

## ATC Determination for Different Transactions Using ACPTDF

Saloni,<sup>1</sup> Meenakshi Dhakla<sup>2</sup>

<sup>1</sup>Department of Electrical and Electronics Engineering, B.M.I.E.T Sonapat/M.D.U., India

<sup>2</sup>Department of Electrical Engineering, D.C.R.U.S.T., Murthal., India

**Abstract:** A fair competition needs open access and non-discriminatory operation of the transmission network. Open access to the transmission system places an emphasis on the intensive use interconnected network reliably, which requires knowledge of the network capability. Available Transfer Capability (ATC) is a measure of the remaining power transfer capability of the transmission network for further transactions. Available transfer capability in the transmission network has become essential quantity to be declared well in advance for its commercial use in a competitive electricity market. The assessment of ATC using AC Power transfer distribution factors (AC PTDFs) based approach has been used for single and simultaneous transactions using power transfer sensitivity and jacobian calculated with N-R method. The AC PTDFs are derived using sensitivity based approach for the system intact case. A study of ATC determination using AC Power Transfer Distribution Factor (AC PTDF). We predicted the AC PTDF is different for different transactions and ATC is also different with the help of MATLAB Programming. Simultaneous and single transactions have been carried out on IEEE 24 bus RTS for the assessment of ATC. The solutions obtained are quite encouraging and useful in the present restructuring environment.

**Keywords:** Available Transfer Capability (ATC), AC Power Transfer Distribution Factor (ACPTDF)

### I. INTRODUCTION

Available transfer capability in the transmission network has become essential quantity to be declared well in advance for its commercial use in a competitive electricity market. Electric power industries throughout the world have been restructured to introduce competition among the market participants and bring several competitive opportunities. A fair competition needs open access and non-discriminatory operation of the transmission network. Open access to the transmission system places an emphasis on the intensive use of the interconnected network reliably, which requires knowledge of the network capability. Available Transfer Capability (ATC) is a measure of the remaining power transfer capability of the transmission network for further transactions. Its fast computation using DC load flow based approach is used worldwide for on line implementation. Many authors have proposed the ATC calculation based on DC/AC load flow approach. AC PTDF based approach has been proposed for multi-transaction cases using power transfer sensitivity and Jacobian calculated with three different methods. The methods can be implemented for any number of transactions occurring simultaneously.

The linear dc power transfer distribution factors (DC PTDF) based on dc power flow method, is possibly the only allocation technique presently in widespread use to

allocate MW flows on the lines for a transaction in the system. However, this has a poor accuracy due to the assumptions involved in the dc power flow model.

In a fast decoupled power flow model for transmission allocation has been suggested, which is based on linearizing ac power flow equations and using incremental steps based on current power flow state. However, it does not allocate losses to individual transactions. In a physical flow-based transmission loss allocation scheme based on expressing loss explicitly in terms of all transactions in a power system network was proposed. However, error between the system losses evaluated by ac load flow (ACLF) and the losses using the methodology based on were relatively high, ranging from 10% to 16%.

The ac power transfer distribution factors, computed at a base case, have been used to find various transmission system quantities for a change in MW transactions at different operating conditions.

### II. ATC PRINCIPLES

Available Transfer Capability (ATC) is 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 existing transmission commitments (which includes retail customer service) and the Capacity Benefit Margin (CBM).

**2.1 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.

Transfer Capability is different from 'Transmission Capacity', which usually refers to the thermal limit or rating of a particular transmission element or component. The capability to meet load (transfer capability) would however depend on several other factors such as spatial distribution and diversity of generation/load, network configuration. Thus, the individual transmission line capacities or ratings cannot be arithmetically added to determine the transfer capability of a transmission path or interface.

**2.2 TRANSMISSION RELIABILITY MARGIN (TRM):** is defined as that amount of transmission transfer capability necessary to ensure that the interconnected transmission network is secure under a reasonable range of uncertainties in system conditions.

