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Load Modelling in studies of Available Transfer Capability in Power System Networks

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Abstract: In the Restructuring of power system networks, calculations of Available Transfer Capability (ATC) has become a key issue for power system operators to know the system strength for effective use of transmission network. In this regard, this paper presents the methodology to calculate the ATC values in a standard power system network for base load and modeling of load conditions. To present the ATC values in a more realistic way, the load modeling has been considered for the standard power system network i.e New England 39 Bus System. The results obtained are quite encouraging and useful in the present deregulated environment.

Keywords: ATC; Load Modelling; ACPTDF; Bi-Lateral Transactions.

I. INTRODUCTION

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). ATC is expressed as:

ATC = TTC – TRM – Existing Transmission Commitments (including CBM).

The ATC between two areas provides an indication of the amount of additional electric power that can be transferred from one area to another for a specific time frame for a specific set of conditions. ATC can be a very dynamic quantity because it is a function of variable and independent parameters. These parameters are highly dependent upon the conditions of the network. Consequently, ATC calculations may need to be periodically updated. Because of the influence of conditions throughout the network, the accuracy of the ATC calculation is highly dependent on the completeness and accuracy of available network data.

A. Evaluation of ATC

There are many methods were existing in the literature to calculate TTC. Initially the techniques were developed base on DC load flows [1]. But in DC power flows calculations are based on approximations, much attention has been gained by AC power flows [2]. Security Constrained Optimal Power Flow (SCOPF) method: This method solves based on interior point approach, two-level approaches and the TTC can be calculated [3-4]. Continuation Power Flow (CPF) method: The implementation of this mathematically complicated method involves predictor, parameterization, corrector and step-size control as discussed by Chiang [5], etc. Repeated Power Flow (RPF) method: This method repeatedly solves power flow equations at a succession of points along the specified load generation increment [6].Probabilistic Approach method: The method is based on probabilistic approaches such as non-sequential Monte Carlo method, stochastic programming method [7] etc. Based on the literature, it is identified that, ATC calculations using ACPTDF method is most efficient method to calculate the values of ATC.

B. Power Transfer Distribution Factor (PTDF)

From the power transfer point of view, a transaction is a specific amount of power that is injected into the system at one bus by a generator and drawn at another bus by a load. The coefficient of linear relationship between the amount of a transaction and flow on a line is represented by PTDF. It is also called sensitivity because it relates the amount of one change - transaction amount - to another change - line power flow.

PTDF is the fraction of amount of a transaction from one bus to another that flows over a transmission line $PTDF_{lm,ji}$ is the fraction of a transaction from bus i to bus j that flows over a transmission line connecting buses l and m.

$$PTDF_{lm,ji} = \frac{\Delta P_{lm}}{P_{ji}}$$

II. ATC CALCULATIONS

ATC is determined by recognizing the new flow on the line from node I to node m, due to a transaction from node I to node j. The new flow on the line is the sum of original flow P_{lm}^0

$$P_{lm} = P_{lm}^0 + PTDF_{lm,ij} P_{ij}$$

Where, P_{lm}^0 is the base case flow on the line and P_{ji} is the magnitude of proposed transfer. If the limit on line Im, the maximum power that can be transferred without overloading line Im, is $P_{lm}^{\max}$, then,

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$$P_{ij,lm}^{\max} = \frac{P_{lm}^{\max} - P_{lm}^{0}}{PTDF_{lm,ij}}$$

$P_{ij,lm}^{\max}$ is the maximum allowable transaction from node I to node j constrained by the line from node I to node m. ATC is the minimum of the maximum allowable transactions over all lines.

Using the above equation, any proposed transaction for a specific hour may be checked by calculating ATC. If it is greater than the amount of the proposed transaction, the transaction is allowed. If not, the transaction must be rejected or limited to the ATC.

$$ATC_{ij} = \min\left(P_{ij,lm}^{\max}\right)$$

Using the above equation, any proposed transaction for a specific hour may be checked by calculating ATC. If it is greater than the amount of the proposed transaction, the transaction is allowed. If not, the transaction must be rejected or limited to the ATC.

