ANALYSIS OF INFLUENCE FACTOR ON TSC FOR DISTRIBUTION SYSTEMS

Jun XIAO
Tianjin University - China
xiaojun.tj@gmail.com

Xiaodan GUO
Tianjin University - China
clearfire@163.com

Wenzhuo GU
Tianjin University - China
guwenzhuo1988@163.com

ABSTRACT

This paper is based on the accurate calculation of the Total Supply Capability (TSC) of a distribution system, proposing a method for distribution planning and optimization. First, it introduces the basic concept and calculation of TSC, depicting its mathematical model. Then, it analyzes all influence factors on TSC, including the substation influence factor and the network influence factor, in quantitative domain using sensitivity to quantify the impact of factors. Economical methods to improve TSC are supplied. By comparing the change of transformers' average loadability by practical case, it verifies the accuracy and effectiveness of the conclusion and methods the paper provides.

INTRODUCTION

Recently, the planning and optimization of distribution system has drawn the power relevant departments' attention [1]. In many developed countries, such as the US and most of Europe, land price is extremely high. It is very difficult and expensive to obtain new substation sites and underground paths for new feeders [2]. Thus, more and more attentions have been put on the current total supply capability (TSC) of the existing network and its potential after some optimization [3]. At the same time, in developing countries like China, with fast expansion of distribution systems, it is necessary to evaluate the TSC for both current real distribution systems and planned virtual systems [4].

Calculation of the TSC has developed into a mature, accurate and reliable method, with the algorithm for TSC is the process to get the objective value of the linear programming model with the aid of linear programming tools like lingo [5-7].

Firstly, the paper introduces the basic concept and calculation of TSC. Then, it analysis all influence factors on TSC, in quantitative domain using sensitivity to quantify the impact of factors. Methods to improve TSC are also supplied. Eventually, it verifies above analysis and method by practical case.

CONCEPT AND CALCULATION FOR TSC

Basic concept for TSC

The TSC for a distribution system is defined as the maximum load it can serve under the expanded N-1 security guideline for distribution systems, taking into account the capacities of the substation transformers, network link topology, link capacity, and other constraints.

Two main factors impact on the TSC, the capacity of each transformer and links between transformers. The link means feeders with tie lines connected a transformer with another one in the same substation or one in another substation. Two types of links exist, the link within substation (LWS) and the link through feeders (LTF). Links influence the security and reliability of distribution systems, ensuring the transferring way in an N-1 case. Capacity of LWS is always considered as enough in reality.

Substation Supply Capability (SSC) is the TSC of a distribution system when each feeder is not linked with any other in a system. Network Transfer Capability (NTC) is the amount of TSC increased by interconnections among feeders.

Hence, TSC is the sum of the SSC and the NTC, as equation (1) shows.

$$TSC=SSC+NTC \tag{1}$$

Calculation for TSC

The calculation is based on a mathematical model whose objective function is the TSC as following.

$$Max\ \ TSC = \sum R_i T_i \tag{1}$$

$$s.t.\ \begin{cases} R_i T_i = \sum\limits_{j\in\Omega_1^{(i)}} tr_{ij} + \sum\limits_{j\in\Omega_2^{(i)}} tr_{ij}\,(\forall i) & (2) \\ tr_{ij} + R_j T_j \le kR_j \left(\forall i, j\in\Omega_1^{(i)}\right) & (3) \\ tr_{ij} + R_j T_j \le R_j \left(\forall i, j\in\Omega_2^{(i)}\right) & (4) \\ tr_{ij} \le RL_{ij} \left(\forall i, j\in\Omega_1^{(i)}\cup\Omega_2^{(i)}\right) & (5) \\ T_{\min} \le T_i \le T_{\max}\,(\forall i) & (6) \end{cases}$$

The model is defined as a linear programming problem, which is easy to be solved by some software such as *Lingo* [7].

ANALYSIS OF INFLUENCE FACTOR ON TSC

According to the basic concept for TSC, the TSC includes SSC and NTC. SSC is mainly influenced by factors of substations, while NTC is mainly influenced by links of the system. Hence, factors can be divided into two kinds, substation influence factors and network influence factors. Substation influence factors consist of a series of parameters related with the substation.