**2.3 CAPACITY BENEFIT MARGIN (CBM):** is defined as that amount of transmission transfer capability reserved by load serving entities to ensure access to generation from interconnected systems to meet generation reliability requirements.

### III. ATC PRINCIPLES

The following Available Transfer Capability (ATC) Principles govern the development of the definition and determination of ATC and related terms. All transmission provider and user entities are expected to abide by these Principles.

**3.1** ATC calculations must produce commercially viable results. ATCs produced by the calculations must give a reasonable and dependable indication of transfer capabilities available to the electric power market.

**3.2** ATC calculations must recognize time-variant power flow conditions on the entire interconnected transmission network. In addition, the effects of simultaneous transfers and parallel path flows throughout the network must be addressed from a reliability viewpoint.

**3.3** ATC calculations must recognize the dependency of ATC on the points of electric power injection, the directions of transfers across the interconnected transmission network, and the points of power extraction. All entities must provide sufficient information necessary for the calculation of ATC.

**3.4** Regional or wide-area coordination is necessary to develop and post information that reasonably reflects the ATCs of the interconnected transmission network.

**3.5** ATC calculations must conform to NERC, Regional, sub regional, power pool, and individual system reliability planning and operating policies, criteria, or guides.

**3.6** The determination of ATC must accommodate reasonable uncertainties in system conditions and provide operating flexibility to ensure the secure operation of the interconnected network.

The calculation of transfer capability is generally based on computer simulations of the operation of the interconnected transmission network under a specific set of assumed operating conditions. These simulations are typically performed "off line," well before the systems approach that operational state. Each simulation represents a single "snapshot" of the operation of the interconnected network based on the projections of many factors. As such, they are viewed as reasonable indicators of network performance and available transfer capability.

### IV. AC POWER TRANSFER DISTRIBUTION FACTOR

Consider a transaction  $P_{mn}$  between a seller bus, m and buyer bus, n. Further consider a line, 'l' carrying a part of the transaction power. Let the line be connected between a bus-i and a bus-j. For a change in real power transaction between the above seller and buyer say by  $\Delta P_{mn}$ , if the change in transmission line quantity  $P_{ij}$  is  $\Delta P_{ij}$ , the AC power transfer distribution factors can be defined as:

$$ACPTDF_{ij,mn} = \frac{\Delta P_{ij}}{\Delta P_{mn}}$$

### V. METHODOLOGY

For a transaction among the buyer and seller buses by  $\Delta P_{mn}$ , if the change in the transmission line quantity is  $\Delta P_{ij}$ , the AC power transfer distribution factors can be defined as,

$$ACPTDF_{ij,mn} = \frac{\Delta P_{ij}}{\Delta P_{mn}} \quad (1)$$

For Power Transfer Distribution Factor calculation using AC load approach, the power flow sensitivity and Jacobian of power injection equations is required. The Jacobian can be calculated using N-R load flow based approach. The power flow equations in polar form can be represented as:

$$P_i = \sum_{j=1}^n |V_i| |V_j| |Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \quad (2)$$

$$Q_i = \sum_{j=1}^n |V_i| |V_j| |Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \quad (3)$$

Where n be the total no of buses  $P_i$  and  $Q_i$  are the real and reactive power injected at any bus i

$|V_i|$ ,  $|V_j|$  are the voltage magnitudes at the buses respectively,  $\delta_i$ ,  $\delta_j$  are the voltage angles at the buses i and bus j, and  $|Y_{ij}|$ ,  $\theta_{ij}$  are taken from  $Y_{bus}$ .