The detailed analysis regarding the calculations of ATC values for any power system network has been given in [11].

III. LOAD MODELLING

To describe the development and implementation of different load models for power system analysis can be possible with load modeling. Load model can be defined as "an analytical, mathematical, equivalent circuit based, physical component based, or any other suitable representation of electrical equipment, which describes changes in the electrical characteristics of the modeled equipment as a function of variations in the relevant supply conditions (e.g. supply system voltage)".

For steady state power flow analysis, the connected loads can be modeled into four different categories as given below [9C1]:

- Constant PQ load model
- Exponential load model
- Load modeling based on power relations

The constant PQ load model is the most commonly used model, where the real and reactive power is being considered constant for the analysis. The exponential load model uses two exponential components for real and reactive power representations. The load model based on power relation represents that, it is a sum of constant impedance, constant current and constant power. The other load model are the loads, where the real and reactive powers variations are not following any of the conditions like linear or exponential relation with the variation of bus voltages.

Depending on the power relation to the voltage, the static characteristics of the load can be classified into constant impedance, constant current and constant power load. For a constant impedance load, the power is a function of square of the voltage, for a constant current load, power is a linear function of voltage and for a constant power load; here, power is independent of change in voltage.

A. Domestic Loads

In this model, at a load bus, the real and reactive power injections can vary directly with the square of the nodal voltage magnitude. This relation can be represented as follows.

$$P = f(V^2)$$

This model can also be called as constant admittance model. Most of the domestic load will comes under this category and they are washing machine, refrigerators, air conditioners, lighting loads etc.

B. Electronic equipment Loads

In this model, at a load bus, the real and reactive power injections can vary directly with the nodal voltage magnitude. This relation can be represented as follows.

$$P = f(V)$$

Most of the electronic equipment's, which are having transistors, transducers will come under this category.

C. Industrial Loads

In this model, at a load bus, the real and reactive power injections will be independent and does not vary with nodal voltage magnitude.

$$P = k$$

Where, 'k' is a constant.

A static load model can be expressed as the characteristics of the load as an algebraic function of the bus voltage magnitude and the frequency of the supply at that instant. The active and reactive power component of the load can be represented in an exponential form as stated below.

$$P_d = P_d^0 \left(\overline{V}\right)^a$$

$$Q_d = Q_d^0 \left(\overline{V}\right)^b$$

Where, $\overline{V} = \frac{V}{V^0}$, P_d and Q_d are the active and reactive power components of the load, 'V' is the magnitude of the bus voltage, P_d^0 and Q_d^0 are the real and reactive powers of the load at initial operating conditions respectively. The exponent component 'a' lies between 0.5 and 1.8 and 'b' lies between 1.5 to 6.

For constant impedance, value of 'a' is 2, for constant current value of 'a' is 1, for constant power value of 'a' is 0.

Therefore, loads can be represented with the following equations.

$$P_d = P_d^0 \left[p_1 \overline{V}^2 + p_2 \overline{V} + p_3\right] \quad (2.10)$$

$$Q_d = Q_d^0 \left[q_1 \overline{V}^2 + q_2 \overline{V} + q_3\right] \quad (2.11)$$

Where, p_1, p_2, p_3 and q_1, q_2, q_3 are load coefficients of the model for real and reactive power loads with $p_1 + p_2 + p_3 = 1$ and $q_1 + q_2 + q_3 = 1$. To calculate ATC with load model, the above equations can be taken as equality constraints, which can also possible to modify as per the load connectivity of the system.

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Industrial loads such as, motor loads are comes under the category of constant power loads.

As per [10c1], Rural & Residential areas of developing areas and commercial areas in economically depressed regions will have a ratio of 20:80 as a constant power and constant impedance loads. Industrial areas will have a ratio of 80:20 as a constant power and constant impedance loads. Residential areas with very strong summer atmospheric conditions will have a ratio of 70:30 as a constant power and constant impedance loads. However residential areas with winter season will have a ratio of 30:70 as a constant power and constant impedance loads. Whereas, very few loads like switching regulators and a ratio of 50:50 ratio of constant power and constant impedance loads will comes under constant current type of the loads. In this paper the load ratios have been considered as 40:10:50 for domestic, electronic and industrial loads respectively.

