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EFFECT OF UNCERTAINTIES IN THE ECONOMIC CONSTRAINED AVAILABLE TRANSFER CAPABILITY IN POWER SYSTEMS

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ABSTRACT

A key concept in the restructuring of the electric power industry is the ability to accurately and rapidly quantify the capabilities of the transmission system. Available transfer capability (ATC) calculation is a complicated task, which involves the determination of Total transfer capability (TTC) and its two margins -- Capacity Benefit Margin (CBM) and Transmission Reliability Margin (TRM). Transmission transfer capability is limited by a number of different mechanisms including thermal, voltage and stability constraints. ATC is a limit to the amount of power that can be exchanged between two buses or areas. The calculation of ATC has traditionally been a deterministic calculation. However, loads and line status are stochastic phenomena that possess uncertainties. Load flow is an essential tool in the assessment of ATC. Once the TTC is computed under one set of operating conditions or assumptions, it is useful to determine the effect of the uncertainties in the input parameters, namely load and line parameters. This paper presents the impact of these uncertainties on the transfer capability and its expected price. This would be particularly helpful in determining the appropriate reliability margin and the respective ATC. The proposed method has been tested on IEEE 14 bus test system and the results are presented. Further the results are compared with their respective deterministic values.

Keywords: Load flow, available transfer capability (ATC), total transfer capability (TTC), power system planning.

INTRODUCTION

The power system transfer capability indicates how much inter-area power transfers could be increased without compromising system security. Accurate identification of this capability provides vital information for both planning and operation of the power market. According to NERC's definition, *ATC is a measure of the transfer capability remaining in the physical transmission network for future commercial activity over and above already committed uses* (NERC, 1996). ATC can be mathematically defined as the total transfer capability (TTC) less the transmission reliability margin (TRM), less the sum of existing commitments and the capacity benefit margin (CBM), i.e., if there is no existing commitments, ATC can be expressed as, ATC = TTC-TRM-CBM.

TRM accounts for the inherent uncertainty in the system conditions and the need for operating flexibility to ensure reliable system operation as system conditions change. CBM is the transfer capability reserved by load serving entities to ensure access to generation from interconnected system to meet the generation reliability requirements. The currently used methods could be divided into three types, namely Continuation Power Flow (CPF) method, Repeated Power Flow (RPF) method and Security Constrained Optimal Power Flow (SCOPF) method. CPF is a general method for finding the maximum value of a scalar parameter in a linear function of changes in injections at a set of buses in a power flow problem. In principle, CPF increases the loading factor in discrete steps and solves the resulting power flow problem at each step as formulated by Ajjarapu and Christy (1992). However, since CPF ignores the optimal distribution of the generation and the loading together with the system reactive power, it can give conservative transfer capability results. The CPF, in spite of its popularity has the disadvantage of its complexity. Hamoud (2000) proved that the Repeated Power Flow (RPF) method possesses several advantages which include the ease of implementation and less time to converge. SCOPF method derived by Yan and Chanan (2002) maximize the transfer capability between two control areas assuming all OPF-optimized parameters can be centrally dispatched. All of the above methods consider fixed input parameters (load demand and line parameters) to find the solution. These parameters are considered to be constant and deterministic. But in reality, the loads are uncertain and vary over a range. Currently many TTC techniques emphasizes on maximizing power transfers alone between interconnected areas, hence overlooking market operation considerations. It is of foremost importance that the dispatching of market should be incorporated into transfer capability assessments in the decentralized market. This paper addresses the issue of uncertainty in input parameters and a framework is proposed to quantify TTC with practical condition of market dispatch conditions.

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MATERIALS AND METHODS

Background of ATC

Quantifying the capabilities of a transmission system for interchange of power has been of interest over many years. A large percentage of ATC calculations performed today utilize linear load flow techniques. ATC indicates how much inter area power transfer could be carried out without compromising system security. Accurate identification of this capability provides vital information for both planning and operation of bulk power market. A system, which can accommodate large inter-area transfers, is generally more robust and flexible than a system with limited capability. ATC can also be expressed as

ATC = TTC – existing transmission commitments

The information of ATC is an important indicator of the system performance in the restructured energy market, as it provides the knowledge of power system capability about the present system condition.

The general procedure to evaluate ATC can be simplified as follows:

- Establish a base case without any violations
- Define a transfer, which includes a power source bus/area and sink bus/area
- Increase power input in the source bus/area and load in the sink bus/area until one of the limit is violated
- Calculate the maximum delivered power from source bus/area to sink bus/area through the transmission network

But due to uncertainty in bus loading, the power flows within a power network becomes uncertain. This in turn implies that the power flow is also probabilistic. Considering the probabilistic aspects of the system input parameters, the transfer capability is also of probabilistic nature. These uncertainties need to be accounted for system planning and operation.

