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Power Flow Based Available Transfer Capability Estimation

C. Vaithilingam and R.P. Kumudinidevi
College of Engineering, Chennai, India 600 025

Abstract: The need for estimating Available Transfer Capability (ATC) has been well understood in the deregulated environment as proper estimation of its value ensures the economically efficient operation of restructured power system. This study proposes a method to estimate ATC of selected branch as a function of power flow through various branches. The conventional methods estimate ATC as a function of real power loads, generation scheduling and outages. The power flows through various branches are influenced by the above said factors ATC can also be estimated as a function of power flow through various branches. Fuzzy logic has been used to develop the ATC estimator. Only the branch power flows that are having considerable effect on the selected branch power flow are considered. IEEE- 30-bus system is used to demonstrate the feasibility of the proposed model.

Key words: Available Transfer Capability (ATC), power flow and bilateral transactions, fuzzy logic

INTRODUCTION

The vertically integrated regulated power system around the world is experiencing restructuring process (Dobson *et al*., 2001). Horizontally distributed deregulated power system emerging successfully where generation and distribution of power are being carried out by many entities enabling healthy competition. Generating companies (Gencos) try to sell as much power as they generate to maximize their profit. Distribution companies will tend to buy power at the cheaper cost. Transmission system being a natural monopoly (Anonymous, 1996) free, fare and non-discriminatory allocation of transmission rights to the various market players plays a key role in maintaining healthy competition.

Gencos cannot accept all the new bids proposed as it may cause violation of system binding limits. All the details about the proposed transactions revealed to independent system operator. After considering the system operating conditions the ISO will estimate the feasibility of the proposed transactions (Ejebe *et al*., 1998). The Gencos can accept transaction only if ISO finds it as feasible after various analysis.

The knowledge about ATC which is defined (Dobson *et al*., 2001) as the additional power that can be transmitted through a specified interface over and above the already committed transactions enables the system operator to decide on feasible transactions. A conservative and over cautions estimation of ATC results into poor utilization of transmission capacity on the other hand optimistic estimation of ATC may endanger the system security. Hence estimation of ATC plays a key role not only in the economically efficient operation of power system also enable free fare and healthy competition in deregulated power system essential to realize the benefit of deregulation.

Numerous methods have been proposed so far to estimate ATC based on conventional power system equation. Methods based on DC load flows (Landgren *et al*., 1972; Landgren and Anderson, 1973; Heydt and Katz, 1975) are very fast, no iteration involved. Complexity in computation is also less as the number of data to be used is less. Besides these advantages voltage limits are not considered, unable to provide accurate estimation when VAR is to be considered, use of linear superposition theory increases the errors were the significant limitations of this method. ATC estimation based on stochastic methods can only be used for planning level. The continuation power flow methods and repeated power flows (Gravened *et al*., 1999; Gravener and Nwankpa, 1999; Khairuddin and Ahmed, 2002) provides accurate values but are not real time compatible as computation and complexity is more. Hence there is a need for a method to estimate ATC faster so that to cater the real time requirements besides maintaining the accuracy to the expected level. To achieve this, a method is proposed to estimate ATC using fuzzy logic as a tool. Fuzzy logic has the ability to provide solutions to the non-linear problems at ease. Estimation using fuzzy logic involves less complexity in computation besides provides accurate results. Already fuzzy logic is been applied successfully (Momoh *et al*., 1995) to many power system problems. In this study, a method is proposed to estimate ATC using fuzzy logic (MATLAB, 2001). The proposed

Corresponding Author: C. Vaithilingam, College of Engineering, Chennai, India 600 025

method is tested on IEEE-14 bus system and validated by comparing its results with the results obtained from conventional ac load flow based method.

Problem identification: Available Transfer Capability of a branch is a nonlinear function of generation scheduling, real power loads at the buses and outages. Hence, ATC estimation should include these factors. This increases the computation involved and also the number of data to be processed particularly when AI techniques such as fuzzy logic or ANN are used. Hence there is a need for an ATC estimator which requires minimum computation with lesser number of data processing.

PROPOSED MODEL

In the proposed model ATC of selected branch is been estimated considering the power flow through various branches. Since, power flows are function of real power loads, generation scheduling and outages the need for considering all the factors while estimating ATC is been eliminated. In precise both ATC and power flow are non-linear function of above said factors ATC can be estimated either as a function of above said factors or as a function of power flows. The number of branch power flows to be considered can also be optimized by selecting the branch power flows having considerable effect on the selected branch power flow.

Design of the proposed model:
Algorithm

- Identify the branch flows influencing the ATC of selected branch appreciably.
- Identify the generator and line outages having significant influence on the above said branch power flows.
- Generate numerous training data sets involving above said power flows, generator and line outages.

