IMPROVEMENT OF POWER SYSTEM VOLTAGE STABILITY USING FUZZY BASED INDEX

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Abstract--**This paper work aims the predication of steady state voltage stability conditions in a transmission network. The voltage stability is checked by formulating an (L) index and the corresponding uncertainties input parameters are efficiently modeled in terms of fuzzy sets by using triangular membership function. The proposed technique will be highly useful to ensure voltage security of power system by predicting the nearness of voltage collapse with respect to the existing load condition. This will in turn help us in determining the maximum load ability of the given system without causing voltage instability. The validity of the technique is tested on a sample 5-bus system and IEEE 14-bus system using software simulation. The results are provided for the feasibility of the technique includes fuzzy load flow solution for base and critical cases. This method can be applied both for off-line as well as on-line applications.**

Keywords—**Voltage Collapse, Voltage Stability, Fuzzy Controller, Newton-Raphson Technique.**

I. INTRODUCTON

In case of modern bulk power system, voltage instability would lead to blackout which is of major concern in planning and operation of power system. Voltage instability is characterized by variation in voltage magnitude which gradually decreases to a sharp value accompanied with simultaneous decrease in power transfer to load end from the source. Prior to voltage instability , bus angle and frequency remain constant but after the occurrence of voltage instability the reactive power absorbed by the transmission line increases to such an extent that it becomes difficult to maintain the voltage magnitude within the limit . Hence it may be rightly said that voltage instability occur due to the inability of the system to supply reactive power to the load. It may also occur due to the network disturbance such as loss of an important transmission line, transformer or generator may also occur due to the line fault or bus fault, heavy HVDC power flow without adequate shunt capacitance and inverters. In practice to over come the above problems, usually controlling devices such as tap changing transformers are employed. However they fail to get activated quickly enough to prevent voltage collapse**.** Most of the indices developed are system-based or based on bus orientation[1]-[3]. There has not been much research in voltage stability assessment via line based voltage stability index. The existing technique is based on a line based voltage stability index which detects the critical lines for a specific load scenario for monitoring the System prior to experiencing line outage. The limitation of the above method is that it does not reach unity under various power factor operations of a transmission lines. Particularly, their index show very less value (much less than 1) for high power factor operation of a transmission line.

In the existing model, a voltage stability criterion is formulated based on power transmission concept in a single line. An interconnected system is reduced to a single line network and then applied to assess the overall system stability. Utilizing the same concept but using it for each line of the network, a stability criterion is developed which is used to assess the system security.

$$L_{km} \text{ (at collapse point)} = \frac{4 \sin \phi}{(1 + \sin \phi)^2}$$

From the above equation that only at zero power factor lag the value of L_{km} reach as 1 at collapse point. On the other hand, at unity power factor (ϕ = 0), the value of above index is zero at collapse point. This means that the index L_{km} gives different maximum value at collapse point for different power factors. The situation thus becomes serious when it is applied to a power network where different lines are operating at different power factors. It is very difficult to identify the critical lines in such situations. This is the draw back of this method.

- It does not account for proper contribution to voltage collapse from real power flow effect.
- This index does not reflect angle effect properly (i.e) if Q_m is small or negligible and the line is heavily stressed, this will not show the critical value of this index. The shown critical value is much less than 1.
- For different values of load power factor, this index also shows different values.

Further from the above observations, it is clear that the severity of situation can be reflected properly only if the effect of real power flow is accounted. Hence, the existing method is unreliable. In this paper, voltage stability assessment via line-based stability index is analyzed using fuzzy based controller and an effective procedure for voltage stability assessment (nearness of the operating point to voltage collapse point) using the exact line voltage stability index is developed. The developed index incorporates correctly the effect of real and reactive power increase scenario in any direction as against the existing line voltage stability index. Here the uncertainties in the input parameters would be dealt with the fuzzy sets. Fuzzy based voltage stability index is calculated in each step after performing Newton-Raphson load flow study [4]-[9]. The fuzzy voltage stability index clearly indicates the location and status of critical bus bar. The software based results are provided for the proposed algorithm to validate its feasibility of operation.

