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Available Transfer Capability Estimation Using Fuzzy Logic

C.Vaithilingam,

Associate Professor SELECT/VIT University, Chennai,
vaithilingam.c@vit.ac.in, 9884279294.

Abstract

Available Transfer Capability (ATC) estimation plays a major role in the operation and control of restructured power system. The value of ATC must be estimated at predefined time intervals and all the market participants must be updated with these values. The market participants use the value of ATC for their transaction planning. Hence it is very important to estimate ATC accurately with lesser computation time. This paper proposes a Fuzzy logic based model for ATC estimation. The proposed method uses three indices as inputs to estimate ATC. The number of inputs will remain the same irrespective of the system size. The proposed method is tested on IEEE 24 bus Reliability Test System (RTS) and IEEE 118 – bus system. To validate the proposed method ATC values obtained from the proposed model are compared with Repeated Power Flow (RPF) results.

1. Introduction

One of the objectives of restructured power systems is to maximize the economic benefits maintaining the reliable operation. Optimal utilization of existing transmission resources and minimize the number of infeasible transactions, is the key to meet this objective. The Independent Power Producers try to sell the maximum power they generate and the consumer shall try to get the reliable power at lower cost. The hurdles faced by the System Operators (SO) in carrying out this task are the system operating and stability limits. It is very important to assess ATC defined as, the power that can be transferred in addition to already committed transactions. The feasibility of proposed transactions will be based on the ATC value. If the ATC value is found to be inadequate, appropriate corrective measures should be taken to enhance it. The assessment and enhancement of ATC have to be carried out during the real-time operation and planning of restructured power system. Luo et al [1] proposed a neural network solution methodology for the problem of ATC calculations. Based on the optimal power flow formulation of the problem, the inputs for a neural network are generator status, line status and load status and the output is the transfer capability. The Quickprop algorithm is used to train the neural network. Khairuddin et al [2] proposed a fuzzy logic approach for determining ATC in a large deregulated power system. The proposed fuzzy method is tested for computing ATC between a numbers of source-sink pairs. The method is also compared with a full-scale AC power flow based method in terms of accuracy and CPU time for evaluating ATCs considering the same array of transactions, base cases and outages. The CPU time requirement of the proposed method is independent of the system size while the power flow based ATC determination method's CPU time is directly proportional to the size despite exploitation of sparse structure of the system. The proposed fuzzy method requires only three inputs irrespective of system size. Berizzi et al [3] proposed a new methodology to reduce the arbitrariness related to the mid and long term ATC computation using a probabilistic approach. A Monte Carlo method is applied to sample many different reference scenarios in terms of generation patterns to be adopted for the ATC computation. Eventually, the probability density function of the ATC is built. Jonathan et al [4] a stochastic calculation of ATC is proposed. A stochastic power flow algorithm is used to quantify and evaluate the uncertainties involved in the ATC estimation. Othman et al [5] presented computationally fast and accurate method for evaluating available transfer capability based on curve fitting technique called as the cubic-spline interpolation technique. This method traces the curves of voltage magnitude and power flow variations with respect to the increase of real power transfer. SrinuNaik et al [6] proposed a method for Determination of ATC with PTDF using linear methods in presence of TCSC. IEEE 14 bus system was used to test the feasibility of the model. Tae Kyung Hahn et al [7] described a fuzzy logic approach to parallelizing contingency-constrained optimal power flow. The fuzzy multi objective problem is formulated for ATC estimation. Xion Pan and GuoyuXu[8] a model for ATC calculations accorded with trade-off mechanism in electricity market was set up. The impact of branch outage contingency on the static voltage stability margin is analyzed and contingency ranking is performed through sensitivity indices of branch flows with respect to the loading margin. Tomohiko Ichikawa et al [9] proposed a method for estimation of ATC from the view point of power system transient stability. Yuan–Kang Wu [10] proposed a novel algorithm for contingency ATC computation and a sensitivity analysis for system uncertainties. It incorporates linear distribution factors and AC load flow sensitivity based method in order to calculate ATC. Vaithilingam and Kumudini Devi proposed Support Vector Machine based ATC estimation method. Three indices were used to estimate ATC.

