ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 3, Issue 12, 2016 December

Computation of Optimum ATC Using Generator Participation Factor in Deregulated System

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Abstract: Open access allows all generators to transmit power into the system, which may lead one or more lines to operate beyond their operating limits and causing network congestion. One of the major challenges is to accurately gauge the transfer capability remaining in the system for further transactions, which is termed as Available Transfer Capability (ATC). This paper describes the evaluation of ATC using Power Transfer Distribution Factors and Participation Factors. The participation factor is a measure of how the real power output of the generator changes in response to load demand. In this paper, by choosing different generator participation factors, its impact on ATC is observed using Power Word Simulator14. The solutions obtained are useful in the present restructuring environment.

Keywords: Deregulation, Network Congestion, Available Transfer Capability (ATC), Participation Factors, Proportional Sharing Principle.

I. INTRODUCTION

In a deregulated power system, unbundling of the generation, transmission and distribution systems has invited various problems as regards to the planning and operation of a transmission infrastructure. While providing the open access to the market participants, the generation companies can transmit the power as per the changes in load demands. Since the generator cost functions are not same, the issues related to differential power tariffs may become more complex. Also due to free trading, some of the lines may get overloaded thereby causing network congestion. The congestion management model considering demand elasticity is proposed in [17].

A deregulated framework has been replacing the traditional vertically integrated structure of power system [3]. One of the objectives of deregulation is to create competitive markets to trade electricity. So as to supply the loads under optimal conditions, generating companies with cheaper power are preferred to transmit their power over the transmission network. In doing so, one or more components of transmission system may operate at or beyond their limits thereby causing network congestion and further threatening the security of the network. Congestion management is a major challenge in deregulated system. Before permitting the power transactions, feasibility of transmission network components is required to be determined. It can be detected by evaluation of Available Transfer Capability (ATC) of the network for various applied power transactions.

North American Electric Reliability Council (NERC), has defined ATC as the amount of the transfer capability remaining in the physical transmission network for further commercial activity over and above already committed uses [12]. Since the system conditions continuously changes, ATC of network must be continuously updated. Available Transfer Capability is an important term in restructured power system that affects the planning and controlling of transmission infrastructure. Main constrains for ATC are thermal limits, voltage limits and steady state stability limits

Various mathematical models have been developed by the researchers to determine the ATC of the transmission system. Continuation Power flow (CPFLOW) [6] is a tool available for the determination of TTC (or ATC). It utilizes a continuation power flow algorithm for the calculation of maximum load ability of electric power system. Accuracy of results is obtained with negligible computational time. Power transfer distribution factor (PTDF) method is used by

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many utilities for determination of ATC .The methods of Power Transfer Distribution Factor (PTDF) using DC power flow and AC power flow are derived to calculate ATC. In DCPTDF method [6], DC load flow i.e. a linear model, is considered. This method is fast but does not provide the accuracy. In [14], ACPTDF method is proposed for determination of ATC of a practical system case. It considers the determination of power transfer distribution factors, computed at a base case load flow using sensitivity properties of NRLF Jacobian. Continuous Newton's Method for solving the power flow problem is proposed in [8].

It is proposed that depending upon the transmission network parameters, generator responses to the variation in loads differ from each other. To know these responses is important from various aspects such as for determination of nodal prices and also helpful in determination of system parameters required to be controlled for transmission capability improvement, in case of less available transfer capability. When the load at a bus is subjected to change, participation factor of generator can decide the ATC of the network [1]. Sensitivity analysis and power transfer distribution factor are used for the determination of ATC for individual transaction. The participation factor is a measure of how the real power output of the generator changes in response to demand when the generator is available for AGC and the area is on participation factor control.

In this paper, the method of ATC determination from the aspect of changes in load is proposed. Generator participation factors are used to split the total change in load into various bilateral transactions. By choosing different generator participation factors, ATC and maximum load applied to a bus without causing insecurity to the network has been found to be changed. The variable load is considered as data to calculate ATC of network, considering various sets of generator participation factors.