II.MATHEMATICAL MODELLING OF PROPOSED SUPERIOR LINE VOLTAGE STABILITY INDEX

The proposed line voltage stability index, is capable of yielding accurate, consistent and reliable results as demonstrated in the case studies carried out under this paper.

$$L_i = \frac{2\frac{B}{A}\left(P_m^2 + Q_m^2\right)^{0.5}}{\frac{V_K^2}{A^2} - 2\frac{B}{A}P_m\cos(\beta-\alpha) - 2\frac{B}{A}Q_m\sin(\beta-\alpha)} \leq 1$$

P_m – Receiving end real power in p.u
Q_m – Receiving end reactive power in p.u
V_k – Sending magnitude voltage in p.u

As long as above index is less than unity, the system is stable. L_i is termed as voltage stability index of the line. At collapse point, the value of L_i will be unity. Based on voltage stability indices, voltage collapse can be accurately be predicted. The lines having high value of the index can be predicted as the critical lines, which contribute to voltage collapse. At or near the collapse point, voltage stability index of one or more line approach to unity. This method is used to assess the voltage stability.

III. FUZZY BASED LOAD FLOW ANALYSIS

In Newton-Raphson load flow method the repetitive solution is obtained by the equations (1). By using these equations 'δ' and 'V' is updated in each iterations. In fuzzy load flow problem 'Fuzzy Logic' is used to update'δ' and 'V'.

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} H & N \\ M & L \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \qquad (1)$$

III. a. Main Idea of Fuzzy Load Flow (FLF) Algorithm

The Equation (1) given by Newton-Raphson can be expressed as for the proposed Fuzzy index by the equation (2)

$$\Delta F = [J].\ \Delta X \qquad (2)$$

The above equation denotes that the correction of state vector ΔX at each node of the system is directly proportional to vector ΔF . The proposed fuzzy load flow algorithm is based on the previous Newton – Raphson load flow equation but the repeated update of the state vector of the system will be performed via expressed by, ΔX = fuzzy (ΔF).

III. b. Fuzzy Logic Load Flow Algorithm

The power parameters such as real power (ΔF_p) and reactive power (ΔF_q) are calculated and introduced to the p-δ and q-v fuzzy logic controller (FLC) respectively. The FLCs algorithm execute the state vector ΔX namely, the correction of voltage magnitude $\Delta\delta$ for the p-δ cycle and the voltage magnitude ΔV for the q-v cycle [10]-[11].

III. c. Structure of Fuzzy Logic Load Flow Controller (FLFC)

The main structure of the proposed FLFC [10]-[11]is shown in the figure 2. .It comprises of four principle components

- Fuzzification interface
- Rule Base
- Process logic
- De-fuzzification

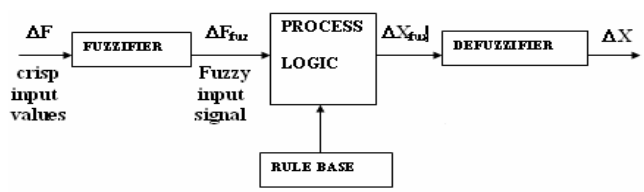

Figure 1 Structure of Fuzzy Load Flow Controller

The FLFC involves the following functions during iteration. Calculate and per-unite the power parameters ΔF_p and ΔF_q at each node of the system. The above parameters are elected as crisp input signals. The maximum (or worst) power parameter (ΔF_{pmax} (or) ΔF_{qmax}) determines the range of scale mapping that transfer the input signals into corresponding universe of discourse at every iteration. The input signals are fuzzified into corresponding fuzzy signals (ΔF_{pfuz} or ΔF_{qfuz}) with seven linguistic variables

- Large negative (LN)
- Medium negative(MN)
- Small negative(SN)
- Zero(ZR)
- Small positive(SP)
- Medium positive(MP)
- Large positive(LP)

