FUZZY BASED VOLTAGE STABILITY ANALYSIS OF RADIAL DISTRIBUTION NETWORK

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ABSTRACT

With a growing concern for maintaining stable voltage operation within the network, many critical issues on voltage stability related studies have been raised in the area of power system research. Voltage stability analysis has recently become a major issue in the operation of power system. This paper presents an approach for voltage stability analysis of electrical power distribution system using fuzzy logic concept. The proposed method has also been tested with IEEE-32 bus architecture.

Key words: *Voltage stability, fuzzy logic.*

I. INTRODUCTION

Voltage stability has always been a very important issue for the operating power systems when the continuous load increase along with economic and environmental constraints has led to systems to operate close to their limits including voltage stability limit. Various methodologies have been proposed for voltage stability analysis [1]-[4]. Most of these methods treat the voltage stability problem with static analysis methods based on the study of the reduced (V-Q) Jacobian matrix and by performing model analysis. Among all the methods on voltage stability analysis, the continuation power flow methods is one of the very useful tools [5]-[11]. But in all the literature, the application of the continuous power flow methods in the voltage stability analysis for positive sequence power systems have been proposed.

Recent researches have shown that voltage stability is very closely associated with the issues of frequency and angular stability [12]-[13].

With the recent integration of large amount of distributed generation into distribution networks, new voltage stability analysis tools, which can have the modeling capability of the unbalanced networks, become increasingly important.

Application of fuzzy logic to the above mentioned problem has attained increasing importance due to its flexibility, ability to model uncertainty and ability to incorporate human experience and heuristics [14-16]. Some work on ANN (Artificial Neural Network) approach to voltage stability assessment has also been proposed [17-21].

II. VOLTAGE STABILITY INDEX

A voltage stability index for a radial distribution system was presented by Chakravorty and et.al in [22]. And the equations that was used to formulate this index was presented by Das and et.al in [23]. The equation for voltage stability index of a radial distribution system from [22] has been shown in equation (1).

$$VSI(N2)=|V(N1)|^4-4\{P(N2)X(ii)-Q(N2)R(ii)\}^2 -4\{P(N2)R(ii)+Q(N2)X(ii)\}\ |V(N1)|^2 \qquad (1)$$

The voltage at the receiving–end node (N2) is expressed as

$$V(N2)=V(N1)-I(ii)Z(ii)) \qquad (2)$$

This voltage stability index has been derived from the system shown in Fig.1.

Where,

NB denotes the total number of nodes.

VSI(N2) is the voltage stability index of node N2 (N2=2,3,4,…..,NB).

ii is the branch number.

R(ii) in the branch resistance.

X(ii) is the branch reactance.

V(N1) is the voltage of node N1.

V(N2) is the voltage of node N2.

P(N2) is the real power load fed through node N2.

Q(N2) is the reactive power load fed through node N2.

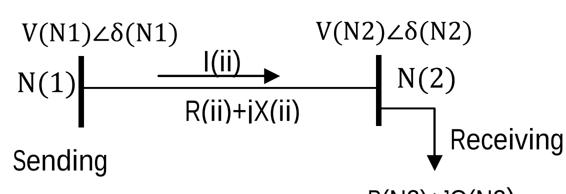

Fig. 1.

III. PROPOSED METHODOLOGY

The method proposed in this paper deals with the application of fuzzy logic in the equation (1) for the calculation of voltage stability index. Here in this paper the node voltages, real and reactive power at the nodes has been represented by a fuzzy membership function. Also a new algorithm for the calculation of voltage stability index has have also been proposed.

The membership functions for the node voltage is shown in Fig.2 and for real and reactive power is shown Fig.3.

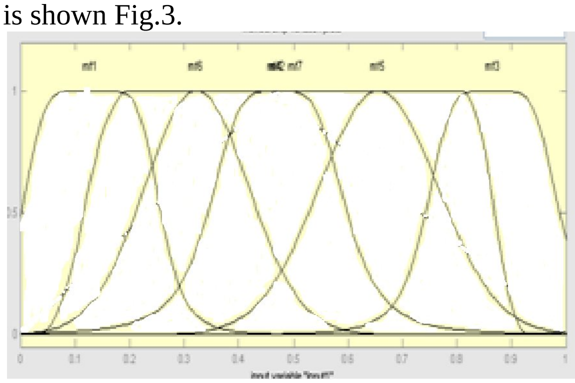

Fig. 2. Membership functions for the node voltage.