The Artificial Intelligence (AI) based methods proposed in the literature for ATC estimation uses the line/generator status as one of the inputs or develops separate AI models for each critical contingencies. This paper proposes single fuzzy model using three indices to estimate ATC of both normal and critical contingency conditions. The data sets are generated using Repeated Power Flow (RPF) algorithm. The effectiveness of the proposed fuzzy model is tested on IEEE 24 bus Reliability Test System (RTS). To test the effectiveness of the proposed model for a large scale power system it is applied to IEEE 118 bus system. The results of fuzzy model are compared with RPF results.

2. ATC Estimation Using Indices

The ATC value between interfaces at any given operating condition is influenced by the following factors,

1. Sink bus load
2. Source bus injection
3. Bus loads at other buses.
4. Outages

Factors 1 and 2 are obvious because the ATC between an interface connected by a source and sink buses, depends on their respective injections and loads. The other bus loads are included because the transaction of an interface, not only depend on the factors 1 and 2, it also depend on the load of the buses which are electrically closer to that interface. The bus whose load variation causes significant change in the selected interface transaction is selected as influential bus.

One of the major challenges in ATC estimation is the inclusion of outage conditions. An operating condition with a critical outage will have lesser ATC value compared to the same operating condition without a critical outage. This is due to the fact that following a line outage, in order to satisfy the committed transactions some of the interfaces may have to take up additional power transactions. This reduces the un-used power transmission capacity of those interfaces. As the ATC value is influenced by the critical outages, it is very important to include those outage conditions as one of the factors while estimating ATC value. Only the outages causing significant change in the selected interface transactions need to be considered as critical outages.

For a large scale power system the number of critical outages and hence the number of influential interfaces will be more. Inclusion of all the interface transactions in the input vector increases the number of inputs significantly. Hence the transactions of influential interfaces can be normalized and may be named as transaction index. P_{TI} defined as:

$$\text{Power Transaction Index } (P_{TI}) = \frac{\sum_{i}^{L} P_{gki}}{\sum_{i}^{L} P_{gki}\text{ base}} \qquad (1)$$

L:Number of influential interfaces
g:Start bus of the influential interface ‘i’
k:End bus of the influential interface ‘i’
P_{gki}:Real power transaction of i^{th} branch
$P_{gkibase}$:Real power transaction of i^{th} branch at base case.

It is worth to note that the higher value of transactions may either be caused by higher degree of loading or due to outages. Hence it is necessary to differentiate between higher loading condition and outage conditions. The power transactions for a particular degree of real power loading will be more for a critical outage hence, if the degree of loading is included as one of the inputs, the reason for the increased transactions can be identified easily. Moreover the power transactions mainly rely on the real power loading. Hence the real power loads must be taken as one of the inputs. But for large scale power system all the bus loads will not have influence on the interface power transactions. Hence it is enough to consider only those bus loads influencing the interface transactions. Instead of giving each bus loads as inputs the degree of loading can be calculated on the basis of base case loading.

The load index for a selected interface is defined as,

$$\text{Load Index } (P_{LI}) = \frac{\sum^{n} P_{di}}{\sum^{n} P_{di}\text{ base}} \qquad (2)$$

n:Number of influential bus loads
P_{di}:Real power load at influential bus ‘i’
P_{di} base:Base case load at influential bus ‘i’.

The power flow pattern and the maximum possible power transactions vary with real power generation. Hence the power injections at the source bus should be included as one of the inputs. At the same time the other bus generations may also have influence on the interface transactions.

The power generation index is defined as:

$$\text{Generation Index } (P_{GI}) = \frac{\sum^{m} P_{gi}}{\sum^{m} P_{gi}\text{ base}} \qquad (3)$$

m – Number of influential generations.
P_g – Real power generations.

Considering transactions as one of the inputs in addition to real power loads and generations differentiates the increased demand and outage conditions. The systematic method to develop AI models for ATC estimation using the proposed new indices is given in the following sections.

