The Journal of CPRI,
Vol. 12, No. 4, December 2016 pp. 671-676

Enhancement of ATC Using Series Compensation In Restructured Power System

Laxmi Niveditha*, Krishna Reddy Ch.V* and Venkata Prasad P*

This paper presents enhancement of the Available Transfer Capability (ATC) using series compensation. It is imperative as part of the nature of the restructured power system to supply reliable and economical power supply. Owing to the expanded nature of the power system and large scale power transactions, it is important to determine ATC in a fast and accurate manner. At the same it is required that the transmission lines be utilised in the most optimum manner and hence requires the enhancement of ATC. The DC-PTDF method is used in this paper to calculate ATC under both intact condition and line outage contingency condition. Further series compensation in done in the transmission lines to enhance the ATC in both the cases. The proposed method is presented using IEEE-6 bus system.

Keywords : *Restructured power system, Available transfer capability, Total transfer Capability, DC load flow, Power transfer distribution factors, Line outage distribution factors.*

1.0 INTRODUCTION

The inception of restructured power system from a vertically integrated system has led to many new challenges. Augmenting to this the open access feature from the FERC had led to large scale power transactions and this will further extend in future. The Independent System Operator (ISO) is now charged with the duties of maintaining the system security and reliability. He is the sole person responsible for conducting fair and equitable transmission tariffs and providing for other system services. Hence an ISO needs to have the knowledge of various power transactions and the amount of power that can be transferred between two interconnected systems. Also the amount of power that can be transacted should be made available for the knowledge of buyers and the sellers on an open access same-time information system. So how does the ISO know the amount of power that can be transferred reliably between two buses? The Available transfer capability and Total Transfer capability (TTC) are useful information regarding the power transferability.

According to FERC, ATC is defined as the transfer capability remaining on a transmission provider's transmission system that is available for further commercial activity over and above already committed uses that has to be made available on OASIS from time to time [1].

Mathematically ATC is give as [2],

ATC = TTC – CBM – TRM - ETC.

Where, CBM is Capacity Benefit Margin, TRM is Transmission Reliability Margin and ETC is the Existing Transmission commitments.

There are various methodologies [3] for the calculation of ATC they are: Continuation power flow, Optimal Power Flow, AC power flow and the DC power flow method. In the continuation

*Department of EEE, Chaitanya Bharathi Institute of Technology(A), Hyderabad

power flow method the ATC value obtained is accurate but it is very time consuming for the large systems as it needs repeated solution of power flow. The PTDF based approach gives very quick results. The AC PTDF's approach sometimes leads to unacceptable results due to its non-linear nature and which are not acceptable. Similarly, the OPF method is also time consuming for large systems. The DC-load flow method is a non iterative and non linear method. DC-PTDF's are easy to calculate and using this the obtained ATC is accurate and reliable. Hence of all the methods available the DC load flow and the DC-PTDF method is very fast. This method can be easily applicable very large systems also. There are various uncertainties to be considered in the calculation of ATC. These uncertainties can be attributed to weather conditions, forced and scheduled transmission outages, and generation unavailability [7].

In this paper, ATC is calculated using the DC load flow method. ATC is calculated under both intact and line outage contingency condition. Further enhancement of ATC using series compensation is done for both the conditions.

This paper is organised as follows: Section II represents the mathematical formulation for enhancement of ATC. Section III presents ATC calculation. Section IV presents the algorithm of the proposed method. Section V presents the results and the discussion. Section VI concludes this work.

2.0 PROBLEM FORMULATION

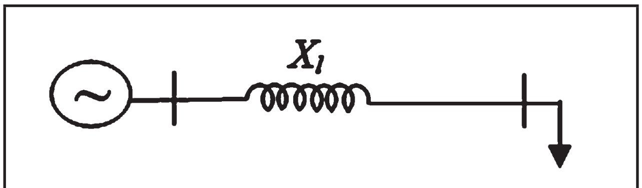

FIG. 1 SINGLE LINE DIAGRAM TRANSMISSION LINE UNDER DC LOAD FLOW ANALYSIS.

