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ATC Evaluation In A Deregulated Power System

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Abstract

Restructured power system helps to meet the active power requirements of the consumers in an effective way. In an Independent System Operator (ISO) model of restructured power system, Available Transfer Capability (ATC) is calculated so as to determine how much extra power can be injected into one site apart from base consumption. ATC computation plays a significant role during power transactions because it helps the participants to schedule their transaction more effectively and quickly. This paper mainly focuses on ATC calculation using linear sensitivity factors for normal mode and line outage mode.

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Keywords: Available Transfer Capability, Power Transfer Distribution Factor, Repeated Power Flow, Linear Sensitivity Factor, Non-Utility Generators

1. Introduction

Earlier, vertically integrated power systems were in use. In this system, all the operations such as generation, transmission and distribution were integrated in a single entity. For developing countries with high demand growth, power system management and making of tariff policies had become a difficult task. Therefore, they switched to restructured power system. Developed countries, on the other hand, opted for restructured power system to provide more choices for their customers. Thus, restructured power system came into existence due to scarcity of financial resources in developing countries and developed countries like UK and Sweden came up with this idea to sell electricity at lower prices. Unlike the vertically integrated utility, restructured power system is not bundled thus

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ensuring transparency in transactions. Two types of model are prevalent in this unbundled system: Independent System operator model (ISO) and Transmission System operator (TSO) model. ISOs are capable of owning and controlling the generation and distribution companies and they encourage a healthy competition between the markets. On the other hand, TSOs are known for their non-discrimination and all eligible markets are provided an open access to the power transmission system.

The few reasons why development of restructured power system is beneficial and economical are:
There is an advantage of selectivity that is the seller can choose its buyer. Apart from the conventional power producers, private power producers can also become a part of the generation unit in a restructured power system. This system is about breaking the monopoly that already exists in the sector. New framework is created to operate the power industry. The advantages of the system are cheaper electricity price, choice for customers, customer-centric service and innovation

A full understanding of transmission capacity and transfer capability is of greater importance in the deregulated power market for the following reasons.

i) The expansion of transmission corridor is limited by environmental and economic constraints

ii) In deregulated market, the generation and demand inputs have significantly different patterns compared with regulated industry

Therefore, effective transmission network and transaction management by ATC determination at regular intervals is needed to commit the established contract between buyer and seller.

Available transfer capability is a measure of the transfer capability remaining in the physical transmission network for the further commercial activity over and above already committed uses [1]. The ATC definitions, guidelines approved by NREC report, and several concepts of ATC and technical challenges of its determination are well documented in [2].

Mathematically ,

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

TTC-Total Transfer Capability-The amount of transmission transfer capability *which* can be transferred through the network with all the uncertainties and contingencies considered;

ETC-Existing Transfer Capability-The amount of transmission transfer capability which is required for committed transactions.

TRM-Transmission reliability margin-The amount of transmission transfer capability which is essential to ensure the safety of the transmission network system under reasonable range of uncertainties.

CBM-Capability benefit margin-The amount of transmission transfer capability which is reserved by the suppliers so that when used, the supplier gains profit. This power transfer capability is accessed when required for interconnected systems.

Power system is stochastic in nature and hence the Independent System Operator has to continuously monitor and update ATC after every transaction.

Repeated power flow (RPF) is a steady state solution of a power system network. The main information obtained from repeated power flow are magnitude and phase angles of load bus voltages, reactive powers at generator buses, real and reactive flows on transmission lines. ATC determination techniques based on repeated power flow approach have been proposed by many in [5–9]. The results are accurate but time consuming and cannot be implemented for the stochastic nature of power system. In static ATC determination a constant PQ load is considered. The nature of load plays an important role in transfer capability calculations.

The power system behaviour in static and dynamic studies are fundamentally different and in the latter case the problem is whether the transmission capacity will be immediately available to the system for satisfying the load in the event of possible generation and load changes. Hence, ATC has to be determined under small and large disturbances with the dynamics of the system [13–16]. However, dynamic ATC determination is time demanding.

In real time, ATC has to be determined fast and posted by ISO. The sensitivity based methods are fast in ATC determination which are based on the power flow sensitivity and are proposed by many authors for fast computation of ATC. Linear sensitivity factors are employed for the fast calculation. These factors gives the approximate change in line flows for changes in generation of the system and can be calculated from DC load flow. The factors are Power Transfer Distribution Factors (PTDFs), line outage distribution factors (LODFs) using DC load flow [17], AC load approaches using sensitivity factors including maximum area concept, and sensitivity analysis of system uncertainties [18–26]. The results of AC load flow based methods are accurate when compared with DC load flow methods but the latter is fast with its assumptions.

