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DETERMINATION OF AVAILABLE TRANSFER CAPABILITY CONSIDERING REAL-TIME WEATHER CONDITIONS

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ABSTRACT
In order to estimate Available Transfer Capability (ATC), Total Transfer Capability (TTC) should be beforehand determined. Typically, the TTC is determined considering three terms; thermal, voltage and stability limits. Considering the transmission line length of Korea Electric Power Corporation (KEPCO) system, Thermal Limits is given a great deal of weight on the evaluation of TTC.

Therefore, this paper presents a new approach to evaluate the TTC using the Dynamic Line Rating (DLR) for the thermal limit.

Since the approach includes not only traditional electrical constraints but also real-time environmental constraints, from economical point of view, this paper could obtain more exact and useful results.

T hrough the case study using KEPCO system, it is confirmed that the proposed method can be used for real-time operation and the planning of electricity market.

KEY WORDS
Available Transfer Capability (ATC), Total Transfer Capability (TTC), Dynamic Line Rating (DLR), Weather Effect

1. Introduction

Since all components of the power system have been controlled by only one organ, the sectional losses due to the excessive investment or low utilization ratio were not big problem in the past. Namely, this problem did not appear on the surface before vertical de-integration. However, during the last a few years there has been a significant change in the operation of power system, and these losses have became to a matter of the utmost concern. In the developed countries in aspect of the power economics, there have been many studies to improve the facility efficiency such as the utilization ratios of each transmission line.

When the power industry is restructured, it is particularly important to evaluate exactly Available Transfer Capability (ATC), where the ATC is defined as the measure of the transfer capability remaining in the physical transmission network for further commercial activity above already committed uses. Because ATC values are the key to competitive electricity markets as indices that determine whether proposed particular transactions of electric power among participants could be approved or not [1]. Therefore, there have been many approaches to quantify ATC, and most approaches were based on deterministic methods such as Continuous Power Flow (CPF) and Power Transfer Distribution Factor (PTDF) [2], [3]. However, there have been few ATC studies considering the external factors; the line lengths of simulated system, atmospheric environments, system's seasonal characters and so on. From a practical view, it is important to determine the evaluation method after giving careful consideration of the actual operation conditions, because each power system has its own peculiarities.

Therefore, this paper would lay emphasis on the scheme to revalue ATC from practical standpoints, and propose to replace the singular thermal limit with Dynamic Line Rating (DLR) considering seasonal system conditions.

To confirm the usefulness of suggested scheme, a case study is performed using the power systems of Korea Electric Power Corporation (KEPCO), and the calculated ATC values are analyzed with the varying standards.

2. Concepts of ATC

According to the definition of North American Electric Reliability Council (NERC), ATC is determined as a function of increase in power transfers between different systems through prescribed interfaces [1].

2.1 Constituent of ATC

ATC determination involves several parameters; Total Transfer Capability (TTC), Capacity Benefit Margin (CBM) and Transmission Reliability Margin (TRM). The definitions of these three parameters are given as follows.

The TTC is the largest flow through the selected interface, which causes no thermal overloads, voltage limit violations, voltage collapse and/or any other system security problems such as transient stability.

The TRM is the reserved capability that accounts for uncertainties related to the transmission system conditions, contingencies, and parameter values. The TRM is the amount of transmission capability required to ensure that the interconnected network is secure under a reasonable range of uncertainties in system conditions.

The CBM is the amount of transmission transfer capability reserved by Load Serving Entities (LSE) to ensure access to generation from interconnected systems. CBM is reserved to meet the generation reliability requirements of LSE.

ATC can be expressed as

$$ATC = TTC - TRM - ETC - CBM \qquad (1)$$

where ETC is Existing Transmission Commitment.

2.2 Assessment of TTC

TTC is limited by any one of Thermal, Voltage, and Stability Limits because this value is defined as the ability to reliably transfer electric power. Therefore TTC is determined by the minimum value among the three limit conditions at that time.

$$TTC = Mim\{Thermal, Voltage, Stability\ \ Limits\} \qquad (2)$$

where Thermal Limits could be physically limited by the weather effect, but others are just electric limits.