Network influence factors consist of the structure of the system net and the transfer capacity of the LTF.
The two kinds of factors will be discussed respectively. With the concept of the sensitivity, the impact of the factors in quantitative domain will be quantified.

Definition of sensitivity

Each influence factor on TSC is chosen to be controlled variable *U*, while the average loadability of all transformers to be state variable $\overline{T}$. As is known that when controlled variable get small changes, state variable get changes as well. By comparing sensitivity of state variable to different controlled variable, influence of different factors can be quantified.
As the influence factors are in different types, having different unit, the percent of controlled variable's small change $dU_{\%}$ and the percent of state variable's small change $d\overline{T}_{\%}$ are used. Then the sensitivity S is expressed by the ratio of $d\overline{T}_{\%}$ and $dU_{\%}$, as the following equation shows.

$$S = d\overline{T}_{\%} / dU_{\%} \tag{7}$$

Substation influence factors

In most developing countries like China, the regional power consumption level is rapidly increasing. Numerous new substations are required to be added yearly, making the substation influence factor dominant in improving TSC.
Substation influence factors consist of the number of substations and main transformers, transformer's capacity combination, overload factor of transformers, the bound of transformers' loadability.

Number of substations and main transformers

Assuming that the supply capability of links is adequate, SSC is obviously improved by adding more substations and transformers. NTC is also improved as the transferring chance increases in an N-1 contingency. Hence, influence on TSC by changing the number of substations and main transformers is clear high. As a general rule, the sensitivity S is always greater than 1.

Capacity combination of transformers

Obviously, maintaining the same number of transformers, simply adding rated transformer's capacity will increase its load ability, improving SSC in normal conditions and NTC in an N-1 contingency, then TSC is improved definitely. The sensitivity S here is approximately equal to 1.
There are so many transformers in a distribution system that adding each one's capacity is impossible and luxurious. Capacity combination is more significant for distribution planning and optimization.
A distribution system can be divided into small parts of mutual contact, each one includes 2-4 substations. For each part, the capacity combination of transformers can separated into different types, by using equilibrium degree, with 3-substation-example in the following bracket:
(1) Each transformer's capacity in the system is equal, no matter which substation it stays in (2×40MVA, 2×40MVA, 2×40MVA).
(2) Transformers have same capacity with ones in local substation, some substations have same capacity, while others different (2×40MVA, 2×40MVA, 2×50MVA).
(3) Transformers have same capacity with ones in local substation, while different capacity with ones in different substations (2×31.5MVA, 2×40MVA, 2×63MVA).
(4) Transformers have different capacity with others either in local substation or in different substations (31.5+40MVA, 40+50MVA, 50+63MVA).
Obviously, the equilibrium degree is getting lower and lower from the first kind to the forth.
The first kind of capacity combination is an ideal situation, while the forth kind is also not common in current system.
According to a number of related tests, rules about the TSC of an area for all kinds of capacity combination conclude as follows:
(1) Average loadability $\overline{T}$ reaches the maximum when each transformer's capacity in the system is equal, belonging to the first kind.
(2) If the total capacity remains the same, the smaller capacity difference between transformers is, the less kinds of transformers' capacity, the higher average loadability $\overline{T}$ reaches.
(3) If the capacity difference between transformers remains the same, the larger the total capacity is, the higher average loadability $\overline{T}$ reaches.
As a consequence, $\overline{T}$ is depended on the equilibrium degree of different transformers' capacity. The higher the equilibrium degree is ,the higher $\overline{T}$ reaches.

Overload factor of transformers

The overload factor of transformers allowed for a short time, *k*, is determined by main transformer parameters, varies from 1 to 1.5. In an N-1 case, the transformer where the fault occurs with which the load on transformers in the same substation cannot exceed their short-term capacity rating, limited by *k*. Choosing a transformer with a higher *k* ensures more transferring chance and a higher TSC of distribution system. For a common small system, the sensitivity S is between 0.1 and 0.3.