Once the influential branch flows and the generation outages and line outages having significant influence on the branch flows are identified, numerous power flow load patterns are generated. The bus loads are selected and varied in such a way that it reflects in the power flows of selected influential branches. The influential generator outages, generation scheduling and line outages are also included for the load patterns. Off line power flows are carried out for the load patterns generated. From the load flow results, influential branch power flows and the branch power flow through which ATC need to be estimated are tabulated for all the generated load patterns. The ATC value is calculated by subtracting the branch power flow from its critical value

ATC = Power Flow* - Power Flow

Power Flow * - Critical value of power flow which causes no limit violation.
Power Flow - Calculated power flow for a selected load pattern.

$$ATC = \Sigma P_{FL*} - P_{FL} \quad (1)$$

Satisfying the following system operating conditions

$$Pi - \sum_{j\varepsilon N} Vi\ Vj\ Yij\ Cos\,(\theta ij + \delta j - \delta i) = 0 \quad (2)$$

$$Qi - \sum_{j\varepsilon N} Vi\ Vj\ Yij\ Sin\,(\theta ij + \delta j - \delta i) = 0 \quad (3)$$

$$P_{gmin} = P_g = P_{gmax} \quad (4)$$

$$Q_{gmin} = Q_g = Q_{gmax} \quad (5)$$

$$S_{ij} = S_{ij\,max} \quad (6)$$

$$V_{i\,max} = V_j = V_{j\,max} \quad (7)$$

P_{FL*} = Maximum power flow or critical power flow between sending and receiving area.
P_{FL} = Current power flow between sending and receiving area.
N = Set of all buses.
Yij, θij = Y bus matrix elements.
Vi, δj = Magnitude and angle of voltage at bus i.

The influential branch power flows and the estimated ATC value are used to train the Fuzzy model. The critical power flow of a branch defined as the maximum possible power flow through that branch which causes no limit violation. The value of critical power flow varies with a loading pattern hence its value must be estimated for each loading pattern. The real power demand is increased in such a way that the selected branch power flow is increased load is increased till the system binding limits reached. The power flow corresponding to this operating condition is the critical power flow of that branch for the selected operating condition.

To identify the branch flows affecting the selected branch ATC, the individual real power loads of all buses varied individually and the corresponding power flows are obtained and analyzed. The variations of selected branch power flow for the variation of influential branch power flows are identified. Numerous off lines power flows are carried out with different generator and line outages. The outages, which cause significant variation in the influential branch power flows and the selected branch power flows, are identified.

Data generation: The power flow through the sensitive branches are varied by varying the selected bus loads, applying selected line and generator outages, The corresponding power flow through the selected branch is noted for all the load patterns. The difference between the critical power flow of that branch and the obtained power flow is the ATC of that branch for the given operating condition. The influential branch power flows are the inputs and the ATC is the output. The change in the loads and, outages will be allowed till the system binding limits are met. The power factor at all buses is maintained constant. Seventy five training patterns are generated includes different power flows through the influential branches caused by load variations and outages.

FUZZY LOGIC

Fuzzy logic has been applied to many power system problems successfully hence its application to ATC estimation is proposed and validated. Following are the steps involved to develop a fuzzy model.

- Selection of input and output variables.
- Construction of fuzzy triangle for input and output variables.
- Assigning the linguistic variables.
- Developing rule base.
- Defuzzification.

The system variables to be estimated the system output. The system parameter which has considerable influence on the output considered as input variables to fuzzy model. As the input and output data are uniformly distributed between their respective minimum and maximum values a symmetrical triangular membership function is constructed. The linguistic variables are selected based on the minimum and maximum values of input and output variables (Fig. 1 and 2).

The normalized input values lies between 0.5-1.75, hence the fuzzy triangle drawn with minimum and maximum value of 0.5 and 2.0. Seven linguistic variables are chosen randomly for input and output.

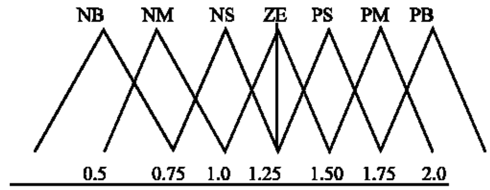

Fig. 1: Fuzzy triangle for input

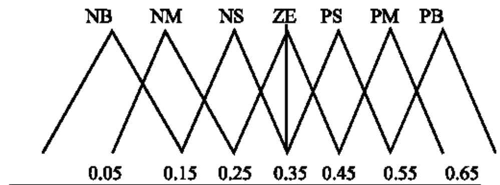

Fig. 2: Fuzzy triangle for output

The fuzzy model is also developed with 5 and 9 linguistic variables separately and the results were shown in the table. Rule base is developed covering all the data set in IF AND THEN format.

