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Improved analytical method of power supply capability on distribution systems

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ABSTRACT

Accurate calculation and evaluation of power supply capability (PSC) for distribution systems is a promising research direction in urban power grid planning. Traditional calculation methods only consider transformer interconnection and $N-1$ contingency in evaluating PSC, without considering interconnection capacity constraint and short-term overloading of main transformers, etc. This paper proposes an improved analytical calculation method for calculating PSC. Firstly, based on traditional calculation process, a connection constraint matrix is built to stand for the capacity differences of tie lines inter different substations. Secondly, a virtual link matrix and load transfer matrix are defined to describe load transfer capability of the overloaded transformer. Thirdly, some improved analytical steps, including minimum element searching, longitudinal adjustment, deviation straightening, are proposed to search the maximum loading capability of connection units between main transformers. Lastly, as demonstrated on an actual distribution system, it is concluded that PSC could be calculated more accurately in order to provide new solutions to distribution system planning.

Introduction

As the link of end-users, generation and transmission systems, the distribution system is an important part to guarantee the reliable and economic power supply. The indices of power supply quality include reliability, voltage quality, line loss rate, load supply capability [1], equipment utilization efficiency, etc. Current researches on distribution system planning only paid attention to the numbers of interconnections between different distribution substations and overloaded equipment [2], but they neglected overall supply capability of the power distribution system. Therefore, it has become a key aspect of urban grid planning to evaluate PSC properly [3].

Studies on PSC of distribution systems mostly referred to the concept of power transmission capability (PTC) on power grids [4–9]. So far, the researches on PSC evaluation are mainly divided into three stages: (1) the existing methods merely considered substation capacity, such as loading factor method [10,11], but ignored the impact of distribution line capacities and connection structure; (2) they considered distribution lines capacities, such as maximum loading multipliers method [12], maximum power flow method [13–18], load supply capability [19], trial method [20] and combined substation capacities and feeder capacities, but ignored the impact of distribution network structure; (3) they can determine detailed PSC based on $N-1$ contingency and the connection between substations [21–26], but achieved results are smaller than they should be due to ignorance of the impact of tie-line capacity constraint and short-term overloading of main transformers, etc.

In order to resolve the problems in the last stage, some improved strategies are proposed by focusing on connection capacity constraints between distribution lines, short-term overloading capability of main transformers in a substation, the adjustment of the element in maximum loading matrix, etc. Through adopting these strategies, an analytical calculation method is achieved to accurately evaluate PSC for distribution systems.

Basic concepts and problems description

Existing research [22–26]

Defined the basic PSC concept of power distribution systems, and presented an analytical method to calculate maximum PSC based on the main transformer interconnection and $N-1$ contingency. This method is more advanced than the calculation method using tentative approximation of objective value and satisfaction of the constraints. The base analysis flow is shown in Fig. 1.

The method analyses connection units, and focuses on the basic fact that network interconnection can produce transfer capability. The transformer connection matrix can show the weakness of

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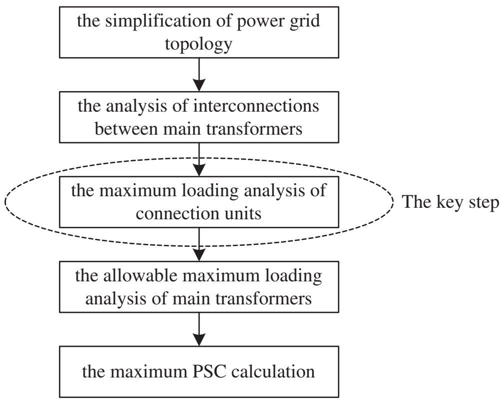

Fig. 1. Steps of the PSC analysis based on interconnections between main transformers.

network connection. The transformer maximum loading matrix shows the load transfer bottleneck of distribution systems. Therefore, the conclusion from the above method can provide valuable information for network structure optimization.

