DETERMINISTIC APPROACH AVAILABLE TRANSFER CAPABILITY (ATC) CALCULATION METHODS

Azhar B. Khairuddin[1] ,Othman O. Khalifa[2], Abdelwahab I. Alhammi[3], Raja Masood Larik[4]
,[1,3,4] Power System Department, Faculty of Electrical Engineering, University Teknologi Malaysia, UTM Skudai, Johor Bahru, Malaysia (E-mail: azhar@fke.utm.my, winaabdel2@live.utm.my ,rmlarik@gmail.com)
[2]Electrical and Computer Engineering Department, Faculty of Engineering , International Islamic University, Kuala Lumpur, Malaysia(E-mail: khalifa@iium.edu.my) * Corresponding author

Abstract: With the new strategy of deregulation electrical power systems, Available Transfer Capability (ATC) is significant indicator. This paper debate for deterministic methods to compute ATC. Concepts and calculation approaches of Optimal Power Flow (OPF), Continuation Power Flow (CPF) and Power Transfer Distribution Factors (PTDF) has been presented. Cons and prons of each with simulated results are presented using **IEEE** 30 -bus test systems without any contingences proposed, the results shows efficient results with high performance accuracy.

Keywords: Available Transfer Capability optimal Power Flow, Continuation Power Flow, Power Transfer Distribution Factor.

I. INTRODUCTION

One of the greatest befits for costumers demands is the highly speed competition via deregulation power system. Explanations related achievement of a better service, reliable operation and competitive market in [1]. In order to introduce great potential facilities and saving for costumers California was one of the first states that embark this system, later on Australia. One of the greatest important indices to keep reliability and security of the power systems are the process of calculating ATC to be efficient systems. Since 1996, the Federal Energy Regulatory Commission (FERC) requires ATC information available to access at Open Access Same-time Information System (OASIS) [2]. There are several technical challenges that appear during computation of ATC and in [6] present several concepts for dealing these challenges.

According to North American Electric Reliability Council's (NERC) - Available Transfer Capability Definition and Determination - [3], ATC is defined as “the measure of the transfer capability remaining in the physical transmission network for future commercial activity, over and above already committed uses”, whereas, FERC has defined ATC as “the amount of transfer capacity that is available at a given time for purchase or sale in the electric power market under various system conditions” [4]. Equation 1. shows how mathematically calculating ATC , its known as the Total Transfer Capability (TTC) less the Transmission Reliability Margin (TRM), less the sum of Existing Transmission Commitments (ETC) and the Capacity Benefit Margin (CBM) [3]. It can be expressed as:

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

TTC should be evaluated first to obtain ATC where TTC is defined as “the largest power that can transfer over the interconnected transmission network which causes no thermal overloads, voltage limit violations, voltage collapse or any other system problems such as transient stability” [3]. Others parameter that involves in ATC calculation is TRM and CBM but many researches has addressed the calculation of TTC as the basis of ATC evaluation because the methodology to determine TRM and CBM may vary among regions, sub-regions and power pools. The definition of these two indices is defined in [3]. The determination of TRM a point estimate method used, in [5]. Some of important instructions that FERC consultation issues informed in [3] as:

1. ATC calculation must produce commercially viable results.
2. ATC calculation must recognize time-variant power flow conditions and simultaneous transfer and parallel path flows throughout the transmission network.
3. ATC calculation must recognize the dependency of ATC on the points of power injection, the directions of power transfer and the points of power extraction.
4. Regional or wide-area coordination is necessary to develop and post information that reasonably reflects the ATCs of the interconnected transmission network.

OASIS is used to post the values of calculated ATC , also the interface identifier, the date and time of the run, the list of constraining facilities, the TTC and ATC. There are several frameworks for On-Line ATC calculation which are State Estimator (SE), Security Analysis (SA), and the OASIS. From SE the current system state can be obtained. While from SA the contingency list can be obtained, while Current Operating Plant (COP) is the source for load predictors, generation schedules, and outage equipment information. OASIS is used to post the values of calculated ATC and also the interface identifier, the date and time of the run, the list of constraining facilities, the TTC and ATC. Figure 1 illustrates the framework for on-line computation.

