Optimization of Coordination of Feeder Section and Connection of Operating Distribution Network

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Abstract. The relation between section and connection of feeder of operating distribution network is researched. The method of an improved optimization algorithm is proposed to solve the problem of coordination of feeder section and connection under the operating constraint conditions. In the optimization process, in addition to the basic goals of load balance, number of the loads and total length of line segments in the feeder, other factors such as feeder specific structure, influence of tie switches and important customers are also considered. The optimal result is finally given as new locations of section switches and tie switches to realize the optimal operation of distribution network. The result is also used to guide the installation of distribution automation terminal devices and propose the self-healing strategy of distribution automation system.

1. Introduction

The primary precondition of distribution automation system construction and renovation is that sections of feeder are reasonable, and line segments in the feeder can transform each other flexibly between the power source and power load. In the initial planning and design of distribution network, the location of section switches and tie switches shall be generally considered. However, with the rapid development of economy, no matter the number of power loads, size of power loads, or importance of power loads, there is great changes between the power load level now and the early predicted power load in the planning stage, and the related rolling planning is lagged behind seriously, so it is urgent to optimize and coordinate the position of section switches in the feeder and tie switches between feeders in the operating distribution network. Besides, according to the actual situation, the electric power operators need to analyze the best section position at present to install various types of intelligent terminal devices, in order to minimize the power load loss in case of fault, improve the effect of economic, and realize distribution network self-healing.

The optimization of coordination of the section and connection of feeders is a discrete, nonlinear, multi-objective and multi-constraint combination optimization problem in distribution network [1][2][3][4]. Many scholars have done much a large number of research works. In reference [5], the valuable research has been done about the installation types and number of measuring terminals in the planning of distribution automation. The calculation method is based on the reliability index, and the basic assumption is the equilibrium of number of power loads in each section. In fact, there are few feeders with the same load number in each section, and it is also not enough to consider only the number of power loads. It is more important to consider the size of power loads in the each section. In addition, the degree of uniformity of length of main line of feeder, the summation of power loads in the section, and
the number and size of important consumers in the section should also be considered along with all the others as constraints. In this method, the configuration of tie switches is considered, but how the tie switches coordinated works with sections is not discussed in detail.

This paper proposes a new method to solve the problem of section rationality, first of all, using the big data of electric quantity to analyze the shape of feeders, get the basic characteristics of feeders, on the second, calculating the basic weights of multiple optimization objectives, then using the weighted evenness as the objective, taking the number of tie switches and important consumers as the penalty factors to construct the objective function, finally, the improved fuzzy differential evolution algorithm is proposed to solve.

2. Objective Function of Feeder Section and Connection Coordination Optimization

The objective of optimization of coordination of distribution network section and connect is to achieve uniform sections, i.e. uniform size of power loads size, uniform number of power loads and uniform length of main lines in each sections. The main constraints are the network security constraints, the tie switch constraints, the important consumer constraints, etc. The solution process is to find a set of optimal decision variables, so as to minimize the investment of reconstruction network and the installation terminator.

\[
\min Z = \lambda (\sum_{i=1}^{n} w_{\text{load}_i} \sigma_{\text{load}_i} + w_{\text{custom}_i} \sigma_{\text{custom}_i} + w_{\text{len}_i} \sigma_{\text{len}_i} + F_{\text{union}} + F_{\text{vip}})
\]

\[
\sigma_{\text{load}} = \sqrt{\frac{\sum_{i=1}^{n} (x_{\text{load}_i} - \mu)^2}{n}}
\]

\[
\sigma_{\text{custom}} = \sqrt{\frac{\sum_{i=1}^{n} (x_{\text{custom}_i} - \mu)^2}{n}}
\]

\[
\sigma_{\text{len}} = \sqrt{\frac{\sum_{i=1}^{n} (x_{\text{len}_i} - \mu)^2}{n}}
\]

In formula (1): Z is the converted investment cost; \( \lambda \) is the converted investment coefficient; \( w_{\text{load}} \) is the weight of power load size; \( \sigma_{\text{load}} \) is the mean square deviation of power load size, denoting the power load size uniformity in each section, the smaller the value is, the more uniform the power load size of each section in the feeder, otherwise it is more uneven. The principle is the same as the length of the main lines in the section, the number of consumer in the section, etc. \( w_{\text{custom}} \) is the weight of the number of consumers; \( \sigma_{\text{custom}} \) is the average variance of the number of consumers, reflecting the uniformity of the number of consumers in the section; \( w_{\text{len}} \) is the weight of the length of each section; \( \sigma_{\text{len}} \) is the average variance of the length of each section, reflecting the uniformity of the length of the section. \( x_{\text{load}_i} \) is the summation of power load size of each section, \( n \) is the number of sections, \( \mu \) is the average value. \( F_{\text{union}} \) is the penalty factor of tie switch. If the number of tie switchers in the section is greater than 1, the penalty will be increased. If there is no tie switcher in the section, the penalty will also be increased. \( F_{\text{vip}} \) is the important consumer penalty factor. If the important consumers in the section more than or equal to 1, and the number of number or size of power load of the section is greater than the average, the penalty will be increased. According to the technical guidelines for distribution automation, the summation of power load in the section shall not exceed 2MW, if size of the power load in the section is too large, the penalty shall be increased. The degree of penalty factor also has been considered. If the penalty degree needs to be increased, the penalty weight will be increased. For example, if the
operator requires that each section corresponds to a tie switch, if violate, the penalty degree can be set to 100%, and if the tie switch is not considered, then the tie switch penalty degree can be set to 0%.