In this paper the amount of power transacted from seller to buyer is determined by ATC computation using Power Transfer Distribution Factors using AC load flow and DC load flow for normal operating mode and line outage mode.

Nomenclature

$\boldsymbol{\delta_i}$, $\boldsymbol{\delta_j}$	Bus Voltage angle of bus i and bus j, respectively.
P_{Gi}, Q_{Gi}	Real and reactive power generation at bus i in MW and MVAR respectively.
P_{Di}, Q_{Di}	Real and reactive power demand at bus i in MW and MVAR respectively.
S_{ij}^{max}	Maximum apparent power line flow on line i-j in MVA.
P_{Gi}^{min}, P_{Gi}^{max}	Minimum and maximum active power generation limits at bus i in MW.
P_{Gm}^{NUG}	Active power generation of non-utility generators at bus m in MW.
P_{Dn}^{NUG}	Active power delivered of non-utility generators at bus n in MW.
V_i^{min}, V_i^{max}	Minimum and maximum bus voltage limits at bus i in V.
θ_{ij}	Impedance angle of line between buses i and j.
NB	Number of buses.
Y_{ij}	Mutual admittance between buses i and j.

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2. Methodology

The problem formulation is as follows:
The objective is to locate and size NUG in a centralized deregulated environment by determining the amount of power transacted from seller to buyer i.e., by ATC computation using linear sensitivity factors.

i. Simulation of bilateral transaction using Repeated Power Flow (RPF)

Bilateral transactions are so simulated that they adhere to two basic rules, *i.e.,*
(1) Demand at a bus = ∑Energy purchase contracts at the bus.
(2) Generation at a generator bus = ∑Energy sell contracts by that generator.

As the name suggests, RPF solves the power flow repeatedly by incrementing the power transfer between the chosen seller and buyer until the system limits (transmission line limits and bus voltage limits) are violated. RPF method is used to obtain power flow of all transmission lines in the system.

ii. Using Linear Sensitivity Factors Method:

Linear Sensitivity method involves using DC power flow model and AC power flow model. In this method, linear sensitivity factor mentioned is the PTDF (Power Transfer Distribution Factor) which differs according to the model chosen. In case of AC power flow model, PTDF calculated is ACPTDF and in case of DC Power flow model, PTDF calculated is DCPTDF. The methods of calculating both are different.
This sensitivity factor is basically multiplied with the ATC (Available Transfer Capability) determined during base case, thus obtaining a more efficient value of ATC which has been found to be more accurate practically.

ETC is the power which is already existing in the system. Further, TTC is calculated using RPF.TRM and CBM are to be decided by the suppliers according to their operating guidelines and reliability requirements which differ from supplier to supplier.
Thus,

$$ATC=TTC-ETC \tag{2}$$

After both ETC and TTC values are recorded, we can easily find ATC subject to the equality and inequality constraints which are as follows:

Equality constraints:

$$(P_{Gi} + P_{Gm}^{NUG}) - (P_{Dj} + P_{Dn}^{NUG}) = \sum_{j=1}^{NB}(|Vi||Vj||Yij|\cos(\delta i - \delta j - \theta ij)) \tag{3}$$

$$(Q_{Gi} - Q_{Di}) = \sum_{j=1}^{NB}(|Vi||Vj||Yij|\sin(\delta i - \delta j - \theta ij)) \tag{4}$$

Inequality constraints:

$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max} \tag{5}$$

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max} \tag{6}$$

$$V_i^{min} \leq V_i \leq V_i^{max} \tag{7}$$

$$S_{ij} \leq S_{ij}^{max} \tag{8}$$

iii. Calculation of PTDF using AC power flow model

Among the three limits normally considered for any method to be opted for ATC calculation (i.e. thermal limit, voltage limit and angular stability limit), both thermal limit as well as voltage limits are considered to play a significant role in this method.

Consider a seller bus ‘m’ and buyer bus ‘n’ in between which the transaction is going to be held. Although there is direct transmission line connected between ‘m’ and ‘n’, there are various other paths in the system (i. e various indirect paths connecting bus ‘m’ and ‘n’ through which power flows too). The power flow in these transmission lines is affected due to the transaction. Consider a part of this indirect path and the end buses of this indirect path to be ‘i’ and ‘j’. The ratio of change which the power flow between ‘i’ and ‘j’ occurs due to the transaction between ‘m’ and ‘n’ to the power transaction between ‘m’ and ‘n’ is found to be ACPTDF.

$$\mathrm{ACPTDF}_{ij,mn} = \frac{\Delta \mathrm{P_{ij}}}{\Delta \mathrm{P_{mn}}} \tag{9}$$