Figure 1 illustrates the concepts of (1), (2).

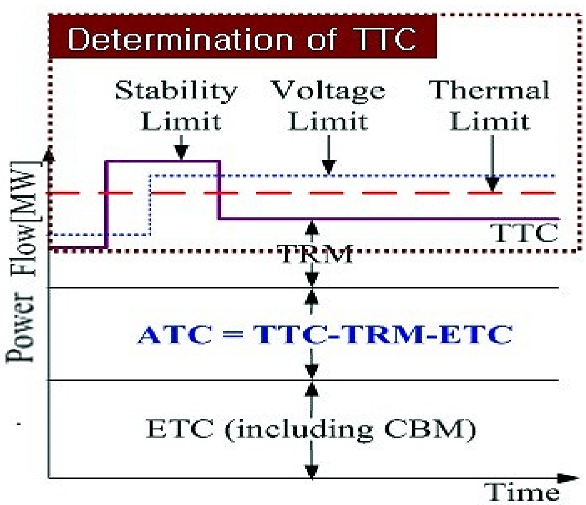

Fig. 1 Concepts of ATC and TTC

2.3 Parameters for Reliability Margin

Among the parameters for ATC, TRM and CBM are the factors that account for the uncertainty and reliability in the power system. Namely, to ensure reliable system operation even if contingency is created, the evaluation of this reliability margin is indispensable.

TRM can be evaluated as shown in Figure 2.

All possible cases in the system should be considered, but the selected several cases are used typically. Alternative cases from 1 to 4 represent the cases selected considering their occurrence potentialities.

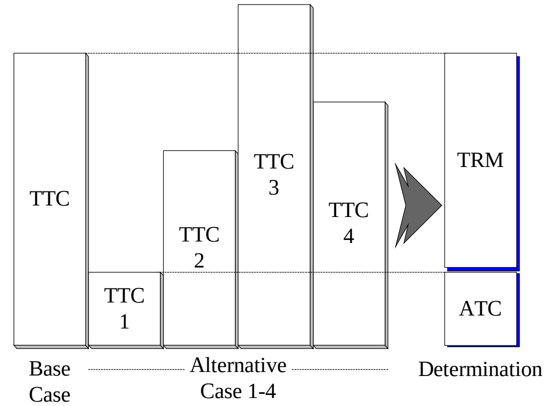

Fig. 2 Determination of TRM from alternative cases

3. ATC evaluation considering seasonal system conditions

3.1 Actual Circumstance of Korean Power Systems

The six main transmission lines above 345(kV) class which are responsible for north bound power flow in Seoul metropolitan region are chosen as tie lines for computing TTC and ATC.

Table 1 shows the approximated values of transmission capability using Load Ability Curve in Figure 4.