ATC determinations could be classified to Deterministic Load Flow (DLF) and Probabilistic Load Flow (PLF) approaches each class has several own methods for calculating of ATC values. This paper Address only three

DLF methods. The first method is Optimal Power Flow (OPF) in section II, the second is Continuation Power Flow (CPF) that will be in section III and lastly Power Transfer Distribution Factors (PTDF) in section IV. PTDF under classifications of two approaches based on neither DC nor AC load flow. The objective function is to maximize total generation supplied and load demand at specific buses. Simulation results were explained in section V.

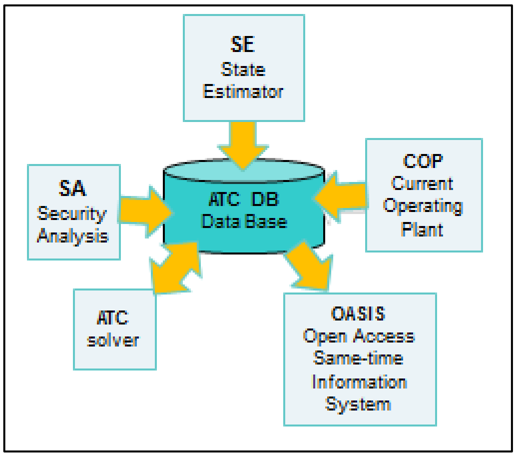


Fig.1 Framework for On-line ATC Computation.

The rest of the paper is organized as follows. After a brief introduction to the principles of the probabilistic collocation method in Section II, Section III proposes the solution to probabilistic load flow with non-Gaussian distributions. In Section IV, the results of an application example on the IEEE30- bus system are presented. The conclusion ends the paper in Section V.

II. OPTIMAL POWER FLOW

One of the most needed method for optimization certain choice of load distributions also in case of calculating ATC values, The objective function is to maximize total generation supplied and load demand at specific buses. more explanations of OPF in [7-12]. Typically the thematic function for this technique is found out with conjunction of hard and soft constraints for example in [8] load flow equation becomes hard constraint while limits imposed in control becomes soft constraint. Likewise OPF is based on full AC power solution in [7].while the maximizing of TTC process at sending and receiving areas expounded in references [7, 9, 10]. single line N-1 security criterion with contingency list available presented in [9,10,12]. Deep research needs to overcome insufficiency incorporate various complex constraints and different objective in the mathematical model. This method can accept the new methodology easily, but it cannot be applied in real time for large system because solution of optimization problem for large system becomes very time consuming. Certain assumptions should be taken in account while implementing this approach [7-10]; first , the base case power flow of the system is feasible corresponds to a stable and secure operating point, second; Loads are increased in constant power factor direction, third; system voltage limit is reached before the system loses voltage stability. Different manner for optimization process in OPF like Sequential Quadratic Programming (SQP) [7], Genetic Algorithm (GA) [8], and Bender decomposition [9-10]. SQP method is proven become an effective method for constrained nonlinear programming. While GA usually used when the information is not sufficient for complicated objective functions. To deal ATC problem with static security constraint SSC Bender decomposition method is proposed.

