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An Estimation Method of Available Transfer Capabilities from Viewpoint of Voltage Stability

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Abstract

Under the deregulated environment, to conduct the electric power transactions effectively and to operate the power system efficiently while maintaining reliability, it is required that ATC (Available Transfer Capability) should be calculated at high speed with reasonable precision. In order to address this issue, in this paper, an Artificial Neural Network based estimation method for evaluating Maximum Transmission Capability (MTC), which is a key step but also a highly time consuming process in ATC, is proposed. It is confirmed through simulation studies that the proposed method is capable of estimating MTC (ATC) with high speed and sufficient precision.

Keywords: ATC, voltage stability, estimation, neural networks

1. INTRODUCTION

Under the liberalization of the electric power retails, it is required that ATC(available transfer capabilities) should be calculated in order to construct the electric power system which can cope with various electric power dealings, maintaining reliability. As main restrictions which determine ATC, heat capacity restrictions, voltage restrictions, and stability restrictions are mentioned. The minimum value is true ATC among the values calculated under these restrictions. Some were proposed about the method of calculating ATC[1]-[5]. In reference [1], when calculating voltage ATC, severe fault conditions were screened by comparing the index Sv obtained from the difference of the node voltage after the fault and usual node voltage. In order to fulfill the N-1 criteria, it is necessary to repeat the power flow calculation of the huge number of times in a large-scale power system. The N-1 criteria are that the supply capability of a power system is maintainable even if arbitrary one of the equipment, which constitutes a power system, stops.

The ATC is decided based on the N-1 criteria considering the thermal capacity constraint, the transient stability constraint and the voltage constraint. In this report, it is assumed that the voltage constraint is the most dominant within these constraints, and we propose an estimation method of ATC from viewpoint of voltage stability by using the neural network. By using the 4-machine Model (loop system) and IEEJ WEST10 Machine Model (longitudinal system), the estimation method of ATC verifies. The estimation method of ATC verifies.

2. CONSTRUCTION OF ATC ESTIMATION SYSTEM

2.1 Proposed estimation method

In this paper, the power transmission capability (Pmarg) shown in Fig.1 is calculated by using the concept of P-V curve. In Fig.1, the Ptrmax shows maximum transmission capability (MTC) and the Ptr is a present transmission power. Pmarg is got by subtraction Ptr from Ptrmax.

The Ptrmax is calculated by repeating and carrying out the power flow calculation every transaction route, amount of transaction, and assumed fault branch. Therefore, very long time is needed for Ptrmax calculation in a large-scale power system. Then the neural network which has an off-line training function is effective for calculation of Ptrmax. Ptrmax is estimated by using the neural network in an instant.

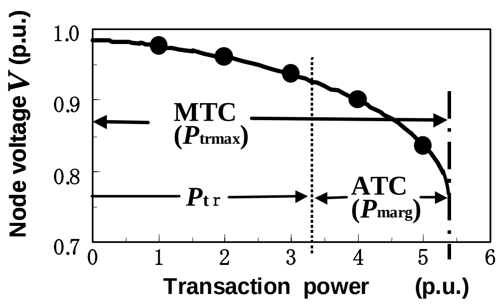

Fig.1 P-V curve

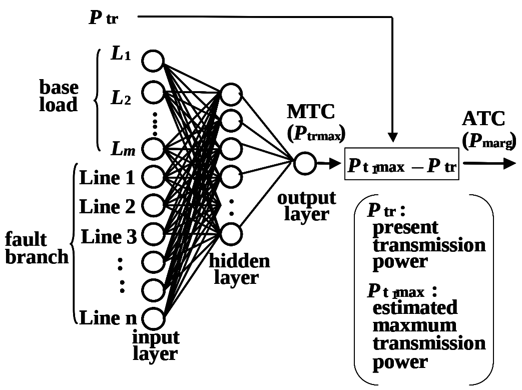

Fig. 2 Structure of Neural network

2.2 Proposed estimation method

The ATC estimation system shown in Fig.2 is proposed. The estimation system has m units corresponding to base load and n units corresponding to assumed fault branch in the input layer. The input layer has m+n units in total. '1' is given to the fault branch and '0' is given to other branches. The estimation system has one unit corresponding to Ptrmax.