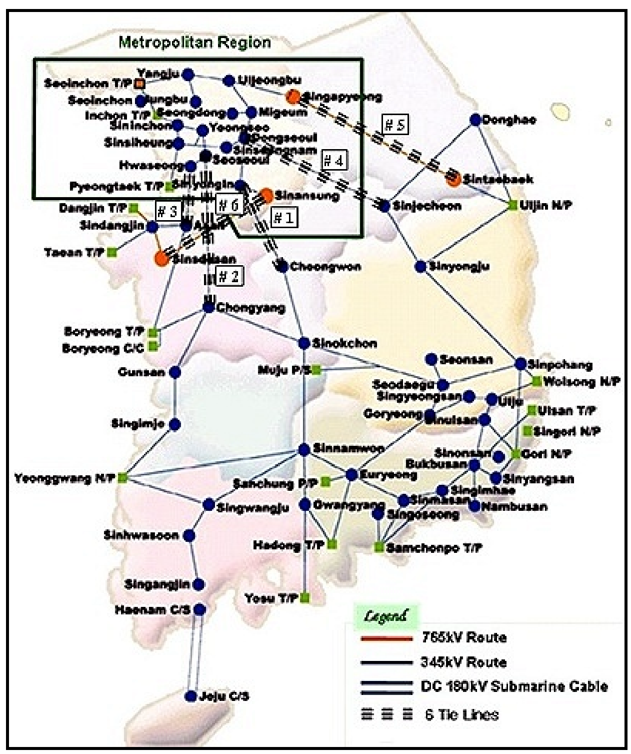

Fig. 3 Six Tie Lines between Two Areas in Korea

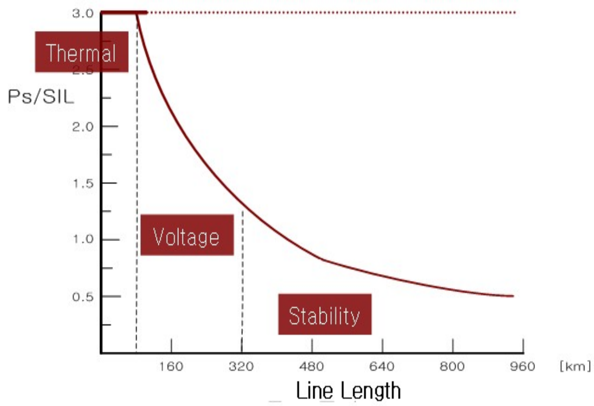

Fig. 4 Load Ability Curve

Table 1. Information and Capability of Tie Lines

Six Tie Lines between Two Areas	Nominal Voltage [kV]	Line Length [km]	Thermal Rating [MW]	Transmission Capability [MW]
#1	345	52.574	1086	1086
#2		108.371	2173	1265
#3		48.184	2173	1910
#4		128.391	2173	1162
#5	765	154.886	7290	4957
#6		137.37	7290	5467

Since the lengths of selected tie lines are below 160 km, Stability Limits do not affect TTC enormously. Besides, Voltage Limits do not matter since the Voltage Drop problem is mostly compensated by FACTS device and so on. Therefore Thermal Limits is the most important factor in the case of KEPCO system.

To evaluate ATC, not only the tie lines but also several representative generators should be selected. They are selected as the biggest unit in each area, and represented in Table 2.

Table 1 and 2 would be used to calculate TRM assuming the contingency of each facility.

Table 2. Information of Representative Generator

Representative Generator	Location	Max. Generation [MW]
GEN#1	Metropolitan	880
GEN#2	Nonmetropolitan	1055

3.2 Thermal Rating considering Korean Weather Conditions

To compare with the seasonal results of ATC, it will be simulated by selecting representative date and time as shown in Table 3.

As state above, Voltage and Stability Limits are determined by just electric characteristic. On the other hand, the weather effect could be applied to Thermal Limits since it is physical limits.

Therefore, this paper suggests estimating Thermal Limits using Dynamic Line Rating (DLR) instead of Static Line Rating (SLR); SLR means the maximum permissible current calculated by the conditions of the worst weather state which is predefined in each country. DLR also can be calculated by Heat Balance Equation with the normal weather conditions instead of the worst state [4]. DLR technique has been already examined for several case studies [5]-[7].

Figure 5 shows the calculated results of Heat Balance Equation using Asan T/L (#3) in KEPCO system [8], and the figure includes the comparison DLR and SLR.

Table 3. Selected Dates and Time of Each Season

Season	Simulated Date & Time	Load Condition	Total Generation [MW]	
			Metropolitan	Other Areas
Spring	2006. 4. 8 4 a.m.	off-peak	5385.0	35519.0
	2006. 4. 8 7 p.m.	peak	9122.0	40493.0
Summer	2006. 8. 8 5 a.m.	off-peak	3454.0	34997.5
	2006. 8. 8 3 p.m.	peak	11617.0	43152.9
Autumn	2006.10. 8 4 a.m.	off-peak	3227.0	33084.9
	2006.10. 8 3 p.m.	peak	7974.0	40776.4
Winter	2007. 1. 8 4 a.m.	off-peak	5453.0	39127.0
	2007. 1. 8 7 p.m.	peak	10437.0	43323.2

