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A Simple and Fastest Method of Evaluating Available Transfer Capability

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Abstract: Congestion management is necessary in electricity market, when the transmission network is unable to accommodate the transactions required in that particular system. If the congestion management is not taken care, then the system operating limits will not be in the prescribed limit. In competitive markets, the congestion management is more complex than the ordinary system and it leads to more disputes among the power suppliers as well as consumers. In order to overcome these limitations, each utility manages the congestion, by following certain physical or financial mechanisms. The ATC of power system network gives the status of unutilized power at any time and depends on many factors due to the thermal, voltage and stability considerations. The main factors which will decide the ATC are system load level, load distribution in network, power transfer between areas, and the limit imposed on the transmission network etc. This information will be helpful for power marketers, sellers and buyers to participate in the commercial activities.For this, severity index is considered to identify the most critical transmission line in a given system. Later, the effect of ATC under normal and contingency conditions is analyzed on IEEE-6 bus & Indian -24 bus test system with supporting numerical and graphical results.

Keywords: ATC; contingency condition; direct method;

I. INTRODUCTION

The knowledge of Available Transfer Capability (ATC) is very important for optimum utilization of existing transmission facility. ATC information conveys how much power can be transmitted through the power network over and above already committed usage without violation of system security limits. Now-a-days, the power trade activity which is involved in the wholesale power market requires accurate information of power transfer between areas. Such vital information can help power marketers, sellers, and buyers in planning, operation, and reserving transmission services. In this thesis, the source bus and sink bus are identified by using the random generation concept with respect to buses of the test system. The ATC is calculated using repeated power flow method for normal case and also, for line outage case. The ATC results for two cases are presented and analyzed.

Transferring an electric power from one place to another is an alternative way to provide effective electric power required by the demand. This may assist towards reduction in a system operational cost. Now-a-days, the power trade activity which is involved in the wholesale power market requires accurate information of power transfer between areas. Such vital information can help power marketers, sellers, and buyers in planning, operation, and reserving transmission services. There is a significant index in the transfer capability assessment, namely, the Available Transfer Capability (ATC). ATC is a measure of the additional amount of power that flows across the interface over and above the base case flows without jeopardize power system security. ATC is significantly limited by heavily loaded lines or buses with relatively low voltages. FACTS device enhance the ATC by redistributing line flows and regulating bus voltages.

Based on the simultaneous transfer of power, an optimization method has been proposed for the calculations of ATC [1].In this method, the power is injected at one location and the same power will be extracted at another location. This will leads to the violation of the system security. Therefore an optimization method has been proposed to maintain the system security. The Monte Carlo method with sequential simulation (MCMSS) is also implemented to assess the sequential variations in the ATC caused by uncertainties related with hourly load fluctuations and equipment unavailability's [2].Based on the advantages of polynomial-time characteristics, an Interior Point Algorithm was used to estimate the ATC. However, more deviation has been witnessed in this technique when compared to the actual values [3].Genetic Algorithm (GA) approach has been extensively used in power system networks, in view of optimization approach, this GA approach has also been extended in calculations of ATC. GAs can find a globally optimal solution [4].Modern heuristic techniques such as Particle Swarm Optimization (PSO) algorithms is one of the method, which is effectively proving that, the optimal values of ATC can be calculated for any power system network [5].Generally ATC can be classified as Static ATC and Dynamic ATC and these optimal calculations are referred in [6].Static ATC can be calculated based on continuous power flow and linear sensitivity methods. But in reality since the generation and loads are dynamic, therefore by maintaining static stability constraints, if the ATC is calculated with the dynamic stability limits, then

