Assessment of Available Transfer Capability (ATC) Using Linear Sensitivity Factors under Deregulated Environment

K. Indhumathy [1], N.B. Rajesh[2], J. Jaya Priya [3]

Abstract – **Electric supply industry throughout the world have been restructured to introduce competition among the market participants and bring several competitive opportunities. The structure of power industry is moving towards deregulatory environment from the regulatory environment. Under this deregulatory, there are many technical issues need to be addressed. In this paper, one such technical issue handled carefully is the Available Transfer Capability (ATC). ATC is the amount of maximum additional power transfer between two control areas (source and sink) that is available without violating thermal overloads. Here ATC is estimated for normal and contingency modes using linear sensitivity factors according to the security and reliability requirements. Simultaneous bilateral transactions have been done on IEEE-30 bus standard system for the assessment of ATC under MATLAB environment. From the results, it is computed that ATC is determined with less computation burden and this study will be useful for the present open access electricity market.**

Keywords: **Available Transfer Capability (ATC), Power Transfer Distribution Factor (PTDF), Outage Transfer Distribution Factor (OTDF), Generator Outage Distribution Factor (GODF).**

I. INTRODUCTION

The electrical power system is continuously increases its size and complexity arises all over the world due to huge population and modernization. Thus government has allowed the private sectors into the power generation, transmission and distribution (Deregulated Power System) by framing certain rules over it. With the introduction of competition in the power industry, there has been a search for the better utilization of the transmission facilities. In this contest Available Transfer Capability (ATC) indicates how much inter area power transfers can be increased without compromising system security must be evaluated. Thus ATC can be used as an important indicator of relative system security. In an inter area system, the loss of generation of one area can be replaced by generation from other areas. ATC calculations are useful for finding the capability of interconnected system to remain secure.

ATC information can help the Independent System Operator (ISO) to find the strength of behest results in an vertically unbundled deregulated market. It can also help the power market participants to place bids strategically when clogging happens. The ATC must be rapidly updated for new capacity reservations, schedules, or transactions. Different numerical models have been developed by the researches to evaluate the ATC of the transmission system. Continuation Power Flow (CPFLOW) [2] is a tool existing for determination of ATC. Power transfer distribution factor method (PTDF) is used by many electric utilities for finding ATC [3]. The Ontario Hydro's Probabilistic Composite System Evaluation program (PROCOSE) [4] is a good tool not only used for finding the ATC of a transmission system but also for identifying the most limiting facilities affecting the ATC. ATC computation for line and generator outage contingencies using OTDF and GODF methods respectively are proposed in [7]. The linear ATC values are computed using DC Power transfer distribution factors (DCPTDFs) and it will allot active power flow on the transmission lines [8].

In this paper, ATC is computed using linear sensitivity factors for both normal case and contingency condition. For the outage of a line and generator outage contingencies, ATC can be calculated using LODF and GODF respectively. This is done by using MATLAB for IEEE 30 bus system.

II. EVALUATION OF ATC

NERC has framed definitions for ATC as a measure of the transfer capability remaining in the physical transmission network for further commercial activity over and above already committed uses. Mathematically ATC is defined as the Total Transfer Capability (TTC) less the Transmission Reliability Margin (TRM), less the sum of the existing transmission commitments (which includes retail customer service) and the Capability Benefit Margin (CBM) [1]

ATC=TTC-TRM-Existing Transmission Commitments (including CBM)

Total Transfer Capability (TTC) is defined as the amount of electric power that can be transferred over the interconnected transmission network in a reliable manner while meeting all of a specific set of defined pre- and post-contingency system conditions. Transmission Reliability Margin (TRM) is defined as the amount of transmission transfer capability necessary to ensure that the interconnected transmission network is secure under reasonable range of uncertainties in system conditions. Capability Benefit Margin (CBM) is defined as the amount of transmission transfer capability reserved by load serving entities to ensure that the interconnected systems to meet generation reliability requirements.

