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The transmission transfer capability: terms, definitions, calculations and applications

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Abstract

This paper reviews the terms used to indicate the transmission transfer capability and their definitions. The calculation techniques are investigated with given numerical examples. The results show that each technique can provide different value of the transfer capacity. The utilization of the value measured transmission transfer capability in power system applications is reviewed and discussed.

Keywords : Transmission transfer capability, Available transfer capability, Total transfer capability

1. Introduction

In electric power system operation, key purpose is to transfer power from generation to end-use in secure manner. Therefore, operating engineers have to ensure that transmission network has enough transfer capability for future transmission in order to support demand growth, activities in electricity market and other changes in electric power system. Indices and values concerning performance and capacity of the transmission system are useful information that the engineers utilize for decision making during both operation and planning phases. Their widely applications are reviewed in section 4 of this paper.

In industries and research works, many terms are used to indicate the transfer capability of transmission network. Their definitions are different depending on the evaluations and using purposes. The widely used terms are Total Transfer Capability (TTC) and Available Transfer Capability (ATC). The TTC is the maximum or all amount of power that can be reliably delivered over transmission network. The ATC is the remaining amount of power above existing transfer that can be reliably delivered over the transmission network. The ATC can have different meanings in details dependent upon security level consideration and operation environment of the system [1] as given in section 2.

Various methods can be utilized to evaluate transmission transfer capability. They are reviewed in section 3. Numerical calculation is made to compare the value obtained from each method as given in section 5. Discussion and comparison are made in section 6.

This paper provides reviewing of the terms referred to transmission transfer capability, definitions, calculation methods and applications. Discussion is made to give idea on utilization of calculation method for a certain application. Better understanding of the

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terms and values leads to effective planning and deploying the transmission network in order to achieve; electric power delivery to customer, flexibility of changing system conditions, reduction of new installed generation capacity and economic exchange of electric power among the system.

2. Terms and Definitions

The value of transmission transfer capability is in MW and the often-used terms are TTC and ATC. The definition of the TTC is given in subsection 2.1 and the definitions of the ATC under variety of names are given in subsection 2.2 – 2.5.

2.1 Total transfer capability (TTC)

The TTC is the amount of electric power that can be transferred over the interconnected transmission network in a reliable manner. The normal consideration for reliably transfer electric power depends on the physical and electrical characteristics of the power system including thermal, voltage and stability limits. Definition provided by NERC [2], the TTC value is based on first contingency consideration. In addition, for higher level of network security, second contingency can be considered.

2.2 Installed incremental transfer capability (IITC)

The IITC is 'the amount of power, incremental above normal base power transfers, that can be transferred over the transmission network in a reliable manner without consideration of any outage [3] The system operated upon to installed transfer capability is at the lowest security level. Therefore, the value of IITC is largest comparison to the values of other terms except TTC value.

2.3 First contingency incremental transfer capability (FCITC)

The FCITC is the most common reference of transmission transfer capability for uncompetitive power system operation. It was provided by North American Electric Reliability Council or NERC in 1995 [4] as 'the amount of power, incremental above normal base power transfers, that can be transferred over the transmission network in a reliable manner based on all of the following conditions'

(1) With normal (pre-contingency)operating procedures, all facility loads are within normal ratings and all voltages are within normal limits.

(2) The electric systems are capable of absorbing the dynamic power swings and remaining stable following any single contingency.

(3) After the dynamic power swings subside following a single contingency, all transmission facility loadings are within emergency ratings and all voltages are within emergency limits.

The first contingency evaluation is taken into account in this definition by considering disturbances which result in loss of single generation unit, transmission circuit or transformer.

2.4 Second Contingency Incremental Transfer Capability (SCITC)

Similar idea to the FCITC with higher security of the power system operation, the SCITC [3] refers to 'the amount of power, incremental above normal base power transfers, that can be transferred over the transmission network in a reliable manner based on all of the following conditions'

(1) With normal (pre-contingency) operating procedures, all facility loads are within normal ratings and all voltages are within normal limits.