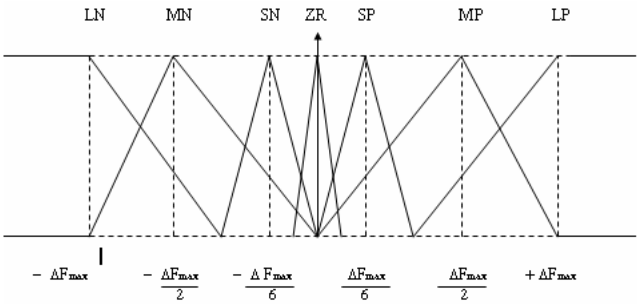

Figure 2 Triangular Membership Function

III. d. Fuzzification

They are represented in triangular membership function sketches of these membership functions are shown in the figure 3. Each three points designed as

LN	:	$[-\infty,-\Delta F_{max},-\Delta F_{max}/3]$
MN	:	$[-\Delta F_{max},-\Delta F^{max}/2,0]$
SN	:	$[-\Delta F_{max}/3,-\Delta F_{max}/6,0]$
ZR	:	$[-\Delta F_{max}/12,0,\Delta F_{max}/12]$
SP	:	$[0,-\Delta F_{max}/6,\Delta F_{max}/3]$
MP	:	$[0,\Delta F_{max}/2,\Delta F_{max}]$
LP	:	$[\Delta F_{max}/3,\Delta F_{max},\infty]$

Similarly the output signals represented in triangular membership function, sketches of these membership functions are shown in the figure 3. Therefore, each three points of the triangular membership function of ΔX_{fuz} are designed as,

LN	:	$[-\infty,-\Delta X_{max},-\Delta X_{max}/3]$
MN	:	$[-\Delta X_{max},-\Delta X_{max}/2,0]$
SN	:	$[-\Delta X_{max}/3,-\Delta X_{max}/6,0]$
ZR	:	$[-\Delta X_{max}/12,0,\Delta X_{max}/12]$
SP	:	$[0,-\Delta X_{max}/6,\Delta X_{max}/3]$
MP	:	$[0,\Delta X_{max}/2,\Delta X_{max}]$
LP	:	$[\Delta X_{max}/3,\Delta X_{max},\infty]$

The rule base involves seven rules with seven linguistic variables.

Rule 1 : if ΔF_{fuz} is LN then ΔX_{fuz} is LN
Rule 2 : if ΔF_{fuz} is MN then ΔX_{fuz} is MN
Rule 3 : if ΔF_{fuz} is SN then ΔX_{fuz} is SN
Rule 4 : if ΔF_{fuz} is ZR then ΔX_{fuz} is ZR
Rule 5 : if ΔF_{fuz} is SP then ΔX_{fuz} is SP
Rule 6 : if ΔF_{fuz} is MP then ΔX_{fuz} is MP
Rule 7 : if ΔF_{fuz} is LP then ΔX_{fuz} is LP

These fuzzy rules are consistent with the observation that corrective action to state vector ΔX is directly proportional to power vector ΔF at every iteration.

III.e. Process Logic

The fuzzy signals ΔF_{fuz} are sent to the process logic which generates the fuzzy output signals ΔX_{fuz} based on the previous rule base which are represented by seven linguistic variables similar to input fuzzy signals. The output fuzzy signal ΔX_{fuz} are then sent to the de-fuzzification interface.

III.f. Defuzzification

The maximum corrective action ΔX_{max} of state variables determines the range of scale mapping that transfers the output signal into the corresponding universe of discourse at every iteration . The maximum correction of these values can be calculated by,

$$\frac{\Delta F_{max1}}{\Delta X_{max}} = \frac{dF_1}{dX_1}$$

$$\Delta X_{max} = \left(\frac{dF_1}{dX_1} \right)^{-1} \Delta F_{max1} \qquad (3)$$

Where,
F_1 - Real or Reactive power balance equation at node with maximum real or reactive power mismatch of the system. X_1 - voltage angle or magnitude at node 1. Finally the defuzzifier will transform fuzzy output signals ΔXfuz into crisp values ΔX for every node of the network. The centroid-of-area (COA) defuzzification strategy is adapted and the state vector is updated using equation (4),

$$X^{i+1} = X^i + \Delta X \qquad (4)$$

Where, ‘ i’ indicates the number of iterations.