II. AVAILABLE TRANSFER CAPABILITY (ATC)

Definition- According to NERC Report Available Transfer capability (ATC) is a measure of transfer capability remaining in the physical transmission network for further commercial activity over and above already committed uses "The term capability here refers to the ability of lines(s) to reliably transfer power from one bus/area to another It is different from transfer capacity in the sense that capacity implies rating of specified line(s) and that accounts for the thermal limits only. Capability on the other hand is the function of that line with other elements in the transmission network. Mathematically, ATC is defined as,

$$ATC=TTC-TRM-\{ETC+CBM\} \quad (1)$$

Where TTC- Total Transfer Capability
TRM-Transmission Reliability Margin
ETC-Existing Transmission Commitments
CBM-Capacity Benefit Margin

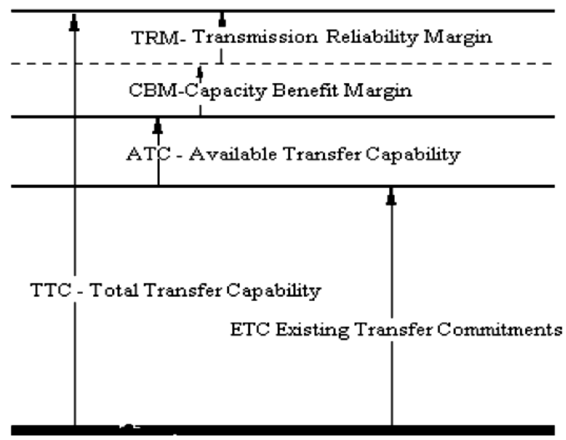

Figure 1: Graphical Representation of ATC and other Associated terms

In eq (1), other terms except TTC are normally decided by the load serving entities. If TRM and CBM are not considered, TTC represents ATC at the base load flow conditions. The term TTC is variable and changes according to the change in line flows, line limits and the transacting power between the buses. The line limit and transacting power are the known quantities. Hence major part of TTC (or ATC) determination is to compute the change in line flows for a specific transaction. These changes can be determined by taking the difference of line flows obtained before and after applying the transactions. Graphically these values are represented in Figure. Power Transfer Distribution Factor (PTDF)

Within ATC computation, a source and a sink are specified for each transaction. Active power will then flow from source to sink in a direction. For each direction, the ATC value is the maximum megawatt source injection that can be transferred to the sink without violating any of the operating limits such as Line thermal limits, voltage limits and system stability limits. In order to investigate how far the system is from an insecure condition, and how a

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transaction of active power can affect the loading of the transmission system, it is necessary to analyze the sensitivities of line flows with respect to bus injections. These sensitivities are termed as Power Transfer Distribution Factors. These values provide a linearized approximation of how the flow on the transmission lines and interfaces change in response to transaction between the seller and buyer. For multi-area ATC, the transaction will be between two areas. The PTDFs are operating point dependent

III. PARTICIPATION FACTOR

The participation factor is used to determine how the real power output of the generator changes in response to demand when the generator is available for AGC and the area is on participation factor control participation factor of a generator is the ratio of change in generator power of that generator to the change in load. It is given as,

$$x_i = \frac{\Delta T_{ik}}{\Delta P_k} \qquad (2)$$

Where x_i is Generator participation factor,

ΔT_{ik} is change in generator power at i^{th} bus due to change in load at k^{th} bus,

ΔP_k Change in load at k^{th} bus.

For the purpose of calculating ATC, buyer and seller transactions are to be specified. This can be slack, a single bus, injection groups, areas etc. When multiple generators exist in the transaction, such as the case of areas or injection groups, participation factors needed to be assigned. so as to know the participation of generators or loads, the load flow solution must be known .