(2) The electric systems are capable of absorbing the dynamic power swings and remaining stable following a disturbance resulting in a sequential and overlapping outage of two facilities.

(3) After the dynamic power swings subside following a second contingency, all transmission facility loadings are within emergency ratings and all voltages

are within emergency limits.

This definition provides highest secure transmission without considering activities in the liberal electricity market. The second contingency evaluation is taken into account by considering disturbances which result in loss of two generation units, transmission circuits, transformers or any two combinations.

2.5 Available transfer capability (ATC) in commercial electric power system

To refine the definition given in 1995 for including operation under power system deregulation, NERC introduced the term ATC in 1996 [2] and provided the meaning as a measure of the transfer capability remaining in the physical transmission network for future commercial activity over and above already committed uses. It is also defined as the Total Transfer Capability (TTC) less the Transmission Reliability Margin (TRM), less the sum of existing transmission commitments (which includes retail customer service) and the Capacity Benefit Margin (CBM).

$$ATC = TTC - TRM - CBM \quad (1)$$

Where TTC is defined in section 2.1

TRM is the amount of transmission transfer capability necessary to ensure that the interconnected transmission network is secure under a reasonable range of uncertainties in system conditions.

CBM is defined as the amount of transmission transfer capability reserved by load serving entities to ensure access to generation from interconnected systems to meet generation reliability requirements.

In general, the power system engineers are interested in the additional amount of MW power that can securely be transferred from the starting point to the end point of the path (connecting two areas or nodes). Considered conditions for secure power transmission across the network vary from one operating system to another system. As the term ATC is often used in the meaning of incremental transfer capacity that is not limited only for the deregulated power system. Therefore, in the following section ATC is used as indication of transmission transfer capability.

3. Calculation techniques

This section gives techniques that can be used to calculate the TTC and ATC of a power system as they are continuously introduced by a number of researchers over decades.

3.1 Linear sensitivity

This method gives fast but low accuracy calculation of the ATC by using linear sensitivity without solving power flow solution. The method employs the DC Power Transfer Distribution Factor (DC-PTDF) which is computed from the transmission network information. With resistance of the transmission lines neglected, the entries relating lines and zones being monitored of the bus reactance matrix X and reactance of the line are required for the DC-PTDF calculation. Note that the bus reactance matrix X is inversion of the susceptance matrix in DC power flow model. The DC-PTDF and the approximation of ATC can be determined using the formulas found in [5]. However, the approximation of ATC using DC-PTDF has low accuracy as the transmission line is assumed to be lossless. To improve the accuracy of the method, it is recommended in [6] that losses be included in the calculation by using bus admittance matrix Z instead of bus reactance matrix X and the original flows obtained from DC power flow solution must be added with the approximated real power losses along line.

Moreover, the approximation of ATC using DC-PTDF has limitation as it does not take voltage stability into account. Thus, the approximation of the ATC using AC- distribution factor (AC-DF) is developed to consider voltage stability in [7]. This factor consists of two subfactors. They are AC Power Transfer

Distribution Factor (AC-PTDF) and the Voltage Distribution Factor (VDF).

Similar to DC-PTDF, the AC-PTDF of a line indicates how transaction between zones or buses affects power flow through the line but its value is obtained from the ratio of, change of the real power flow in line (due to change of transaction between zones) and change of the real power transfer between zones.

The VDF of a bus indicates how transaction between zones or buses affects voltage at the bus. The VDF of a bus due to transaction from zones or buses is the ratio of change in bus voltage (due to change of transaction between zones) and change of the real power transfer between zones.

The ATC is the minimum of the maximum allowable transaction over all lines due to both power flow and voltage limits. The formula for approximating the ATC value using AC-DF can be found in [8]. By adding the ATC value to base normal transfer, the TTC is obtained.

The maximum voltage limit is considered in case the transaction affects bus voltage to increasing and the minimum voltage limit is considered in case the transaction affects bus voltage to reduction.