The constraints are:

Connectivity and radial constraints;

2) Voltage constraints:

\[
K_u(U_{\text{min}} - U_j)^2 \quad U_j < U_{\text{min}}
\]

\[
K_u(U_{\text{max}} - U_j)^2 \quad U_j > U_{\text{max}}
\]

\[
k_i(U_j) = \begin{cases} 
K_u(U_{\text{min}} - U_j)^2 & U_j < U_{\text{min}} \\
K_u(U_{\text{max}} - U_j)^2 & U_j > U_{\text{max}} \\
0 & U_{\text{min}} < U_j < U_{\text{max}}
\end{cases}
\]  

(2)

Current restraint:

\[
k_i(I_j) = \begin{cases} 
K_u(I_{hi} - I_j)^2 & I_j >= I_{hi} \\
0 & I_j < I_{hi}
\end{cases}
\]  

(3)

Section amount restraint:

The number of sections is obtained according to the feeder configuration. If the number of tie switches is less than or equal to 2 in a feeder, it should be divided into three sections; if the number of power load access points in the main line is less than 3, it should be divided into two sections; if there are more than two tie switches in the feeder, each one more tie switch needs to add one more section. For example, if there are three tie switches, then the feeder should be divided into three sections. The number of sections cannot exceed six in a feeder.

3. Differential Evolution Algorithms with Feedback Factor

The reference [3] introduces the basic principle of differential evolution algorithm. The algorithm has two adjustable parameters: scaling factor F and crossover probability constant Cr. The general setting range is F \in [0.5, 1], Cr \in [0.1, 0.9]. How to control the values of F and Cr in the calculation process is a complex problem, involving many factors, which are difficult to express with accurate formula. The fuzzy control with the calculation result as the feedback factor is considered as an effective method to solve this kind of problems. The basic principles are as follows:

1. Determine the error and error rate of change current time
2. Transform the exact value of error and error rate of change into a fuzzy state as the input
3. Calculate the fuzzy control variables from the fuzzy control rules (i.e. synthesis algorithm)
4. Put the calculated fuzzy control quantity into the exact value as the feedback to the control object.

In the calculation process of each generation, the feedback mechanism of fuzzy control is used to adjust the values of F and Cr per time, so as to speed up the convergence and avoid falling into the state of premature.

In this paper, two two-dimensional fuzzy controllers [6] are proposed, one controls parameter F and the other controls Cr. There are two inputs, one is the root-mean-square e1 of the gene difference between the previous generation and next generation, and the other is the root-mean-square e2 of the fitness of the previous generation and the next generation, as shown in the following formula:

\[
e_{1i} = \sqrt{\frac{1}{NP} \sum_{j=1}^{NP} \sum_{j=1}^{D} (x_{i,j}^{(n)} - x_{i,j}^{(n-1)})^2}
\]

\[
e_{2i} = \sqrt{\frac{1}{NP} \sum_{i=1}^{NP} (f_i^{(n)} - f_i^{(n-1)})^2}
\]  

(4)
In formula (4):
el1 is the difference between the previous generation and the next generation, and e2 is the difference between the previous and the next generation. NP is the population size, i = 1, 2..., NP; D is the number of chromosome genes, j = 1, 2..., D. n represents evolutionary generation; f represents individual fitness.

Normalize e1 and e2 to get the following equations:

\[
d_{11} = 1 - (1 + e1) \cdot e^{-e1}
\]
\[
d_{12} = 1 - (1 + e2) \cdot e^{-e2}
\]
\[
d_{21} = 2 \cdot (1 - (1 + e1) \cdot e^{-e1})
\]
\[
d_{22} = 2 \cdot (1 - (1 + e2) \cdot e^{-e2})
\]

(5)

