Fuzzy Approach to Voltage Collapse based Contingency Ranking

Dr. Shobha Shankar
(Department of Electrical and Electronics Engineering,
Vidyavardhaka College of Engineering, Mysore, India)

ABSTRACT

The importance of preventing the voltage collapse is gaining importance due to increase in dependency on the use of electricity. This has compelled the utilities to maintain high system reliability. The evaluation of a power systems ability to withstand dangerous contingencies and to survive to a normal or acceptable operating point is a prerequisite for security analysis. Fast and accurate security assessment, has become a key issue to ensure secure operation of power system. Steady-state security assessment enables the operating personnel to know which system disturbances or contingencies may cause limit violations and force the system to enter into emergency state. Line outages often cause blackouts due to voltage collapse. Voltage Stability Margin of the system on occurrence of specific contingency gives good information about the severity of the contingency of the system. This paper presents fuzzy approach to voltage collapse based contingency ranking. It uses L index as Voltage Collapse Proximity Indicator. This indicator is used as post contingent quantity in addition to bus voltage profiles to evaluate contingency ranking. The proposed approach is tested under simulated condition on IEEE-30 bus system.

Keywords: **Composite Index, Fuzzy Set, L index, Voltage Collapse Proximity Indicator, Voltage Stability Margin**

I. INTRODUCTION

A power system is said to be operating in secure state, if the system remains in a reliable, normal operating state for every contingency case under consideration. Due to time limitation in real-time situations, those contingency cases which are potentially harmful to the system must be picked out and detailed analysis is carried out only for these cases. This process of ranking the contingencies according to their severities is referred to as contingency ranking. In the past, contingency rankings were carried out using the algorithms based on line loadings and bus voltages [1]-[3]. As the recent power systems are experiencing the threat of voltage instability, the contingencies are required to be ranked incorporating this phenomenon. A method based on curve fitting approach is proposed and is compared with continuation power flow method, multiple load flow method and test function method [4]. A new partitioning technique based on tangent vector to the bifurcation manifold is proposed. A tangent vector clustering technique is used for the identification of the critical area with respect to the collapse point at any loading condition. It is used for the computation of new voltage stability index, which speeds up the computation of the collapse point [5]. The second order information derived from the Singular Value Decomposition analysis of the load flow Jacobian matrix is used to obtain the contingency ranking [6]. The implementation of both Point of Collapse method and Continuation method for the computation of voltage collapse point (saddle-node bifurcations) and its application to detection and solution of voltage stability problem is demonstrated [7]. Fuzzy set theory is a very powerful tool to model uncertainty and to incorporate human experience and heuristics [8]-[13]. A fuzzy set based reasoning approach for contingency ranking is developed using line flows and bus voltage deviations as post contingency quantities to achieve desired contingency list [14].

Line outage often causes blackouts due to voltage collapse. This signifies that reduction in loadability margin under each line outage condition should be given due attention in the ranking process. Voltage Stability margin of the system on occurrence of specific contingency gives good information about the severity of the contingency of the system. Though, the system pre-contingency operating point may be away from the voltage collapse point, contingency will push the system close to proximity to voltage collapse point. Hence, computation of voltage stability margin at this operating point serves as a good indicator of criticality of contingency. The changes in voltage stability margin are computed using static voltage collapse proximity indicator. This paper uses L index as Voltage Collapse Proximity Indicator to rank line outage contingencies. Fuzzy approach is used to combine the effect of voltage collapse proximity indicator and bus voltages to effectively rank the line outage contingencies. The bus voltage profiles and L index are expressed in fuzzy set notation before they are processed by the fuzzy reasoning rules. The severity indices are also divided into different categories based on extensive off-line analysis. The fuzzy rules are used to evaluate the severity of each post contingent quantity. The severity of a contingency is determined by evaluating composite index, which is the summation of severity index of L index and severity of bus voltage profiles. The Fuzzy inference structure FIS is tested in MATLAB 7 Fuzzy Toolbox. The proposed approach is tested under simulated condition on IEEE-30 bus system.

II. L INDEX

L - Index is widely used Voltage Collapse Proximity Indicator for various studies. Among the various indices for voltage-stability and voltage collapse prediction, the L index gives fairly consistent results. This is an accurate indicator and is easily computed [15].