3.2 The repeated power flow method

The calculation of ATC using repeated power flow (RPF) method [9] is performed by slightly increase demand at the receiving zone and increase dispatched power generation from the sending zone to cover increased demand and losses in the considered power system. A typical step size is 1 MW. The smaller step size of demand increment, the higher accuracy of computed ATC value. However, the larger step size can accelerate computation time. Once the demand and generation are increased, the power flow calculation has to be solved for the solution. This process is recursive until system violations are found. Therefore, this method is computationally expensive.

The accuracy of this method depends on the power flow calculation which is in either DC or AC models. For higher accuracy, the AC calculation such as Newton-Raphson method should be utilized. The considered conditions (limits and contingency as stated in the definitions) should be taken to suite an application.

3.3 The continuation power flow method

The continuation power flow (CPF) method [10] is used to find the bifurcation point or point of voltage collapse when load in power system increases up to a certain amount. The trace of PV curve when load at bus 6 of 6-bus test system [11] increases, is shown in figure 1.

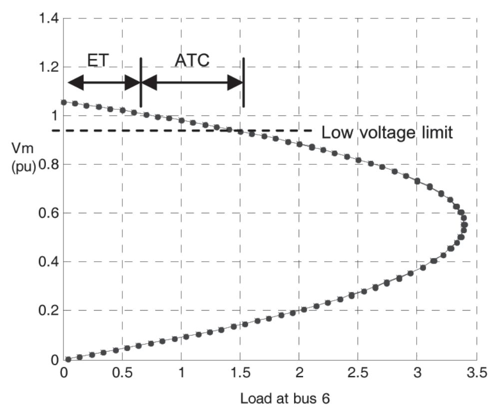

Figure 1 PV curve obtained using CPF

Using this method provides information on the maximum load of a bus at the point of voltage collapse, such as in figure 1, the load at bus 6 can increase upto 3.4 pu and voltage at this bus decreases to 0.55 pu before getting collapse. Without the TRM consideration, the ATC is demand at low voltage limit less existing transaction (ET)[12]. The demand at low voltage limit, equally to ET plus ATC, is the TTC value.

The CPF method is recursive. It starts from the power flow solution of a base case and proceeds with increasing load at considered bus(es). The new bus voltage for new increased demand is firstly predicted and then corrected. Details of steps and formulas used in the CPF method can be found in [12].

The CPF method can be used to determine ATC value of the system. Developed method to include multiple uncertainties is fuzzy CPF [13].

3.4 Optimization method

The conventional optimization methods that are applied to solve the power flow calculation can be employed to determine the ATC value with typical considered constraints [14]. Similarly, the heuristic optimization such as Genetic Algorithm (GA)[15], Tabu Search (TS)[16], Simulated Annealing (SA) [17] and etc. can be used to calculate the ATC associated with the power flow calculation. The searching process of the optimization method produces trial values of generation dispatch from sending zone[18].

The objective is to maximize power transmission between two considered zones subject to thermal, voltage and stability limits. The maximum power transfer can be called the TTC and the TTC less base power transfer becomes the ATC.

3.5 Probabilistic approach

In probabilistic approaches, the variation of power generation is taken into account. Therefore, they give more information of the practical system which normally has demand and supply fluctuations. Statistic approaches such as Monte Carlo simulation [19], stochastic programming [20] and bootstrap technique [21] can be implemented to cope the variations and subsequently, introduce recursively time-consuming process. To accelerate the calculation, linear load flow is employed[22] as it provides faster calculation in comparison to the non-linear one. To apply statistic approaches, a distribution function of transmission transfer capability of considered system is required.

3.6 Pattern recognition method

To avoid the AC power flow calculation which is introduction of computational expensive, the cubic-spline interpolation is used to trace the curves of voltage and power flow variations with respect to the increase of real power transfer to finally obtain the ATC value [23].