$\Delta \mathrm{P_{ij}}$ can be calculated using Newton-Raphson method which uses Jacobin matrix

Using Newton-Rapshon method, we get Δδ (load angle) and ΔV (Voltage) which corresponds to the real power ΔP and reactive power ΔQ respectively. The equation thus becomes

$$\begin{bmatrix} \Delta\delta \\ \Delta|\mathrm{V}| \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix}^{-1} * \begin{bmatrix} \Delta \mathrm{P} \\ \Delta \mathrm{Q} \end{bmatrix} \tag{10}$$

Where J_1,J_2,J_3 and J_4 are as follows

$$\frac{\partial \mathrm{P_{ij}}}{\partial \delta_{\mathrm{ij}}} = \mathrm{V_i\, V_j\, Y_{ij}}\, \sin(\theta_{\mathrm{ij}} + \delta_{\mathrm{j}} - \delta_{\mathrm{i}}) \tag{11}$$

$$\frac{\partial \mathrm{P_{ij}}}{\partial \delta_{\mathrm{ij}}} = -\mathrm{V_i\, V_j\, Y_{ij}}\, \sin(\theta_{\mathrm{ij}} + \delta_{\mathrm{j}} - \delta_{\mathrm{i}}) \tag{12}$$

$$\frac{\partial \mathrm{P_{ij}}}{\partial \delta_{\mathrm{ij}}} = \mathrm{V_j\, Y_{ij}}\, \cos\big(\theta_{\mathrm{ij}} + \delta_{\mathrm{j}} - \delta_{\mathrm{i}}\big) - 2\mathrm{V_i\, Y_{ij}} \cos\theta_{\mathrm{ij}} \tag{13}$$

$$\frac{\partial \mathrm{P_{ij}}}{\partial \mathrm{V_j}} = \mathrm{V_i\, Y_{ij}}\, \cos(\theta_{\mathrm{ij}} + \delta_{\mathrm{j}} - \delta_{\mathrm{i}}) \tag{14}$$

Thus,

$$\Delta \mathrm{P_{ij}} = \begin{bmatrix} \frac{\partial \mathrm{P_{ij}}}{\partial \delta_2} & \cdots & \frac{\partial \mathrm{P_{ij}}}{\partial \delta_{\mathrm{n}}} & \frac{\partial \mathrm{P_{ij}}}{\partial \mathrm{V_{g+1}}} & \cdots & \frac{\partial \mathrm{P_{ij}}}{\partial \mathrm{V_n}} \end{bmatrix} \begin{bmatrix} \Delta\delta_2 \\ \vdots \\ \Delta\delta_{\mathrm{n}} \\ \Delta|\mathrm{V_{g+1}}| \\ \vdots \\ \Delta|\mathrm{V_n}| \end{bmatrix} \tag{15}$$

$$\Delta \mathrm{P_m} = +\mathrm{P_t} \tag{16}$$

$$\Delta \mathrm{P_n} = -\mathrm{P_t} \tag{17}$$

$$\Delta \mathrm{P_{ij}} = \begin{bmatrix} \frac{\partial \mathrm{P_{ij}}}{\partial \delta_2} & \cdots & \frac{\partial \mathrm{P_{ij}}}{\partial \delta_{\mathrm{n}}} & \frac{\partial \mathrm{P_{ij}}}{\partial \mathrm{V_{g+1}}} & \cdots & \frac{\partial \mathrm{P_{ij}}}{\partial \mathrm{V_n}} \end{bmatrix} \mathrm{J}^{-1} \begin{bmatrix} 0 \\ \vdots \\ +\mathrm{Pt} \\ 0| \\ \vdots \\ -\mathrm{Pt} \end{bmatrix} = \mathrm{ACPTDF} * \mathrm{Pt} \tag{18}$$

$$\mathrm{P^{max}_{ij-mn}} = \begin{cases} \dfrac{\mathrm{Limit^{max}_{ij}} - \mathrm{P_{ij}}}{\mathrm{ACPTDF_{ij,mn}}} & ; \mathrm{ACPTDF_{ij,mn}} > 0 \\ \text{infinite} & ; \mathrm{ACPTDF_{ij,mn}} = 0 \\ \dfrac{-\mathrm{Limit^{max}_{ij}} - \mathrm{P_{ij}}}{\mathrm{ACPTDF_{ij,mn}}} & ; \mathrm{ACPTDF_{ij,mn}} < 0 \end{cases} \tag{19}$$

Where,

$\mathrm{P_{ij}}$ = Real power flow through line i-j

$\mathrm{Limit}_{ij}^{max}$ = Thermal or transaction line limit of line i-j

P_{ij-mn}^{max} = Maximum amount of transaction allowed from bus m to bus n considering the line limit constraints.