A. Mathematical Formulation

Consider a system where n is the total number of buses, with 1, 2, ...g generator buses, and g+1, g+2… g+s SVC buses, g+s+1,….n, the remaining (n-g-s) buses. For a given system operating condition, using the load-flow results, the voltage-stability L - index is computed as,

$$L_j = \left| \sum_{i=1}^{g} F_{ji} \frac{V_i}{V_j} \right| \quad (1)$$

Where j = g +1,....,n and all the terms within the sigma on the right hand side are complex quantities. The values of F_{ji} are complex and are obtained from the network Y-bus matrix. For a given operating condition,

$$\begin{bmatrix} I_G \\ I_L \end{bmatrix} = \begin{bmatrix} Y_{GG} & Y_{GL} \\ Y_{LG} & Y_{LL} \end{bmatrix} \begin{bmatrix} V_G \\ V_L \end{bmatrix} \quad (2)$$

Where I_G, I_L, V_G, and V_L represent complex current, voltage vectors at the generator nodes and load nodes. $[Y_{GG}]$, $[Y_{GL}]$, $[Y_{LL}]$ and $[Y_{LG}]$ are corresponding partitioned portions of the network Y-bus matrix.

Rearranging, we obtain

$$\begin{bmatrix} V_L \\ I_G \end{bmatrix} = \begin{bmatrix} Z_{LL} & F_{LG} \\ K_{GL} & Y_{GG} \end{bmatrix} \begin{bmatrix} I_L \\ V_G \end{bmatrix} \quad (3)$$

Where, $[F_{LG}] = -[Z_{LL}]^{-1}[Y_{LG}]$ (4)

For stability, the index L_j must not be violated (maximum limit = 1) for any node j. Hence, the global indicator L describing the stability of the complete subsystem is given by L= maximum of L_j, for all j load buses. An L index value away from 1 and close to 0 indicates improved system security. For an unloaded system with generator/load buses voltage at 1.0∟0 p.u. the L indices for load buses are closest to zero, indicating that the system has maximum stability margin. For a given network, as the load/generation increases, the voltage magnitude and angles change near maximum power-transfer condition and the voltage-stability index L_j values for load buses tend to close to unity, indicating that the system is close to voltage collapse. While the different methods give a general picture of the proximity of the system voltage collapse, the L index gives a scalar number to each load bus. The L indices for given load condition are computed for all the load buses. The maximum of the L-indices gives the proximity of the system to voltage collapse.

III. FUZZY APPROACH TO CONTINGENCY RANKING

Fuzzy logic provides an excellent framework to effectively model uncertainty in human reasoning with the use of linguistic variables with membership function. The use of fuzzy logic is increasing in the power systems problems, as it is an intelligent processing. Many promising applications have been reported in the broad fields of system control, optimization, diagnosis, information processing, decision support, system analysis and planning. In modern power systems, voltage alone cannot be used for assessing voltage security. Due to increased use of compensating devices which raise voltage to normal levels even when adequate reactive support is lacking, voltage becomes a poor indicator of security. The fuzzy approach uses L index as post contingent quantity in addition to bus voltage profiles to evaluate contingency ranking. The bus voltage profiles and L index are expressed in fuzzy set notation before they are processed by the fuzzy reasoning rules. The severity indices are also divided into different categories based on extensive off-line analysis. The fuzzy rules are used to evaluate the severity of each post contingent quantity. The severity of a contingency is determined by evaluating composite index, which is the summation of severity index of L index and severity of bus voltage profiles. The Fuzzy inference structure FIS is tested in MATLAB 7 Fuzzy Toolbox.

A. Bus Voltage Profiles

The post contingent bus voltage profiles are divided into three categories using fuzzy set notations: low voltage (LV), below 0.95 p.u.; normal voltage (NV), 0.95-1.05 p.u.; and over voltage (OV), above 1.05 p.u. The boundaries of these categories are fuzzified based on extensive off-line analysis performed for various load conditions. Trapezoidal membership function is used for describing bus voltage profile shown in Fig. 1.

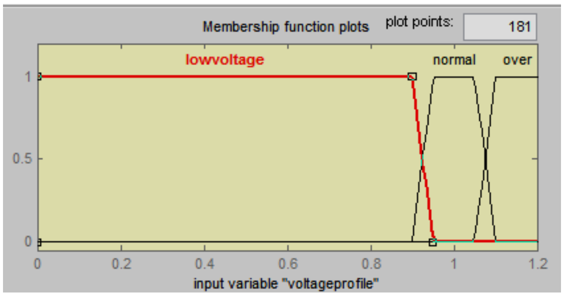

Fig. 1 Membership function for 3 linguistic variables of bus voltage profiles

B. L index

The post contingent L index are divided into five categories using fuzzy set notation; very small (VS), 0-0.18; small (S), 0.24-0.36; medium (M), 0.42-0.56; high (H), 0.62-0.76; very high (VH) 0.82-1.0. Each category represents a severity class of the L index. The boundaries of these categories are fuzzified based on extensive off-line analysis. Fig. 2 shows the membership function of L index.