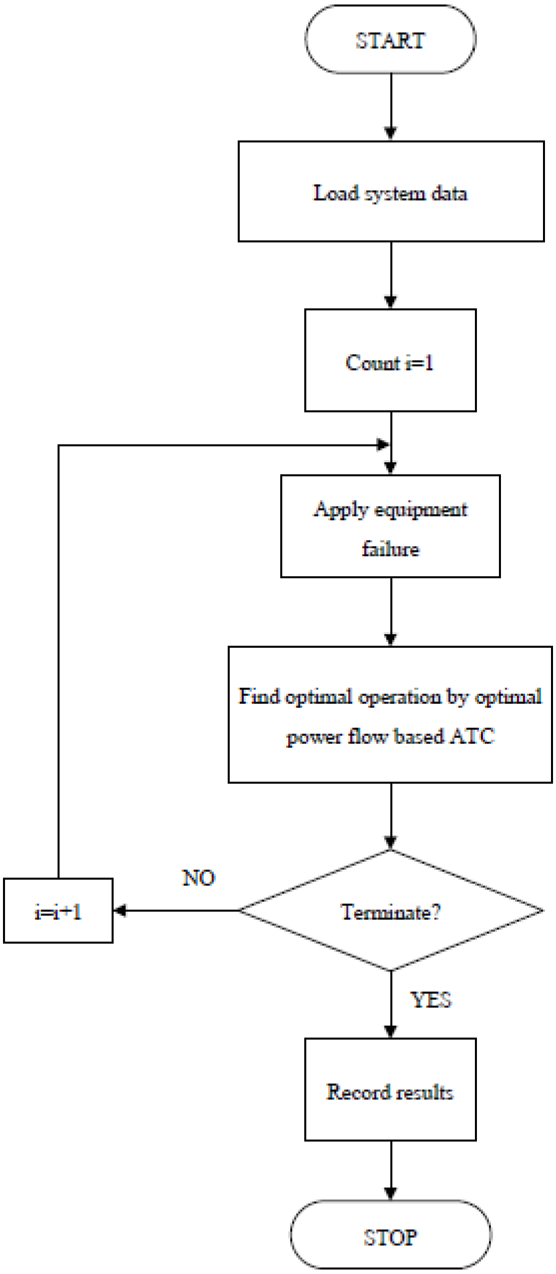


Fig 2. A Flow Chart of the Optimal Power Flow.

Mathematically to calculate ATC by this method can be represented as:

$$Max\, J = f(x,u) \qquad (2)$$

$$g(x,u) = 0$$

$$h^{min} \leq h(x,u) \leq h^{max}$$

Where $f(x,u)$ is an objective function, x is a system state variable, u is control parameter vector, $g(x,u)$ is an equality constraint function and $h(x,u)$ is an inequality constraint function.

The function J is defined to be the sum of total generation and total load of a load bus

$$J = \sum P_{Gk} + \sum P_{Ld} \qquad (3)$$

Subject to:

$$Pi - V_i \sum_{j=1}^{N} V_i\,(G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}) = 0 \qquad (4)$$

$$Q_i - V_i \sum_{j=1}^{N} V_i\,(G_{ij}\sin\theta_{ij} - B_{ij}\cos\theta_{ij}) = 0 \qquad (5)$$

$$P_{Gk}^{min} \leq P_{Gk} \leq P_{Gk}^{max}$$

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max}$$

$$0 \leq P_{Ld} \leq P_{Ld}^{max}$$

$$V_i^{min} \leq V_i \leq V_i^{max}$$

$$0 \leq I_{ij} \leq I_{ij}^{max}$$

Where is the P_{Gk} generation at bus k and the P_{Ld} is the load at bus. P_i and Q_i are the active and reactive power injection at bus *i*. N is the total number of network buses. $V_i\angle\theta_i$ is the voltage at bus *i*. $G_{ij} + jB_{ij}$ is the correspond elements in system Y-matrix. $P_{Gk}^{\max}$ and $P_{Gk}^{\min}$ are the upper and lower limits of the generator active power at bus *k*. $Q_{Gi}^{\max}$ and $Q_{Gi}^{\min}$ are reactive power limits for generator *i*. $P_{Ld}^{\max}$ is the upper limit of the load active power which is constrained by distribution facility capacity. I_{ij} and I_{ij}^{max} are the actual and maximum current of line *i-j* respectively.

III. CONTINUATION POWER FLOW

The common accurate approach for computing the ATC in multi possible scenarios is to use the power flow software repeatedly and is called Continuation Method (CM) [13-15]. The theory and practical of CPF method can be obtained in [14-15]. CPF can trace power system steady-state behaviour due to load and generation variation. continuum of power flow solutions for a given load change scenarios in [15]. CPF has comprehensive modelling capability and also can handle power systems with havehuge buses which is about 12000 buses. Two different schemes are used to calculate ATC which is serial and parallel scheme, with review of this method in reference [13]. The man idea of CPF algorithm function is increasing the controlling parameter in discrete steps and then solves the resulting power flow problem at each step. This will continue until it reaches a physical limit that prevent further increase. Newton power flow algorithm is used because the solution is difficult and need the Jacobin matrix at each step. CPF also can yields solution at voltage collapse points.