3. SIMULATIONS FOR ESTIMATION OF AVAILABLE TRANSFER CAPABILITIES

3.1 Estimation for four-machine system of loop type

The simulations of estimation of ATC were carried out for the four-machine system shown in Fig. 3. Each branch in this figure consists of two transmission lines. The distributed generators that PPS owns are contained in G3 and the consumer that contracted a transaction with PPS is contained in L2. It is assumed that power transaction is performed from G3 to L2. The generator constants and the line impedances are shown in Table 1 and Table 2, respectively.

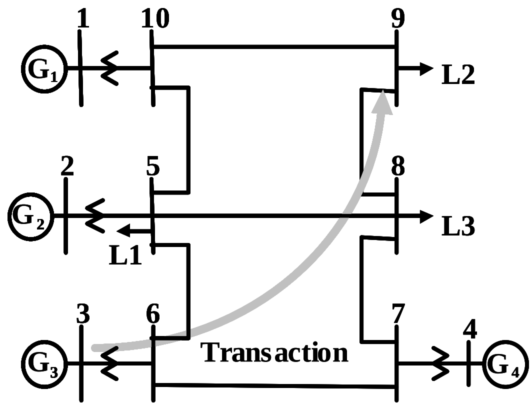

Figure 3. Four-machine model system(loop type)

Table 1 Generator constants

Generator No.	Moment of inertia [s]	Damping constants [p.u.]	$x_{d'}$ [p.u.]	x_d [p.u.]	x_q [p.u.]
G 1	500	0.01	0.44	0.40	0.40
G 2	4.3	0.01	1.00	1.11	1.11
G 3	8.6	0.01	0.50	0.55	0.55
G 4	5.8	0.01	0.40	0.44	0.44

Table 2 Line impedance

Node No. of lines	Line impedance (values of two lines)	
	R [p.u.]	X [p.u.]
1 − 10	0.00	0.03
2 − 5	0.00	0.03
3 − 6	0.00	0.03
4 − 7	0.00	0.03
5 − 6	0.10	0.50
5 − 8	0.20	0.50
5 − 10	0.05	0.20
6 − 7	0.20	0.80
7 − 8	0.10	0.30
8 − 9	0.20	0.40
9 − 10	0.10	0.15

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It was assumed carrying out the electric power transaction between G3 and L2. In the each load flow condition, three-phase earth faulting on a line of the two ones was assumed (N-1 Criteria). On the power system after the fault line removal, maximum transmission capability Ptrmax as shown in the Fig. 2 was calculated by the increase of the transaction power by 0.01 p.u. The training of the neural network as shown in Fig. 2 is carried out by using the relationship between load flow condition, place of fault lines and Ptrmax..

In this report, the estimation method[7] of the available transfer capabilities from the viewpoint of voltage stability was used in order to prevent the deterioration of the convergence of training for the increase of the input unit number. Then the severe fault lines were screened, and the fault branch was selected.

The units corresponding to an assumed fault branch were set as four units, that is, branch 5-6, 6-7, 7-8and 8-9. A total of seven units, that is, three units corresponding to the base loads L1-L3, and four units corresponding to an assumed fault branches, were set in the input layer of the estimation system. One units corresponding to the Ptrmax were set in the output layer. Four units were set in the hidden layer as a result of examining the convergence and error of training. The extract of the data used for training was shown in Table 3. This table shows the Ptrmax after the clearance of assumed fault branch when changing base load and ‘1’ was given to assumed fault branch and ‘0’ was given to other usual branches.

Table 3 Data for training of neural network

No.	Base load[p.u.]			Fault brabch				MTC (P_{trmax})
	L1	L2	L3	5-6	6-7	7-8	8-9	[p.u.]
1	0.40	0.30	0.20	0	0	0	0	1.82
2	0.40	0.30	0.20	1	0	0	0	1.80
3	0.40	0.30	0.20	0	1	0	0	1.83
4	0.40	0.30	0.20	0	0	1	0	1.73
5	0.40	0.30	0.20	0	0	0	1	1.63
6	0.56	0.42	0.28	0	0	0	0	1.69
7	0.56	0.42	0.28	1	0	0	0	1.66
8	0.56	0.42	0.28	0	1	0	0	1.70
9	0.56	0.42	0.28	0	0	1	0	1.59
10	0.56	0.42	0.28	0	0	0	1	1.50
11	0.64	0.48	0.32	0	0	0	0	1.62
12	0.64	0.48	0.32	1	0	0	0	1.60
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:	:	:	:	:	:	:	:	:
28	0.32	0.48	0.64	0	1	0	0	1.57
29	0.32	0.48	0.64	0	0	1	0	1.44
30	0.32	0.48	0.64	0	0	0	1	1.42