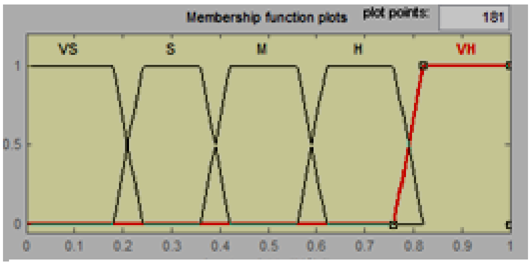

Fig. 2 Membership function for 5 linguistic variables of L index

The fuzzy rules used for evaluation of severity index of bus voltage profiles and L index are given in the following Table 1. Centre of area or gravity method is used for defuzzification.

Table 1: Fuzzy Rules

Post contingent quantity	Severity index
L index: VS S M H VH	VLS LS BS AS MS
Voltage : LV NV OV	MS BS AS

Note: VLS- very less severe; LS- less severe;
BS- below severe; AS – above severe; MS – more severe.

C. Severity Index of Post Contingent Quantities

The output membership functions used to evaluate the severity of bus voltage profile are also divided into three categories using fuzzy set notation. As the linguistic variables are imprecise, each linguistic variable covers a range rather than a single severity index. The boundaries of these categories are fuzzified based on extensive off-line analysis. Trapezoidal membership function is used for describing a linguistic variable.

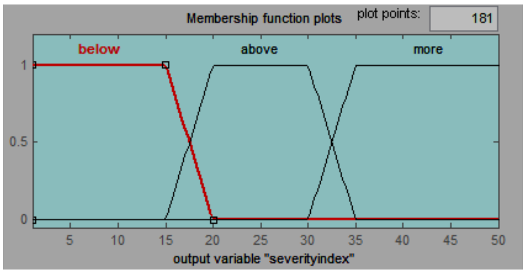

Fig. 3 Membership function for severity index of bus voltage profile

The output membership functions used to evaluate the severity of L index are divided into five categories using fuzzy set notation. Trapezoidal membership function is used for describing a linguistic variable.

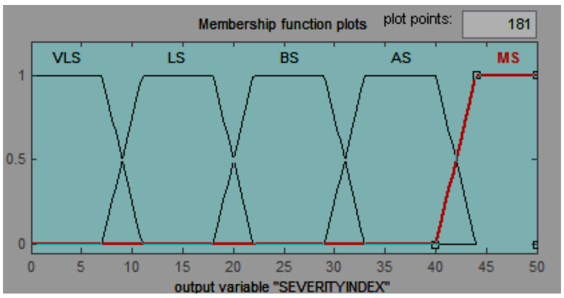

Fig. 4 Membership function for severity index of L index

The overall severity index (composite index) for a particular line outage is given by CI = $SI_L + \Sigma SI_{VP}$; Where, SI_L is the severity index of L index for a particular line outage and ΣSI_{VP} is the sum of severity index of all bus voltage profiles for a particular line outage. Thus, the overall severity index indicates the actual severity of the system for a contingency.

IV. METHODOLOGY

The major steps involved in this approach for contingency ranking is as follows

a) For the given system, considering a line outage at a time, load flow study is performed to determine bus voltage profiles.
b) L index is computed using (1) and is used as post contingent quantity.
c) Assuming trapezoidal membership function, the bus voltage profiles and L index are represented in fuzzy set notation.
d) Severity index of L index and bus voltage profiles are also represented in fuzzy set notation.
e) Using Fuzzy-If-Then rules overall severity index for bus voltage profiles and L index is determined. The Fuzzy Inference System is tested in MATLAB 7 Fuzzy Toolbox.
f) Composite index is found using the formula CI = $SI_L + \Sigma SI_{VP}$
g) The above procedure is repeated for all the line outages and the contingencies are ranked based on composite index.

V. TEST RESULTS

The proposed approach is tested under simulated condition on IEEE-30 bus system. A.C load flow is carried out to select the heavily loaded lines based on Voltage Collapse Proximity Indicator. The IEEE-30 bus system consists of 6 generators, 2 shunt capacitors and 41 transmission lines. Contingency screening is carried out to identify all the heavily loaded lines. On contingency screening total 13 transmission line outages are considered for ranking. The line outages considered for ranking are listed in Table 2.