The common famous usages of CPF are to analysis voltage problems due to load and/or generation variation [14].
CPF is quite complicated because its implementation involves parameterization, predictor, corrector and step-size control. Fig.1 Contingencies analysis must be taken in considerations while calculating ATC results obtained by CPF, ATC results based method are accurate because it considers system non-linearity and control changes. Nevertheless, it becomes very time consuming when applied on larger system and cannot be used in real time due to requirement of repeated solution of power flow. Compered with OPF method where it can give conservative result for ATC because it increases the loading factor only along certain direction without considering control effects. It also able to incorporate the effects of reactive power flows, static voltage limitations, voltage collapse as well as

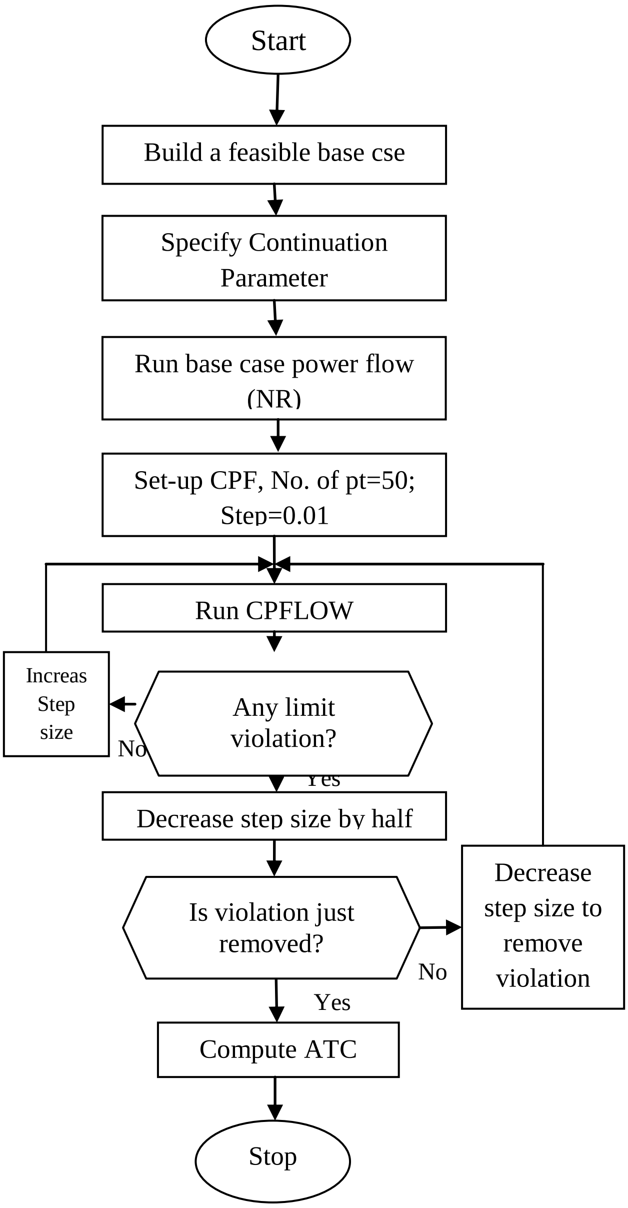


Fig 3. A Flow Chart of the Continuation Power Flow.

the traditional thermal loading effects. Besides, the divergence can be avoided around the voltage limit point. Figure 2. shows a brief summary in the form of a flow chart of the continuation power flow calculation process.

IV. POWER TRANSFER DISTRIBUTION FACTOR

Power transfer distribution factor (PTDF) is another method to compute ATC. This method has proposed in [16-21]. PTDF are most useful to estimate the change in flows for a particular transfer and identify which flow gates are most affected by the transfer. Power transfer distribution factor based on DC load flow is called DCPTDF and has demonstrated in [16-19]. To calculate linear ATC usually use DCPTDF which is used to allocate real power flows on the transmission lines. The advantages of this method are easy to calculate and can give quick estimate Where ΔP_{ij} is a change in real power flow on line *ij* for a change of ΔP_m occurs at bus *m*. While Increase Step size by x2

of ATC. But the ATC values calculated using this method are not very accurate as DC power flow voltage and reactive power effects due to the assumption involved in the DC power flow model. Besides that, for future it becomes doubtful to use in the competitive marker because of its limitations. DCPTDF or linear sensitivity factor show the approximate change in line flows for changes in generation on the network and are derived from DC load flow.