Table 5 Estimated result

Load			Fault branch	Trans-action power P_{tr}[p.u.]	Estimated		TRUE		Error [p.u.]
L1	L2	L3			MTC (P_{trmax}) [p.u.]	ATC (P_{marg}) [p.u.]	MTC (P_{trmax}) [p.u.]	ATC (P_{marg}) [p.u.]	
0.49	0.36	0.24	5-6	0.0	1.75	1.75	1.73	1.73	0.02
				0.5		1.25		1.23	0.02
				1.0		0.75		0.73	0.02
				1.5		0.25		0.23	0.02
			6-7	0.0	1.77	1.77	1.76	1.76	0.01
				0.5		1.27		1.26	0.01
				1.0		0.77		0.76	0.01
				1.5		0.27		0.26	0.01
			7-8	0.0	1.66	1.66	1.66	1.66	0.00
				0.5		1.16		1.16	0.00
				1.0		0.66		0.66	0.00
				1.5		0.16		0.16	0.00
			8-9	0.0	1.58	1.58	1.56	1.56	0.02
				0.5		1.08		1.06	0.02
				1.0		0.58		0.56	0.02
				1.5		0.08		0.06	0.02
0.29	0.41	0.56	5-6	0.0	1.63	1.63	1.64	1.64	-0.01
				0.5		1.13		1.14	-0.01
				1.0		0.63		0.64	-0.01
				1.5		0.13		0.14	-0.01
			6-7	0.0	1.65	1.65	1.64	1.64	0.01
				0.5		1.15		1.14	0.01
				1.0		0.65		0.64	0.01
				1.5		0.15		0.14	0.01
			7-8	0.0	1.53	1.53	1.53	1.53	0.00
				0.5		1.03		1.03	0.00
				1.0		0.53		0.53	0.00
				1.5		0.03		0.03	0.00
			8-9	0.0	1.47	1.47	1.49	1.49	-0.02
				0.5		0.97		0.99	-0.02
				1.0		0.47		0.49	-0.02
				1.5		-0.03		-0.01	-0.02
Average of estimated error of ATC (P_{marg})									0.01
Average of maximum error of ATC (P_{marg})									0.02

By using the trained neural network, the Ptrmax was estimated by data for for estimating in Table 4.The estimated results of MTC(maximum transmission capability; Ptrmax) and ATC(available transfer capabilities; Pmarg) are shown in the Table 5. The estimated value of ATC(Pmarg) obtained from the estimated Ptrmax is the value which is comparatively approximate to the true value as shown in the table. The average of the error of estimated ATCs is 0.01 p.u. and the maximum one is 0.02 p.u.. Therefore, according to the simulation result of the ATC for the four-machine system model as an object, it is proven that the proposal technique is effective.

3.2 Estimation for IEEJ WEST10 model system of loop type

The simulations of estimation of ATC were carried out for the IEEJ WEST10 model system[8] of longitudinal type shown in Fig. 4. Each branch in this figure consists of two transmission lines. The distributed generators that PPS owns are contained in G5 and the consumer that contracted a transaction with PPS is contained in L8. It is assumed that power transaction is performed from G5 to L8.

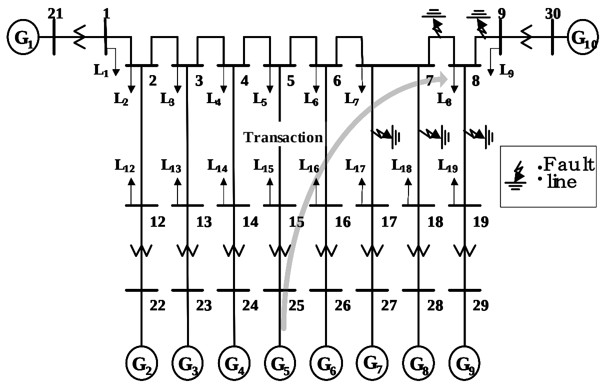

Fig.4 IEEJ WEST10 model system

Table 6 Data for training of neural network
(IEEJ WEST10 model system)