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the ATC is called as dynamic ATC. An iterative methodology has been implemented to check the dynamic behavior of the system in calculating the ATC. In this method the trajectories which lie on the stability margin must approach an unsteady equilibrium point [7].A nonlinear programming method has been implemented for determination of ATC. The capability of this method is to maintain static and dynamic security constraints [8].To evaluate the dynamic ATC, an interior point nonlinear approach is implemented in [9]. This method is based on the technique that, the transient stability constraints are being integrated and converted into steady-state problem. By considering Transient stability and Voltage stability analysis termination criterion, A Fast and Accurate Dynamic method for ATC (FAD-ATC) is identified for the calculations of ATC [10].A Quasi-steady-state (QSS) approximation is proposed in [11] and implemented on a test for evaluation of ATC. In this method the dynamic voltage stability constraints also considered. The real part of the critical eigenvalue is considered as objective subjected to the Hopf bifurcation an optimization assessment of dynamic ATC is calculated [12].To determine the optimal calculations of ATC for a power system network, a Real coded genetic algorithm related to analytical hierarchy process (AHP) is implemented[13]. A bi-level programming problem (BLPP) is proposed in [14] which gives the ATC on the optimum generation share and determines the optimum loading factor for different combination of generator bus share by maintaining the Hopf bifurcation also as one of the aspect in the power system network.

ATC problem formulation

At first, the source bus/area and sink bus/area are randomly selected to calculate ATC. The amount of load is increased slowly at the sink bus so as not to violate any of the system constraints. The increased power demand when compared to normal condition is considered to be the system ATC. The mathematical representation of ATC is as follows:

The source bus (*p*) $= rand\ int(1,1,[1,nb])$

The sink bus (*q*) $= rand\ int(1,1,[1,nb])$

The increase in real power generation at source bus '*p*' is

$$P_{gp}^{new} = P_{gp}^{old} + \Delta x$$

The increase in real power load at source bus '*q*' is

$$P_{dq}^{new} = P_{dq}^{old} + \Delta x$$

The increase in reactive power load at source bus '*q*' is

$$Q_{dq}^{new} = Q_{dq}^{old} + \Delta x$$

The ATC can be mathematically represented as

$$ATC = P_{dq}^{new} - P_{dq}^{old} \quad (1)$$

Where, 'nb' is the total number of buses, 'P_{gp}^{new} and Q_{gp}^{new}' are the new active and reactive power generators at source bus '*p*', 'P_{dq}^{new} and Q_{dq}^{new}' are the new active and reactive power loads at sink bus '*q*', ''Δx' is the step increase in power at source.

II. CONTINGENCY ANALYSIS

The system severity should be evaluated for one of the severe conditions such as contingency condition. The result of this analysis allows the system to be operated securely. Now a day, because of the modernization of the power system with the help of computers, it is possible to identify the most critical transmission lines and generator that causes the system to be operates in an uncontrolled manner and leads cascading outages and failures. From this, it is necessary to perform a contingency analysis to predetermine the system effectiveness before they arise.

As the present power system is an interconnected network, when a generator is lost, the lost generation should be picked up by the other generator, due to which some of the transmission lines get overloaded and some of the generators are operating at its maximum limits. in general, the lost generation may be picked up by the slack generator and this leads to increase of power flow in transmission lines connected to this bus.

From this discussion, it is necessary an operational person should know the information regarding the severity of the transmission lines and the possibilities of the generator outages to maintain the system secure. In common practice, contingency analysis is performed on a given system with single outage events (one transmission line outage or one generator outage) or multiple outage events (two/more transmission lines outage or two/more generators outage or combinations thereof) are analyzed. For each of the events, the limit violations of power flows in transmission lines and voltage magnitude deviations at buses are identified.

Finally, the event which has highest severity is identified and the respective precautions are suggested to improve the system security for safer operation.

In general, the main aim of power system operation and control is to meet the demand continuously without any failures. While, in this operation, sometimes, outage of generator due to failure of the auxiliary equipment or removal of a transmission line for maintenance purpose or due to storm and other effects may happens. Due to which, the system frequency may drops and leads to load shedding or uncontrolled operation and sometimes leads to system collapse condition. This happens mainly due to the overloading of the transmission lines, voltage deviation at the load buses and lack of reactive power support at the load buses.

In general, the severity index of each of the contingency is calculated using

$$\text{Severity index } = \sum_{i=1}^{N_{ol}} (PI_i)^{2m} = \sum_{i=1}^{N_{ol}} \left(\frac{S_i}{S_i^{max}}\right)^{2m} \quad (2)$$

Where, S_i and S_i^{max} are the MVA flow and rating of line-'i'. 'm' is an integer exponent taken as 1(one). 'N_{ol}' is the total number of over loaded transmission lines and 'PI' is the performance index.