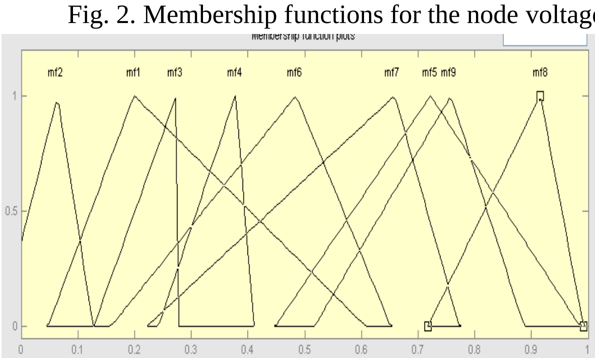

Fig.3: Membership functions for real and reactive power.

The few of the fuzzy rules are shown in Table.1.

Table.1. Fuzzy Rules
1. If (input1 is mf1) then output1 is(mf1) AND (mf5)
2. If (input1 is mf2) then output1 is (mf4) AND (mf5)
3. If (input1 is mf3) then output1 is (mf3) AND (mf4)
4. If (input1 is mf4) then output1 is (mf4) AND (mf3)
5. If (input1 is mf5) then output1 is (mf1) AND (mf4)
6. If (input1 is mf6) then output1 is (mf4) AND (mf2)
7. If (input1 is mf7) then output1 is (mf5) AND (mf2)

IV. PROPOSED ALGORITHM

The proposed algorithm for the calculation of voltage stability index is shown in Table.2.

Table.2. Proposed Algorithm	
Step 1	Read the system data
Step 2	Set V(m1) =1.0 + j 0.0
Step 3	Set LP(jj) = LQ(jj) = 0
Step 4	Set iteration count k =1
Step 5	Set kMAX = 100(say)
Step 6	Set VMAX = 0.0 and ε = 0.00001
Step 7	Compute P_s and Q_s using algorithm proposed by [24]
Step 8	Compute the current through each branch.
Step 9	Set jj =1
Step 10	Compute receiving–end voltage V (m2) for all m2 using Equation (2)
Step 11	Compute the absolute change in voltage at node m2. *i.e.* DV(m2) = ABS(|V(m2)|–|VV(m2)|)
Step 12	jj = jj + 1
Step 13	If jj < LN1, go to step 11, otherwise go to step 14
Step 14	Find max value of DV(m2) from DV(m2) For m2 =2,3,4,….,NB.
Step 15	VMAX = DV(m2)
Step 16	If VMAX < ε go to step 20 else go to step 8.
Step 17	k = k + 1
Step 19	If k < kMAX, go to step 8, otherwise go to step 28.
Step 20	Print “Solution has converged”
Step 21	Compute voltages of each node.
Step 22	Check the node point.
Step 24	Compute the voltage stability index of all nodes using equation (1).
Step 25	Identify the node of the network having minimum voltage.
Step 26	Identify the node of the network having minimum VSI and print the results. Goto Step 28.
Step 27	Print “Solution has not converged”
Step 28	Stop

V. CASE STUDY

The proposed algorithm is tested on IEEE 69-node radial distribution network. Line Data of

69–Node Radial Distribution Network is shown in Table.3 and the Load Data of 69–Node Radial Distribution Network is shown in Table.4. The value of the Voltage Stability Index of Each Node of 69–Node Radial Distribution Network for Constant Power (CP) Load Modelling and Substation Voltage of 1.00 (pu) is shown in Table.5. The test result have also been compared with the methods proposed by [22] and [25] and has been tabulated in Table.5