IV. Simulation Parameters and Results

IV.a. Simulation Parameters

Table 1. Line Input for the IEEE 5 Bus system.

Line No.	Between buses	Line impedance		Half line charging admittance (p.u)
		R (p.u)	X (p.u)	
1	1-2	0.02	0.06	0.030
2	1-3	0.08	0.24	0.025
3	2-3	0.06	0.18	0.020
4	2-4	0.02	0.18	0.020
5	2-5	0.04	0.12	0.015
6	3-4	0.01	0.03	0.010
7	4-5	0.08	0.24	0.035

Table 2. Bus Data for the IEEE 5 Bus system.

Bus No.	Bus Voltage		Generation		Load	
	Magnitude (p.u)	Phase angle (degrees)	Real (p.u)	Reactive (p.u)	Real (p.u)	Reactive (p.u)
1	1.06	0.0	-	-	-	-
2	1.01	-	0.2	-	0.00	0.1
3	-	-	-	-	0.45	0.15
4	-	-	-	-	0. 4	0.05
5	-	-	-	-	0. 6	0.1

Table 3. Line Input for the IEEE 14 Bus system.

Line No.	Between buses	Line impedance		Half line charging susceptance (p.u)
		R (P.U)	X (P.U)	
1	1 – 2	0.01938	0.05917	0.02640
2	2 – 3	0.04699	0.19797	0.02190
3	2 – 6	0.05811	0.17632	0.01870
4	1 – 7	0.05403	0.22304	0.02460
5	2 – 7	0.05695	0.17388	0.01700
6	3 – 6	0.06701	0.17103	0.01730
7	6 – 7	0.01335	0.04211	0.01000
8	7 – 4	0.00000	0.25202	0.02000
9	6 – 8	0.00000	0.20912	0.01000
10	8 – 5	0.00000	0.17615	0.02000
11	6 – 9	0.00000	0.55618	0.01000
12	8 – 9	0.0000	0.11001	0.02000
13	9 – 10	0.03181	0.08450	0.01000
14	4 – 11	0.09498	0.19890	0.01000
15	4 – 12	0.12291	0.25581	0.02000
16	4 – 13	0.16615	0.13027	0.01000
17	9 – 14	0.12711	0.27038	0.01000
18	10 – 11	0.08205	0.19207	0.02000
19	12 – 13	0.22092	0.19988	0.01000
20	13 – 14	0.17093	0.34802	0.01000

Table 4. Bus Data for the IEEE 14 Bus system.

Bus No.	Bus voltage		Generation		Load	
	Magnitude (p.u)	Phase angle (degrees)	Real (p.u)	Reactive (p.u)	Real (p.u)	Reactive (p.u)
1	1.060	0.0	-	-	-	-
2	1.045	-	0.400	-	0.217	0.127
3	1.010	-	0.000	-	0.942	0.191
4	1.070	-	0.000	-	0.112	0.075
5	1.090	-	0.000	-	0.000	0.000
6	-	-	0.000	0.000	0.478	0.039
7	-	-	0.000	0.000	0.076	0.016
8	-	-	0.000	0.000	0.000	0.000
9	-	-	0.000	0.000	.0295	0.116
10	-	-	0.000	0.000	0.090	0.058
11	-	-	0.000	0.000	0.035	0.018
12	-	-	0.000	0.000	0.061	0.016
13	-	-	0.000	0.000	0.135	0.058
14	-	-	0.000	0.000	0.149	0.050

The proposed fuzzy index algorithm for voltage stability is developed in the Matlab/Simulink software environment to analysis with IEEE 5-bus and IEEE-14 bus. The algorithm is verified for various load power factor and load conditions by line compensation for the accuracy of the proposed fuzzy index technique. The simulation results also provided for Newton-Raphson method for comparison with the proposed algorithm for its feasibility. The single line diagram for the IEEE 5 and 14 bus systems taken for analysis are shown in figure 5 and 6 respectively.

IV.b. Simulation Results

Table 5. Variation Of Line Voltage Stability using Fuzzy Index With Load Increments for IEEE 5 Bus System.