IV. RESULTS AND ANALYSIS

The proposed ATC evaluation procedure is implemented for New England 39 Bus System. This test system is having ten generators and forty six transmission lines. However out of thirty nine buses, the loads are connected to nineteen buses only. Since out of these one bus is taken as a slack bus (bus - 1). Therefore the possible bi-lateral transactions for both the loads (i.e base load and load modeling conditions) with generator at bus -30 are listed in Table I. and also variation of ATC values for possible bi-lateral transactions with generator at bus-30 is shown in Fig.1.

TABLE I. ATC EVALUATION FOR POSSIBLE BI-LATERAL TRANSACTIONS WITH GENERATOR AT BUS-30 FOR BASE LOAD AND LOAD MODELING CONDITIONS

S. No	Transaction details		ATC value under						
	Generator bus number	Load bus number	Base load condition	Limiting line			Load Modeling condition	Limiting line	
1		3	1247.14	2	30		1246.787	2	30
2		4	1246.69	2	30		1246.497	2	30
3		7	1246.658	2	30		1246.638	2	30
4		8	1246.669	2	30		1246.676	2	30
5		12	1246.504	2	30		1246.372	2	30
6		15	1245.8	2	30		1245.646	2	30
7		16	1079.212	16	17		1202.04	16	17
8		18	1246.343	2	30		1245.967	2	30
9	11	20	465.7926	16	19		490.693	16	19
10		21	783.6068	16	21		834.3376	16	21
11		23	700.5496	21	22		723.5742	21	22
12		24	1021.292	16	24		1085.633	16	24
13		25	1149.625	2	25		1245.218	2	30
14		26	1245.451	2	30		1245.003	2	30
15		27	1245.545	2	30		1245.158	2	30
16		28	1245.507	2	30		1245.026	2	30
17		29	1206.378	28	29		1224.795	28	29
18		39	1246.74	2	30		1247.631	2	30

Similarly variation of ATC values for possible bi-lateral transactions with generator at bus-32,33,34,35,36,37,38,39 are shown in Figs.2,3,4,5,6,7,8 & 9 respectively.

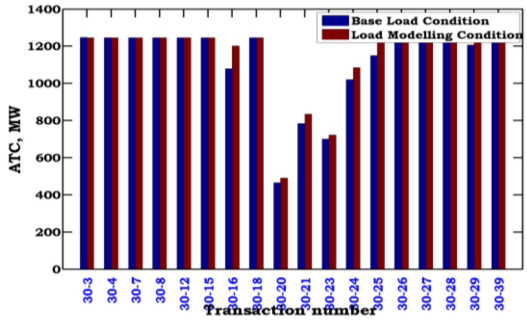

Fig. 1. Variation of ATC values for possible bi-lateral transactions with generator at bus-30 of New England 39 bus system

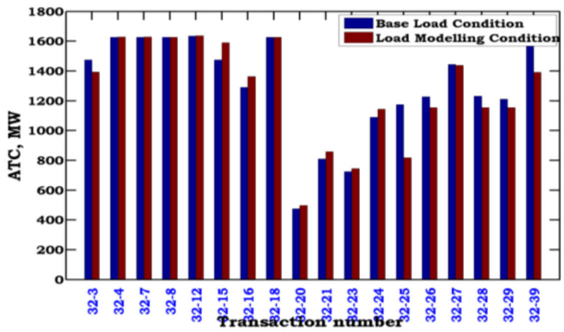

Fig. 2. Variation of ATC values for possible bi-lateral transactions with generator at bus-32 of NewEngland 39 bus system