No.	Base load [p.u.]							Fault branch					Ptrmax
	L2	L3	L4	L5	L6	L7	L8	7-17	7-18	8-19	8-7	8-9	[p.u.]
1	3.5	3.5	3.5	3.5	3.5	5.2	3.5	0	0	0	0	0	5.40
2	3.5	3.5	3.5	3.5	3.5	5.2	3.5	1	0	0	0	0	5.22
3	3.5	3.5	3.5	3.5	3.5	5.2	3.5	0	1	0	0	0	5.32
4	3.5	3.5	3.5	3.5	3.5	5.2	3.5	0	0	1	0	0	5.38
5	3.5	3.5	3.5	3.5	3.5	5.2	3.5	0	0	0	1	0	5.30
6	3.5	3.5	3.5	3.5	3.5	5.2	3.5	0	0	0	0	1	5.36
7	4.9	4.9	4.9	4.9	4.9	7.4	4.9	0	0	0	0	0	4.22
8	4.9	4.9	4.9	4.9	4.9	7.4	4.9	1	0	0	0	0	3.99
9	4.9	4.9	4.9	4.9	4.9	7.4	4.9	0	1	0	0	0	4.12
10	4.9	4.9	4.9	4.9	4.9	7.4	4.9	0	0	1	0	0	4.18
11	4.9	4.9	4.9	4.9	4.9	7.4	4.9	0	0	0	1	0	4.10
12	4.9	4.9	4.9	4.9	4.9	7.4	4.9	0	0	0	0	1	4.17
13	5.6	5.6	5.6	5.6	5.6	8.4	5.6	0	0	0	0	0	3.55
14	5.6	5.6	5.6	5.6	5.6	8.4	5.6	1	0	0	0	0	3.27
15	5.6	5.6	5.6	5.6	5.6	8.4	5.6	0	1	0	0	0	3.44
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30	6.3	6.3	6.3	3.8	3.8	6.3	3.8	0	0	0	0	1	6.31
31	7.2	7.2	7.2	4.4	4.4	7.2	4.4	0	0	0	0	0	5.72
32	7.2	7.2	7.2	4.4	4.4	7.2	4.4	1	0	0	0	0	5.57
33	7.2	7.2	7.2	4.4	4.4	7.2	4.4	0	1	0	0	0	5.66
34	7.2	7.2	7.2	4.4	4.4	7.2	4.4	0	0	1	0	0	5.69
35	7.2	7.2	7.2	4.4	4.4	7.2	4.4	0	0	0	1	0	5.69
36	7.2	7.2	7.2	4.4	4.4	7.2	4.4	0	0	0	0	1	5.71

Table 7 Data for estimating
(IEEJ WEST10 model system)

No.	Base load [p.u							Fault branch				
	L2	L3	L4	L5	L6	L7	L8	7-17	7-18	8-19	8-7	8-9
1	4.2	4.2	4.2	4.2	4.2	6.3	4.2	0	0	0	0	0
2	4.2	4.2	4.2	4.2	4.2	6.3	4.2	1	0	0	0	0
3	4.2	4.2	4.2	4.2	4.2	6.3	4.2	0	1	0	0	0
4	4.2	4.2	4.2	4.2	4.2	6.3	4.2	0	0	1	0	0
5	4.2	4.2	4.2	4.2	4.2	6.3	4.2	0	0	0	1	0
6	4.2	4.2	4.2	4.2	4.2	6.3	4.2	0	0	0	0	1
7	5.4	5.4	5.4	3.3	3.3	5.4	3.3	0	0	0	0	0
8	5.4	5.4	5.4	3.3	3.3	5.4	3.3	1	0	0	0	0
9	5.4	5.4	5.4	3.3	3.3	5.4	3.3	0	1	0	0	0
10	5.4	5.4	5.4	3.3	3.3	5.4	3.3	0	0	1	0	0
11	5.4	5.4	5.4	3.3	3.3	5.4	3.3	0	0	0	1	0
12	5.4	5.4	5.4	3.3	3.3	5.4	3.3	0	0	0	0	1

Table 8 Estimated result
(IEEJ WEST10 model system)