Using Taylor series expansion, the change in power flows at any bus i can be formulated in terms of Jacobian as:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} \quad (4)$$

Where

$$[J_1] = \frac{\partial P}{\partial \delta}, [J_2] = \frac{\partial P}{\partial |V|}, [J_3] = \frac{\partial Q}{\partial \delta}, [J_4] = \frac{\partial Q}{\partial |V|} \quad (5)$$

The change in the angle and voltage magnitude can be determined as:

$$\begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix}^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \quad (6)$$

Using N-R load flow analysis bus voltage magnitudes and angles can be evaluated. For calculation of AC Power Transfer Distribution Factors, Jacobian and power flow sensitivity can be calculated. The power flow sensitivity can be determined using the power flow equations for real power.

The real power flow ( $P_{ij}$ ) in a line-k, connected between buses i and j, can be written as:

$$P_{ij} = V_i V_j Y_{ij} \cos(\theta_{ij} + \delta_j - \delta_i) - V_i^2 Y_{ij} \cos \theta_{ij} \quad (7)$$

Where  $V_i$  and  $\delta_i$  are the voltage magnitude and angle at bus- i.  $Y_{ij}$  And  $\theta_{ij}$  magnitude and angle of  $ij^{th}$  element of  $[Y_{Bus}]$ .

Using Taylor's series approximation and ignoring higher order terms, change in real power can be written as:

$$\Delta P_{ij} = \frac{\partial P_{ij}}{\partial \delta_i} \Delta \delta_i + \frac{\partial P_{ij}}{\partial \delta_j} \Delta \delta_j + \frac{\partial P_{ij}}{\partial V_i} \Delta V_i + \frac{\partial P_{ij}}{\partial V_j} \Delta V_j \quad (8)$$

The sensitivity coefficients appearing in (7) can be obtained using the partial derivatives of real power flow (6) with respect to variables  $\delta$  and V as:

$$\frac{\partial P_{ij}}{\partial \delta_{ij}} = V_i V_j Y_{ij} \sin(\theta_{ij} + \delta_j - \delta_i) \quad (9)$$

$$\frac{\partial P_{ij}}{\partial \delta_{ij}} = -V_i V_j Y_{ij} \sin(\theta_{ij} + \delta_j - \delta_i) \quad (10)$$

$$\frac{\partial P_{ij}}{\partial v_i} = V_j Y_{ij} \cos(\theta_{ij} + \delta_j - \delta_i) - 2 V_i Y_{ij} \cos \theta_{ij} \quad (11)$$

$$\frac{\partial P_{ij}}{\partial v_j} = V_i Y_{ij} \cos(\theta_{ij} + \delta_j - \delta_i) \quad (12)$$

The sensitivity of power flow equation can be written in the compact matrix form as:

$$\Delta P_{ij} = \begin{bmatrix} \frac{\partial P_{ij}}{\partial \delta_2}, \dots, \frac{\partial P_{ij}}{\partial \delta_n}, \frac{\partial P_{ij}}{\partial v_{g+1}}, \dots, \frac{\partial P_{ij}}{\partial v_n} \end{bmatrix} \begin{bmatrix} \Delta \delta_2 \\ \vdots \\ \Delta \delta_n \\ \Delta |V_{g+1}| \\ \vdots \\ \Delta |V_n| \end{bmatrix} \quad (13)$$

Where  $\begin{bmatrix} \frac{\partial P_{ij}}{\partial \delta_2}, \dots, \frac{\partial P_{ij}}{\partial \delta_n}, \frac{\partial P_{ij}}{\partial v_{g+1}}, \dots, \frac{\partial P_{ij}}{\partial v_n} \end{bmatrix}$