III. IMPLEMENTATION PROCEDURE

The repeated power flow method is implemented to calculate the ATC value for a given system.

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1. Read the system data, source bus and sink bus data.
2. Form the admittance matrix by direct inspection method.
3. Assume a step increase in power transfer at source bus and sink bus.
4. Solve the power flow equations using Newton-Raphson method and check whether any limit is violated.
5. If no limit is violated, go to step 3.
6. If limit is violated, calculate ATC using Equation (1) and print the results.

IV. RESULTS AND ANALYSIS

To demonstrate the effectiveness of the proposed methodology to calculate ATC, two test systems namely IEEE-6 bus and Indian-24 bus test systems are considered.

At first for each system, the critical transmission line is identified using the procedure given in section III.Later this critical transmission line is removed from the system to create transmission line outage condition. Under this contingency condition, the system ATC is evaluated.

A. Example-1

IEEE-6 bus system with four generators and seven transmission lines is considered. Using contingency analysis, the critical transmission line for this system is 6th line i.e. line connected between buses 4 and 5. The system ATC is evaluated under this contingency condition to show the effect of the same. The system ATC values for the considered transactions with the system generators are tabulated in Table.1. The variation of ATC values under transmission line outage condition with generators connected at buses 2, 3 and 4 are shown in Figs.1-3.

From Table.1, it is identified that, the system ATC values are decreased under contingency condition. The maximum variation is observed in the transmission lines connected nearer to the outage line. The same analysis is observed from Figs.1-3.

Table.2.1 ATC evaluation for possible bi-lateral transactions of IEEE-6 bus system

S. No	Transaction details		ATC value (MW) under					
	Seller bus	Buyer bus	Normal condition	Limiting line		Contingency condition	Limiting line	
1	2	1	194.9006	3	5	158.4297	3	5
2		3	207.9674	3	6	192.8381	3	6
3		4	111.2309	4	5	55.783	1	5
4		5	96.12941	4	6	53.81337	4	6
5		6	126.8879	1	2	31.4226	1	2
6	3	1	105.2853	4	5	99.21469	4	6
7		2	56.72968	4	5	50.40862	4	6
8		4	37.5689	4	5	27.29682	4	6
9		5	68.22109	4	5	41.1423	4	6
10		6	57.0409	4	5	31.2098	4	6
11	4	1	246.2033	2	4	174.4855	1	5
12		2	5.950961	4	6	2.870346	4	6
13		3	203.4091	4	5	177.8506	2	4
14		5	3.019434	4	6	1.86106	4	6
15		6	163.8133	1	2	62.84053	1	2

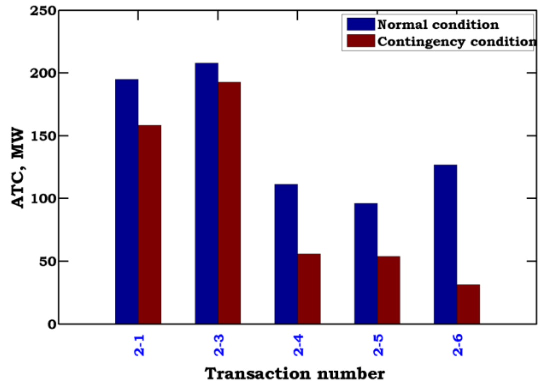

Fig.1 Variation of ATC values for possible bi-lateral transactions with generator at bus-2 of IEEE-6 bus system

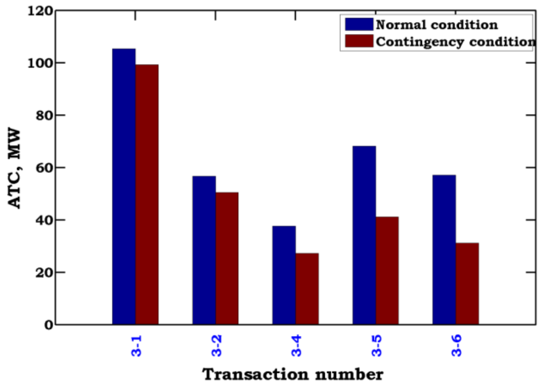

Fig.2 Variation of ATC values for possible bi-lateral transactions with generator at bus-3 of IEEE-6 bus system