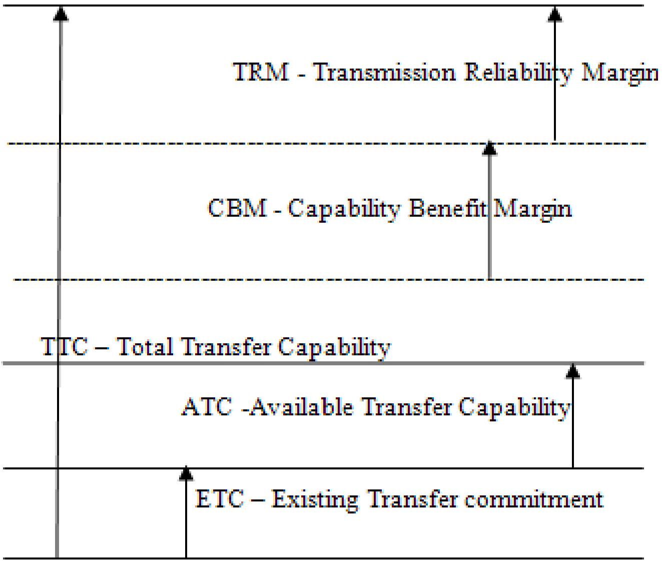

Fig 1. Basic Definition of ATC

Sensitivity analysis is the latest method suggested for approximate ATC calculation.

$$ATC_{mn} = \min \{T_{ij,mn}\} \quad .... \quad (1)$$

Where, $T_{ij,mn}$ is the transfer capability for each line in the system.

There are three methods to determine ATC namely,

1. From multiple load flow and continuation power flow,
2. From optimization power flow,
3. From Linear Sensitivity Factors.

Here ATC is calculated using various Linear Sensitivity Factors.

III. ATC DETERMINATION USING LINEAR SENSITIVITY FACTORS

This factor provides an immense potential for real time calculation of ATC. Use of these factors suggests an approximate but extremely fast model for the static ATC determination.

A. DCPTDFs method of ATC Evaluation under normal operating conditions

The linearity property of the dc power flow model has been used to find the transaction amount that would give rise to a specific power flow, such as an interface limit [9]. The PTDF defined from dc load flow relationship is being called DCPTDF. Using dc power flow and the assumptions associated with it, the real power flow on a transmission line connecting bus i to j,P_{ij} is given by,

$$P_{ij} = \frac{1}{x_{i,j}}(\theta_i - \theta_j) \quad .... \quad (2)$$

Now, $PTDF_{ij,mn}$ is the ratio of a transaction from *m* (bus) to *n* (bus) that flows over a transmission line connecting buses *i* and *j* [3],

$$DCPTDF_{ij,mn} = \frac{X_{im} - X_{jm} - X_{in} + X_{jn}}{x_{ij}} = (\Delta P_{ij}^{New} / P_{mn}^{New}) \quad .... (3)$$

where,

x_{ij} - Reactance of a line connecting *i* and *j* bus,

X_{im} - Entry in the i^{th} row and m^{th} column of the bus reactance matrix X

The change in line flow ΔP_{ij}^{New} linked with a new transaction P_{mn}^{New} is then,

$$\Delta P_{ij}^{New} = DCPTDF_{ij,mn} * P_{mn}^{New} \quad .... \quad (4)$$

Since, the PTDFs define a linear relationship, for a multilateral transaction case, the new real power flows in the lines can be determined by superimposing those corresponding to the individual transactions.

B. ACPTDFs formulation under normal operating conditions

The *ACPTDF* for finding ATC were used to find a range of transmission system quantities for the variation in MW transaction at different operating conditions. For the variation in the active power, deal among the above buyer and seller by Δt_k MW, if the variation in a transmission line quantity q_l is Δq_l,power transfer distribution factors can be defined as,

$$ACPTDF_{ij,mn} = \frac{\Delta q_l}{\Delta t_k} \qquad \text{.........} \quad (5)$$

These factors are computed at a base case load flow with solutions using NRLF Jacobian. The change in active power flow of line *i-j* with respect to changes in state variables is determined as,

$$\partial P_{ij} \Big/ \partial \delta_e = \left\{ \begin{array}{cc} 0 & ; \quad e \neq i \,\&\, j \\ V_i V_j Y_{ij} \sin(\delta_i - \delta_j - \theta_{ij}) & ; \quad e = i \\ -V_i V_j Y_{ij} \sin(\delta_i - \delta_j - \theta_{ij}) & ; \quad e = j \end{array} \right\}$$

$$\partial P_{ij} \Big/ \partial V_e = \left\{ \begin{array}{cc} 0 & ; \quad e \neq i \,\&\, j \\ 2V_i Y_{ij} \cos(\theta_{ij}) - V_j Y_{ij} \cos(\delta_i - \delta_j - \theta_{ij}) & ; \quad e = i \\ -V_i Y_{ij} \cos(\delta_i - \delta_j - \theta_{ij}) & ; \quad e = j \end{array} \right\} \qquad \text{.........} \quad (6)$$