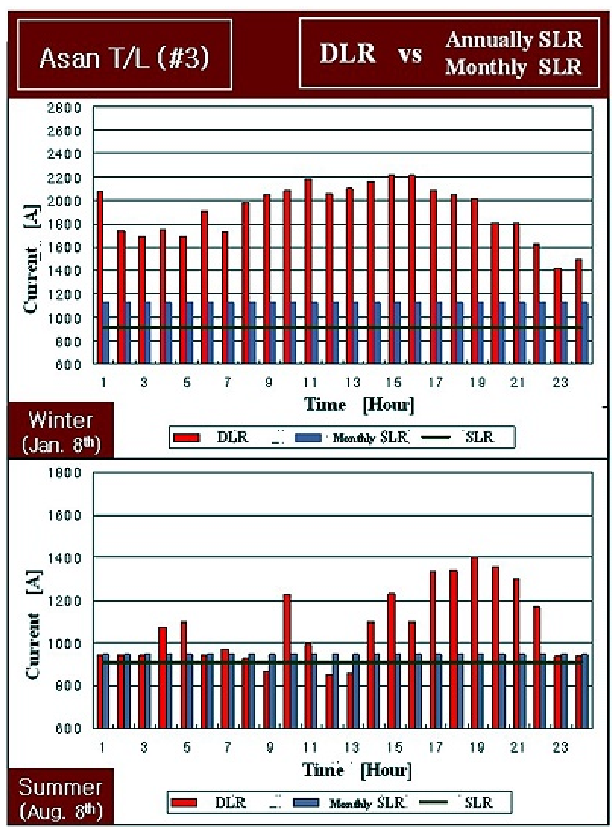

Fig. 5 Comparison of Thermal Ratings

The results illustrate that DLR to consider real- time weather effects is not only exacter but also more economical than SLR to determine in disregard of weather condition's variation.

Table 4 shows the calculated thermal ratings during the period of summer peak representatively.

To illustrate the real-time variance of Thermal Limits according to hourly weather conditions, Figure 6 represents three Limits for TTC including the proposed concept.

Table 4. Thermal Rating Results by Two Standards

Tie Lines	Allowable Current [A/Bundle]		Ratio (SLR /DLR)	Thermal Rating [MW]	
	SLR	DLR		Calculation based on SLR	Calculation based on DLR
#1	917	973	1.06	1086	1152
#2		1419	1.55	2173	3363
#3		1229	1.34	2173	2913
#4		1225	1.34	2173	2903
#5		1300	1.42	7290	10335
#6		1574	1.72	7290	12513

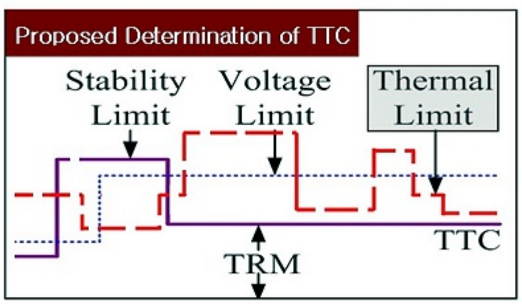

Fig. 6 Proposed Concept for TTC Determination

4. Case Study

In order to confirm usefulness of the proposed ATC evaluation method, the KEPCO systems is simulated.

ATC was calculated by dividing Korean power systems into the metropolitan area and the outside, and the results using PSS/E (ver.30) was computed by monitoring the selected six tie lines. Finally, the calculated ATC values were analyzed with varying standards.

TTC of Base Case is determined as total amounts of transmission between two areas, when the amount of a certain line is reached the limit value with increasing the amount of tie line's power flow. If T/L #3 most uses among the six tie lines at this point of time, for instance, TTC would be determined by this line's congestion as expected.

In order to confirm the effect of voltage compensation [9], this paper is performed with two opposite Assumptions as following.

'Assumption I': It is supposed that the voltage Drop is perfectly compensated and TTC is determined by only Thermal Limits.

'Assumption II': It is supposed that the voltage Drop is not compensated and TTC is determined considering Load Ability Curve in Figure 4.