3. Implementation of the Method

Identification of critical outages, influential transactions and buses can be done off-line as it requires several load flow studies. After identifying them, more number of data patterns has to be generated with selected inputs and their respective ATCs. For a given operating condition, Load index, generation index and the transaction index forms the input vector. Inclusion of ATC value corresponding to this operating condition makes one complete data set. The three inputs can be calculated using the method described in the preceding section. The ATC value can be obtained from Repeated Power Flow (RPF) studies by increasing the sink bus load and source bus injection by a fixed value till any one of the system binding limits reached. From the value of maximum transaction which causes no limit violation, ATC value can be estimated. More number of data sets is generated to cover all possible operating conditions. Similar studies are carried out to estimate indices and the ATC for all the generated operating conditions.

The process of developing AI model to estimate ATC can be summarized as follows:

1. Select an interface through which ATC has to be estimated

2. Identify the critical outages, influential buses and influential transaction
3. Generate data sets covering all possible operating conditions using RPF
4. Develop AI model using data sets.

4. Fuzzy logic

Fuzzy logic has been widely used for many power system problems. This paper uses fuzzy inference system for ATC estimation. Power Transaction Index, generation index and load index are the three inputs used for ATC estimation. ATC of the given operating condition will be the output. Triangular membership function is used and centroid method is used for defuzzification. The fuzzy triangles for input and output were made in MATLAB fuzzy inference system. The linguistic variables were chosen based on the minimum and maximum values of each input and their range. Figure 1-3 shows the fuzzy triangles for inputs PLI, PGI, PTI and the output ATC respectively.