Load							Fault branch	Trans-action power	Estimated		TRUE		Error
L2	L3	L4	L5	L6	L7	L8		Ptr[pu]	MTC (Ptrmax) [pu]	ATC (Pmarg) [pu]	MTC (Ptrmax) [pu]	ATC (Pmarg) [pu]	[pu]
4.2	4.2	4.2	4.2	4.2	6.3	4.2	7-17	0.0	4.62	4.62	4.63	4.63	-0.01
								0.5		4.12		4.13	-0.01
								1.0		3.62		3.63	-0.01
								1.5		3.12		3.13	-0.01
								2.0		2.62		2.63	-0.01
							7-18	0.0	4.73	4.73	4.74	4.74	-0.01
								0.5		4.23		4.13	0.10
								1.0		3.73		3.63	0.10
								1.5		3.23		3.13	0.10
								2.0		2.73		2.63	0.10
							8-19	0.0	4.78	4.78	4.80	4.80	-0.02
								0.5		4.28		4.30	-0.02
								1.0		3.78		3.80	-0.02
								1.5		3.28		3.30	-0.02
								2.0		2.78		2.80	-0.02
							8-7	0.0	4.76	4.76	4.72	4.72	0.04
								0.5		4.26		4.22	0.04
								1.0		3.76		3.72	0.04
								1.5		3.26		3.22	0.04
								2.0		2.76		2.72	0.04
							8-9	0.0	4.77	4.77	4.79	4.79	-0.02
								0.5		4.27		4.29	-0.02
								1.0		3.77		3.79	-0.02
								1.5		3.27		3.29	-0.02
								2.0		2.77		2.79	-0.02
5.4	5.4	5.4	3.3	3.3	5.4	3.3	7-17	0.0	6.49	6.49	6.59	6.59	-0.10
								0.5		5.99		6.09	-0.10
								1.0		5.49		5.59	-0.10
								1.5		4.99		5.09	-0.10
								2.0		4.49		4.59	-0.10
							7-18	0.0	6.60	6.60	6.69	6.69	-0.09
								0.5		6.10		6.19	-0.09
								1.0		5.60		5.69	-0.09
								1.5		5.10		5.19	-0.09
								2.0		4.60		4.69	-0.09
							8-19	0.0	6.64	6.64	6.74	6.74	-0.10
								0.5		6.14		6.24	-0.10
								1.0		5.64		5.74	-0.10
								1.5		5.14		5.24	-0.10
								2.0		4.64		4.74	-0.10
							8-7	0.0	6.63	6.63	6.70	6.70	-0.07
								0.5		6.13		6.20	-0.07
								1.0		5.63		5.70	-0.07
								1.5		5.13		5.20	-0.07
								2.0		4.63		4.70	-0.07
							8-9	0.0	6.63	6.63	6.70	6.70	-0.07
								0.5		6.13		6.20	-0.07
								1.0		5.63		5.70	-0.07
								1.5		5.13		5.20	-0.07
								2.0		4.63		4.70	-0.07
Average of estimated error of available transaction power ATC (Pmarg)													0.06
Average of maximum error of available transaction power ATC (Pmarg)													0.10

It was assumed carrying out the electric power transaction between G5 and L8. The Ptrmax was estimated by the same method as previous section.

Using the relationship between load flow condition, place of fault lines and Ptrmax, carries out the training of the neural network as shown in Fig. 2. The estimation method[(7)] of the available transfer capabilities from the viewpoint of voltage stability was used in order to prevent the deterioration of the convergence of training for the increase of the input unit number. Then the severe fault lines were screened, and the fault branch was selected.

The units corresponding to an assumed fault branch were set as five units, that is, branch 7-17,7-18,8-19,8-7 and 8-9. A total of twelve units, that is, seven units corresponding to the base loads L2-L8, and five units corresponding to an assumed fault branches, were set in the input layer of the estimation system. One units corresponding to the Ptrmax were set in the output layer. Four units were set in the hidden layer as a result of examining the convergence and error of training.

The extract of the data used for training was shown in Table 6. By the same method as previous section, this table shows the Ptrmax after the clearance of assumed fault branch when changing base load and ‘1’ was given to assumed fault branch and ‘0’ was given to other usual branches.

By using the trained neural network, the Ptrmax was estimated by data for for estimating in Table 7. The estimated results of MTC(Ptrmax) and ATC(Pmarg) are shown in the Table 8. The estimated value of ATC(Pmarg) obtained from the estimated Ptrmax is the value which is comparatively approximate to the true value as shown in the table. The average of the error of estimated ATCs is 0.06 p.u. and the maximum one is 0.10 p.u. Although error is more slightly large than the result in Table 5, according to the simulation result of the ATC for the IEEJ WEST10 model system, it is proven that the proposal technique is effective.

4 CONCLUSION

The technique of estimation using the neural network was proposed for the purpose of high-speed calculation of the ATC from viewpoint of voltage stability, and the validity was confirmed. However, in a real system with huge nodes and branches, it is strange whether it can apply only by one estimation system. It is due to improve the estimation technique applicable to a real system, for example, by dividing a large-scale system into several blocks and constructing the estimation system corresponding to each block.

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