Research and implementation of multi-level transfer path identification based on topology simplification of electric distribution network diagram

Xindong Zhao*[,a], Dizhuoran Ye[a,1], Jinming Chen[a,2], Hao Jiao[a,3], Zhijun Zhou[a,4], Ye Chen[a,5]
[a]Electric Power Research Institute of State Grid Jiangsu Electric Power Co.,Ltd., Nanjing 211103, China.

ABSTRACT

With the sustained growth of scale of electric power system, the safety of distribution grid and the ability to deal with failures are facing new challenges. Aiming at the problem that the failure of a middle and high voltage transformer in the electric distribution grid leads to a large area of power failure and it is impossible to quickly select a transfer path to restore power supply in a short time, a transfer path identification scheme is proposed, which assumes that when a main transformer fails, multiple path selections are made after the transfer scheme is obtained through integer programming, and the electricity fluctuation problem before and after the new extended energy is considered. First, the topology of the distribution network diagram is simplified through topology analysis, Then, integer programming can overcome dispatching of electric power trouble to get the maximum recovery amount and the transfer path. Then, the transfer path obtained is filtered for many times, and finally the transfer path satisfying the conditions is output. The results after application in provincial power companies show that the method has short recovery time, strong real-time, high execution efficiency and strong adaptability.

Keywords: Electric distribution network; topology simplification; multiple transfers; integer programming; electricity market business.

1. INTRODUCTION

With the rapid expansion of electric distribution, which presents the trend of large-scale, multi connection, cabling and automation [1]. The harm caused by the power grid failure is more and more serious. At the same time, With the gradual in-depth research and implementation of new power grid, more and more new electrical appliances are increasingly dependent on electric power, and the requirements for power supply reliability and power quality are also increasing [2]. In order to make sure the stability and safety of electric grid, preventing the occurrence of power failure accidents and quickly restoring power supply after the accidents have become an urgent and important task faced by the contemporary Chinese power industry [3]. The increasing complexity and automation of the distribution network make the factors considered in the load transfer decision of the distribution network increase when a large area of blackout occurs. The disadvantages of too long manual decision time and low efficiency begin to appear [4]. In the event of a substation full shutdown accident, the power transfer between substations and the selection of the transfer path are crucial in the process of power recovery [5]. With the increasingly complex distribution network structure, how to quickly and effectively complete the transfer process of blackout loads has become an important problem faced by distribution network dispatching.

*15105168216@139.com; [1] edie0922@qq.com; [2] cjm_nju@163.com; [3] jiaohaopeter@163.com,
[4] 2276377001@qq.com; [5] joey_ chenye@foxmail.com

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This paper studies the hypothetical fault of some main transformers when there is no fault in the electric distribution grid, and then builds a distribution network topology model according to the interconnection between different transformers of electric distribution grid and the characteristics of the feeders. With the goal of maximizing the supply capacity for the fault area, and fully considering the constraints such as the adaptability of the feeder and the capacity of each related main transformer, the maximum recovery capacity and the transfer path are obtained by using integer programming, And the path selection operation is carried out for the obtained transfer path to find the optimal transfer path that can meet the electricity conditions, the overall electricity fluctuation before and after recovery is small and has strong stability. In this way, when the main transformer fails, the found transfer path can be identified quickly, and the transfer path can be used for fast power supply recovery in the fault area with relatively small delay, which has strong real-time performance and strong adaptability of the algorithm.