Is line power flow sensitivity corresponding to angle and voltage magnitude. For a single transaction case between seller bus m and buyer bus n, the change in power transactions can be substituted at position of bus m and bus n as:

$$\Delta P_m = +P_t$$

$$\Delta P_n = -P_t$$

$$\Delta P_{ij} = \begin{bmatrix} \frac{\partial P_{ij}}{\partial \delta_2}, \dots, \frac{\partial P_{ij}}{\partial \delta_n}, \frac{\partial P_{ij}}{\partial v_{g+1}}, \dots, \frac{\partial P_{ij}}{\partial v_n} \end{bmatrix} [J]^{-1} \begin{bmatrix} 0 \\ \vdots \\ +P_t \\ 0 \\ \vdots \\ -P_t \\ 0 \end{bmatrix} =$$

$$ACPTDF_t * P_t \quad (14)$$

So, ACPTDFs for the transaction between seller bus m to buyer bus n can be represented as:

$$ACPTDF_{ij,mn} = \begin{bmatrix} \frac{\partial P_{ij}}{\partial \delta_2}, \dots, \frac{\partial P_{ij}}{\partial \delta_n}, \frac{\partial P_{ij}}{\partial v_{g+1}}, \dots, \frac{\partial P_{ij}}{\partial v_n} \end{bmatrix} [J]^{-1} \begin{bmatrix} 0 \\ \vdots \\ +1 \\ 0 \\ \vdots \\ -1 \\ 0 \end{bmatrix} \quad (15)$$

ACPTDFs are obtained for each line for particular transaction between seller and buyer bus. In the present work, the method of N-R Jacobian based approach ( $J_{N-R}$ ) have considered for ACPTDFs determination.

#### 4.1 N-R Jacobian based Approach

The power flow change can be expressed corresponding to line flow sensitivities with angle and voltage and change in angle and voltages can be obtained from N-R approach as:

$$\Delta P_{ij} = \begin{bmatrix} \frac{\partial P_{ij}}{\partial \delta_2}, \dots, \frac{\partial P_{ij}}{\partial \delta_n}, \frac{\partial P_{ij}}{\partial v_{g+1}}, \dots, \frac{\partial P_{ij}}{\partial v_n} \end{bmatrix} [J_{N-R}]^{-1} \begin{bmatrix} 0 \\ \vdots \\ +\Delta P_t \\ 0 \\ \vdots \\ -\Delta P_t \\ 0 \end{bmatrix} =$$

$$ACPTDF_t * P_t$$

$$ACPTDF_{ij,mn} = \begin{bmatrix} \frac{\partial P_{ij}}{\partial \delta_2}, \dots, \frac{\partial P_{ij}}{\partial \delta_n}, \frac{\partial P_{ij}}{\partial v_{g+1}}, \dots, \frac{\partial P_{ij}}{\partial v_n} \end{bmatrix} [J_{N-R}]^{-1} \begin{bmatrix} 0 \\ \vdots \\ +1 \\ 0 \\ \vdots \\ -1 \\ 0 \end{bmatrix} \quad (16)$$

Both Jacobian and line flow sensitivity factors are taken without considering any assumptions.

4.2 ATC Determination for Intact System Methodology remains same for calculation of ATC. The method of N-R Jacobian method provide different Jacobin and line flow sensitivity factors which are used for calculation of AC Power Transfer Distribution Factors. Real power flows in base case obtained from N-R approach and line limits as a given data are utilized for ATC determination.

Now  $P_{ij-mn}^{max}$  for any transaction seller bus m to buyer bus n can be obtained as:

$$P_{ij-mn}^{max} = \begin{cases} \frac{Limit_{ij}^{max} - P_{ij}}{ACPTDF_{ij,mn}} & ; ACPTDF_{ij,mn} > 0 \\ \infty \text{ (infinite)} & ; ACPTDF_{ij,mn} = 0 \\ \frac{-Limit_{ij}^{max} - P_{ij}}{ACPTDF_{ij,mn}} & ; ACPTDF_{ij,mn} < 0 \end{cases} \quad (18)$$

Where  $P_{ij}$  is the real power flow through any line  $i-j$ ,  $Limit_{ij}^{max}$  is thermal limit of any line  $i-j$ ,  $P_{ij-mn}^{max}$  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 and obtained as:

$$ATC_{min} = \min\{P_{ij}^{max} | j \in N_1\} \quad (19)$$

Where,  $N_1$  is the total number of lines in the system?