IV. SIGNIFICANCE OF ATC

The information of ATC, as an important indicator of the system performance, is useful in restructured energy market in the following ways:

1. It provides the knowledge of power system capability about the present system condition.
2. Running the system under the ATC limits also ensures system security and reliability to some extent, since the calculation of ATC is based on the security constraints with the consideration of critical contingencies that can lead the system normal state to alert state.
3. The ATC is required in making decisions for the transactions between the market participants after checking the power contracts between themselves.
4. The ATC is also useful in enhancing system capability. With the knowledge of the limiting condition for the ATC, the system operator can take some operating or planning decision to avoid this limiting condition and thus enhance the system capability.
5. The ATC value can also serve as an indicator of power congestion through transmission lines.
6. The ATC is useful in transmission costing function. The ISO can put more transmission cost for the transaction through transmission path having low value of ATC. This extra transmission cost can be used in increasing the transmission capabilities for the transmission path.

V. COMPUTATION OF ATC

Congestion Management is the most important issue to be tackled in deregulated power system. To have congestion free transmission system knowledge of Available Transfer Capability (ATC) of the network is very important. Available transfer capability is the measure of remaining transmission capability of the network. The usual method of calculating ATC is by Network Response Method. In which bilateral transaction is only considered and then, whether the transaction is feasible for the network or not is concluded.

For calculating ATC, Changes in line flow are obtained, considering all the transactions individually. After that PTDF and ATC of all the transactions are obtained separately using Network Response Method. PTDF is the coefficient of linear relationship between the amount of a transaction and the flow on a line. The change in line flow associated with a new transaction is then,

$$\Delta P_{ij}^{New} = PTDF_{ij,mn} P_{mn}^{New} \qquad (3)$$

Where i and j are buses at the ends of the line being monitored, m and n are “from” and “to” zone numbers for the proposed new transaction,

P_{mn}^{New} is new transaction in MW amount.

$$P_{mn,ij}^{Max} \leq \frac{P_{ij}^{Max} - P_{ij}^{0}}{PTDF_{ij,mn}} \qquad (4)$$

$p_{mn,ij}^{Max}$ is the maximum allowable transaction amount from zone m to zone n.

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ATC of the network is constrained by the minimum of the allowable transaction over all lines.

$$ATC_{mn} = \min_{ij} P_{mn,ij}^{Max} \quad (5)$$

After ATC computation, network condition for congestion can be known to remove congestion in case of known ATC, a proper strategy for its improvement must be applied. Here ATC computation by changing the participation factor is carried out.

If ATC_i represents the ATC for this transaction, then ATC of the network for change in load at bus "k" will be

$$ATC_k = \min(\frac{ATC_i}{x_i}) \quad (6)$$

Here represents the capability of the network to apply the load at bus "k". In this paper ATC computation by varying the load is made .

Algorithm

1. GPF are set
2. base case such as, bus voltage, bus angle ,power flows
3. and current flow are computed
4. A variation in active power at a load bus is applied and power flow analysis using Power Word Simulator 14 is computed.
5. The line PTDF and ATC for each transaction has been calculated.
6. Individual TC has been calculated for each transaction after that ATC of the network is calculated.
7. The next transaction is applied and the steps 3, 4 and 5 are repeated.

The PWS 14 Simulation software is designed for ATC computation. The consideration of bus load changes GPF and ATC is set and computed linearly.

Case study

Effect of change of Generator Participation Factor on ATC of network by varying the load has been carried out on a 11 Bus System.(Fig 2)

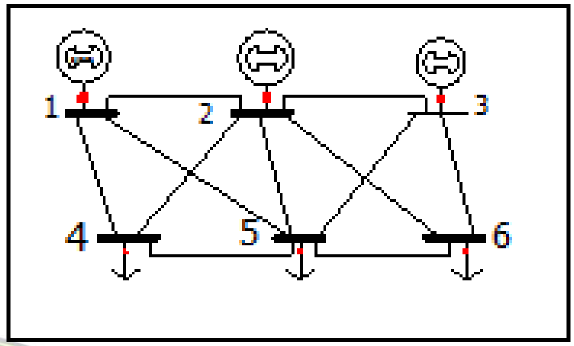

Figure 2 6 bus system.