Table 2 List of Line Outage Contingencies in IEEE 30 bus system

Contingency no.	Type of contingency	From bus	To bus
1	SLO	1	2
2	SLO	1	3
3	SLO	3	4
4	SLO	2	6
5	SLO	4	6
6	DLO	1	3
		2	4
7	DLO	2	4
		2	5
8	DLO	2	4
		3	4
9	DLO	3	4
		2	5
10	DLO	2	5
		2	6
11	DLO	2	6
		4	6
12	DLO	4	6
		5	7
13	DLO	4	6
		6	7

Simulations were carried out to compute L index and bus voltage profiles for all the contingencies listed in the Table 2. Table 3 and 4 shows the ranking using Fuzzy approach for 100% and 140% load. Fuzzy approach effectively ranks contingencies under different load conditions. Table 5 shows the ranking based on L index and Minimum Singular Value of load flow Jacobian matrix [16] using Fuzzy approach.

Table 3 Contingency Ranking Based on L index using Fuzzy Approach: 100 % load

Line outages	$SI_{V(SUM)}$	SI_L	CI	Rank
1-2	189.08	31.90	220.98	1
1-3	188.88	14.63	203.51	7
3-4	189.32	11.70	201.02	9
2-6	190.55	6.21	196.76	13
4-6	190.58	9.60	200.18	11
1-3,2-4	184.14	21.10	205.24	5
2-4,2-5	186.45	20.30	206.75	4
2-4,3-4	184.94	20.20	205.14	6
3-4,2-5	185.73	22.40	208.13	3
2-5,2-6	185.06	23.90	208.96	2
2-6,4-6	183.71	19.40	203.11	8
4-6,5-7	191.01	19.90	200.91	10
4-6,6-7	186.45	12.90	199.35	12

Table 4 Contingency Ranking Based on L index using Fuzzy Approach: 140 % load

Line outages	$SI_{V(SUM)}$	SI_L	CI	Rank
1-2	486.88	44.30	513.18	1
1-3	173.32	32.80	206.12	8
3-4	173.67	30.60	204.27	9
2-6	173.67	21.40	195.07	13
4-6	174.62	23.30	197.92	11
1-3,2-4	463.56	41.30	504.86	5
2-4,2-5	470.65	39.30	509.95	4
2-4,3-4	453.84	41.30	495.14	6
3-4,2-5	485.48	42.20	527.6	2
2-5,2-6	481.77	41.30	523.07	3
2-6,4-6	171.68	41.20	212.88	7
4-6,5-7	174.62	23.40	198.02	10
4-6,6-7	175.19	21.30	196.49	12

Table 5 Comparison of Contingency Ranking using Fuzzy Approach based on L index and MSV

Line outages	100% load		140% load	
	L Index	MSV	L Index	MSV
1-2	1	1	1	1
1-3	7	7	8	7
3-4	9	9	9	9
2-6	13	10	13	13
4-6	11	12	11	12
1-3,2-4	5	5	5	5
2-4,2-5	4	4	4	4
2-4,3-4	6	6	6	6
3-4,2-5	3	2	2	2
2-5,2-6	2	3	3	3
2-6,4-6	8	8	7	8
4-6,5-7	10	11	10	10
4-6,6-7	12	13	12	11

From the above results, it can be observed that the contingency ranking obtained using L index and MSV is in close agreement with each other. The proposed fuzzy based composite index is accurate in ranking the contingencies. The contingencies ranked using this index provides very useful information about the impact of the contingency on the system as a whole and helps in taking necessary control measures to reduce the severity of the contingency avoiding possible voltage collapse. The fuzzy approach is very effective in modelling imprecision and uncertainty in power system. Thus, fuzzy reasoning mimic's experienced human operator judgement. Fuzzy approach for contingency ranking will serve as a powerful tool for power system operator to foresee the possible occurrence of voltage collapse and initiate appropriate action.

VI. CONCLUSIONS

Fuzzy approach is used for combining the effect of L index with bus voltage profiles for ranking the contingencies. Fuzzy approach effectively ranks contingencies under different load conditions. The Fuzzy approach is flexible in incorporating human experience and heuristics. It includes the imprecision of linguistic terms associated with voltages and L index translates them into numerical values, which offers more flexibility, better insight into reality than conventional methods. Through proper tuning of membership functions in fuzzy representation, the approach can mimic experienced operators' performance in conducting contingency ranking.