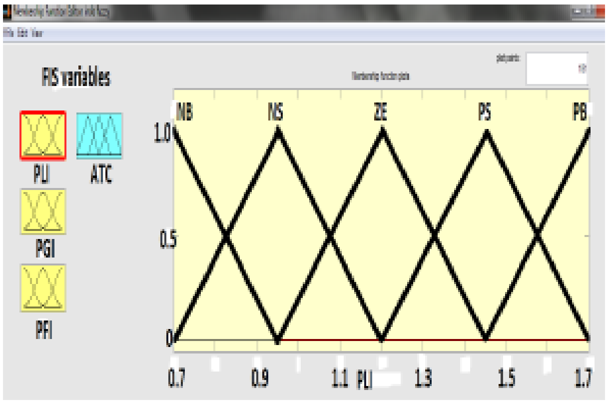


Figure 1 Fuzzy triangle for PLI

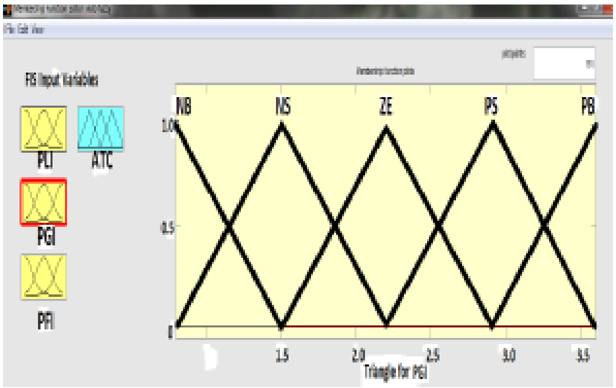


Figure 2 Fuzzy triangle for PGI

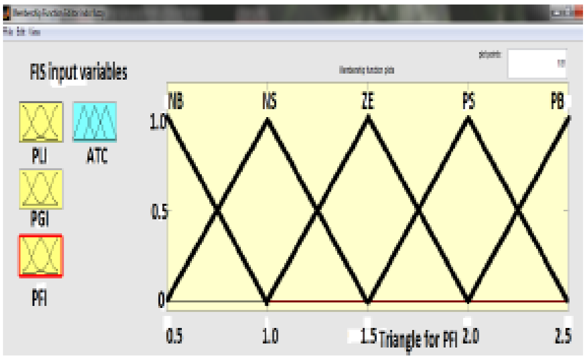


Figure 3 Fuzzy triangle for PTI

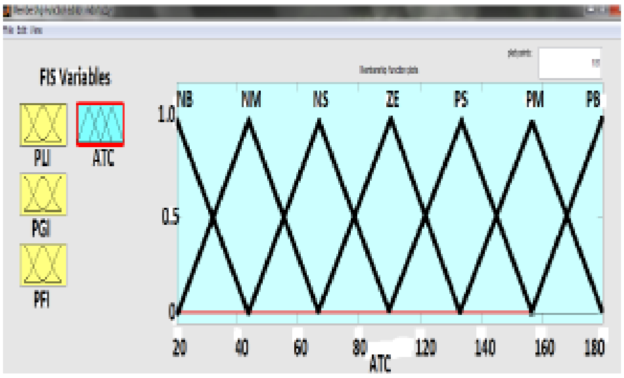


Figure 4 Fuzzy triangle for ATC

5. System Studies and Results

One of the important factors which will decide the performance of any AI based methods is the number of inputs (size of input vector). In the methods proposed in the literature, the number of inputs will increase with the system size. This paper proposes a method for ATC estimation with three indices. The number of inputs will be three irrespective of the system size.

IEEE 24 – bus RTS is used to demonstrate the feasibility of the proposed model. Bus 23 is considered as source bus and the bus 3 is considered as sink bus. The power injection will be at the bus 23. The influential sink bus loads are identified as 3,4,8,9,10,14,15 and 16 and the influential interfaces are selected as 1-3, 3-24, 9-12, 9-11, 10-11 and 14-16. Line 15-24 is identified as one of the critical lines.

The effectiveness of the proposed model for large scale power system is tested by applying to IEEE 118 bus system. The interface is connected between 46 and 80. The influential bus loads are identified as 45,46,47,48,49,74,76,77,78,79,80,82,88,90,92,93,94,95 and 100. The influential interfaces are identified as 43-34,44-43,45-44, 46-45, 69-77,66-65,68-81,77-82,81-80,80-99,99-100,80-97,97-96 and 96-95.

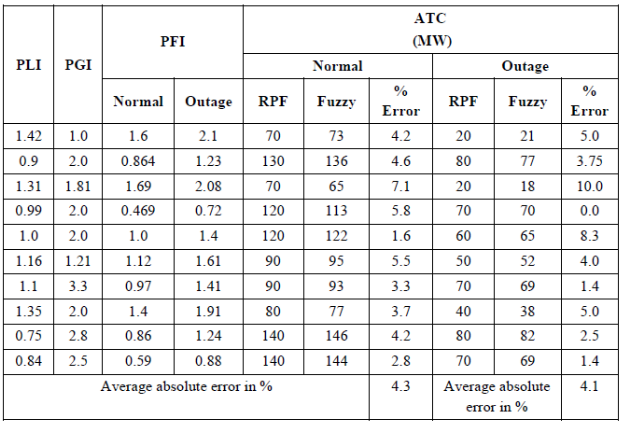
For the given operating condition Load index (P_{LI}) is calculated using the demands at the influential bus loads. Similarly the Generation index (P_{GI}) is calculated using the generations at influential generator buses and power transactions index (P_{TI}) is calculated using transactions at the influential branches. ATC of the operating condition is estimated using RPF. The indices and the respective ATC value form one data set. Fifty data sets are used to develop the AI model for each test system. Ten data sets which were not used in developing the AI models are used for testing of the AI models.

A ATC Estimation IEEE 24 bus RTS

IEEE 24-bus Reliability Test System (RTS) is used to demonstrate the feasibility of the proposed model. For the given operating condition ATC is obtained using RPF method. For the same operating condition ATC is estimated by fuzzy model using indices. The fuzzy model for ATC estimation is developed using MATLAB fuzzy inference system. The results are discussed in this section, to justify the technical viability of the proposed model.

ATCs obtained using RPF and fuzzy are presented in Table 2. The values of indices and their respective ATC values also presented in Table 2.