In this eleven bus system bus 1 is slack bus, bus 10 and 11 are generator buses whereas bus 3, 5, 6, 8 and 9 are load buses. It is assumed that the load sharing by generator buses are times the change in load. For example, if 0.2 and 0.3 are the participation factors of generator 10 and 11 respectively, for Change in load of 10 MW at bus 3, generator 10 and 11 will contribute 2 and 3 MW respectively. Generator 1 being a slack bus generator will contribute the remaining power of 5 MW and the change in losses. The bilateral transaction to meet the change in load will be,

1 – 3 = 5 MW
10 – 3 = 2 MW
11 – 3 = 3 MW

Outcomes of change of GPF on ATC of transmission network has been evaluated on 11 bus system as shown in fig-2

For this ATC determination, the system is designed in Power Word Simulator 14 .The Participation Factors of Generators are set and ATC is computed by considering changes in load at bus 6.

TABLE 1. AVAILABLE TRANSFER CAPABILITY, CONSIDERING VARIOUS GENERATOR PARTICIPATION FACTOR AND CHANGES IN LOAD AT BUS 6

TRANSACTIONS AND CHANGES IN LOAD AT BUS 6 (PARTICIPATION FACTORS OF X_1=0.2,X_2=0.4,X_3=0.4 INITIAL LOAD AT BUS 6 =70 MW)

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Computing time in Hr	Appl. Change in load at bus 6	Generato r and load bus pair	Transacting power (MW)	N/W ATC for individual transaction MW	N/W ATC for simultaneous power transactions
1	2	1-6	0.4	115.49	112.64
		2-6	0.8	114.76	
		3-6	0.8	112.64	
2	2	1-6	0.4	110.69	110.69
		2-6	0.8	114.20	
		3-6	0.8	111.67	
3	-6	1-6	-1.2	116.09	116.09
		2-6	-2.4	116.69	
		3-6	-2.4	116.04	
4	8	1-6	1.6	119.47	111.87
		2-6	3.2	112.38	
		3-6	3.2	111.87	
5	4	1-6	0.8	110.05	110.05
		2-6	1.6	111.59	
		3-6	1.6	111.59	
6	4	1-6	0.8	109.45	109.45
		2-6	1.6	118.35	
		3-6	1.6	114.76	
7	4	1-6	0.8	108.59	108.59
		2-6	1.6	109.55	
		3-6	1.6	110.08	
8	4	1-6	0.8	117.93	108.14
		2-6	1.6	108.14	
		3-6	1.6	110.86	
9	4	1-6	0.8	107.443	107.44
		2-6	1.6	121.25	
		3-6	1.6	118	
10	4	1-6	0.8	107.31	107.31
		2-6	1.6	124.75	
		3-6	1.6	110.48	
11	4	1-6	0.8	105.96	105.96
		2-6	1.6	125.45	
		3-6	1.6	143.56	
12	-2	1-6	-0.4	110.16	110.16
		2-6	-0.8	110.16	
		3-6	-0.8	116.74	
13	-4	1-6	-0.8	114.57	114.57
		2-6	-1.6	115.67	
		3-6	-1.6	115.67	

TABLE 2 ATC WITH CONSIDERATION OF CHANGES IN LOAD AT BUS 6 AND DIFFERENT PARTICIPATION FACTORS (INITIAL LOAD AT BUS 6=70 MW)