Tab1 Membership Functions

| Controller F | Controller Cr |
|--------------|--------------|
| D11          | D21          |
| \(\mu_S(d_{11})=f_S(d_{11},0.25,0.05)\) | \(\mu_S(d_{21})=f_S(d_{21},0.5,0.1)\) |
| \(\mu_M(d_{11})=f_M(d_{11},0.25,0.05)\) | \(\mu_M(d_{21})=f_M(d_{21},0.5,0.8)\) |
| \(\mu_B(d_{11})=f_B(d_{11},0.25,0.05)\) | \(\mu_B(d_{21})=f_B(d_{21},0.5,1.5)\) |
| D12          | D22          |
| \(\mu_S(d_{12})=f_S(d_{12},0.35,0.01)\) | \(\mu_S(d_{22})=f_S(d_{22},0.5,0.1)\) |
| \(\mu_M(d_{12})=f_M(d_{12},0.35,0.05)\) | \(\mu_M(d_{22})=f_M(d_{22},0.5,0.8)\) |
| \(\mu_B(d_{12})=f_B(d_{12},0.35,0.09)\) | \(\mu_B(d_{22})=f_B(d_{22},0.5,1.5)\) |
| F            | Cr           |
| \(\mu_S(F)=f_S(F,0.5,0.3)\) | \(\mu_S(Cr)=f_S(Cr,0.35,0.4)\) |
| \(\mu_M(F)=f_M(F,0.5,0.6)\) | \(\mu_M(Cr)=f_M(Cr,0.35,0.7)\) |
| \(\mu_B(F)=f_B(F,0.5,0.9)\) | \(\mu_B(Cr)=f_B(Cr,0.35,1.0)\) |

Table 2. The rules table

| rules | Di1 | Fuzzy Set | F/Cr |
|-------|-----|-----------|------|
| 1     | S   | S         | S    |
| 2     | S   | M         | M    |
| 3     | S   | B         | B    |
| 4     | M   | S         | S    |
| 5     | M   | M         | M    |
| 6     | M   | B         | B    |
| 7     | B   | S         | B    |
| 8     | B   | M         | B    |
| 9     | B   | B         | B    |

The variables D11 and D12 are selected as the control variables of parameter F, and their universe is \{0, 1, 2\}. The corresponding fuzzy set is: \{S (Small), M (Medium), B (Big)\}.

The main rules are:

When D11 and D21 are larger, F and Cr should also be larger, indicating that evolution is in the early stage, and the distance between them is far from the optimal value; when D12 and D22 are smaller, F and Cr should also be smaller, which is close to convergence. The membership function FG of Gaussian distribution is adopted, and the table of membership function is shown in Table 1. The fuzzy rule reasoning table (9 x 2) is shown in Table 2. The new control parameters F and Cr are obtained by the method of Mamdani center of gravity.
4. Optimization of CoordinationSection and Connection of Feeder of OperatingDistribution Network

4.1. Morphological Identification of Big Feeder in Distribution Network.
State Grid Corporation of China (SGCC) has spent several years to trim feeders in the distribution network. Power Management Information System (PMIS) and power user electric energy data acquire system (PUEEDAS) have been connected from the data source. The so-called "big feeder" refers to the main line from the outgoing switch of the substation to the tie switch in the end, including all branch lines derived from the main line, such as overhead lines, insulated wires, cables, as well as public transformers and special transformers connected to the feeder. For big feeders, it is particularly emphasized that all the main lines from the tie switch to the power resource are connected. In other words, if there is more than one tie switch in the feeder, the main line of large feeders is no longer a straight line, other than a tree including branch lines.

4.2. Calculation Flow.
1) Read the data and initialize
2) Morphological identification of big feeder in distribution network. According to the predetermination weight of each objective, the nodes participating or not participating in calculation, the program generates the initial group, converts the chromosome of the initial group into electrical topology, executes topology analysis and power flow calculation, calculates the initial fitness of chromosome in the group
3) Each sub population executes crossover and mutation, generates new individuals, executes topology analysis for new individuals, and judges whether the section scheme is effective according to the result
4) Comparing the adaptability of parents and children. The greedy selection strategy is adopted to select the individuals with high adaptability to form a new sub group
5) According to formulas (4) and (5), the feedback value of fuzzy control is calculated, and new F and Cr are obtained. Repeat 3)–5) until the maximum generation or the best fitness no longer changes.

Figure 1. Flow chart of improved fuzzy differential evolution algorithm
4.3. Basic Application Process.
(1) Reading data from the distribution network management and control platform, including CIM/SVG
data and electricity quantity data, etc. Trim, wash and verify them.
(2) Main lines analysis. According to the definition of big feeders and the results of power flow
calculation, determine the load size of nodes (excluding the actual line loss), the number of loads
associated with nodes, the number of important consumers, the distance from the power source, and
other indicators.
(3) Big data analysis of electric quantity. By combining with curve of historical power load in last 2
years, determinate of basic shape of feeder, evaluatethe number of sections, the optimization weight,
and penalty factor weight, etc.
(4) Start the intelligent optimization algorithm, carry out the optimization calculation according to
the maximum load day, get the preliminary section points and other section detailed information.
(5) If improved analysis is needed, modify optimization parameters and actual load values, then
recalculate.
(6) Output calculation results, including charts and data.

5. Conclusion
(1) In the process of optimization of feeder section and connection of operating distribution network, it is
needed to consider the characteristics of distribution network, not only the number and size of power
loads, the length of each section, but also the influence factors of tie switch and important electric
consumers.
(2) After the differential evolution algorithm is added to the fuzzy controller for parameter adaptive
control, the convergence speed and stability are enhanced, it can converge to the effective solution each
time.

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