2. RELATED WORK

Load transfer refers to the operation of switches and the removal of some unimportant loads after the distribution network fails and is isolated. Under the condition of meeting the safety constraints, it can quickly and preferentially restore the power supply of important loads downstream of the fault, and also restore the power supply of other loads as much as possible. Shanghai Key Laboratory of Electric Power Transmission and Power Transformation proposed the load method, which takes the tie line between main transformers as the load transfer path to form a model of load transfer between stations, but the calculation process is cumbersome [6]. Tianjin Electric Power Simulation Laboratory proposed the main transformer interconnection and transfer method. The main transformer interconnection and transfer method evenly distributes the load of the fault main transformer to the main transformer with which it is connected. The transfer idea is clear and the calculation amount is small [7]. However, the assumption that the load transfer path is smooth and the equipment capacity is sufficient does not take into account the constraints of network structure and equipment capacity. The intelligent control laboratory of North China Electric Power University uses integer programming, branch and bound, mixed integer and other mathematical optimization algorithms [8]. Because of the complete and strict mathematical theory foundation, mathematical optimization methods have been widely used in distribution network fault recovery. However, power supply recovery is a NP hard problem [9]. The traditional mathematical optimization methods have the problem of dimension disaster, and also have high dimensions Nonlinear and other characteristics require a lot of simplification, large amount of calculation, long calculation time, weak real-time and other issues. Chongqing Electric Power Control Laboratory uses binary search tree and depth first search strategy to solve the problem [10]. This method has a huge search space and a slow solution speed. Foreign research institutions use search strategies based on evaluation functions and heuristic rules to solve problems, and reduce the solution space by using heuristic rules to guide the search. The Chinese Academy of Electric Power Sciences has proposed a distribution network restoration model based on constraint satisfaction problem, which is solved by backtracking algorithm, and greatly improves the efficiency of online calculation. Artificial intelligence has developed rapidly and is gradually trying to be applied to a variety of scenarios. The path transfer identification algorithms based on artificial intelligence mainly include genetic algorithm, tab search algorithm, ant colony algorithm, algorithm and particle swarm algorithm. The literature uses genetic algorithm to find the optimal power supply path with the goal of minimizing the load rejection loss cost, network loss cost and switching operation cost of different weights. The ant colony algorithm aims to minimize the network loss of the reconstructed distribution network. Some research institutions take the minimum outage loss as the objective function, and then use tab search algorithm to reconstruct the network.

The mainstream algorithm which existing now focus on fault recovery aim to restore the maximum supply of electric power, but can not offer the reasonable electric power supply scheme planning. If the input parameters of the model are changed, the structure of the entire algorithm has to be reconstructed. In this case, it is difficult to effectively play a key role in the application of real power scenarios.

3. CONSTRUCTION OF MULTI-LEVEL TRANSFER PATH MODEL FOR ELECTRIC DISTRIBUTION NETWORK

3.1 Electric distribution network topology analysis model

When a certain problem occurs in the distribution network and causes power failure, the fault main transformer is defined as a transformer unable to operate due to fault, and the direct connected to that transformer is defined as the step-down transformer that has a connection relationship with the central step-down transformer. The subordinate that has a connection relationship with the direct connected step-down transformer is called the secondary connected step-down transformer. The failure of the central main transformer has led to the power failure of the entire distribution area. In order to enable the central main transformer to maintain the power supply of the entire area, it is necessary to directly connect the main transformer to transfer power to the central main transformer for load transfer. A load transfer area can be determined by these main transformers. The different power supply areas composed of all the closely related main transformers and secondary related step-down transformers of the central step-down transformer. In areas with high load density, each directly connected to the transformer which in the central and the next connected main transformer form a load transfer cell. Every main transformer in the electric distribution grid will form an area of transformer which centered on itself offline. When the main transformer is repaired once the fault is determined, and the area of electric transformer will be maintained timely.

After the load transfer area is determined, the electric distribution network topology can be analyzed directly, and the adjacent feeders of each main transformer are identified as single path feeders and multi-path feeders. Single path transfer feeder means that there is only one recovery path when a load is cut off; multi-path feeder refers to that there are at least two recovery paths when a load is cut off.

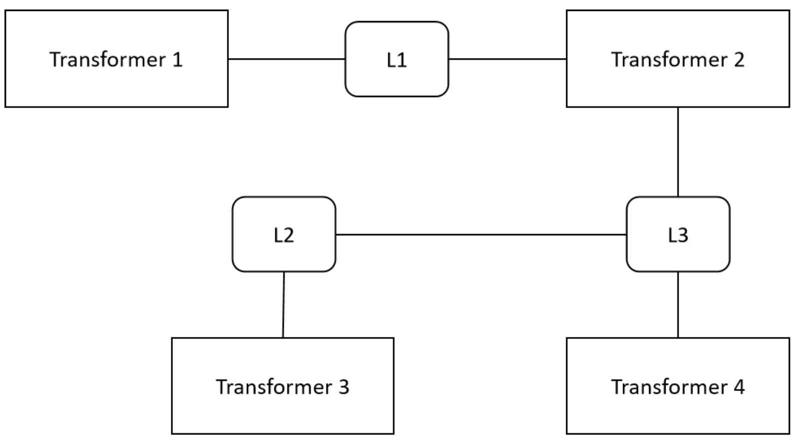

Figure 1. Relation diagram of main transformer.