Disadvantages of the existing method

In the maximum loading analysis of connection units, the method in [25] mainly has the following three disadvantages:

(1) It does not consider the constraints of the actual connection capacity between main transformers, which can overestimate the results.
(2) In considering the main transformer overloading factor k, it just expands the transformer capacity directly, but neglects the fact that the main transformer only is allowed to be overloaded for a short term, and the overloading has to be transferred (indirect load transfer).
(3) It obtains the main transformer loading vector just by selecting minimum value of each column in the main transformer loading matrix, but it could underestimate the results.

This paper will provide some reasonable solutions for resolving above problems.

The improved strategies

Constraint of connection capacity between main transformers

There are different numbers of tie-lines between main transformers and each connection has different loading. When one transformer is faulty, transfer capacity provided by other transformers would be constrained by the connection routes differently. Therefore, the connection constraint matrix should be built to describe the problem in the second step of Fig. 1.

Indirect load transfer for overloaded transformer

The actual load transfer mode considering the overloading capability of transformers is shown in Fig. 2.

As seen from Fig. 2, when one transformer (transformer 1) breaks down, the transformers (such as transformer 2 and 3) directly connected to it can share its load. Among them, the transformers (such as transformer 3) inter substation cannot be overloaded, and the transformers inner substation (transformer 2) are allowed to bed overloaded for a short time, but the overloading cannot exceed a certain constraint. Moreover, through manual or automatic operation, overloading has to be transferred to other transformers (transformer 4, 5 and 6) inter substation, and all transformers (transformer 2, 3, 4, 5 and 6) should not be overloaded at this time. In this calculation process, the capacity constraints of tie-lines should be considered. A virtual connection matrix needs to be built to describe the indirect load transfer in the third step of Fig. 1.

Potential mining of transformer loading matrix

In the fourth step of Fig. 1, it produces the mismatch of the PSC to find the minimum value of each column in the transformer loading matrix. Therefore, the potential mining strategy presented in this paper is shown as follows. Firstly, the minimum non-zero element is searched in transformer loading matrix. Secondly, other elements in the same column are adjusted to the same value. Thirdly, the differences in the adjustment are distributed into others elements in the same row, which should satisfy $N-1$ contingency. All rows should be traversed. Lastly, the above steps need to be repeated for all other columns until all columns are traversed.

Specific improving method

Definition of connection constraint matrix $\mathbf{C}$

There are n substations in the research area, which are numbered as 1, 2, ..., n. The main transformers in each substation are numbered as N_1, N_2, ..., N_n. Therefore, the main transformer j in substation i is numbered as $(\sum_1^{i-1} N_i + j)$, and $\sum_1^i N_i$ is marked as $N_{i\Sigma}$. Then the main transformer j in substation i is also numbered as $(N_{(i-1)\Sigma} + j)$, and the $N_\Sigma = \sum_{i=1}^n N_i$ represents the total number of main transformers in this area. The capacity of main transformer i is R_i.

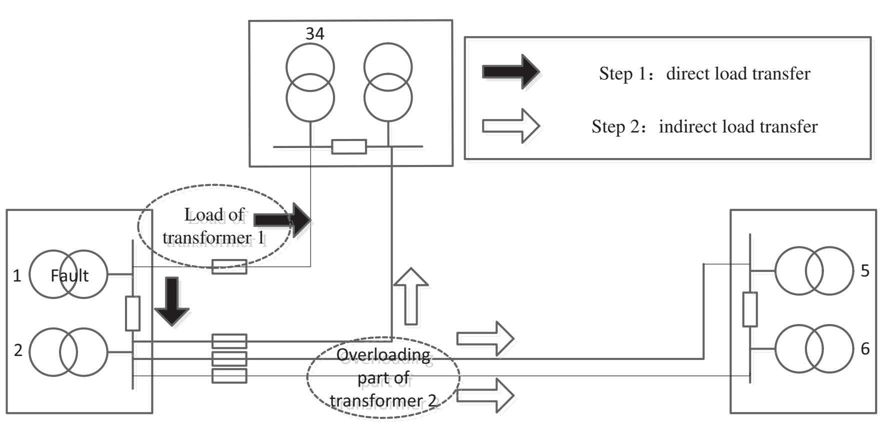

Fig. 2. Load transfer mode of actual distribution systems.