Economic considerations

Market restructuring has posed a new challenge in the context of TTC computation as transfer capability is no longer bounded solely by system operating limits and security limits. In the present scenario, there are two main types of electricity markets: namely bilateral trade type market and Pool markets. The bilateral trade type market is dominated by independent contracts between generators and consumers; while the Pool Co market is a transparent structure that allows instantaneous matching of electricity supply and demand, whereby generators and consumers compete to bid for electricity supply and demand under a set of rules and regulations. It is the responsibility of the Independent System Operator (ISO) to ensure economic generation, security of the system and reliability prior to dispatching in the decentralized market. Interconnected systems are aimed to improve economic operation and reliability. Therefore it is essential for ISOs to assess ATC and electricity pricing in order to meet the goals.

Proposed method

In electrical power system, the power flow problem is the calculation of line power flow for the given load / generator schedule and network data. It is quite impossible to estimate these precisely, but they could be predicted subject to certain variations. Conventionally the input parameters are considered deterministic by Ejebe *et al*. (1998) and Venkatesh *et al*. (2004). In this paper, the uncertainties due to the input load and line parameters are taken into account. The system is assumed to operate under normal conditions, but load and line parameters vary within certain range. A variation of 10% and 5% are considered for the load parameters and line parameters respectively. Various case studies have been simulated and results of the following are presented.

- System under normal operating conditions
- Uncertainties due to load parameters
- Uncertainties due to line parameters
- Uncertainties due to both load and line parameters

Optimal Power Flow (OPF) is an optimizing tool for power system planning, energy management, etc. This has been briefly discussed by Wood and Woolenberg (1996). Use of OPF is becoming more important in deregulated power industry to deploy the resources optimally. In this paper, the optimization of the ATC problem has been mathematically formulated as below from equations (1 – 5).

Objective Function

Maximize

f(x) = $Max(\sum_{i \in S_D} \Delta P_{Di})$ and

Minimize

$$C_g = \sum_{i=ng} a_i + b_i P_{gi} + C_i P_{gi}^2 \quad (1)$$

The objective function of the OPF reflects the maximum power transfer from one bus/area to another bus/area.

The objective function is subjected to the equality constraint:

- The power flow equation of the power network

$$g(|v|, \theta) = 0 \quad (2)$$

The inequality constraints are: generation limit, transmission line limit and voltage limit.

- Generator limit

$$| P_{Gi} |_{\min} \leq | P_{Gi} | \leq | P_{Gi} |_{\max} \quad (3)$$

- Transmission line limit

$$| S_{ij} | \leq | S_{ij} |_{\max} \quad (4)$$

- Voltage limit

$$|V_i|_{\min} \leq |V_i| \leq |V_i|_{\max} \quad (5)$$

where,

ΔP_{Di} active power increment of load bus
P_{Gi} real power generation at bus i
P_{Di} real load demand at bus i
n bus number of the system
V_i voltage magnitude at bus i, j
S_{ij} transmission line MVA limit
C_g total generation cost of the system
a_i, b_i, c_i cost coefficients

Case Study

The IEEE 14 bus test system is used to demonstrate the calculations of ATC using the proposed scheme. The uncertainties in the input load and line parameters are taken into account. The simulation is carried out using the MATLAB. Duane and Bruce (2001) provide an excellent reference for the same.

The diagram of the system is shown in figure1.

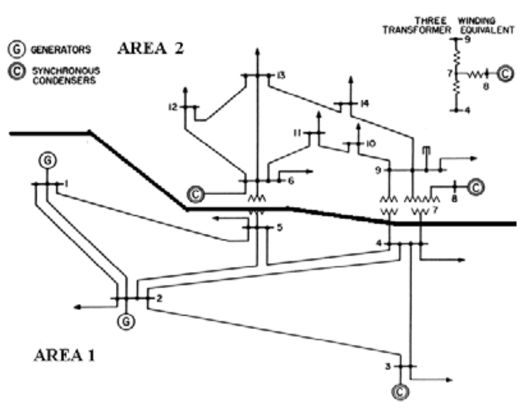

Fig.1. IEEE 14 bus test system.

Bus 1 is the swing bus. The study of ATC and the effect due to uncertainties in the input parameters are carried out by considering bus to bus transfer for the system. The bus data is given in table 1. The active power of all the generators is kept constant except for the slack bus generator, so that the power increase in the load would be drawn from the slack bus. The maximum and minimum acceptable voltage magnitudes at all load buses are taken as 1.1 and 0.95 p.u. The flow limits in all transmission lines are given in table 2. When the system is operating under the normal operating conditions, the line flows are simulated and this gives the results for base case power flow. This is achieved by using the fast decoupled load flow introduced by Stott and Alsac (1974) which is further modified accordingly Prabha and Venkataseshaiah (2007). The Optimal Power Flow is used to make a step increase in transfer of power. It is taken care that the power flow solution does not have any limit violation. The TTC level is calculated. The ATC (Megawatt) is calculated by using the value of total transfer capability minus the base case transfer in the normal operating condition. In order to incorporate the uncertainties in the input load parameters P(k) and Q(k), a variation of 10% is considered and it is termed as $P(k)_{new}$ and $Q(k)_{new}$.