As is shown in Figure 1, there are four main transformers in the figure. If there is a problem with main transformer 1, power can only be transferred from main transformer 2 by changing L1 switch. The combination of main transformer 1, L1 and main transformer 2 is a single path transfer feeder. If there is a problem with main transformer 2, the switch status of L2 and L3 can be changed, and the power will be transferred by the lines of main transformer 3 and main transformer 4 in two days. Therefore, the combination of main transformer 2, main transformer 3, main transformer 4, L2 and L3 is a multi-path transfer feeder.

3.2 Construction of electric load transfer path model

After the distribution network is completely shut down due to faults, it should be carried out quickly to restore the capacity of electric supply of the central main transformer as much as possible, so that other main transformers are required to transfer load to the central main transformer as much as possible to meet the demand of electric consumption. Therefore, in the article, the maximum of the electric supply restore of the central step-down transformer and the optimal transfer path are taken as objective functions, and the objective functions are shown in formula 1.

$$\max F = \sum_{i=1}^{n} \alpha_i D_i + \sum_{j=1}^{m} \beta_j P_j \tag{1}$$

Where F represents the maximum recoverable power supply for power transfer; D_i represents the electric load to be transferred on the α_i feeder of single path; P_j represents the load to be transferred on the j feeder of multi-path; n represents the number of single path feeder lines; m represents the number of multi-path feeder lines; α_i is the recovery coefficient of single path feeder; β_j is the recovery coefficient of multi-path feeder.

When the direct connected main transformer carries out coincident transfer to the central main transformer, when there is only one recovery path, it should be taken into account of the load rate of the feeder and the load amount to be transferred. The load of the transferred feeder cannot be exceeded, otherwise it will cause security problems. Constraints for constructing single path feeder are shown in Formula 2.

$$\alpha_i D_i \leq \min \{V_i(1 - m_i), D_i\} \tag{2}$$

In the formula 2, V_i represents the rated capacity of the line at the transfer side of the single path feeder; m_i indicates the initial load rate of the line on the transfer side.

When directly connecting the step-down transformer to the central step-down transformer for load transfer, it is necessary to consider the capacity of the step-down transformer, which cannot exceed the load, and build the load constraint conditions of the step-down transformer.

$$\sum_{i,j\in \Omega} (\alpha_i D_i + \beta_j P_j) \leq W_h(e_{hmax} - e_h) \tag{3}$$

In Formula 3, Ω represents the set of all single path and multi-path feeder lines transferred to the same step-down transformer; W_h indicates the limited capacity of the step-down transformer; e_h represents the initial occupancy of load of the main transformer; e_{hmax} indicates the maximum allowable occupancy of load of the main transformer.

4. IMPLEMENTATION OF MULTI-LEVEL TRANSFER PATH IDENTIFICATION TECHNOLOGY FOR DISTRIBUTION NETWORK

Electric data feature extraction technology is closely related to specific data applications or modeling tasks. In the traditional machine learning methodology, the introduction of business knowledge can better perform feature extraction. Although violent dimension upgrading does not rely on business knowledge, the cost of computing resources consumed is high. In order to deal with the multi-dimensional data of power big data across disciplines, this paper conducts research from three aspects.

The task of data feature extraction is often aimed at specific power data applications or modeling tasks. For example, a modeling task involves the input of 160 original fields. It needs to filter out the original fields closest to the task and process them into features through a series of data process, feature transformation, feature derivation and feature selection. Considering the specificity of the modeling task, it is difficult to provide a universal and fully automatic feature processing logic. Therefore, this chapter provides rich feature operators, and implements graphical interface components. Each component implements a specific feature engineering action to ensure the certainty of the action execution results. The user dominates the workflow editing. However, it also provides fully automated feature derivation and feature selection algorithms, provides reference example workflows for typical scenarios, and realizes the generation of feature engineering workflows in a semi-automatic manner.

4.1 Multi level transfer path solution

Particle Swarm Optimization (PSO) is a swarm intelligence evolutionary algorithm based on the simulation of birds' flight and foraging behavior. Compared with the genetic algorithm, the particle swarm optimization algorithm is easier to implement because there are no "crossover" and "mutation" operations. At the same time, the algorithm also has the characteristics of memory and fast convergence. Compared with single objective optimization, the solution of multi-objective optimization problem is not unique, but there is an optimal solution set, which is called Pareto optimal solution or non dominated set. The multi-objective particle swarm optimization algorithm is as follows:

1) Input the objective function and various constraints of the above model.