Consider a bus *m* and a line joining buses *i* and *j*. ΔP_m is a change in generation at bus *m*.

Some amount of power will inject into the system at bus *m* by a generator and removed at another bus by a load at another bus *n*. For this case, PTDF can be written as:

$$PTDF_{ij,m} = \frac{\Delta P_{ij}}{\Delta P_m} \qquad (6)$$

$$PTDF_{ij,mn} = \frac{X_{im} - X_{jm} - X_{in} + X_{jn}}{x_{ij}} \qquad (7)$$

Where x_{ij} is the reactance of the transmission line connecting bus *i* and *j*. X_{im}, X_{jm}, X_{in}, and X_{jn} are the elements of bus reactance matrix.

The maximum power flow limits the ATC and for determination ATC, it is necessary to compute the maximum power transfer, $T_{l,mn}$ for each line of the system.

$$T_{l,mn} = \frac{max_l - P_l}{PTDF_{l,mn}}$$

The smallest $T_{l,mn}$ identifies the most constraining branch and thus gives the maximum power transfer. Hence, ATC can be written as:

$$ATC = min\{T_{l,mn}\}$$

In recent times, researchers have use AC power transfer Distribution factors (ACPTDF) to compute ATC [20-21]. The uses of AC distribution factors to determine ATC are quite accurate compared to DC distribution factor. This method is based on derivatives around the given operating point. It also can lead to unacceptable results when used at different operating point to compute ATC. At different operating point, ACPTDF are used to find a variety of transmission system quantities for a change in MW transaction. This method are described as linear sensitivity calculated at initial operating point and can be derived from Jacobin matrix of an operating point load flow. The Jacobin matrix can be written as:

$$\begin{bmatrix} \Delta \delta \\ \Delta V \end{bmatrix} = [J_0]^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}$$

Now for a given transaction of ΔT MW between sellers bus *m* and buyer bus *n*, only the following two entries in the mismatch vector of RHS of the above equation will be non-zero.

$$\Delta P_m = \Delta T \,;\, \Delta P = -\Delta T$$

The change in voltage angle and magnitude at all buses can be computed by using the above mismatch and then the new voltage profile can be calculated. From the new voltage profile, the new line flows and the change in line flows also can be computed. The ACPTDF can be obtained using following equation:

$$PTDF_{ij,mn} = \frac{\Delta P_{ij}}{\Delta T}$$

To calculate ATC, use the same equation as DCPTDF:

$$ATC = min\{T_{l,mn}\}$$

V. SIMULATION RESULTS

in this work, CPF techniques has been developed. The MATLAB software was used to calculate ATC in this paper. Fast decouple were choose to perform load flow. It was chooses because the solution is fast and decouple between mismatches of real and reactive power. The analysis had been done by using 30-bus transmission system shown n Fig. 4 Table 1 show the result of ATC for this simulation:

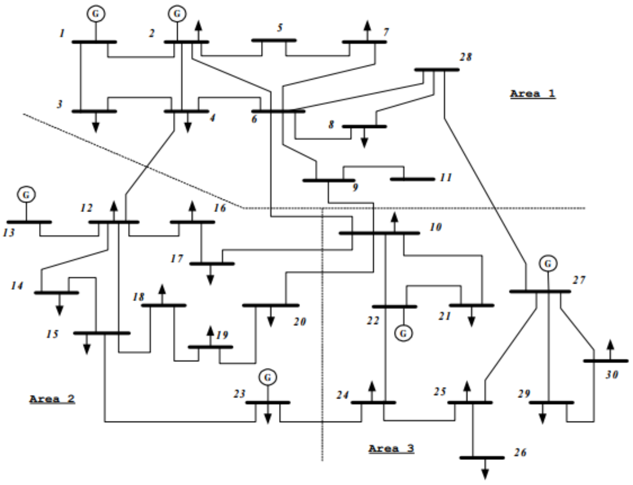
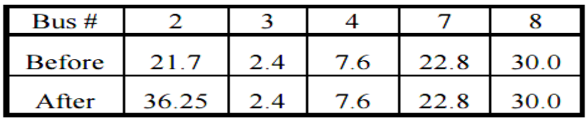


Fig.4 IEEE 30-bus system

Table 1. Active loading of area 1 in MW for a transaction between area 2 and area 1 Simulation result for ATC



Bus #	2	3	4	7	8
Before	21.7	2.4	7.6	22.8	30.0
After	36.25	2.4	7.6	22.8	30.0

Table 2. The optimal values of ATC transactions in each system .