### VI. RESULTS

In this chapter, discuss about the results of Available Transfer Capability (ATC) with respect to AC Power Transfer Distribution Factors (ACPTDFs) for different transactions. The results of ACPTDFs for all the lines and its ATC. The results have been determined for IEEE RTS 24 bus system. The results include PTFDF calculations for intact system in case of all transactions. Based on the PTFDFs, ATC have been calculated for all transaction cases. The ACPTDF is shown in Figure 1 for all the lines and the ATC for T1 is 7.57. ATC for T2 and T3 are 2.83 and 2.76 respectively.

ATC is calculated for IEEE RTS 24 bus system. ATC has been obtained for different transactions taken as single transaction and simultaneous transactions. These transactions have been categorized as:

**T<sub>1</sub>:** Transaction between seller buses 23 to buyer bus 15 (Figure 1).

**T<sub>2</sub>:** Transaction between seller buses 10 to buyer bus 3 (Figure 2).

**T<sub>3</sub>:** Transaction between seller bus 23, 10 to buyer bus 15, 3 (simultaneous transaction) (Figure 3).

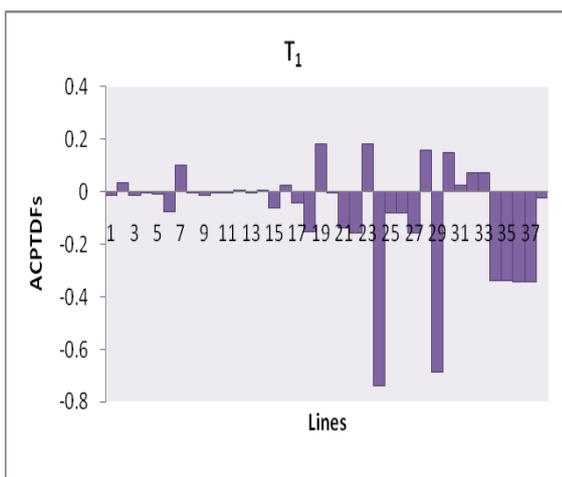


Fig. 1 Bar graph of ACPTDF for all the lines for T<sub>1</sub>

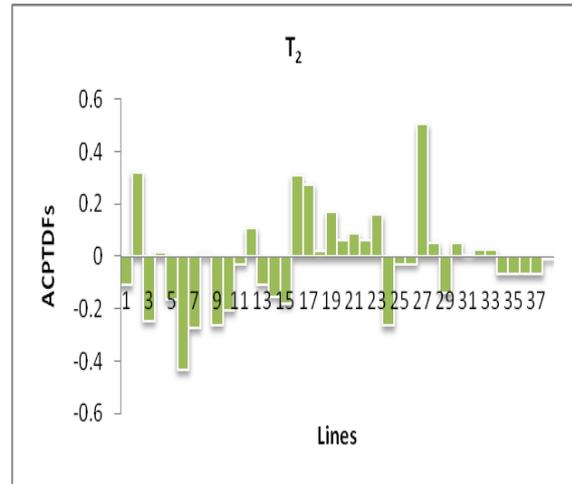


Fig. 2 Bar graph of ACPTDF for all the lines for T<sub>2</sub>.

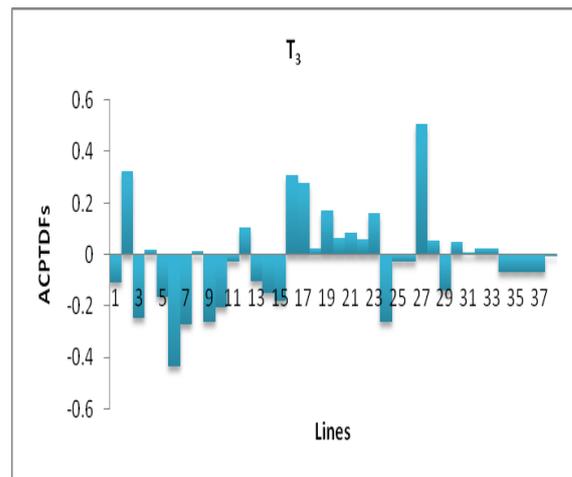


Fig. 3 Bar graph of ACPTDF for all the lines for T<sub>3</sub>.