$\Delta P_i = \Delta t_k$;

$\Delta P_j = -\Delta t_k$;

These ACPTDFs at a base case flow conditions are for computing the variation in transmission quantities at all operating situations. The PTDF may be either DCPTDF or ACPTDF and it all depends on the method of formulation.

ATC at base case, between buses *m* and *n* considering the thermal overloads for each line are accurately formulated for both III (*A* and *B)* by using (1)

$$T_{ij,mn} = \left\{ \begin{array}{l} \dfrac{\left(P_{ij}^{max} - P_{ij}^{0}\right)}{PTDF_{ij,mn}}; \quad PTDF_{ij,mn} > 0 \\ \alpha(\text{infinite}); \qquad PTDF_{ij,mn} = 0 \\ \dfrac{\left(-P_{ij}^{max} - P_{ij}^{0}\right)}{PTDF_{ij,mn}}; \quad PTDF_{ij,mn} < 0 \end{array} \right\} \quad \ldots\ldots (7)$$

Where P_{ij}^{max} is the thermal limit of a line between buses *i and j,*

$P_{ij}^{0}$is the base case power flow in line between buses *i and j.*

IV. ATC DETERMINATION CONSIDERING THE EFFECT OF CONTINGENCY ANALYSIS

A. OTDF for line outage contingencies

Formulation of LOPTDF and OTDF are necessary for the determination of ATC under line outage contingency. LOPTDF is a factor in which change in a line's status affects the flows on the remaining lines in the system. PTDF values are actually called OTDF when the system includes contingent lines. An OTDF gives the post-outage change in flow on a transmission line in response to a transaction between the seller and the buyer in a linear manner.

Consider the line outage between users *r* and *s* having pre-outage real power flow $P_{rs}^{0}$and P_{sr}^{0} from bus *r* to bus *s* and *s* to bus *r* respectively. Let $P_{ij,rs}$be the postoutage line flow between buses *i* and *j*. The change in the line can be determined using (8),

$$\Delta P_{ij,rs} = P_{ij,rs} - P_{ij}^{0} \qquad \text{..........} \quad (8)$$

The LOPTDF can be defined as the ratio of $P_{ij,rs}$ to the real power flow transmitted in the line taken for outage and connected between buses *r* and *s*. The LOPTDF can be determined using (9),

$$LOPTDF_{ij,rs} = \frac{\Delta P_{ij,rs}}{P_{rs}^{0}} \qquad \text{...........} \quad (9)$$

The OTDF value for line *i-j* during line outage *r-s* is determined using (8),

$$OTDF_{ij,rs}= PTDF_{ij,mn}+LOPTDF_{ij,rs}*PTDF_{rs,mn}$$

Having determined $OTDF_{ij,mn}$, the required transfer capability can be determined using (10),

$$T_{ij,mn} = \left\{\begin{array}{ll} \frac{\left(P_{ij}^{max}-P_{ij,rs}\right)}{OTDF_{ij,k}}; & OTDF_{ij,k} > 0 \\ \alpha(\text{infinite}) \quad ; & OTDF_{ij,mn} = 0 \\ \frac{\left(-P_{ij}^{max}-P_{ij,rs}\right)}{OTDF_{ij,k}}; & OTDF_{ij,k} < 0 \end{array}\right\} \text{.........} \quad (10)$$

For line outage between *m* and *n*, and by considering thermal limit, ATC is determined by,

$$ATC_{mn,rs} = \min\left\{T_{ij,mn}, T_{ij,rs}\right\} \; ; \; i,j \in N_L \; and \; k \in N_{LC} \quad \text{...........} \quad (11)$$

Where,

N_{LC}- Total number of line outage contingencies

$P_{ij,rs}$- Power flow on the line after outage of the line *r-s*

$LOPTDF_{ij,rs}$- Line outage PTDF for line *i-j* when *r-s* is out

$PTDF_{ij,mn}$ - PTDF for line *i-j* when transaction is taking place between bus *m* and *n*