Table 2 Indices and their respective ATC using RPF and fuzzy for normal and outage conditions



PLI	PGI	PFI		ATC (MW)					
				Normal			Outage		
		Normal	Outage	RPF	Fuzzy	% Error	RPF	Fuzzy	% Error
1.42	1.0	1.6	2.1	70	73	4.2	20	21	5.0
0.9	2.0	0.864	1.23	130	136	4.6	80	77	3.75
1.31	1.81	1.69	2.08	70	65	7.1	20	18	10.0
0.99	2.0	0.469	0.72	120	113	5.8	70	70	0.0
1.0	2.0	1.0	1.4	120	122	1.6	60	65	8.3
1.16	1.21	1.12	1.61	90	95	5.5	50	52	4.0
1.1	3.3	0.97	1.41	90	93	3.3	70	69	1.4
1.35	2.0	1.4	1.91	80	77	3.7	40	38	5.0
0.75	2.8	0.86	1.24	140	146	4.2	80	82	2.5
0.84	2.5	0.59	0.88	140	144	2.8	70	69	1.4
Average absolute error in %						4.3	Average absolute error in %		4.1

The first set of data in the Table 2, the load index (P_{LI}) is 1.42 and generation index (P_{GI}) is 1.0. The third input decides the output. For this P_{LI} and P_{GI}, values of P_{TI} are 1.6 and 2.1 for normal and outage conditions respectively. The value of P_{TI} for the outage condition is higher than the normal operating condition. This is due to the fact that, in order to meet the existing transmission commitments the branches will be carrying more power than the scheduled value.

The ATCs obtained by RPF method and fuzzy model are compared on the basis of absolute error and given in Table 2. From Table 2 it is evident that the ATC obtained by fuzzy model is very much closer to the values obtained by RPF method.

From the Table 2 it is inferred that the average absolute error of fuzzy model for normal and outage conditions are 4.3% and 4.1%. As the model gives accurate results for outage conditions it is clear that the transactions can be used as an index for outage conditions. The second advantage is, the transactions are used as an index for outage conditions. Hence there is no need for developing a separate AI model for each outage conditions or the status of line or generator need not be included in the input vector. Hence the computation time of AI model will be lesser even for large scale power system. Therefore the proposed method can be used for real time ATC estimation of large scale power system.

B ATC estimation 118-bus system

The effectiveness of the proposed method for the application of large scale power system should be tested to conclude that the proposed method can be applied for practical power system. IEEE 118 – bus system is used to demonstrate the feasibility of the proposed model for large scale power systems. The interface connecting the buses 46 and 80 is selected for investigations. Bus 46 is considered as source bus and the bus 80 is considered as sink bus. The power injection will be at the bus 46. Ten data sets are used to test the fuzzy model. These data sets are different from the data sets which are used for developing the fuzzy model. The test data sets are generated by varying the loads and the generations. The ATCs of these data sets are obtained using RPF. For the same data sets, using the indices as inputs the ATCs are obtained by fuzzy model.

ATC is estimated for interface 46-80 using fuzzy and the results are compared with RPF results. The ATC estimated by fuzzy model and the absolute error are given in Table 3

Table 3 ATC of an interface 46 -80 of IEEE 118 bus system with fuzzy

Test case	ATC (MW)		Error %
	RPF	FUZZY	
A	230	225	2
B	310	309	0
C	170	166	2
D	370	377	2
E	70	74	6

From the Table 3 it is observed that the ATC estimated by fuzzy model using indices as inputs are much closer to the RPF results. The average absolute error of fuzzy model is 2.4%. The RPF based methods took11.23 seconds to compute the ATC of one operating condition.Whereasin MATLAB fuzzy inference system once the input values are entered the ATC value will be displayed at no time delay. Thus ATC can be estimated with lesser computation time. This unique feature of fuzzy inference system makes it suitable for real time estimation of ATC values.

6. Conclusion

The method suggested in this paper uses only three inputs to estimate ATC of a given interface. The effect of outages has been taken into account by considering the influential power transactions as one of the inputs. The idea of considering few transactions as an index for outages has been justified with the simulation results in the preceding section. The ATC estimation using the proposed indices found to be effective as the computation time is reduced significantly with reasonably good accuracy.For any given interface identification of influential transactions and influential loads can be identified off-line. The data patterns can be obtained from load flow studies and repeated power flow studies hence developing an ATC estimator for any given interface can be done off-line.

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C.Vaithilingam obtained his B.E in Electrical and Electronics Engineering from University of Madras in the year 1996. He completed his M.E in Power Systems in Annamalai University in the year 2001. He received his Ph.D in Power systems from Anna University in the year 2011. His research areas are Power System operation and control, AI techniques application to power systems.

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