P(k) = real power load of k^{th} bus
$P(k)_{new}$ = real power load of k^{th} bus
Q(k) = reactive power load of k^{th} bus
$Q(k)_{new}$ = reactive power load of k^{th} bus

Similarly a variation of 5% is considered for the uncertainties in line resistance and reactance and $R(jj)_{new}$ and $X(jj)_{new}$ are calculated.

R(jj) = resistance of the branch – jj
$R(jj)_{new}$ = resistance of the branch – jj
X(jj) = reactance of the branch – jj
$X(jj)_{new}$ = reactance of the branch – jj

The proposed simulation is demonstrated on this test case and the results are discussed.

Table 1. Bus Data.

Bus Number	Real Power (MW)	Reactive Power (MVar)	Generation (MW)
1	0	0	0
2	21.7	12.7	40
3	94.2	19	0
4	47.8	-3.9	0
5	7.6	1.6	0
6	11.2	7.5	0
7	0	0	0
8	0	0	0
9	29.5	16.6	0
10	9	5.8	0
11	3.5	1.8	0
12	6.1	1.6	0
13	13.5	5.8	0
14	14.9	5	0

Table 2. Line MVA Limits.

From Bus	To Bus	MVA Limit
1	2	130
1	5	130
2	3	130
2	4	130
2	5	130
3	4	130
4	5	130
4	7	130
4	9	130
5	6	130
6	11	130
6	12	130
6	13	130
7	8	130
7	9	130
9	10	130
9	14	130
10	11	130
12	13	130
13	14	130

RESULTS AND DISCUSSION

The IEEE 14 bus test system is used to perform the simulation. The simulation is performed considering two cases. Case 1 is simulated for the base case load flow without any contingency and case 2 is simulated for calculating ATC. For both cases, the different uncertainties are incorporated as individual sub problems and their results are discussed in this section.

Case 1: The voltage profile for the base case load flow is presented in table 3.

For all the uncertainties, it is observed that the actual real and reactive power generation has increased by around 10% from its original base case value. Also, real and reactive power losses in the lines are significantly increased. Particularly, when line uncertainty alone is taken into account, there is a considerable increase in the real and reactive power losses compared with uncertainty in load parameters.

Case 2: The ATC values calculated for different transactions between the buses are shown in table 4.

The ATC values are calculated for each of the transaction

Table 3. Voltage profile for different uncertainties.

Bus #	Base case	Load variation only	Line variation only	Load & Line variation
1	1	1	1	1
2	1	1	1	1
3	1	1	1	1
4	0.98	0.977	0.979	0.976
5	0.982	0.979	0.981	0.978
6	1	1	1	1
7	0.985	0.982	0.984	0.98
8	1	1	1	1
9	0.979	0.975	0.978	0.973
10	0.975	0.971	0.973	0.969
11	0.984	0.981	0.983	0.98
12	0.984	0.982	0.983	0.981
13	0.978	0.975	0.977	0.974
14	0.959	0.953	0.957	0.951

Table 4. Atc and expected price.

Sending Bus	Receiving Bus	ATC in MW	Expected Price in $	Limiting Element (Bus and Line limits)
3	6	2.41	241	Buses 5 and 6
2	9	8.15	815	Buses 4 and 7
3	13	14.57	1457	Buses 6 and 12
1	13	2.91	291	Line MVA limit 1-2
2	14	16.08	1608	Bus 14
1	3	4.71	471	Line MVA limit 1-2 and Bus14

between all the bus pairs. Also the ATC values are calculated for different uncertainties listed in this paper.

Effect of ATC considering load variation only
It is observed that the line MVA limits for the lines 1-2 got violated earlier than the base case ATC.

Effect of ATC considering line variation only
The voltages of bus 6 and bus 7 are violated and its value reached less than $V_{min.}$ Also, the line MVA limits violated for lines 1-2 earlier than the base case ATC.

Effect of ATC considering both load and line variation
When the uncertainties in both load and line parameters are considered, it is noted that the voltages of bus 4,5,6 and 7 violated and the line MVA limits for lines 1-2 violated much earlier than the base case ATC.

It is understood that whenever the uncertainties exist in load parameters, line parameters or both parameters together, the ATC value is considerably affected. In this paper, only a fixed percentage of variation is considered and the different scenarios are discussed.

CONCLUSION

The ATC calculation is performed by an Optimal Power Flow (OPF) routine, based on a Fast Decoupled power flow algorithm. The program is so designed that the voltage of all the buses, line MVA limits and Generator capacity limits are checked simultaneously in a parallel scheme. In general, the inputs to load flow solutions are considered to be deterministic values. But in reality, these values are subject to uncertainties due to load and line parameter variations. In the present work, these variations are incorporated in the evaluation of ATC. Various cases for uncertainties are simulated. It is observed that the uncertainties affect the allowable transactions between the buses and hence in turn it affects the ATC. The proposed approach is tested on IEEE 14 bus test system and the results are presented and discussed. It is suggested that the proposed method of evaluating ATC along with its electricity prices, considering the input line and load parameter uncertainties, could be useful for planners and operators in interconnected power systems.

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