### REFERENCES

- [1] North American Electric Reliability Council (NERC), "Available Transfer Capability Definitions and Determination", NERC Report, June 1996.
- [2] Venkatesh, Dr. Paramasivam; Gnanadass, Ramachandran; and Padhy, Dr. Narayana Prasad (2004), "Available Transfer Capability Determination Using Power Transfer Distribution Factors", International Journal of Emerging Electric Power Systems: Vol. 1: Iss. 2, Article 1009.
- [3] G. C. Ejebe, J. G. Waight, M. Santos-Nieto and W. F. Tinney, "Fast Calculation of Linear Available Transfer Capability", IEEE Trans. on Power Systems, vol. 15, no. 3, Aug. 2000, pp. 1112-1116.
- [4] G. Hamoud, "Assessment of Available Transfer Capability of Transmission Systems", IEEE Trans. on Power Systems, vol. 15, no. 1, Feb. 2000, pp. 27-32.
- [5] Narasimha Rao, K., Amarnath, J. and Kiran Kumar, K., Kamakshiah, S. S., "Available Transfer Capability Calculations Using Neural Networks in Deregulated Power", 2008 International Conference on Condition Monitoring and Diagnosis, Beijing, China, April 21-24, 2008.
- [6] Yajing Gao, Jin Yang, Ming Zhou, and Gengyin Li, "Available Transfer Capability Assessment of AC/DC Transmission System", 2010 International Conference on Power System Technology.
- [7] A. Kumar, S. C. Srivastava, and S. N. Singh, "Available Transfer Capability Assessment in a Competitive Electricity Market Using a Bifurcation Approach", IEE Proc. on

- Generation, Transmission and Distribution, vol. 151, no. 2, March 2004, pp. 133 – 140.
- [8] Mohamed Shaaban, Yixin Ni, Felix F. Wu, “Available Transfer Capability Evaluation by Decomposition”, Vol. No. 0-7803-7173-9/01/\$10.00 © 2001 IEEE.
- [9] Ashwani Kumar, S. C.Srivastava, “AC Power Transfer Distribution Factors for Allocating Power Transactions in a Deregulated Market”, IEEE Power Engineering Review, July 2002.
- [10] A. Kumar, S. C. Srivastava, and S. N. Singh, “Available Transfer Capability (ATC) Determination in Competitive Electricity Market Using AC Distribution Factors”, Electric Power Components and Systems, vol. 32, June 2004, pp. 927-939.
- [11] Hsiao-Dong Chiang, Alexander J. Flueck, Kirit S. Shah, Neal Balu, “CPFLOW: A Practical Tool for Tracing Power System Steady-State Stationary Behaviour Due to Load and Generation Variations”, IEEE Transactions on Power Systems, Vol. 10, No. 2, May 1995.
- [12] IEEE Reliability Test System, A report prepared by the Reliability Test System Task Force of the Applications of Probability Methods Subcommittee, IEEE Trans. on Power Apparatus and Systems, vol. PAS-98, pp. 2047-2054, Nov.-Dec. 1979.
- [13] Jitendra Kumar and Ashwani Kumar, “ACPTDF for Multi-transactions and ATC Determination in Deregulated Markets”, International Journal of Electrical and Computer Engineering (IJECE), Vol.1, No.1, September 2011, pp. 71~84, ISSN: 2088-8708.
- [14] Fernando L. Alvarado, “Solving Power Flow Problems with a Matlab Implementation of the Power System Applications Data Dictionary”, Proceedings of the 32nd Hawaii International Conference on System Sciences – 1999.