ATC from the DC-PTDF method is dependent on the line reactance alone neglecting the line resistance. The single line diagram of a transmission line m-n under DC-load flow method can be shown in Figure 1.

When a series capacitor is connected in series with the line, then the combined reactance on the line is reduced. As shown in Figure 2.

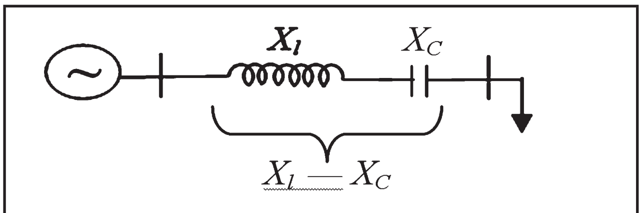

FIG. 2. SINGLE LINE DIAGRAM OF TRANSMISSION LINE WITH SERIES COMPENSATION.

Hence, from Figure 2 it is observed that the line reactance is reduced due to the addition of a series capacitor. Further, the ATC value is dependent on the PTDF's and LODF's (sensitivity factors). These factors are again dependent on the line reactance alone. Hence by changing the line reactance using the series compensation, the ATC also changes.

The new reactance of line ij due to addition of a series capacitor is given as:

$$X_{ij,\ new} = X_{ij} - X_c \qquad ...(1)$$

Due to this change in the reactance, the X_{bus} is changed as $X_{bus,new.}$

Considering a transaction between seller bus m and a buyer n, the DCPTDF for a line between i and j bus with the inclusion of series capacitance is given as:

$$DCPTDF_{ij\text{-}mn\text{-}new} = \frac{X_{im} - X_{jm} - X_{in} + X_{jn}}{x_{ij-new} - x_C} \qquad ...(2)$$

Where, the terms in the numerator are taken from the $X_{bus,new.}$

$X_{ij\text{-}new}$ is the line reactance

X_c is the series capacitance.

2.1 Line Outage Distribution Factors

To include the effect of line outage contingencies on determination of ATC, line outage distribution factors are defined. The DC power flow can be directly used to calculate the effects of each line outage. However, the linear sensitivity factors can speed up the computation. When an outage occurs, the power flowing over the outage line is redistributed on the remaining lines in the system. The line outage distribution factors (LODF) is a measure of this redistribution. $DCLODF_{ij\text{-}rs}$ is the fraction of the power flowing on the line from bus/zone r to bus/zone s before the line outage (P_{rs}^{0}), which now flows over a line from bus/zone i to bus/zone j and can be defined as[6]:

$$DLODF_{ij\text{-}rs} = \frac{\Delta P_{ij-rs}}{P^{0}{}_{rs}} \quad ...(3)$$

Where, r and s are the buses/zones connecting a line, whose outage is being simulated. The concept of the series compensation is applied to line outage and the DCLODF's are expressed as:

$$DCLODF_{ij\text{-}mn} = \frac{N_{rs} \times x_{rs}(X_{ir}-X_{js}-X_{is}+X_{js})}{N_{ij} \times x_{ij-new}[N_{rs}x_{rs}-(X_{rr}-X_{ss}-2X_{rs})]} \quad ...(4)$$

Where,

$X_{ij\text{-}new}$ is the new line reactance due to series compensation and X_{rs} is the series reactance of line under outage connected between r and s bus. The remaining elements are obtained from the $X_{bus,\ new}$.

N_{ij} = number of parallel circuits connecting bus/zone i and bus/zone j.

N_{rs}= number of parallel circuits connecting bus/zone r and bus/zone s.