$PTDF_{rs,mn}$ - PTDF for line *r-s* outage and for transaction between bus *m* and *n*

B. GODF for Generator outage contingencies

Generation shift sensitivity factor $a_{ij,k}$[10] are calculated, denoting the MW power flow on the line *i-j* to a change or outage of generation occurring at bus *k*. It is assumed that the change in generation, ΔP_k is exactly compensated by an opposite change in generation at the reference bus, and that all other generators remain fixed. The change in power flow on each line due to the generator outage is given by (12).

$$P_{ij,k} = P_{ij}^{0} \; + \Delta P_{ij,k}; \; i,j \in N_L \; and \; k \in N_{GC} \quad \text{.......} (12)$$

Where,

P_{ij}^{0} - pre outage power flow

N_{GC}- total number of generator outage contingencies considered.

The transfer capability for each generator outage contingency is evaluated using (13).

$$T_{ij,k} = \left\{\begin{array}{ll} \frac{\left(P_{ij}^{max}-P_{ij,k}\right)}{GODF_{ij,k}}; & GODF_{ij,k} > 0 \\ \alpha(\text{infinite}) \; ; & GODF_{ij,k} = 0 \\ \frac{\left(-P_{ij}^{max}-P_{ij,k}\right)}{GODF_{ij,k}}; & GODF_{ij,k} < 0 \end{array}\right\} \quad \text{.........} \quad (13)$$

Where,

$GODF_{ij,k}$- GODF for line *i-j* due to the generator *k* out for the transaction taking place between bus *m* and *n* For line outage between *m* and *n*, and by considering thermal limit, ATC is determined by,

$$ATC_{mn,k} = \min\left\{T_{ij,mn}, T_{ij,k}\right\}; \; i,j \in N_L \; and \; k \in N_{GC} \quad \text{........} \quad (14)$$

V. STEPS FOR STATIC ATC DETERMINATION

The steps for computing the ATC for each applied transaction are given below:

Step 1: Take particular system details.

Step 2: Run a base case load flow.

Step 3: Assume the transactions (*m-n*) .

Step 4: Calculate the PTDF using (3).

Step 5: Determine the transfer capability (TC) for each branch (*i, j*) using (7)

Step 6: Do the possible transactions and determine the ATC using (1).

Step 7: If any line or generator is out, simulate the contingency and then go on; otherwise, go to step 12.

Step 8: If any of the line is out, then calculate the LOPTDF and OTDF using (9) and (10) respectively; or else, go to step 10.

Step 9: Determine the ATC for line outage contingency condition

Step 10: If any of the generator is out, then calculate ATC for the generator outage contingency using

GODF using (13); or else, go to step 11.

Step 11: After completing one transaction, proceed with another transactions.

Step 12: Display the value of ATC computed.

VI. TEST SYSTEM AND RESULTS

Available Transfer Capability has been calculated for various bilateral transactions for normal as well as with contingency conditions for IEEE 30 bus system. IEEE 30 bus system contains 6 generators, 41 transmission lines.

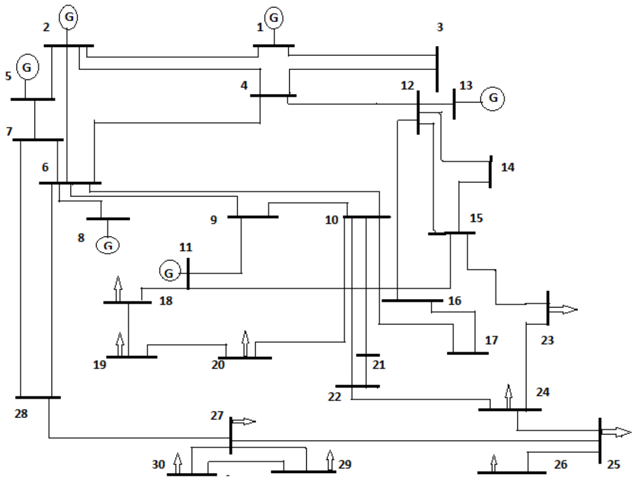

Fig.2 IEEE 30 bus system

The various transactions considered here are,

T1 (30): transaction between 2 (seller bus) to 28 (buyer bus)