4.1 Case using SLR

In this section, the results of ATC would be analyzed using the method applying Thermal Limits to SLR. That has been the general way up to the present.

4.1.1 Results with 'Assumption I'

Table 5 shows the alternative cases and the TTC of the each case. The results are performed in spring when loads are off-peak, and use to calculate TRM.

Table 6 shows results calculating ATC using Table 5.

Table 5. Alternative TTC Results (*Assumption I*)

Alternative Case		Result of TTC [MW]
Contingency of Tie Lines	#1	18614.1
	#2	13468.9
	#3	16499.7
	#4	19121.2
	#5	18461.3
	#6	**12192.0**
Contingency of Generator	#1	18862.1
	#2	19371.6
Reduction (-3%) of Line Rating	Six Tie Lines	19085.9

Table 6. ATC Results (*Assumption I*)

Subject / Case	TTC [MW]	TRM [MW]	ETC [MW]	ATC [MW]
Base Case	19739.6	7547.6	8493.6	3698.4
Min. Value of Alternative Case	12192.0	7547.6	8493.6	3698.4

In the same manner, Table 7 is ATC results estimated at the selected representative time of each season. It is obvious facts that ETC moving into the Metropolitan area increases at the moment when considering the characteristics of KEPCO systems. That's why ATC is comparatively the small value in analyzing the results at the peak hours of all seasons.

On the other hand, although the peak hours of summer season are the annual peak hours, ATC of summer peak is the bigger than the others. The reason could be found the reserve generators in the metropolitan area, which have the characteristic of low capacity and high production cost. In other times, the generators of the non-metropolitan area could supply the all loads throughout all over the country .However, at annual peak hours, they mostly take charge of the loads located in non-metropolitan area, and there is the tie lines little possibility of occurring congestion since the reserve generators are operated. Therefore, though the total loads of each area are recorded to the highest value at annual peak, the amounts of transmission are comparatively decreased.

Table 7. Seasonal ATC Results (*Assumption I*)

Season	Load Condition	TTC [MW]	TRM [MW]	ETC [MW]	ATC [MW]
Spring	off-peak	19739.6	7547.6	8493.6	3698.4
	peak	19927.1	6992.7	11320.4	1614.0
Summer	off-peak	21109.6	7214.1	9852.0	4043.5
	peak	21231.5	7457.6	10369.7	3034.2
Autumn	off-peak	19451.5	6956.8	8649.2	3845.5
	peak	20702.3	7021.9	11710.6	1949.8
Winter	off-peak	20460.9	7624.5	8825.9	4010.5
	peak	20502.8	7818.4	11062.5	1621.9

4.1.2 Results with 'Assumption II'

Table 8 shows TTC values of the each Alternative Case by using Table 1 (summer, off-peak).

Table 8. Alternative TTC Results (*Assumption II*)

Alternative Case		Result of TTC [MW]
Contingency of Tie Lines	#1	15299.4
	#2	13243.8
	#3	11551.1
	#4	15137.5
	#5	**8873.5**
	#6	11806.0
Contingency of Generator	#1	15009.2
	#2	15324.9
Reduction (-3%) of Line Rating	Six Tie Lines	15626.9

Table 9. Seasonal ATC Results (*Assumption II*)

Season	Load Condition	TTC [MW]	TRM [MW]	ETC [MW]	ATC [MW]
Summer	off-peak	16010.7	4459.6	9950.1	1601.0
	peak	16654.5	4226.7	10369.7	2058.1
Winter	off-peak	18012.4	4833.0	8825.8	4353.6
	peak	18061.5	5013.0	11062.5	1986.0

At summer off-peak hours, ETC is 9852.0MW as shown in Table 6, but TTC is 8873.5MW when the contingency of T/L #5 should occur as shown in Table 7. The result means that there is quite a possibility of system disruption if the compensation devices are not operated when the contingency of a line among the 765kv class occur.

Table 9 shows results of estimation of ATC considering just 345 kV line's faults when calculating TRM. The results would use to compare with results of estimation of ATC applying DLR in the next section.