Eg:
IF input 1 is NS
AND input 2 is PM (or) NM
. . . .
. . . .
AND input n is ZE (or) PS
THEN output is PS (or) PM.
n-the number of input variable.

Defuzzification: It is the method used to obtain the actual value from the fuzzy model. Centroid method is followed for defuzzification.

$$\text{Actual value} = \frac{(\text{LVO1})\min(\mu_{11}\ \mu_{21}) + (\text{LVO2})\min(\mu_{12}\ \mu_{22})}{\text{Min}(\mu_{11}\ \mu_{21}) + \min(\mu_{12}\ \mu_{22})} \quad (8)$$

Where,
LVO1 and LVO2 are the values of Linguistic variables between which the output lies.

μ - membership values of input variables

The membership value of input say X lies between NB and NS in the fuzzy triangle.

$$\mu_{NS} = \frac{X-0.75}{1-0.75} \quad (9)$$

$$\mu_{NB} = \frac{1.0-X}{1.0-0.75} \quad (10)$$

TEST SYSTEM

IEEE-30 bus system is used to demonstrate the feasibility of the proposed model. The standard system loads at all buses are increased by 50% and treated as base case. Using random number generation various load patterns are generated by multiplying them with the base caseloads. Power flows are carried out and the necessary results are obtained. ATC estimator for the branch 4-6 is developed using the proposed model. The sensitive branches are 2-4, 3-4, 2-6, 6-7, 1-2, 1-3, 7-5 and 2-5. ATC is estimated as a function power flow through these sensitive branches. The effect of line outages 2-6, 2-4 and 1-3 is also incorporated.

The number of inputs can be reduced further by considering power flow index. It's the ratio of the power flows of the influential branches to their respective base case power flows. The values of the power flow index lies in a narrow range hence can be combined into few groups. The branches having similar variation in their power flows for almost all the loading patterns are combined and can be considered as one input. For the test system the number of inputs is reduced to three.

The fuzzy model is developed for both the reduced data and for actual branch power flows. The results were compared with the value of ATC estimated by conventional repeated power flow method (Fig. 3 and 4).

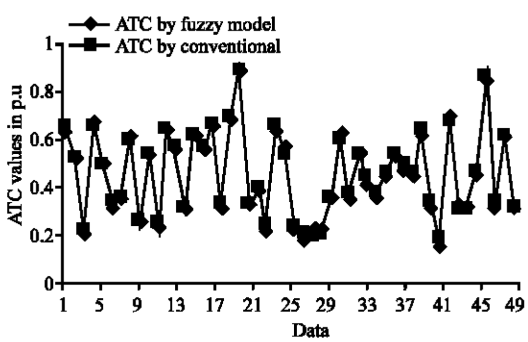

Fig. 3: Comparison of ATC values by fuzzy model and repeated powerflow

Table 1: Power flow through sensitive branches

Branch	2-4	3-4	2-6	6-7	1-2	1-3	7-5	2-5	ATC 4-6*	ATC 4-6†	ATC 4-6#
Power flow1	0.389	0.523	47.2	0.053	0.982	57.4	8.50	35.8	0.712	0.695	0.692
Power Flow2	0.70	0.858	0.0	0.233	1.35	0.919	0.08	1.00	0.229	0.226	0.224

*: ATC value obtained using repeated power flow, †: ATC value obtained using actual power flows as input, #: ATC value obtained using power flow index as input

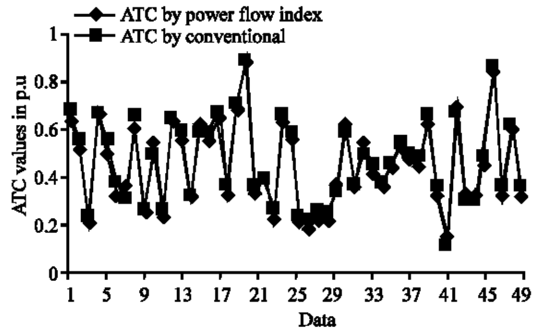

Fig. 4: Comparison of ATC values by fuzzy model using power flow index and repeated power flow

RESULTS AND DISCUSSION

The proposed model is tested and validated with 50 data set, which were not used in the training of fuzzy model and tabulated. From the Table 1, the ATC estimated using the proposed model is closer to the value estimated by repeated power flow algorithm. The value of ATC is estimated with the power flows as input which reduces the number of inputs will have significant outcome especially for large power system. The values are closer to the value obtained using conventional power flow. Hence there is no need to estimate the value of ATC with and without outages separately which reduces the computation time. The value of ATC is also estimated using the power flow index which further reduces the number of inputs while retaining the accuracy with in the required level.

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