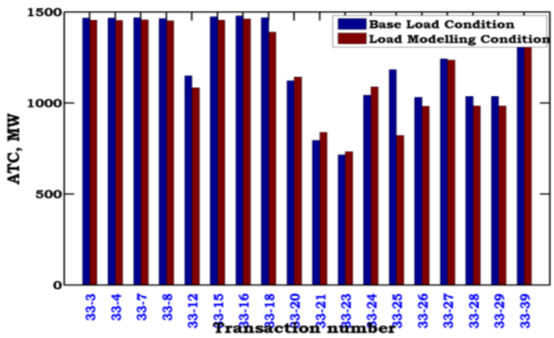

Fig. 3. Variation of ATC values for possible bi-lateral transactions with generator at bus-33 of New England 39 bus system

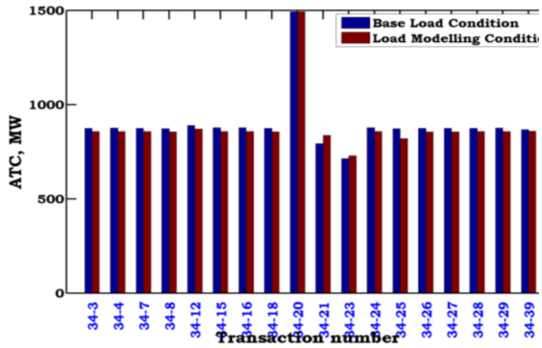

Fig. 4. Variation of ATC values for possible bi-lateral transactions with generator at bus-34 of New England 39 bus syste

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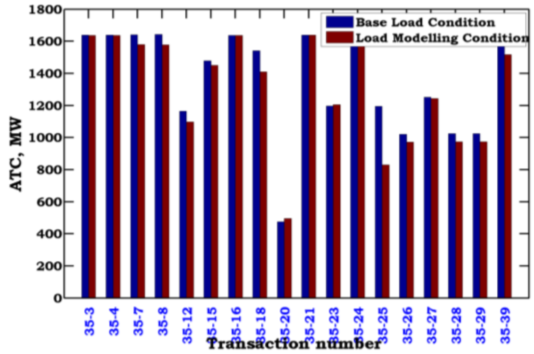

Fig. 5. Variation of ATC values for possible bi-lateral transactions with generator at bus-35 of New England 39 bus system

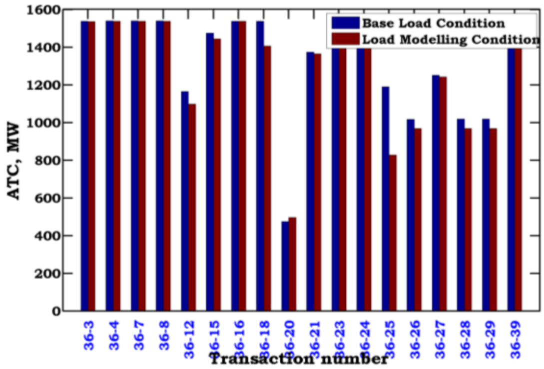

Fig. 6. Variation of ATC values for possible bi-lateral transactions with generator at bus-36 of New England 39 bus system

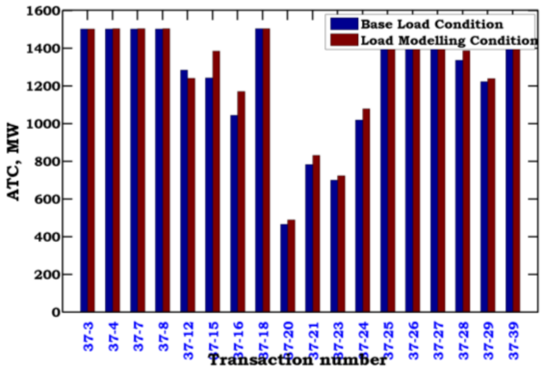

Fig. 7. Variation of ATC values for possible bi-lateral transactions with generator at bus-37 of New England 39 bus system