2) Initialize the population, initialize the particle swarm size, particle position x and velocity v.

3) Calculate the objective function of each particle, find the current individual extreme value of each particle, and find the current global optimal solution of the entire particle swarm.

4) Particle optimal updating includes individual optimal particle updating and population optimal particle updating. The updating method of individual optimal particle is to select the dominant particle from the current particle and individual optimal particle. When neither of the two particles is the dominant particle, randomly select one of them as the individual optimal particle. The population optimal particle is a particle randomly selected from the pare-to optimal solution set.

5) The Pareto optimal solution set is updated. When the new particles are not dominated by other particles and the particles in the current Pareto optimal solution set, the new particles are put into the pare-to optimal solution set.

Updates the speed and position of individual particles. If the iteration is over, the optimal Pareto solution set will be output; otherwise, the calculation iteration will be carried out.

Firstly, the problem of fault location in distribution network is described, and the specific way to combine the problem with graph convolution neural network is proposed. The basic theory of graph convolution neural network and the process of signal transformation show the transmission process of information features in the graph. The essence of spectral domain graph convolution is the transformation process of graph signals on the spectral characteristics of the graph. Spatial domain convolution establishes a flexible general expression framework. These frameworks provide a unified paradigm for the model design of graph convolution neural network, and achieve a general summary of various graph convolution network structures. The problem of load transfer in distribution network is described. Through the analysis of the basic theory of reinforcement learning and Markov decision-making process, the basic elements of the construction of reinforcement learning environment are pointed out, as well as the difference and relationship between strategy iteration and value iteration algorithm.

It can be seen from the above steps that the method in this paper transfers part of the load on the heavy load line to the light load line through two tie lines, recovers all the loads in less action times, and reaches a lower network loss level. For the reinforcement learning algorithm without improved actions, basically all attempts will lead to out of limit, so part of the load will be cut off finally. After the load is transferred, the heuristic hybrid algorithm still adopts the heavy load line transfer, and the line loss rate is 9.8% higher than the method in this paper after all loads are restored. The algorithm in this paper basically realizes the optimal control strategy.

4.2 Implementation of feature extraction technology for electric data

When the transfer path scheme B and the maximum power supply for restoration F are obtained after solving the multi-level transfer path, when selecting the transfer path, it is necessary to consider the situation after the transfer of power from the direct connected main transformer to the central main transformer. At this time, the path of load transfer from the direct connected main transformer to the central main transformer may lead to the failure of the direct connected main transformer. For example, the direct connected main transformer provides a large load to the central main transformer, resulting in insufficient power supply for the direct connected main transformer, Make a section of the distribution network stop completely.

When there is more than one recovery path, in addition to the single path feeder needs to be considered, it is also necessary to integrate the load transfer coefficient of the multi-path feeder. The transfer amount of each feeder is different, which can be obtained from Formula 4.

$$F_j = \sum_{k=1}^{u} C_k \tag{4}$$

Where parameter u is the total number of interconnection switches to be actuated on the load transfer path; parameter k is the interconnection switch to be operated for each transfer path; the C_k unit value can be taken for the time taken for the interconnection switch to be actuated to close, and C_k basic dimension can be set according to the actual situation.

Then, the constraint conditions of multi-path feeder are shown in formula 5.

$$F_j \beta_j P_j \leq \min \quad \{V_j(1-n_j), P_j\} \tag{5}$$

Where V_j is the line capacity of multi-path feeder j; n_j indicates the initial load rate of the line; F_j is the load transfer coefficient of multi-path feeder.