3.0 ATC CALCULTION

3.1 ATC Determination for Intact System

The *DCPTDFs* are used to determine ATC for different transactions. A transaction from bus/zone m to bus/zone n creates a change ΔP_{ij} in the flow on a line from bus/zone i to bus/zone j. The new flow on the line is the sum of the original flow P_{ij}^{0} and the change in the flow. It must be less than the line flow limit P_{ij}^{max}. Thus, the new line flow [13] is given as:

$$P_{ij}^{new}\left(= P_{ij}^{0} + \Delta P_{ij}\right) \le P_{ij}^{max} \quad ...(5)$$

The maximum increase in the flow of the line between buses i and j for transaction between buses m and n, ΔP_{ij}^{max} can be written as:

$$\Delta P_{ij}^{max} = DCPTDF_{ij,mn-new} \times P_{ij,mn}^{max} \quad ...(6)$$

From eq. (3.9) and eq. (3.10), the allowable maximum transaction amount can be written as:

$$P_{ij,mn}^{max} \le \begin{cases} \dfrac{P_{ij}^{max}-P_{ij}^{0}}{DCPTDF_{ij,mn-new}} & PTDF_{ij,mn} > 0 \\ \dfrac{-P_{ij}^{max}-P_{ij}^{0}}{DCPTDF_{ij,mn-new}} & PTDF_{ij,mn} < 0 \\ \infty & PTDF_{ij,mn} = 0 \end{cases} \quad ...(7)$$

Where,

P_{ij}^{max} is the maximum allowable transaction amount from bus/zone m to bus/zone n constrained by the line flow limit from bus/zone i to bus/zone j. For the given transaction, the ATC can be defined as:

$$ATC_{mn} = min\{P_{ij,mn}^{max}\ ij \in N_l\} \quad ...(8)$$

Where, N_l is the total number of lines in the system.

3.2 ATC determination under Line Outage Condition

According to ATC principles, reasonable level of uncertainties should be accommodated in ATC calculations [6]. Line outage as contingency cases should be considered for ATC calculations as it is limited by the effect of contingencies. DCLODFs and DCPTDFs can be combined together to calculate first contingency incremental transfer capability. This is the maximum increase in the transaction amount from a bus/zone to another bus/zone under (n-1) contingency condition. Consider a transaction from zone m to zone n and the outage of the line from bus/zone r to bus/zone s (line-rs). The change in the flow on the line-rs due to the given transaction including the series compensation is given as:

$$\Delta P_{rs}^{new} = DCPTDF_{rs,mn} \times P_{ij,rs-mn}^{new} \quad ...(9)$$

When the outage of line-rs is considered, the part of the flow appears on line ij. Thus, the change in flow in the line *ij* resulting from outage of the line-*rs* along with a new transaction from bus/zone *m* to bus/zone *n* is given by:

$$\Delta P_{ij,rs}^{new} = \left(OTDF_{ij,rs-mn-new}\right) \times P_{ij,rs-mn}^{new} \quad ...(10)$$

Where,

$$OTDF_{ij,rs-mn-new} = \left(DCPTDF_{ij,mn-new} + DCLODF_{ij,rs} \times DCPTDF_{rs,mn}\right) \quad ...(11)$$

OTDF=outage transfer distribution factor.

Hence, the allowable maximum transaction amount can be written as:

$$P_{ij,rs-mn}^{new} = min\begin{Bmatrix} \frac{P_{ij}^{max} - P_{ij}^{0}}{OTDF_{ij,rs-mn-new}} & OTDF_{ij,rs-mn} > 0 \\ \frac{-P_{ij}^{max} - P_{ij}^{0}}{OTDF_{ij,rs}-mn-new} & OTDF_{ij,rs-mn} < 0 \\ \infty & OTDF_{ij,rs-mn} = 0 \end{Bmatrix} ij \in N_l \quad (12)$$

All possible combinations of outaged lines and limiting lines should be checked. Then, ATC can be evaluated as:

$$ATC_{mn,rs} = min\left(P_{ij,mn}^{max}, P_{ij,rs-mn}^{new}\right) \quad ...(13)$$

4.0 PROPOSED METHOD

The above described methodology for the calculation of ATC and its enhancement both under intact condition and contingency considering the line outage can be summarised in the following Algorithm.