REFERENCES

[1]. F. Albuyeh, A. Bose and B.Heath, " Reactive Power Considerations in Automatic Contingency Selection", *IEEE Transactions On Power Apparatus and Systems, Vol. PAS-101, No. 1,* pp. 107- 112, January 1982.

[2]. S. Vemuri and R. E. Usher, "On-line Automatic Contingency Selection Algorithms", *IEEE Transaction on Power Apparatus and Systems, Vol. PAS-102, pp.346-354,* February 1983.

[3]. D. G. Taylor and L.J. Maahs, "A reactive contingency analysis algorithm using MW and MVAR distribution factors", *IEEE Transactions on Power Systems, Vol. 6, No. 1,* pp. 349-355, February 1991.

[4]. G.C. Ejebe, G.D. Irissari, S. Mokhtari, O. Obadina, P. Ristanovic, J. Tong, "Methods for Contingency Screening and Ranking for Voltage Stability Analysis of Power Systems", *IEEE Transactions on Power Systems, Vol. 11, No. 1,* pp. 350-356, February 1996.

[5]. Antonio C. Z. de Souza, Claudio A. Canizares and Victor H. Quintana, " New Techniques to Speed Up voltage Collapse Computations Using Tangent Vectors", Approved by IEEE Power System

Engineering committee of the IEEE Power Engineering Society of publication in *IEEE Transactions on Power Systems*, Nov. 1996.

[6]. Alberto Berizzi, Yong-Gang, Zeny, Paolo Marannino, Alessandro Vaccarini, and Pierangela A. Scrapellini, " A Second Order Method for Contingency Severity Assessement with respect to Voltage Collapse", *IEEE Transaction on Power Systems, Vol. 15, No.1*, pp. 81-87, February 2000.

[7]. Claudio A. Canizares and Fernando L. Alvarado, "Point of Collapse and Continuation Methods for Large AC/DC Systems", *IEEE Transactions on Power Systems, Vol.8, No.1*, pp.1-8, February 1993.

[8]. P. Marannino, A. Berizzi, M. Merlo, G. Demartini, "A Rule-based Fuzzy Logic Approach for the Voltage collapse Risk Classification", *IEEE Power Engineering Society Winter Meeting, Vol. 2* , pp. 876-881,2002.

[9]. P.R. Bijwe, M. Hanmandlu, V.N.Pande, "Fuzzy power flow solutions with reactive limits and multiple uncertainties", *Electric Power systems Research, No. 76*, pp.145-152, 2005.

[10]. A. Narendranatha Udupa, D. Thukaram, K. Parthasarathy, "An expert fuzzy control approach to voltage stability enhancement", *Electrical Power and Energy Systems, No. 21*, pp.279-287, 1999.

[11]. N. Yadaiah, A. Ganga Dinesh Kumar, J.L. Bhattacharya, "Fuzzy based coordinated controller for power system stability and voltage regulation", *Electric Power systems Research, No. 69*, pp.169-177, 2004.

[12]. Carson W. Taylor, Mani V. Venkatasubramanian, Yonghong Chen, "Wide Area Stability and Voltage Control", *VII Symposium of Specialists in Electric Operational and Expansion Planning*", Brazil 2000.

[13]. V. Mirinda and J.T. Saraiva, "Fuzzy Modelling of Power System Optimal Load Flow", *IEEE Transactions on Power Systems, Vol.7, No.2*, pp. 843-849, May 1992.

[14]. Ching-Tzong Su and Chien-Tung Lin, "A New Fuzzy Control Approach to Voltage Profile Enhancement for Power Systems", *IEEE Transactions on Power Systems, Vol. 11, No. 3*, pp. 1654-1659, August 1996.

[15]. P. Kessel, H. Glavitsch, "Estimating the Voltage Stability of a Power System", *IEEE Transactions on Power Delivery, Vol. PWRD-1, No.3*, July 1986.

[16]. Tiranuchit and R.J. Thomas, "A Posturing Strategy against Voltage Instabilities in Electric Power Systems", *IEEE Transactions on Power Systems, Vol. PWRS-3, No.1*, February 1988.

BIOGRAPHY

Shobha Shankar received the B.E. degree in Electrical Engineering in 1994, M.Tech degree in Power Systems in 1997 from the University of Mysore, Mysore. She obtained her Ph.D. degree from Visveswaraya Technological University in 2011. She is working as Professor in the Department of Electrical and Electronics Engineering, Vidyavardhaka College of Engineering, Mysore, India. Her areas of interest are AI applications to Power System Studies, Voltage and Reactive Power Control,.