Thus,

$$\mathrm{ATC}_{min} = \min\{P_{ij}^{max}\ ; ij \in N_1\} \tag{20}$$

Where,

N_1 = Total number of lines in the system.

iv. Calculation of PTDF using DC power flow mode

Similar to the AC power flow model, in DC power flow model seller bus is considered to be 'm' and buyer bus is considered to be 'n'. Few assumptions are considered. They are:

(i) |V|=constant
(ii) Transmission losses =0
(iii) Variation in angles is negligible and therefore insignificant.

Unlike AC power flow model, the only limit considered to play a significant role is thermal limit.

DCPTDF is the ratio of the change in power flow between the arbitrary line connecting bus 'i' and bus 'j' to the total transaction which occurred between the seller bus 'm' and buyer bus 'n'.

The advantages of this method are:

(i) Less computation time
(ii) Linearity and superposition

But, this method is not preferred since the results are found to be inaccurate at times. The reason for this are the assumptions considered while deriving the DCPTDF equations since the stated assumptions are too ideal to be practical.

The real power flow (P_{ij}) between buses i and j using dc power flow is,

$$P_{ij} = \frac{1}{x_{ij}}\left(\delta_i - \delta_j\right) \tag{21}$$

x_{ij} = series resistance of the line.

δ_i = voltage angle at bus i.

δ_j = voltage angle at bus j.

The dc power flow can be used to solve the bus angle vector $[\delta]$ for a given real power injection vector [P].

$$[\delta] = [X][P] \tag{22}$$

For a transaction between buses m and n , the DCPTDF can be expressed as,

$$\mathrm{DCPTDF}_{ij,mn} = \frac{X_{im}-X_{jm}-X_{in}+X_{jn}}{x_i} \tag{23}$$

For a new transaction, the change in the line flow is given as,

$$\Delta P_{ij}^{new} = \mathrm{DCPTDF}_{ij,mn} * P_{min}^{new} \tag{24}$$

3. Results and Discussion

System Description

The IEEE – 30 bus system is our test system for the simulation studies. This system has 6 generators (including slack bus) , 30 buses and 41 transmission lines. Bus 1 is considered as slack bus.

Design of cases for analysis

Three transactions are considered as follows; T1 between buses 12 and 24,T2 between buses 15 and 24, T3 between buses 5 and 26. ATC is computed using ACPTDF and DCPTDF for normal mode of operation and line outage contingency mode. For line outage contingency mode the transmission line connected between buses 10 and 17 is outaged.

Table : 1ATC in MW for IEEE 30 bus system using ACPTDF

Transaction	ATC using ACPTDF	
	Normal Mode	Line outage mode
T1	17.71	16.98
T2	19.98	19.422
T3	19.25	19.214

Table : 2 ATC in MW for IEEE 30 bus system using DCPTDF

Transaction	ATC using DCPTDF	
	Normal Mode	Line outage mode
T1	16.89	11.52
T2	12.40	11.20
T3	19.25	19.65

From table 1 it is evident that NUG of 17.71 MW, 19.98 MW, 19.25 MW and 16.98 MW, 19.422 MW, 19.214 MW can be added for the transactions T1, T2, T3 during normal mode of operation and during line outage mode respectively using ACPTDF. From table 2 it is evident that NUG of 16.89 MW, 12.40 MW, 19.25 MW and 11.52 MW, 11.20 MW, 19.65 MW can be added for the transactions T1, T2, T3 during normal mode of operation and during line outage mode respectively using DCPTDF.

Table : 3 Total time taken in seconds for ATC evaluation of IEEE 30 bus system

Transaction	Normal Mode	
	ACPTDF	DCPTDF
T1	13.99	15.77
T2	15.67	16.24
T3	14.99	18.14

Table : 4 Total time taken in seconds for ATC evaluation of IEEE 30 bus system

Transaction	Line Outage Mode	
	ACPTDF	DCPTDF
T1	11.47	13.51
T2	14.49	14.71
T3	9.23	14.66

From Table 3 and Table 4, total time taken for ATC evaluation by ACPTDF is less than DCPTDF.

Conclusion

This paper mainly focuses on congestion management in a power system. ATC calculation is helping us to ensure that future transactions be feasible, that is it should not violate the transmission network constraints.The proposed method could specifically identify the location of the seller, buyer buses and determine the rating of the generator to be added to the network for any specified bilateral transaction. Since the proposed model is applied to IEEE 30 bus test system, it can also be extended to any practical network. The results above show that ACPTDF method is quick and effective compared to DCPTDF and base case. It also applies a simple mathematical procedure for ATC determination and provides us with feasible results.

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