Step 1: Read the system input data.

Step 2: Calculate B and X matrices.

Step 3: Initialize transaction (m-n) count.

Step 4: Perform DC load flow.

Step 5: Select percentage compensation.

Step 6: Compute the DCPTDF using eq. (2).

Step 7: Determine the ATC using eq. (7) and eq. (8)

Step 8: Check for Contingency, if contingency occurs go to step 9, otherwise go to step 13.

Step 9: Check for any line outage. If line outage occurs then go to step 10

Step 10: For the line outage calculate the LODF using eq. (4).

Step 11: Determine the ATC under contingency condition using eq. (13) and eq. (14)

Step 12: Check if all the contingencies are considered, if yes go to step 13 if not go to step 8.

Step 13: Check whether all the transactions are carried, if not consider the next transaction and then go to step 5, if yes go to step 14.

Step 14: Display the results

Step 15: Stop

5.0 RESULTS

The proposed method is presented using IEEE-6 bus system. The transactions chosen are:

(i) Bilateral transactions T1: transaction between seller bus 2 to buyer bus 3.

(ii) Multi-transactions/ Simultaneous Transactions Ts: transaction between seller buses 2, 3 and buyer buses 2, 5.

(iii) Line outage contingency under line 5-6 outage

The ATC obtained under various transactions without series compensation is given in Table 1.

TABLE 1
ATC WITHOUT SERIES COMPENSATION

Transaction	ATC without compensation
2-3	0.1353
2-3, 2-5	0.2153
5-6 Line outage (2-3 transaction)	0.1169
5-6 Line outage (2-3 and 2-5 transaction)	0.2015

TABLE 2
ATC USING COMPENSATION UNDER 2-3 TRANSACTION

Line compensated	% of compensation	ATC
1-5	0.1	0.3769
2-3	0.1	0.2773
2-4	0.5	0.1706
2-5	0.3	0.2756
3-6	0.8	0.2023
4-5	0.2	0.1769
5-6	0.1	0.1561

TABLE 3 ATC USING SERIES COMPENSATION UNDER LINE OUTAGE CONTINGENCY (5-6 OUT)			
Line (s) compensated	% of compensation	Transaction	ATC
1-5	0.1	2-3	0.3909
2-3	0.1		0.2457
1-5,2-3	0.4	2-3 and 2-5	0.3412
3-5,3-6	0.8		

6.0 CONCLUSION

In this paper the ATC is calculated using DC PTDF's for both single transaction and multi transaction case. Also the ATC is calculated under line contingency case using the LODF's. The obtained ATC is then enhanced using series compensation. The DC PTDF method is very fast. It is applicable to vast systems. Enhancement of ATC using series compensation is also gives reliable results.

REFERENCES

[1] Federal Energy Regulatory Commission (FERC), "Regional Transmission Organizations", Washington, DC, Docket RM99-2-000, order 2000, Dec. 20, 1999.

[2] "Available Transfer Capability Definitions and Determination", North American Electric Reliability Council, Reference Document, June 1996.

[3] Manish Patel, Adly A. Girgis, "Review of Available Transfer Capability (ATC) calculation methods" IEEE transactions 2009.

[4] Jitendra Kumar, Ashwan Kumar "Multi-transactions ATC Determination using PTDF based approach in Deregulated Markets" Annual IEEE India Conference, 2011

[5] A. J. Wood and B. F. Woolenberg, "Power Generation, Operation And Control", John Wiley & Sons, 2nd Edition, 1996.

[6] S.Nagalakshmi, S.Kalyani, V.Alamelu Shobana, R.Naga Ranjeni and P.Deepamangai "Estimation of Available Transfer Capability under normal and contingency conditions in Deregulated Electricity Market" IEEE trans. Advances in Engineering, Science and Management (ICAESM), 2012

[7] Mohammed Shahidepour and Muwaffaq Alomoush, Restructured Electrical Power Systems, Operation, Trading, and Volatility, Marcel Dekker, Inc. New York, 2001.