T2 (30): transaction between 5 (seller bus) to 30 (buyer bus)

T3 (30): transaction between 6 (seller bus) to 28 (buyer bus)

TABLE I
ATC FOR IEEE 30 BUS SYSTEM FOR NORMAL CONDITION (IN MW)

Transaction	*Normal mode Using DCPTDF Method*	*Normal mode Using ACPTDF method*	*limiting element*
T1(30) *(2-28)*	22.65	23.78	6-28
T2 (30) *(5-30)*	12.19	14.7105	24-25
T3 (30) *(6-28)*	21.97	23.5875	8-28

TABLE II
ATC FOR IEEE 30 BUS SYSTEM FOR LINE OUTAGE CONTINGENCY CONDITION (IN MW)

Transaction	*Line outage mode using LOPTDF method*	*limiting element*
T1(30) ***(2-28)***	18.96	6-28
T2 (30) ***(5-30)***	10.67	24-25
T3 (30) ***(6-28)***	20.23	8-28

Considering a bilateral transaction applied between buses (2-28, 5-30, 6-28) in the test system under study, transfer capabilities of all lines and the ATC of the network are calculated using DCPTDF and ACPTDF methods for normal condition. These values are shown in TABLE I in which minimum of all transfer capabilities is considered as ATC of the network. In the contingency mode of operation, the line and generator outage is considered for the same bus system. ATC values obtained for the contingency case are less than the normal operating case which are shown from TABLE I and TABLE II. It is observed that minimum ATC obtained in line outage contingencies mode is taken as limiting element.

Similar to line outage, the minimum ATC for generator outage cases with generator outage (k=2) is observed for line (2-6), with generator outage (k=5) is observed for line (5-7), with generator outage (k=8) is observed for line (6-8), with generator outage (k=11) is observed for line (9-10), with generator outage (k=13) is observed for line (12-15) respectively. These observations are done in which GODF is calculated for all 41 transmission lines and ATC values are determined from that GODF as shown in TABLE III.

TABLE III
ATC CALCULATED USING GODF

Generator considered for outage	*ATC calculated using MATLAB*	*limiting element*
K=2	16.03	2-6
K=5	22.72	5-7
K=8	41.50	6-8
K=11	10.39	9-10
K=13	43.68	12-15

From all these results, we can conclude that the ATC is decreased compared to the normal operating case. It is further observed that for the case of generator outage, ATC values are not much decreased in all transactions. Similar results of ATC determination are carried out for different transactions but due to the page limit only three transactions are discussed in this context.

VII. CONCLUSION

ATC enhancement is the potential issue in deregulated electric power market. This paper has analyzed traditional PTDF methods including DCPTDF, LOPTDF and GODF for ATC evaluation. This work would help to improve the ATC results based on various bilateral transactions under normal and contingency conditions. This will help to reduce extra transmission lines for the structural investments and expansion planning issues. The main application for ATC is to provide users an index for finalizing better generation locations and for marketing transactions which will increases the economic benefits in the competitive power markets. The solutions obtained are satisfactory and linear sensitivity factors applied here is of speedy and less computation burden.

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IX. AUTHORS' INFORMATION

K.Indhumathy received her B.E. degree in Electrical and Electronics Engineering from St.Peter Engineering College in 2011 and is currently pursuing her M.Tech degree in Power Systems in SASTRA University . Her areas of interest are Deregulation of Power System, Power System Operation & Control, Power System Economics and Distributed Generation

N.B.Rajesh received his B.E degree in Electrical and Electronics Engineering from KLN College of Engineering in 2003 and his M.Tech degree in Power System from Arulmigu Kalasalingam College of Engineering in 2006. He is working as Asst. Prof.-II in SASTRA University. His areas of interest are Power System Stability & Control, Restructuring Environment, Dynamic VAR allocation, Converter and Power Quality issues.

J.Jaya priya received her B.E. degree in Electrical and Electronics Engineering from R.V.S College of Engineering and Technology in 2011 and is currently pursuing her M.Tech degree in Power Systems in SASTRA university . Her areas of interest are Distributed Generation and its technical and economic influence in DN, Power System Restructuring and Power System Operation & Control.