Computing time in Hr	Load at bus 6 (MW)	ATC of a N/W (MW) X_1=0.2 X_2=0.4 X_3=0.4	ATC of a N/W (MW) X_1=0.3 X_2=0.5 X_3=0.2	ATC of a N/W (MW) X_1=0.6 X_2=0.2 X_3=0.2	ATC of a N/W (MW) X_1=0.4 X_2=0.3 X_3=0.3
1	72	112.64	112.64	118	118.49
2	74	110.69	110.69	113.54	114.17
3	68	116.09	116.04	119.28	120.38
4	76	111.87	108.56	111.51	110.62
5	80	110.05	107.53	107.53	106.22
6	84	109.45	106.47	105.78	103.47
7	88	108.59	104.72	104.06	103.08
8	92	108.14	102.76	102.76	100.41
9	96	107.44	101.12	101.12	97.52
10	100	107.31	99.46	99.46	95.96
11	104	105.96	97.31	97.32	92.72
12	102	110.16	103.89	103.89	100.67
13	98	114.57	115	114.57	113.37

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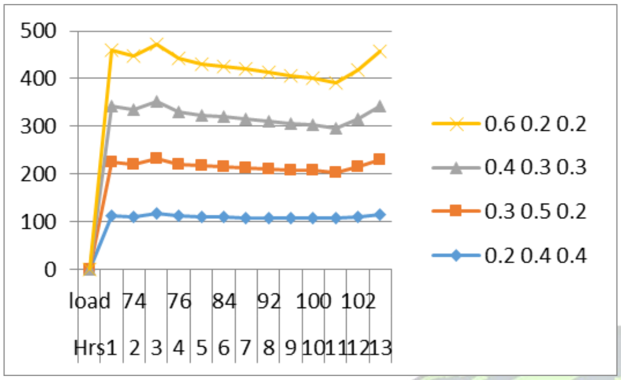

Figure 3. Network ATC for various sets of generator participation factor for same load cycle

VI. Result

A part of typical load cycle at bus 6, (1- 13 Hours), is considered for computation of Network ATC. The generator responses for changes in load at bus 6 are decided by generator participation factors which are previously set. Change in load demand of a particular hour can be predicted or obtained from the demand bid. Sharing of this change in load by the different generators is computed as per the participation factors. Table-I represents the ATCs as obtained for various computing hours. Network ATCs with consideration of individual transactions (splitting of total change in load into different bilateral transactions) are obtained first, from which network ATC, as regards to change in load, can be obtained. It is shown in the last column of this table and indicates the additional load with assumed generator participations that can be connected to bus 6 without overcoming the network limits. Table-II represents the network ATCs by considering only changes in power at load bus 6 for different participation factors, set earlier

It is observed that when load at bus-6 is increased at 2nd computing hour ATC of network is decreased. From 3rd computing hour as the load is increased, the ATC of network decreases and again increases from 12th computing hour when load at bus 6 is decreased. It is observed that ATC of network changes when the generator participation factor is changed. Figure.3 represent the variation of load and network ATC for a set of generator participation factor. Figure 3 represents the graphical comparison of network ATC for different sets of generator participation factors when same load cycle at bus-6 is considered. The ATC values are also determined by Power World Simulator 14.

VII. Conclusion

The ATC value serves as an important indicator of system performance. The ATC values are determined by conventional Network response method. It can be observed form Table-I and II that as the load increases, ATC of the network decreases. The decrease in the load increases the network ATC, which was obtained in earlier hour. When load at a bus is to be shared by different generators, the ATC must be computed from the aspect of maximum allowable load at that bus. By selecting a set of participation factors of the generators, network ATC is computed in the previous hour. This value represents the maximum load that can be connected to the load bus, in the next hour. From Fig 4 it is very much clear that ATC of network can be changed by changing the generator participation factor. In multiple transaction when simultaneous power flow from all generator to meet the load demand, generator with higher participation factor mainly decides the network ATC. Generator with larger participation factor can have a more positive effect on improving the system power transfer capability. The method is suitable for hour- ahead.

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