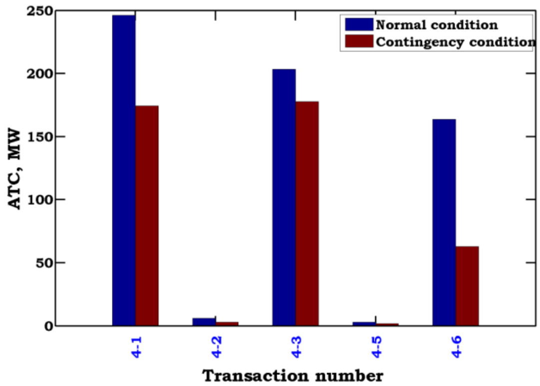

Fig.3 Variation of ATC values for possible bi-lateral transactions with generator at bus-4 of IEEE-6 bus system

B. Example-2

To extend the applicability of the proposed methodology, a real time Indian-24 bus test system is considered. For this system, there are four generators and twenty seven transmission lines. Out of this, 17th line i.e. the line connected between buses 19 and 20 is the critical transmission line. To verify the effect of transmission line contingency on system ATC, the system ATC is evaluated for each of the transaction with respect to each generator. The obtained results for system ATC values for the transactions with respect to generators connected at buses 2, 3 and 4 are tabulated in Tables.2-4. Similarly, the variation of system ATC values is shown in Figs.4-6.

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From Tables.2-4, it is identified that, the system ATC values are decreased under contingency condition. The maximum variation is observed in the transmission lines connected nearer to the outage line. The same analysis is observed from Figs.4-6.

Table.2 ATC evaluation for possible bi-lateral transactions with generator at bus-2 of Indian-24 bus system

S. No	Transaction details		ATC value (MW) under					
	Seller bus	Buyer bus	Normal condition	Limiting line		Contingency condition	Limiting line	
1	2	6	11.41258	8	9	11.96793	8	9
2		7	8.41608	8	9	8.731266	8	9
3		9	7.644873	8	9	7.896126	8	9
4		10	16.29563	8	9	17.54277	8	9
5		11	13.53958	8	9	14.36151	8	9
6		12	14.63437	8	9	15.61554	8	9
7		13	19.47617	8	9	21.32973	8	9
8		16	11.61195	16	17	11.86031	16	17
9		17	149.5504	19	20	106.4264	20	24
10		19	157.7208	8	9	101.2952	22	21
11		20	40.81852	22	21	38.69108	22	21
12		21	171.5883	22	21	143.6244	22	21
13		23	90.50332	8	9	92.14924	20	24
14		24	22.5917	8	9	25.33465	8	9

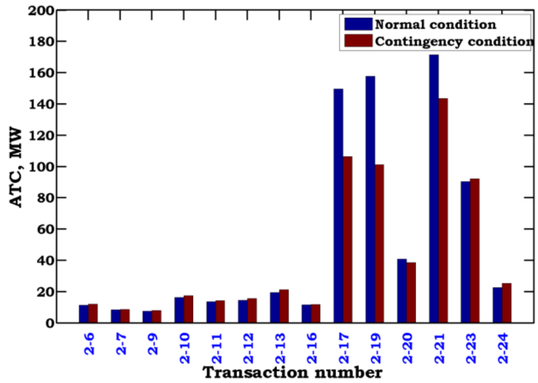

Fig.4 Variation of ATC values for possible bi-lateral transactions with generator at bus-2 of Indian-24 bus system

Table.3 ATC evaluation for possible bi-lateral transactions with generator at bus-3 of Indian-24 bus system