Bound of transformers' loadability

The lower bound T_{min} and the upper bound T_{max} of transformers' loadability limit load rate under both normal operation and N-1 case, which are depended on local electricity consumption and system parameters. T_{min} is always between 0.3 and 0.5, as high T_{min} may lead to system going beyond N-1 security. Increasing T_{max} will enlarge transformers' available capacity, then improve the TSC. The sensitivity of T_{max} is similar to the one of transformers' capacity, which is equal or less than 1.

Network influence factors

In many developed countries, improving the links appropriately and optimizing the network structure on the basis of currently existing distribution system has become the primary measures of developing the supply capability of distribution system. This is improving supply capability by changing network influence factors.

Network influence factors consist of the number of links, the location of LTF and the limit transfer capacity of the LTF, while the first two factors stand for the structure of the system net.

Network structure

In current existing distribution system, generally speaking, more links will improve TSC while less reduce it. While in some cases, TSC maintains the same when some links are added or removed. Thus, the effectiveness of links on TSC is defined:

If disconnecting L_{ij}（L_{ji}）, LTF between transformer i and transformer j, makes TSC decrease, link L_{ij} has the effect to improve the TSC of the system. It's called that link L_{ij} is effective on TSC. Else, if it makes no difference, that L_{ij} doesn't improve the TSC of the system, it's called that link L_{ij} is ineffective on TSC.

The control variate method is used in smaller size distribution network. The topology of network structure is changed merely, while other influence factors maintain unchanged. Through comparing the former TSC with the one after added on L_{ij}（L_{ji}）, whether the link is effective can be judged.

According to the effectiveness of links on different network topology, some conclusions can be reached.

1. Regularity applied to most systems with multiple links: the analysis shows that for the general system with several links (whose quantity of links is less than the half of the entire quantity), whether links of different transformers in the same substation are equal affects the TSC of the system. That means that it's the equilibrium degree of links on one substation's different transformers making sense. The higher the equilibrium degree is, the larger the TSC is.

If adding a link to a current system makes the equilibrium degree higher on both ends, the link is always effective to the TSC. If makes the equilibrium degree lower on both ends, the link is always ineffective to the TSC. If makes one end higher while the other lower, the link's effectiveness cannot be decided. Other methods are needed.

The regularity above can be expressed by formulas as follows:

Suppose that the transformer *i* and transformer *j* linked by $L_{i,j}$ belong to substation S_i and substation S_j respectively. Apart from transformer *i*, the other transformer in substation S_i is shown as $i1$, while in substation S_j the other transformer is $i2$. The number of links with transformer *i* is shown as N_i, while with transformer *j* is N_{i1}. Also N_j and N_{j1}.

(1) If $N_i > N_{i1}$, and $N_j > N_{j1}$, the link is always effective to the TSC.

(2) If $N_i < N_{i1}$, and $N_j < N_{j1}$, the link is always ineffective to the TSC.

(3) If $N_i > N_{i1}$, but $N_j \le N_{j1}$, or $N_i < N_{i1}$, and $N_j \ge N_{j1}$, he link's effectiveness cannot be judged.

Some special situations, for example: a system with main-spare links, may not meet the regularity above.

2. Regularity applied to special systems with multiple links: If a transformer is only attached to transformers in local substation, not connected with any transformers in other substation, it is called closed transformer. For an unattached small system with links through feeders, if every substation has closed transformers, the system's NTC is zero. It means that all links in the system are ineffective to TSC.

Limit transfer capacity of LTF

As the equation(5), the load transferred in an N-1 case cannot exceed the capacity of any LTF that assumes the transferred load . When some LTF's capacity is not enough, it is not surprising that the load transfer under a presumable fault will be limited. The limit transfer capacity of LTF is a influence factor on TSC, whose sensitivity is not high, between 0.03 and 0.1.

The limiting LTF is called bottleneck links. As the existence of bottleneck links limit the TSC, it's necessary to resize the conductor of them in distribution systems to supply more load in an existing network.