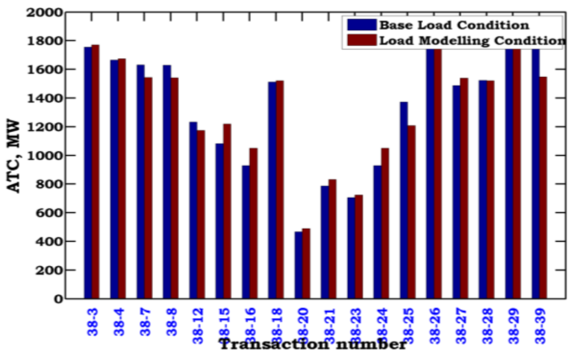

Fig. 8. Variation of ATC values for possible bi-lateral transactions with generator at bus-38 of New England 39 bus system

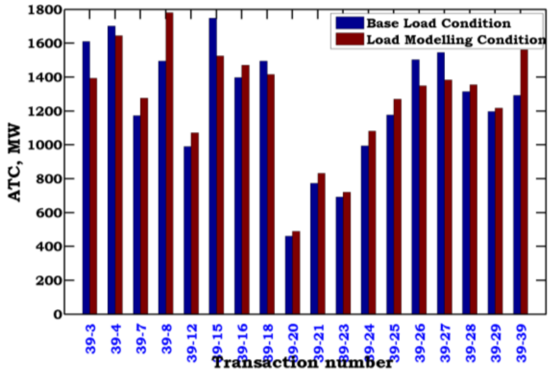

Fig. 9. Variation of ATC values for possible bi-lateral transactions with generator at bus-39 of New England 39 bus system

Based on the practical requirement, there is a necessity of identifying the seller and buyer bus for the excess power transaction. To demonstrate this the top two ranked ATC values for possible bi-lateral transactions with all the generators of New England 39 bus system for base load conditions and load modeling conditions are represents in Fig. 10 & 11 respectively.

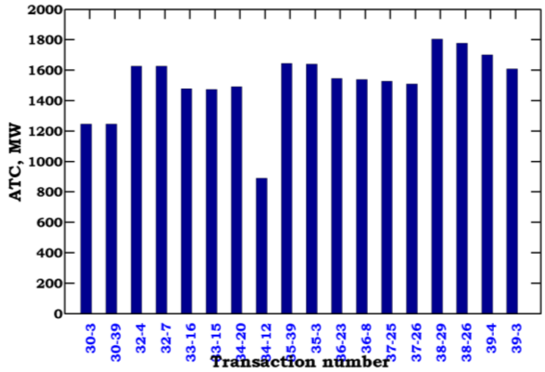

Fig. 10. Representation of top two ranked ATC values for possible bi-lateral transactions with all the generators of New England 39 bus system for Base Load Conditions

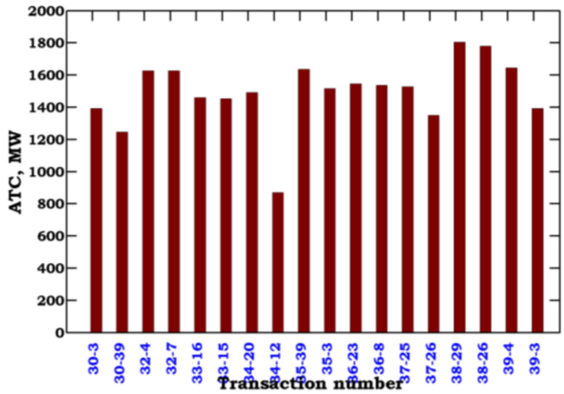

Fig. 11. Representation of top two ranked ATC values for possible bi-lateral transactions with all the generators of New England 39 bus system for Load Modeling Conditions

V. CONCLUSION

This study presents evaluation of ATC for New England 39 Bus System, which was used to demonstrate availability of excess power beyond the existing power flow. Since the

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practical loads are very uncertain, in order to present the more realistic values, the load modeling has been considered for evaluations of ATC calculations. The presented results will also provide the information regarding choosing of the bi-lateral transactions based on the requirement for both power generation and transmission companies. The results obtained are quite promising and useful in the present deregulated environment.

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