Line Details			Load in Percent of Base Case								
No.	Start ing Bus	Ending Bus	100%	200%	300%	400%	440%	460%	480%	490%	Max. Load 493.35 %
1	1	2	0.1233	0.1233	0.1233	0.1233	0.1233	0.1233	0.1233	0.1233	0.1233
2	1	3	0.1579	0.2522	0.3797	0.5651	0.6709	0.7363	0.8195	0.879	0.9251*
3	2	3	0.0318	0.1231	0.2495	0.4418	0.5561	0.6298	0.7274	0.8012	0.8622
4	2	4	0.0378	0.13	0.2569	0.4489	0.5628	0.6362	0.7338	0.8079	0.8696
5	2	5	0.0596	0.1614	0.3024	0.5177	0.646	0.7284	0.8363	0.9143	0.9720*
6	3	4	0.0065	0.0072	0.0075	0.0074	0.0074	0.0075	0.0084	0.001	0.0132
7	4	5	0.0422	0.0508	0.0637	0.0889	0.1102	0.1287	0.1646	0.2091	0.2766

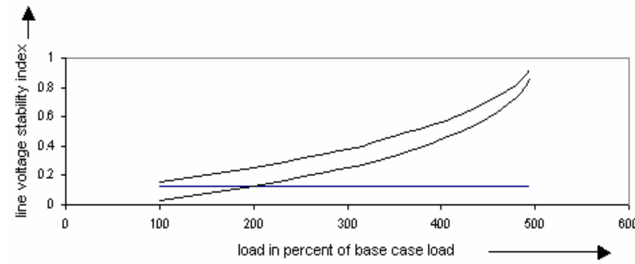

Figure 3 Variation of Bus Voltage Stability using Fuzzy Index with Load Increments of Line 1-3 and Line 4-7 of the IEEE5 Bus system.

Table6. Variation of Bus Voltage Magnitude With Load Increments of IEEE5 Bus system.

Bus No.	Load In Percent Of Base Case Load										
	100%	200%	300%	350%	400%	420%	440%	460%	480%	490%	Max. Load 493.35 %
1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06
3	0.9879	0.9452	0.8907	0.8564	0.814	0.7935	0.7698	0.741	0.7011	0.6685	0.6383
4	0.9850	0.9421	0.8876	0.8535	0.8113	0.7909	0.7672	0.7384	0.6984	0.6654	0.6343
5	0.9728	0.9265	0.8675	0.8301	0.7833	0.7603	0.7332	0.6945	0.6504	0.6069	0.5606

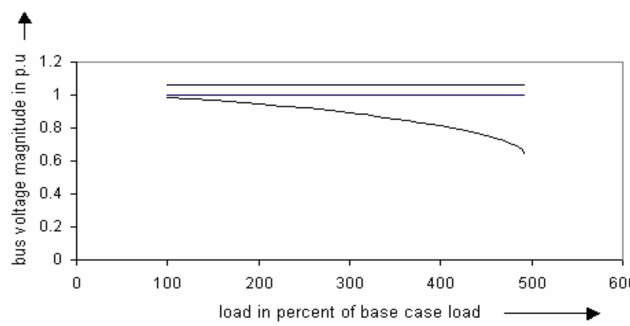

Figure 9 Variation Of Bus Voltage Magnitude With Load Increments of Bus 1-3 of the IEEE 5 Bus system.

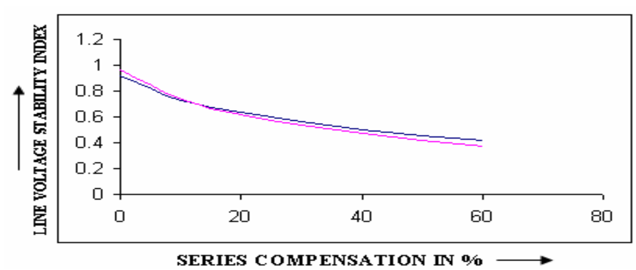

Figure 4 Variation of Line Voltage Stability using Fuzzy Index for series compensation system for IEEE 5 Bus System.