Due to its robustness, speed and ability to deal with incomplete or noisy data, the Artificial Neural network (ANN) becomes interesting method for ATC estimation under a certain condition of power system. Some amount of ATC information and the following system conditions such as loads, status of generations and transmission lines are initially used for ANN training process. Thereafter, ANN can provide the estimation of ATC for new system conditions [24,25].

To increase accuracy of the ANN, the Euclidean distance based clustering technique is employed to select the number of hidden radial basis function of neural network in[26] (and to group single line outage contingencies which result into almost similar ATC values in [27].

3.7 Evaluation of transmission reliability margin (TRM) and capacity benefit margin (CBM)

As NERC [2] recommended that ATC in commercial electricity power system be calculated by equation (1), the evaluations of TRM and CBM are parts of ATC calculation for such kind of systems.

The TRM accounts for uncertainties related to the transmission system conditions, contingencies, and parameter values. Thus, it is more likely to require the application of statistic approaches such as parametric bootstrap technique [28] and sequential Monte Carlo simulation [29] to verify the reliability margin. However, the TRM can be estimated using formulas presented in [30] to determine a linear model for changes in transfer capability in terms of changes in any of the power system parameters. The changes of parameters are estimated or measured with some desired degree of safety.

The CBM is usually utilized only in emergency when the amount of generation of some areas is not enough and following loads have to be supplied by purchasing power from other areas. Since the CBM is defined as a specified reserve or capacity margin, it can be based on in-functional capability of the largest generating unit. Thus, the loss of load expectation (LOLE) is often utilized to present the reliability consideration in calculation procedure [31]. For faster calculation, generation reliability exponential analytic model is utilized and solved using the sequential quadratic programming [32]. Additionally, another method is use of heuristic search methods and considers CBM as firm and non-firm transfer. To get rid of complicated and computationally time consuming for large system, CBM is determined for each area[33].

4. Applications

The value indicated transmission transfer capability is normally utilized in both planning and operation. During planning stage, the probabilistic evaluation methods are usually proposed and served as offline tool [24]. The ATC presents how secure the system is, under current operation. It also indicates how long the transmission system is in function within its limit for certain amount of loads and generators. Therefore, it is used in the planning for network reinforcement [5,34] or transmission expansion[35]. It is important information that how good the planning engineers allocate the FACTS devices [8,36].

The ATC increases its important for the electric power system operated under liberal market. It measures the amount of power that can be transmitted through power network over committed transmission usage without system violations. In the operation of bilateral markets, it is used to allocate reservations of transmission rights[37]. The system operators can make use of the ATC value for decision making on the third party access allowance [38]. In the operation of pooled markets, transfer capability combined with bid information can be used to help allocate financial transmission rights or transmission congestion contracts.

In both planning and operations, the ATC can be used to assess power system security when local power sources are replaced by imported power supplied from the other zone(s). The useful value is ATC between the local, sink zone and the source zone(s). In addition, it can be used to provide capacity data for simplified power system models suitable for nodal price forecasting [39].

5. Numerical example

This section gives numerical results of transmission transfer capability evaluation of 6-bus test system in terms of the TTC and ATC. Additionally, the ATC values calculated using methods in subsection 3.1 – 3.4 are also given as those methods provide the ATC value under an instantaneous network conditions. The values obtained using methods in subsections 3.5 and 3.7 which include consideration of system variations are not presented here as this section is aimed to illustrate the difference of ATC evaluation due to method exclude randomness in statistical process.

Table 1 transmission transfer capability under different definitions

TTC(MW)	ATC (MW)		
	IIT	FCIT	SCIT
83.43	13.43	0	0

The configuration of the 6-bus test system is shown in figure 2. The network data can be found in[11]. Table 1 presents the transmission transfer capability in terms of TTC and ATC values under different definitions for transaction between buses 1 and 6 of the test system. The TTC value is calculated without contingency consideration and all values in this table are obtained using the RPF method. In calculation process, the transaction is increasing under a constant power factor of demand.