Table.3: Line Data of 69–Node Radial Distribution Network

Branch No.	Sending end Node	Receiving end Node	Branch Resistance (Ω)	Branch Reactance (Ω)
1	1	2	0.0005	0.0012
2	2	3	0.0005	0.0012
3	3	4	0.0015	0.0036
4	4	5	0.0251	0.0294
5	5	6	0.3660	0.1864
6	6	7	0.3811	0.1941
7	7	8	0.0922	0.0470
8	8	9	0.0493	0.0251
9	9	10	0.8190	0.2707
10	10	11	0.1872	0.0619
11	11	12	0.7114	0.2351
12	12	13	1.0300	0.3400
13	13	14	1.0440	0.3450
14	14	15	1.0580	0.3496
15	15	16	0.1966	0.0650
16	16	17	0.3744	0.1238
17	17	18	0.0047	0.0016
18	18	19	0.3276	0.1083
19	19	20	0.2106	0.0696
20	20	21	0.3416	0.1129
21	21	22	0.0140	0.0046
22	22	23	0.1591	0.0526
23	23	24	0.3463	0.1145
24	24	25	0.7488	0.2475
25	25	26	0.3089	0.1021
26	26	27	0.1732	0.0572
27	3	28	0.0044	0.0108
28	28	29	0.0640	0.1565
29	29	30	0.3978	0.1315
30	30	31	0.0702	0.0232
31	31	32	0.3510	0.1160
32	32	33	0.8390	0.2816
33	33	34	1.7080	0.5646
34	34	35	1.4740	0.4873
35	3	36	0.0044	0.0108
36	36	37	0.0640	0.1565
37	37	38	0.1053	0.1230
38	38	39	0.0304	0.0355
39	39	40	0.0018	0.0021
40	40	41	0.7283	0.8509
41	41	42	0.3100	0.3623
42	42	43	0.0410	0.0478
43	43	44	0.0092	0.0116
44	44	45	0.1089	0.1373
45	45	46	0.0009	0.0012
46	4	47	0.0034	0.0084
47	47	48	0.0851	0.2083
48	48	49	0.2898	0.7091
49	49	50	0.0822	0.2011
50	8	51	0.0928	0.0473
51	51	52	0.3319	0.1114
52	9	53	0.1740	0.0886
53	53	54	0.2030	0.1034
54	54	55	0.2842	0.1447
55	55	56	0.2813	0.1433
56	56	57	1.5900	0.5337
57	57	58	0.7837	0.2630
58	58	59	0.3042	0.1006
59	59	60	0.3861	0.1172
60	60	61	0.5075	0.2585
61	61	62	0.0974	0.0496
62	62	63	0.1450	0.0738
63	63	64	0.7105	0.3619
64	64	65	1.0410	0.5302
65	11	66	0.2012	0.0611
66	66	67	0.0047	0.0014
67	12	68	0.7394	0.2444
68	68	69	0.0047	0.0016

Table.4: Data of 69–Node Radial Distribution Network

Node No.	Pl (kW)	Ql (kVAr)	Node No.	Pl (kW)	Ql (kVAr)
1	00.00	00.00	36	26.00	18.55
2	00.00	00.00	37	26.00	18.55
3	00.00	00.00	38	00.00	00.00
4	00.00	00.00	39	24.00	17.00
5	00.00	00.00	40	24.00	17.00
6	2.600	2.200	41	1.200	1.000
7	40.40	30.00	42	00.00	00.00
8	75.00	54.00	43	6.000	4.300
9	30.00	22.00	44	00.00	00.00
10	28.00	19.00	45	39.22	26.30
11	145.0	104.0	46	39.22	26.30
12	145.0	104.0	47	00.00	00.00
13	8.000	5.000	48	79.00	56.40
14	8.000	5.500	49	384.7	274.0
15	00.00	00.00	50	384.7	274.0
16	45.50	30.00	51	40.50	28.30
17	60.00	35.00	52	3.600	2.700
18	60.00	35.00	53	4.350	3.500
19	00.00	00.00	54	26.40	19.00
20	1.000	00.60	55	24.00	17.20

21	114.0	81.00	56	00.00	00.00
22	5.000	3.500	57	00.00	00.00
23	00.00	00.00	58	00.00	00.00
24	28.00	20.00	59	100.0	72.00
25	00.00	00.00	60	00.00	00.00
26	14.00	10.00	61	124.0	888.0
27	14.00	10.00	62	32.00	23.00
28	26.00	18.60	63	00.00	00.00
29	26.00	18.60	64	227.0	162.0
30	00.00	00.00	65	59.00	42.00
31	00.00	00.00	66	18.00	13.00
32	00.00	00.00	67	18.00	13.00
33	14.00	10.00	68	28.00	20.00
34	19.50	14.00	69	28.00	20.00
35	6.000	4.000			

Table:5 Voltage Stability Index of Each Node of 69–Node Radial Distribution Network for Constant Current (CI) Load Modelling and Substation Voltage of 1.00 (pu).