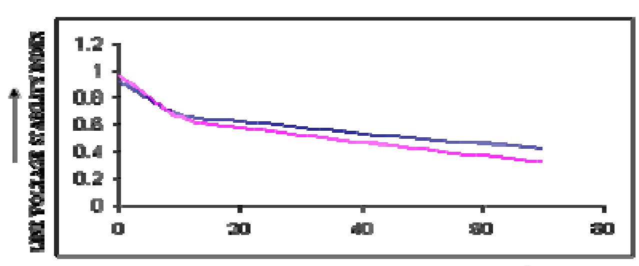

Figure 5 Variation of Line Voltage Stability using Fuzzy Index for shunt compensation system for IEEE 5 Bus System.

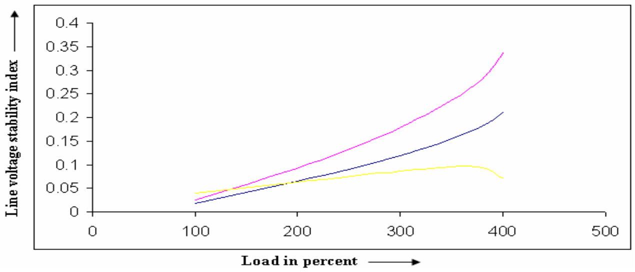

Figure 6 Variation of Bus Voltage Stability using Fuzzy Index with Load Increments of Line 15-17 of the IEEE 14 Bus system.

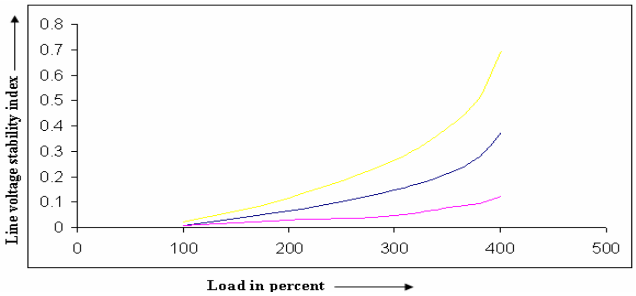

Figure 7 Variation of Bus Voltage Stability using Fuzzy Index with Load Increments of Line 18-20 of the IEEE 14 Bus system.

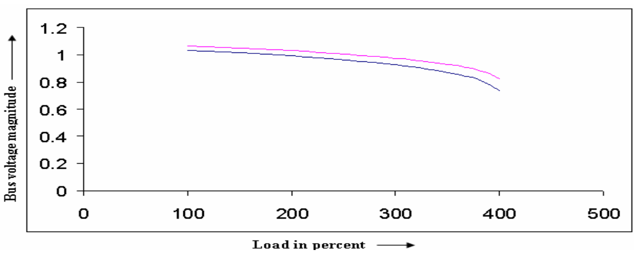

Figure 8 Variation Of Bus Voltage Magnitude With Load Increments of Bus 6-8 of the IEEE 14 Bus system.

Table 7. Variation of Line Voltage Stability using Fuzzy Index for series and shunt compensation system for IEEE 5 Bus System.

	Series Compensation		Shunt Compensation	
% Compensation	Line voltage Stability index of Line 2	Line voltage Stability index of Line 5	Line voltage Stability index of Line 2	Line voltage Stability index of Line 5
0	0.9156	0.9665	0.9156	0.9665
10	0.7298	0.7324	0.6249	0.5844
20	0.6337	0.6168	0.5786	0.5242
30	0.5615	0.5335	0.5359	0.4693
40	0.5039	0.4692	0.4962	0.4188
50	0.4570	0.4179	0.4592	0.3722
60	0.4182	0.3763	0.4243	0.3288

Table10. Variation of Line Voltage Stability using Fuzzy Index for series and shunt compensation system for IEEE 14 Bus System.

