text{end}} \) represents the initial and termination crossover rate and mutation rate; \( T_{\text{max}} \) is the maximum number of iterations; \( \Delta f(t) \) is the \( k+1 \)-th and \( k \)-th generation difference in mean of population fitness.

4. Simulation analysis

4.1. Simulation platform and example parameters
Take the IEEE33 node distribution network system as an example to verify the effectiveness of the method in this paper. The network structure connects the photovoltaic power with a installed capacity of 30kW at nodes 18 and 23, connects the wind turbine with a installed capacity of 30kW at nodes 26 and 33. The network topology is shown in Fig.2.

![Network topology](image)

**Fig.2 Network topology**

Considering the uncertainty of wind power, photovoltaic power generation and system load, it is set to conform to a certain distribution, as shown in Fig.3.

![The changes of wind-light and load](image)

**Fig. 3 The changes of wind-light and load**

4.2. **Static reconfiguration improves the operation level of distribution network**

In order to study the situation of network reconfiguration to improve the operation effect of the distribution network system, select a certain moment to reconstruct the distribution network, and compare the changes of the system operation index before and after the reconfiguration, the results as shown in Table 1.

| Index                 | Un-reconfiguration | reconfiguration |
|-----------------------|--------------------|-----------------|
| Disconnect switch     | 33/34/35/36/37     | 7/9/14/32/37    |
| Power loss (kW)       | 202.7              | 138.76          |
| Voltage offset        | 1.7012             | 1.1074          |

4.3. **Dynamic reconfiguration improves the operation level of distribution network**

In order to study the impact of dynamic reconfiguration on the operation of distribution networks containing wind and photovoltaic power generation and the ability to absorb renewable energy, this article sets four scenarios for comparison:

Scenario 1: No reconfiguration;
Scenario 2: No reconfiguration, the network contains renewable energy;
Scenario 3: Perform dynamic reconfiguration;
Scenario 4: Dynamic reconfiguration and renewable energy in the network.

Regarding the time division method of dynamic reconfiguration, according to the method of [10], one day is divided into three reconfiguration time periods, and the results are shown in Table 2.

| Scenario | Time division I | Time division II | Time division III |
|----------|----------------|-----------------|------------------|
| 7,11,14,28,34 | 7,9,14,24,33 | 6,9,14,24,33 |
| 5,9,13,27,31 | 5,9,14,28,32 | 7,9,14,28,32 |

It can be seen from Table2 that one day is divided into three periods, which are 00:00-08:00, 08:00-22:00 and 22:00-24:00. These periods are characterized by load and wind compared with...
photovoltaic power generation, by changing the closed state of the switch, the system operation level and the capacity of renewable energy consumption are improved.

The simulation results of the four scenarios are shown in Fig. 4-6, followed by the network loss index, voltage offset index and renewable energy abandonment rate index change curve. Comparing the change curves of the four scene indicators in figure 4 to 6, the network loss without reconfiguration is the highest (Scenario 1), and the change trend is consistent with the load change trend. The heavier the load, the greater the network loss. After access renewable energy at certain node and dynamic reconfiguration (Scenario 2 and Scenario 3), the network loss of the system is significantly reduced, especially during peak load, the improvement effect is particularly obvious. When both renewable energy is connected and reconfiguration is performed (Scenario 4), the network loss of the system is between scenario 2 and scenario 3. Although the network loss has increased in scenario 4, it has absorbed a large amount of renewable energy and achieved certain environmental benefits.

Scenario 2 to 4 have significantly improved voltage offset compared with scenario 1, especially during peak load, the improvement effect is obvious. When the system is reconstructed, the fluctuation of voltage offset curve has also significantly decrease, such as scenario 3 and 4.

Scenario 4 has a higher utilization rate of renewable energy than scenario 2. The main reason is that by changing the network topology, a large amount of renewable energy is consumed.

5. Conclusions
A dynamic reconfiguration model of distribution network considering the economics, reliability and absorption capacity of renewable energy of distribution network is proposed, and the following conclusions are obtained through simulation analysis:

(1) Reconfiguration of the network can effectively improve the economics and reliability of the system operation, and at the same time can improve the ability to consume renewable energy and enhance environmental protection benefits;

(2) By introducing the concept of nodes, the network is simplified to effectively improve the optimization ability of the algorithm, which shows that the algorithm in this paper has certain promotion significance.
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