Node No.	Proposed Method	Method proposed by Chakraborty and Das(2001)	Method proposed by Ranjan *et al.* (2004a)
2	0.999999	0.989872	0.488930
3	0.989849	0.967721	0.495892
4	0.959997	0.999324	0.499720
5	0.989243	0.995988	0.498151
6	0.964605	0.960630	0.481195
7	0.979122	0.924826	0.471707
8	0.944510	0.916362	0.476453
9	0.936370	0.912066	0.476396
10	0.951622	0.893466	0.467575
11	0.792351	0.888730	0.470250
12	0.877060	0.877036	0.465080
13	0.856423	0.866047	0.462395
14	0.865565	0.855324	0.459539
15	0.854849	0.844800	0.456720
16	0.844452	0.842578	0.458431
17	0.842500	0.839417	0.457226
18	0.839308	0.839277	0.458051
19	0.839272	0.837646	0.457150
20	0.837650	0.836526	0.457010
21	0.834474	0.834792	0.456353
22	0.874714	0.834690	0.456800
23	0.834689	0.834438	0.456666
24	0.838825	0.833879	0.456428
25	0.833853	0.833263	0.456247
26	0.833235	0.832992	0.456272
27	0.832980	0.832912	0.456300
28	0.999507	0.999670	0.499909
29	0.999664	0.999378	0.499760
30	0.999325	0.998841	0.499584
31	0.998819	0.998733	0.499661
32	0.998729	0.998303	0.499464
33	0.995282	0.997260	0.499047
34	0.997213	0.995876	0.498618
35	0.995815	0.995547	0.498816
36	0.999597	0.999642	0.499894
37	0.999331	0.998945	0.499531
38	0.997812	0.998178	0.499380
39	0.999157	0.997974	0.499446
40	0.996968	0.997959	0.499487
41	0.998950	0.995174	0.498070
42	0.996070	0.993907	0.498171
43	0.994863	0.993709	0.498385
44	0.994703	0.993670	0.498406
45	0.992668	0.993276	0.498213
46	0.995257	0.993255	0.498311
47	0.999554	0.999054	0.499704
48	0.986630	0.994048	0.497043
49	0.982828	0.977915	0.489945
50	0.975199	0.973068	0.492581
51	0.935299	0.916166	0.478548
52	0.935165	0.916129	0.478563
53	0.912011	0.901655	0.472041
54	0.911416	0.889611	0.468423
55	0.899120	0.873203	0.462872
56	0.811808	0.857376	0.458739
57	0.809515	0.778937	0.419566
58	0.724135	0.740530	0.419618
59	0.728540	0.725608	0.421787
60	0.704345	0.709280	0.416236
61	0.715534	0.685755	0.407257
62	0.694599	0.684725	0.413474
63	0.681214	0.683546	0.413027
64	0.682184	0.677816	0.409902
65	0.695754	0.676039	0.410580
66	0.88643	0.888360	0.471206
67	0.876348	0.888346	0.471260
68	0.875508	0.875414	0.467483
69	0.883447	0.825454	0.567001

VI. CONCLUSION

In this chapter, a new expression of voltage stability index (VSI) for all the nodes of a balanced radial distribution network has been determined. Node with minimum voltage stability index (VSI) is being identified as the weakest link in the network and highly susceptible to voltage collapse.

Effectiveness of the proposed method has been tested with IEEE 69–node radial distribution systems with constant current load model. The assessment is carried out at system voltage of 1.00 (pu) with base kV of 12.66 and base MVA of 100.

Results tabulated with the proposed technique are compared with method proposed by Chakraborty and Das [22] and Ranjan *et al.*[25]. This node is identical in proposed method and the method proposed by Chakraborty and Das [22] and is the last node of the network.

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