	Series Compensation			Shunt Compensation		
% Compensation	Line voltage Stability index Of line 3	Line voltage Stability index of line 4	Line voltage Stability index of line 5	Line voltage Stability index of line 3	Line voltage Stability index of line 4	Line voltage Stability index of line 5
0	0.9157	0.9722	0.9445	0.9157	0.9722	0.9445
10	0.6071	0.6394	0.6028	0.5814	0.6194	0.5825
20	0.4764	0.4976	0.4595	0.5261	0.5629	0.5254
30	0.3893	0.4037	0.3653	0.4788	0.5152	0.4773
40	0.3263	0.3364	0.2980	0.4374	0.4740	0.4359
50	0.2794	0.2868	0.2486	0.4004	0.4377	0.3994
60	0.2451	0.2512	0.2132	0.3670	0.4052	0.3669

Table 8. Variation of Line Voltage Stability using Fuzzy Index with Load Increments for IEEE 14 Bus System

Line Details			Load In Percent Of Base Case Load					
No.	Starting Bus	Ending Bus	100%	200%	300%	350%	380%	401%
1	1	2	0.0359	0.0359	0.0359	0.0359	0.0359	0.0359
2	2	3	0.0867	0.0867	0.0867	0.0867	0.0867	0.0867
3	2	6	0.0332	0.1373	0.3225	0.4875	0.6517	0.9157
4	1	8	0.0572	0.1558	0.3420	0.5144	0.6895	0.9722
5	2	8	0.0209	0.1184	0.3036	0.4764	0.6536	0.9455
6	3	6	0.0516	0.0494	0.2313	0.3964	0.5639	0.8427
7	6	8	0.0121	0.0180	0.0175	0.0104	0.0019	0.0361
8	8	4	0.0785	0.1682	0.3208	0.4467	0.5638	0.7430
9	6	7	0.0830	0.0947	0.1251	0.1587	0.1979	0.2793
10	7	5	0.0531	0.1382	0.2661	0.3639	0.4160	0.5821
11	6	9	0.0821	0.0529	0.0258	0.0162	0.0170	0.0449
12	7	9	0.0010	0.0435	0.1047	0.1524	0.1968	0.2652
13	9	10	0.0070	0.0039	0.0069	0.0199	0.0353	0.0672
14	4	11	0.0062	0.0808	0.1893	0.2719	0.3465	0.4578
15	4	12	0.0185	0.0642	0.1200	0.1553	0.1822	0.2133
16	4	13	0.0265	0.0928	0.1783	0.2357	0.2819	0.3399
17	9	14	0.0389	0.0637	0.0866	0.0944	0.0935	0.0711
18	10	11	0.0091	0.0630	0.1460	0.2126	0.2753	0.3741
19	12	13	0.0082	0.0282	0.0464	0.0773	0.0956	0.1211
20	13	14	0.0214	0.1143	0.2646	0.3903	0.5106	0.6965

Table 9. Variation of Bus Voltage Magnitude With Load Increments of IEEE 14 Bus system.

Bus	Load in Percent of Base Load					
No.	100%	200%	300%	350%	380%	401%
1	1.06	1.06	1.06	1.06	1.06	1.060
2	1.045	1.045	1.045	1.045	1.045	1.045
3	1.01	1.01	1.01	1.01	1.01	1.01
4	1.07	1.07	1.07	1.07	1.07	1.07
5	1.09	1.09	1.09	1.09	1.09	1.09
6	1.0314	0.9905	0.9238	0.8687	0.8156	0.7278
7	1.0364	0.9977	0.9304	0.8723	0.8150	0.7175
8	1.0669	1.0296	0.9726	0.9278	0.8862	0.8207
9	1.0635	1.0119	0.9335	0.8743	0.8212	0.7412
10	1.0635	1.0104	0.9361	0.8814	0.8330	0.7613
11	1.0675	1.0366	0.9944	0.9640	0.9376	0.8995
12	1.0622	1.0433	1.0209	1.0073	0.9970	0.9854
13	1.0589	1.0317	0.9985	0.9771	0.9604	0.9398
14	1.0502	0.9868	0.9022	0.8425	0.7916	0.7207