4.2 Case using DLR

This section represents simulated ATC considering the weather effects.

The ATC results estimated by DLR in Table 4 are shown in Table 10, where (a), (b) are simulated with '*Assumption I*' and '*Assumption II*', respectively. Also, TRM results in Table 10-(b) have been simulated considering only 345kV line's contingencies just as Table 10.

Table 10. ATC results estimated by DLR

(a) Seasonal ATC Results (*Assumption I*)

Season	Load Condition	TTC [MW]	TRM [MW]	ETC [MW]	ATC [MW]
Summer	off-peak	21809.3	7497.6	9852.0	4459.8
	peak	21891.2	7457.6	10369.7	4063.9
Winter	off-peak	25435.2	9634.5	8825.9	6974.8
	peak	25340.6	9435.6	11062.5	4842.5

(b) Seasonal ATC Results (*Assumption II*)

Season	Load Condition	TTC [MW]	TRM [MW]	ETC [MW]	ATC [MW]
Summer	off-peak	16103.6	4558.4	9852.0	1693.2
	peak	16654.5	4226.7	10369.7	2058.1
Winter	off-peak	18012.4	4833	8825.8	4353.6
	peak	18061.5	5013	11062.5	1986.0

When comparing results in '*Assumption II*' case (See Table 10-(b) with Table 9.) that compensator is not normally operated, the results of ATC estimation little change though thermal rating increases greatly defending on weather condition. Because the electrical limits are lower than the thermal limits, therefore have priority over physical capacity in this case.

On the other hand, when comparing results in '*Assumption I*' case (See Table 10-(a) with Table 7.) assumed that voltage drop is accomplished perfectly, the time results of the proposed ATC estimation increase greatly. Namely, this case can be economically useful information to line operator. These results are compared in Figure 7.

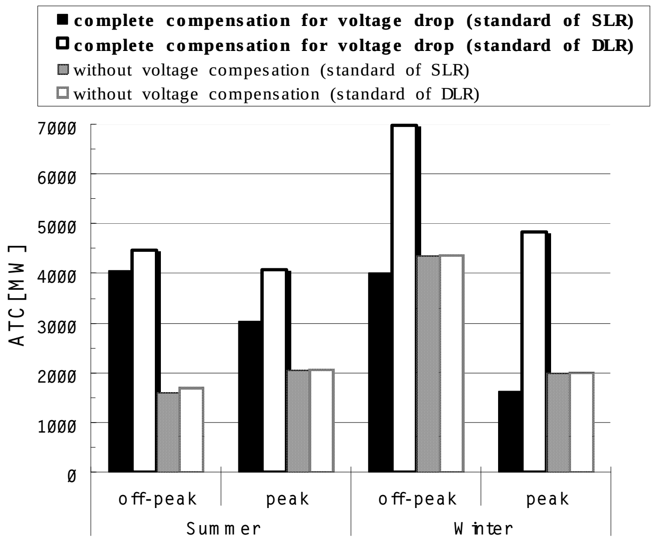

Fig. 7 Comparison of Results

5. Conclusion

The previous studies have been typically applied SLR to ATC estimation. However they were not economical in aspect of the practical operation. Therefore, this paper suggests how to estimate ATC applied DLR in order to overcome the low economic feasibility. The proposed method carries an important meaning that is not only tiding over the economic loss of the static thermal limits but also considering several characteristics of Korean power system. Considering the lengths of Korean power systems, Thermal Limits is the most important condition among three limits to determine TTC .Moreover, Thermal Limits unlike other electrical limits is possible to pre-estimate considering the physical circumstance.

In order to confirm the usefulness of the suggested way, we separate KEPCO system into two areas, analyze seasonal variation of the ATC results, and compare the results of proposed way with the previous one. The fact that the suggested method is useful is verified by analyzing results of a varying point of a simulation, when the voltage drop is compensated well in Korean power systems.

Since the exact ATC estimation should be preceded on restructured power markets for the fair transaction of the electric power, this paper would be used usefully to a base study for the practical estimation of ATC.

Acknowledgement

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