CASE STUDY

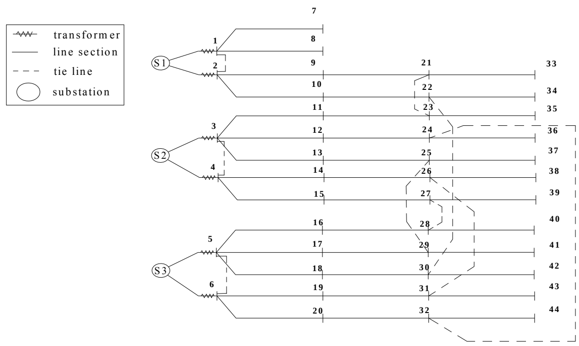

Fig. 1 Test distribution system with 44 nodes

Analysis of the test system

In this section, analysis results about all influence factors are tested on an actual distribution system with 44 nodes and 6 transformers in 3 substations (node 1-6). The data of the test system are shown in Tables 1 and 2. The conductor name is based on the national electrical code in China. The conductors of all the main feeders are JKLYJ-185 with a capacity of 11.3 MVA.

Tab.1 Substation data of the network

Substation	Transformer	Voltage Ratio (kV/kV)	Capacity(MVA)
S1	1	35/10	40.0

	2	35/10	40.0
S2	3	35/10	40.0
	4	35/10	40.0
S3	5	110/10	63.0
	6	110/10	63.0

Tab.2 Conductors and capacities of the tie lines in the study case

Tie line	Conductor	Capacity (MVA)
21-23	JKLV-120	6.35
22-30	JKLYJ-185	11.3
25-29	JKLYJ-120	7.64
24-32	JKLYJ-70	4.43
27-28	JKLYJ-150	8.83
26-31	JKLYJ-95	6.02

According to basic concept for TSC, the TSC, SSC, NTC of the test system can be calculated respectively to be 211.20 MVA, 143.00MVA, 68.20 MVA. And the average loadability $\overline{T}$ is 0.738.

Test on influence factors

Using the control variate method, change the substation and network influence factor respectively and compare the test result with the paper.

Different capacity combination of transformers

Assume that capacity of LTF is enough, changes of capacity combination cause different TSC and $\overline{T}$, as shown in table 3.

Tab.3 TSC and $\overline{T}$ for different capacity combination of transformers

Substation	Transformer	Original capacity (MVA)	Plan 1 capacity (MVA)	Plan 2 capacity (MVA)	Plan 3 capacity (MVA)
S1	1	40.0	40.0	63.0	50.0
	2	40.0	40.0	63.0	50.0
S2	3	40.0	40.0	63.0	30.0
	4	40.0	40.0	63.0	30.0
S3	5	63.0	40.0	63.0	63.0
	6	63.0	40.0	63.0	63.0
TSC (MVA)		213.9	184	289.8	206.9
$\overline{T}$		0.748	0.767	0.767	0.723

Test on link effectiveness

Assume that capacity of LTF is enough, the original TSC_o is 213.9MVA. Disconnect $L_{2,5}$, $L_{3,5}$, $L_{4,6}$ respectively, the TSC changes as table IV shows. According to the paper, the links' effectiveness on TSC is estimated by their condition, shown as well in table 4. Obviously, the test result is corresponding to the paper.

Tab.4 Test on link effectiveness of the practice system

Disconnect link	$L_{2,5}$	$L_{3,5}$	$L_{4,6}$
Condition	$N_2 = 2 > N_1 = 0$ $N_5 = 3 > N_6 = 2$	$N_3 = 3 > N_4 = 2$ $N_5 = 3 > N_6 = 2$	$N_4 = 2 < N_3 = 3$ $N_6 = 2 > N_5 = 3$
Effectiveness on TSC	ineffective	ineffective	effective
TSC(MVA)	213.9= TSC_o	213.9= TSC_o	209.9< TSC_o

Sensitivity of influence factors

The result of sensitivity for different influence factors on the practical system is shown in table 5.

Tab.5 Sensitivity of influence factors

Influence factor	sensitivity
Transformers' number	1.2
Transformers' capacity	1
Overload factor of transformer	0.1621
upper bound of transformer loadability	1
network structure	0.45
link capacity	0.0375

CONCLUSION

As TSC is a potential and significant quantitative index for distribution systems, the paper analysis all influence factors on TSC. Using the concept of sensitivity, it quantify the impact of factors in quantitative domain. Different methods to improve TSC are described. By comparing the results of a practical case with the conclusion the paper supplies, it illustrates its correctness and effectiveness. The paper provides theoretical basis and specific measures for distribution planning and optimization.

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