Before selecting the transfer path scheme B, it is necessary to screen the transfer path scheme B obtained from the integer planning. Each main transformer needs to judge whether it is overloaded due to the transfer, and the maximum power supply recovery cannot be less than the current power supply when the fault occurs, and perhaps the maximum power supply recovery can be far greater than the current power supply, meeting the current conditions to a large extent, However, since the large fluctuation of electricity before and after recovery may cause instability of the entire distribution network, and also cause large economic losses due to the transfer of electricity, this scheme should not be selected as far as possible, but rather a stable transfer scheme that can meet the current electricity demand. After finding the transfer route scheme that meets the conditions, if the current main transformer has been completely shut down due to a fault, the best transfer route scheme can be selected at the first time. The specific algorithm steps are as follows:

(1)Traverse the directly connected main transformer of the central main transformer. According to the transfer path scheme B, use the following formula to obtain the overload capacity p_k of each main transformer, and form the overload vector P={p_1, p_2,..., p_k,..., p_n} of the main transformer.

$$p_k = \sum_{i,j\in \Omega} \left(X_i + Y_j\right) - U_k(e_{kmax} - e_k) \quad (6)$$

As is shown in formula 6, p_k represents the overload capacity of the kth main transformer; Ω represents the set of single path and multi-path feeder lines transferred to the kth main transformer; U_k is the limited capacity of the kth main transformer; e_{kmax} is its maximum allowable load rate; e_k is its initial load rate.

(2) Traverse the overload variable P of the main transformer, and judge the positive and negative p_k. If p_k>0 exists, set the id_k direct connected step-down transformer to the fault step-down transformer D, transfer the secondary connected main transformer to the direct connected main transformer, and re use integer programming to obtain a new transfer path of the fault main transformer.

(3) Judging if maximum restored supply of electric power F of the current scheme B is greater than the current supply of electric power of the central step-down transformer, and discard the transfer path scheme B that is less than the current power supply. Save the qualified transfer path in the transfer path selection set.

(4) Traverse the total energy E_i of the power system under each transfer path scheme Bi in the transfer path selection set, and then compare it with the total energy E_0 of the entire power system under the current state. Discard the transfer path scheme that is less than E_0. The transfer path scheme that meets the conditions will arrange the transfer path schemes Bi from small to large according to the value of E_i.

(5) The simulation program is taken into the application on the electric power flow section calculating after power transfer from front to back for the sorted set of transfer path schemes. When the transfer path scheme meeting the stability and security conditions of the power grid is found, the scheme at this time meets the requirements. If all the transfer paths have been traversed and there is no transfer path scheme meeting the requirements, the multi-level transfer path of the central main transformer is solved again.

5. APPLICATION RESULTS

Through the simulation experiment on the feeder of a regional central substation in an eastern prefecture level city, 22 feeder lines belonging to the substation are obtained, among which 18 feeder lines can be switched to the opposite side by means of switching tie switches, 9 single path feeders and 9 multi-path feeders. According to the research results proposed in this paper, any one or more feeders are simulated to be powered off due to fault, and load transfer paths are quickly screened out within 1-3 seconds for decision making departments to choose, and the screening results are further screened in combination with restrictions.

Table 1. Comparison of line load rates corresponding to different supply transfer path schemes

Number of line	Original load rate	Transfer path 1	Transfer path 2	Transfer path 3	Transfer path 4
1	0.25	0.55	0.83	0.56	0.55
2	0.33	0.72	0.55	0.65	0.58
3	0.24	0.54	0.45	0.61	0.53
4	0.27	0.41	0.46	0.42	0.5

It can be concluded from the table 1 above that the electric load rates of the corresponding lines 2 and 1 have been greatly improved by adopting the first and second supply transfer path schemes, and the load rates are extremely high. Compared with the supply transfer schemes of supply transfer path 3 and 4, the supply transfer scheme of supply transfer path 3 has a significantly higher impact on the line load rates, Therefore, the transfer route 4 is chosen as the optimal transfer route scheme.

In the article, a new multilevel transfer path scheme is proposed under the assumption that some main transformers are in failure. This scheme aims at the maximum power recovery in the fault area, and fully considers the load rate of the feeder and the step-down transformer and other constraints. It transfers the direct connected step-down transformer to the central main transformer. If the direct connected main transformer cannot meet its own power load after transferring the load to the central main transformer, it transfers the direct connected step-down transformer to the secondary main transformer. For the final transfer path, there may be other security risks. This scheme selects the optimal path from the conditions of the supply of electric power in the fault area, the overall power supply, the power fluctuation before and after the power recovery, and the power stability under the transfer path. If the subsequent main transformer fails, it can quickly transfer the load according to the identified transfer path, effectively solving the problem of long transfer time The algorithm efficiency is low, and the scheme comprehensively considers multiple factors, making the scheme robust. The experiment shows that this scheme can identify the optimal multi-level transfer path scheme quickly, reliably and safely when the main transformer fails, and effectively improve the fault emergency capability of the distribution network.

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