Buss	**Total Generation**		**ATC**	
	Real power (MW)	**Reactive power (MVAR)**	**Real power (MW)**	**Reactive power (MVAR)**
30-bus	**153.053**	**73.233**	**122.947**	**110.767**
24-bus	**350.435**	**249.510**	**201.565**	**72.490**
118-bus	**608.633**	**455.464**	**201.367**	**84.536**

VI. CONCLUSION

This paper presents several methods to calculate available transfer capability (ATC). Recently OPF is studied with new approach and it can incorporate various complex constraints but cannot apply in real time for large system because of time consuming. The CPF method cannot be used in real time even though it includes all the control changes because the solution of power flow is repeated. The approach that uses DC-PTDF is fast but not accurate because it ignores the effect of voltage and reactive power flow in the system. Meanwhile, ATC based on AC-PTDF use derivatives around the given operating point and may lead to unacceptable result if use at different operating point.

REFERENCES

[1] Mariesa L. Crow, “Power System Deregulation”, IEEE, 2001.

[2] “Open Access Same-Time Information System (formerly Real-Time-Information Networks) and Standards of Conduct, Docket No. RM 95-9-000, Order 889, April 1996.

[3] Transmissiom Transfer Capability Task Force, “Available transfer capability definitions and Determination,” Tech. Rep., North American Electric Reliability Council, Princeton, NJ, 1996.

[4] Hamoud G., “Assessment of Available Transfer Capability of Transmission Systems”, IEEE Trans. Power Syst., vol. 15, Feb 2000.

[5] Chun-Lien Su, “Transfer Capability Uncertainty Computation”, International Conference on Power System Technology – POWERCON 2004, Singapore, 21-24 Nov, 2004

[6] Peter w. Sauer, “Technical Challenges of Computing Available Transfer Capability (ATC) in Electric System”, Pserc:97-04, 7-10 Jan, 1997

[7] M. Shaaban. Y. Ni, F.F. Wu, “Transfer Capability Computations in Deregulated Power System”, IEEE, 2000.

[8] B. Mozafari, A.M. Ranjbar, A.R Shirani, A. Barkeseh, “A Comprehensive Method for Available Transfer Capability Calculation in a Deregulated Power System”, IEEE, April 2004.

[9] W. Li, M. Shaaban, Z. Yan, Y. Ni, F. F. Wu, “Available transfer capability calculation with static security constraints”, Proceedings of IEEE PES General Meeting, Vol 1, 2003.

[10] Shaaban M., Li W., Liu H., Yan Z., Ni Y.X., Wu F., “ATC Calculation with Steady-State Security Constraints Using Benders Decomposition”, IEEE Proc. Gen. Tran. & Dis., vol. 150, No. 5. Sept 2003.

[11] Y. Ou and C. Singh, “Assessment of available transfer capability and margins,” IEEE Transactions on Power Systems, vol. 17, no. 2, May 2002.

[12] P. Bresesti, D. Lucarella, P. Marannino, R. Vailati, and F. Zanellini, “An OPF based procedure for fast TTC analyses,” Proc. Power Eng. Soc. GeneralMeeting, 2002.

[13] G.C. Ejebe, J. Tong, G.C. Waight, J.G. Frame, X. Wang, and W.F. Tinney, “Available transfer capability calculations,” IEEE Transactions on Power Systems, vol. 13, no. 4, Nov. 1998.

[14] H.S. Chiang, A.J. Flueck, K.S. Shah, and N. Balu, “CPFlow: A practical tool for tracing power system steady-state stationary behavior due to load and generation variations,” IEEE Transactions on Power Systems, vol. 10, no. 2, May 1995.

[15] Ajjarapu, Venkataramana, and Colin Christy. "The continuation power flow: a tool for steady state voltage stability analysis." *Power Systems, IEEE Transactions on* 7.1 (1992): 416-423.