S. No	Transaction details		ATC value (MW) under					
	Seller bus	Buyer bus	Normal condition	Limiting line		Contingency condition	Limiting line	
1	3	6	14.59805	8	9	14.46747	8	9
2		7	10.03011	8	9	9.990523	8	9
3		9	8.953652	8	9	8.911996	8	9
4		10	21.85373	16	17	21.72229	16	17
5		11	16.87739	16	17	16.76361	16	17
6		12	18.74288	16	17	18.62402	16	17
7		13	28.76506	16	17	28.6132	16	17
8		16	11.50593	16	17	11.45593	16	17
9		17	103.3146	13	16	108.7698	13	16
10		19	90.14248	19	20	17.83712	24	5
11		20	44.24144	22	21	16.78505	24	5
12		21	101.8697	19	20	16.79784	24	5
13		23	78.19126	24	5	19.01172	24	5
14		24	39.77141	8	9	39.94319	8	9

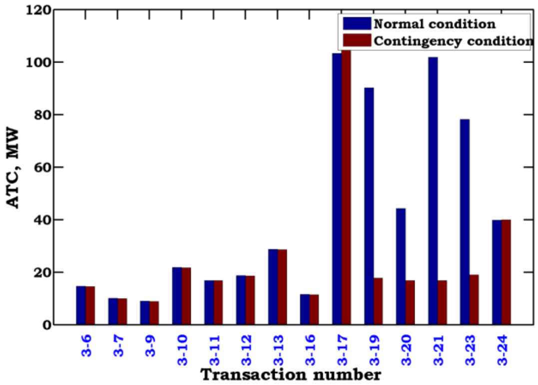

Fig.5 Variation of ATC values for possible bi-lateral transactions with generator at bus-3 of Indian-24 bus system

Table.4 ATC evaluation for possible bi-lateral transactions with generator at bus-4 of Indian-24 bus system

S. No	Transaction details		ATC value (MW) under					
	Seller bus	Buyer bus	Normal condition	Limiting line		Contingency condition	Limiting line	
1	4	6	12.49722	8	9	12.35784	8	9
2		7	8.99157	8	9	8.936987	8	9
3		9	8.116768	8	9	8.063997	8	9
4		10	18.60075	8	9	18.39346	8	9
5		11	15.09374	8	9	14.92668	8	9
6		12	16.46703	8	9	16.28601	8	9
7		13	22.86241	8	9	22.60064	8	9
8		16	12.10997	16	17	12.03591	16	17
9		17	189.2477	19	5	179.7566	19	5
10		19	89.40238	19	20	17.90653	24	5
11		20	43.97605	22	21	16.8465	24	5
12		21	100.9255	19	20	16.85939	24	5
13		23	78.72972	24	5	19.0906	24	5
14		24	27.2783	8	9	27.14792	8	9

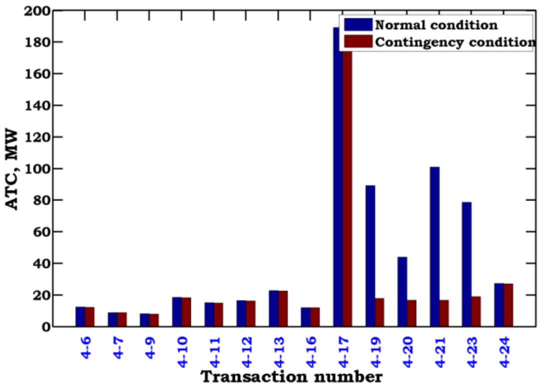

Fig.6 Variation of ATC values for possible bi-lateral transactions with generator at bus-4 of Indian-24 bus system

V. CONCLUSION

In this paper, the evaluation of ATC has been presented using severity index calculations. The procedure to identify the most critical transmission line has been presented. Using this, the comparison of ATC has been presented under normal and contingency conditions. The proposed method of establishing contract will improves the ATC of the transmission system in the electricity market which encourages more number of future contracts without violating the transmission system constraints.

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This study will help the power system network operators to evaluate the ATC at one platform for accurate assessment of the ATC and its access on the website for online reservation in open access environment. The effect of transmission line contingency has also been analyzed. The proposed methodology has been tested on IEEE-6 bus & Indian -24 bus test system with supporting numerical and graphical results.

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