From table 5 shows the load variation of the system with uniform increment and clearly indicates that voltage collapse is to be occurred in the critical lines (2 and 5) of the IEEE 5 bus system. Figure 7 & 8 show the same variation of the critical lines with maximum index 1. From table 6 depict the load variation with respect to magnitude and clearly implies as the load increases the voltage at all the load buses are decreased. Figure 9 & 10 show the same variation of the magnitude of the buses. Table 7 indicates the series and shunt compensation of the 2 and 5 line of the bus system. From the analysis as the compensation increases the stability is improved quit largely and prevent the voltage collapse as mentioned in table 5 and 6.Table 8 implies the load variation of the system with uniform increment and clearly indicates that voltage collapse is to be occurred in the critical lines (3, 4 and 5) of the IEEE 14 bus system. Figure 10, 11 & 12 show the same variation of the critical lines with maximum index 1. Table 9 predicts the load variation with respect to magnitude and clearly implies as the load increases the voltage at all the load buses are decreased. Figure 13 & 14 show the same variation of the magnitude of the buses. Table 10 indicates the series and shunt compensation of the (3, 4 and 5) line of the IEEE 14 bus system. From the analysis as the compensation increases the stability is improved quit largely and prevent the voltage collapse as mentioned in table 8 and 9. Compensation can be done for IEEE 14 bus system in similar to IEEE 5 bus system.

V. CONCLUSION

This work presents the successful analysis on voltage stability using Fuzzy Based Index and performs satisfactorily on power systems under all possible conditions such as increased load and line compensation with series and shunt capacitances for both in off-line and on- line simulation applications. The shortcomings of previous methods are overcome and consistent results are obtained. Though the number of iterations is more in fuzzy logic load flow method, the proposed algorithm does not require the factorization, refactorization and computation of jacobian matrix at each iteration which shows the validity of the proposed algorithm. This technique will be highly useful to ensure voltage security of power system by predicting the nearness of voltage collapse with respect to the existing load condition and help us in determining the maximum load ability of the given system without causing voltage instability. For the feasibility of the analysis the comparison of Newton-Raphson method and proposed technique are given as appendix.

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VII. APPENDIX

Table11. Comparison of Conventional and Fuzzy Load Flow in Voltage Stability Index for IEEE 5 Bus System.

Bus No.	Voltage stability index			
	Base Case load		Critical case load	
	Conventional	Fuzzified	Conventional	Fuzzified
1	0.03359	0.0359	0.0359	0.0359
2	0.0867	0.0867	0.0867	0.0867
3	0.0338	0.0432	0.9157	0.9160
4	0.0572	0.0638	0.9722	0.8915
5	0.0209	0.0275	0.9455	0.9452
6	0.0516	0.0420	0.8427	0.8430
7	0.0121	0.0154	0.0361	0.0361

Table12. Comparison of Conventional and Fuzzy Load Flow in Voltage Magnitude for IEEE 5 Bus System.

Bus No.	Voltage Magnitude			
	Base Case load		Critical case load	
	Conventional	Fuzzified	Conventional	Fuzzified
1	1.0	1.0	1.0	1.0
2	1.06	1.04	1.06	1.06
3	0.979	0.963	0.6383	0.6231
4	0.9850	0.972	0.6343	0.6321
5	0.9728	0.964	0.5606	0.5601

Table13. Comparison of Conventional and Fuzzy Load Flow in Voltage Magnitude for IEEE 14 Bus System.

Bus No.	Voltage magnitude			
	Base Case load		Critical case load	
	Conventional	Fuzzified	Conventional	Fuzzified
1	1.0600	1.0600	1.0600	1.0600
2	1.0450	1.0450	1.0450	1.0450
3	1.0100	1.0100	1.0100	1.0100
4	1.0700	1.0700	1.0700	1.0700
5	1.0900	1.0900	1.0900	1.0900
6	1.3140	1.0273	0.7278	0.7279
7	1.0364	1.0549	0.7175	0.7178
8	1.0669	1.0337	0.8207	0.8204
9	1.0635	1.0485	0.7412	0.7415
10	1.0635	1.4510	0.7613	0.7618
11	1.0675	1.0539	0.8995	0.8998
12	1.0622	1.0546	0.9854	0.9855
13	1.0589	1.4940	0.9398	0.9398
14	1.0502	1.3100	0.7207	0.7207

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