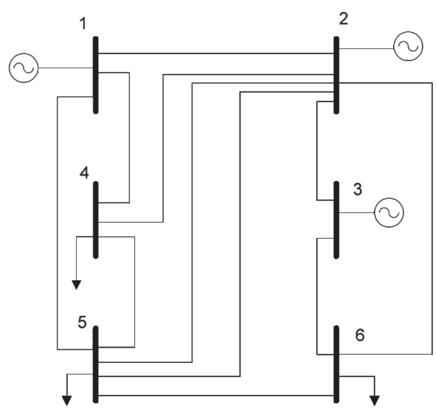

Figure 2 A 6-bus test system

The existing transaction or base power transfer is 70 MW. The ATC as the system installed incremental transfer is 13.43 MW with limitation on thermal limit at branch 3, connecting buses 1 and 5. Under first contingency, the ATC for this test network is zero. Branches 1, 2, 3, 5 and 9 cannot be outage for the incremental transaction. The most flexible line for outage is branch 11 in which its ATC as the FCIT is 17.677 MW. The most limitation found during branch outage is overflow through branch 3. Under second contingency, the ATC is also zero. The most flexible pair for branch outage is branches 4 and 11. The test system can deliver 14.14 MW more during their outages.

To consider calculation techniques, the results of ATC evaluations using different methods are presented in table 2. All values are calculated without contingency consideration.

Table 2 ATC values evaluated using different methods

Methods	ATC (MW)
Linear sensitivity – using DC-PTDF	14.78
Linear sensitivity – using AC-DF	13.43
RPF	13.43
CPF	65
Optimization method - GA	13.43

From Table 2, the ATC values calculated using RPF method, linear sensitivity using AC-DF and optimization method are 13.43MW. Limitation of the transaction is over flow through branch 3. It can be noticed that the value obtained from CPF method is much larger as thermal limit is not taken into account. In case, the thermal limit is neglected under proceeding of RPF method, the ATC value is 64.34MW which is very close to that obtained from CPF method. In addition, the CPF method does not always give higher ATC value as in some case the voltage limit is more stressful than thermal limit.

The linear sensitivity using AC-DF gives the same value obtained from RPF method in this case. However, the linear sensitivity is generally an approximate which is less accurate than a small-step RPF. In the beginning phase of planning task, the linear sensitivity using AC-DF is recommended as it gives fast calculation and adequate-information value.

The linear sensitivity using DC-PTDF, in this case, gives approximately 10% higher ATC value than that obtained from other methods (except CPF) as lossless model is employed in calculation.

6. Discussion

From the numerical example in section 5, the TTC value is always higher than the ATC value as it includes the base normal transfer. The ATC value is dependent on definition. In other words, it depends on security and operating conditions.

Under deregulated operation, the ATC value is smaller than that under the regulated one as transmission margin is required for transfer activities due to trading in electricity market.

The ATC evaluation under N-1, N-2 contingencies provide information on the most stressful circuit or equipment. Consequently, it can be used to order the priority of system reinforcement strategies. Associated with knowledge about the system of the operating engineers, good and economic planning can be made.

During planning phase, time is not as limit as that in operating phase. Therefore, the time consuming evaluation method such as RPF and CPF methods can ideally be implemented. In the system regularly facing voltage stability problem, the CPF method is recommended. However, in some application that accuracy of the value is not necessary, faster method such as linear sensitivity should be employed. Additionally, stochastic method should be utilized for better evaluation in practical system.

During operating phase especially in liberalized electricity market, it is necessary that the ATC value is evaluated in short time. Pattern recognition method has increase of its popularity as it fast provides the value from the pattern of value changing in the past.

7. Conclusion

The value indicating transmission transfer capability is usually stated in two terms; TTC and ATC. The transfer capability is depending on operating and security conditions. They are widely implemented in both planning and operating phases of power system. The method and taken condition during evaluation should be selected in order to be appropriate with the application.

This paper gives basic knowledge on the terms, definitions, calculation methods and applications of the transmission transfer capability. This revision provides information that support increase of understanding about the indication and utilization of the transmission

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