Fuzzy Approach to Nodal Reliability Ranking for Radial Distribution Systems

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Abstract

Power distribution systems are always exposed to disturbances, which can lead to voltage instability and collapse. The most important task for a distribution engineer is to identify the sensitive nodes and rank them according to their severity. This paper presents the application of fuzzy logic to define percentage reliability and accordingly define nodal reliability ranking of each node, considering reliability as a function of voltage and Voltage Stability Index. The variation in percentage reliability is also calculated due to the impact of load variation. The proposed technique is useful to ensure the reliability of distribution system by predicting the nearness of voltage collapse with respect to existing load conditions and can be used as an early warning so that the necessary action can be taken in order to avoid the occurrence of voltage collapse. For the load flow calculation purpose, a three phase fuzzy load flow algorithm for unbalanced radial distribution systems is developed, which is based on algebraic recursive expression of the voltage magnitude.

Index Terms— Branch Voltage, Fuzzy set, Nodal Reliability Ranking, Three phase load flow, Voltage Stability Index.

I. Introduction

IN modern power system, voltage stability is a major concern as systems operate at points which are steadily approaching the maximum operating limits. Voltage instability can lead to blackouts which is a major concern in the planning and operation of power system. Voltage instability is characterized by the variation in voltage magnitude which gradually decreases to a dangerously low value accompanied by simultaneous decrease in the power transfer to the load end from the source. Hence it is important to have a reliable power system, which will maintain the voltages within the permissible limits to ensure high quality of service. To maintain voltage stability, it is desirable to estimate the effect of any unforeseen events and identify nodes which are most sensitive.

Chi-Wen Liu presents a neurofuzzy network proposed for voltage security monitoring using synchronized phasor measurement [1]. A work on knowledge based system for supervision and control of regional voltage profile and security is presented in [2]. Manjaree Pandit et al present fast voltage contingency selection using fuzzy parallel self organizing hierarchical Neural Network [3]. M.Aruna presents a new reconfiguration algorithm that enhances voltage stability and improves the voltage profile[4].Work on reconfiguration of the networks has already been reported which defines that the voltage stability can be maximized for a particular set of loads in the distributed systems [5,6,7].

A method for detecting voltage collapse in radial distribution systems is presented where two indicators for evaluating voltage stability of radial distribution systems are derived [8]. An algorithm for optimal locations and sizing of static and/or switched shunt capacitors is reported, with a view to enhance voltage stability [9]. Voltage stability analysis of radial distribution networks, where a new voltage stability index is proposed for identifying the nodes that are on the verge of voltage collapse, but does not use a fuzzy approach for the analysis [10]. Shobha presents the fuzzy approach for ranking the contingencies using composite index [11], for transmission network.

Hence, the literature review shows that the work done are mainly focused on enhancement techniques of voltage stability and not much work has been reported on the reliability analysis, describing the status of each node for a distribution system.

This paper presents the application of Fuzzy Logic for determining the percentage reliability and nodal ranking, considering percentage reliability as a function of voltage, stability index independently and also as a function of both voltage and stability index. The variation in nodal reliability ranking due to the impact of load changes is studied and an acceptable percentage reliability cut-off level is also proposed.

The paper is organized as follows. In section II, the methodology used for nodal reliability ranking is discussed. The bus voltage and the stability index are expressed in fuzzy notation and further processed through fuzzy reasoning rules using fuzzy logic. Section III, IV & V elaborate the nodal voltages, voltage stability index (SI) and percentage reliability computations with results. Section VI concludes the paper.

II. METHODOLOGY OF NODAL RELIABILITY RANKING

In recent years, fuzzy system applications have received increasing attentions in various areas of power systems. Fuzzy set based reasoning approach has been developed for nodal reliability ranking, which is a process of indexing each node and rank them according to their severity. The bus voltage and the stability index are expressed in fuzzy notation and further processed using fuzzy reasoning rules.

Nodal reliability ranking is basically done using following steps;

- Using fuzzy modeled load flow algorithm to calculate nodal voltages
- Using fuzzy modeled load flow algorithm to calculate voltage stability index (SI).
- Using fuzzy If-Then rules to calculate node’s percentage reliability.
- Rank the nodes based on above.

III. FUZZY MODELED LOAD FLOW ALGORITHM TO CALCULATE NODAL VOLTAGES

For nodal voltage calculation, this paper uses an algorithm, as described in this section [12], modified to suite the fuzzy model. The load flow calculation methodology uses the basic systems analysis method and circuit theory and requires only the recursive algebraic equations to get the voltage magnitudes, currents & power losses at all the nodes. This load flow methodology also evaluates the total real and reactive power fed through any node.

A simple circuit model of the system is shown in Figure 1. The calculation uses Carson & Lewis matrix method, which takes into account the self and mutual coupling effects of the unbalanced three phase line section.

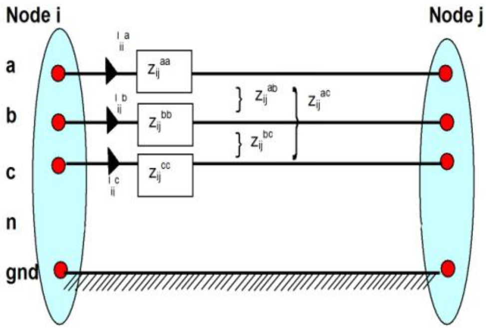


Fig. 1 – Three phase four wire line model

Using concept of simple circuit theory, the relation between the bus voltages and the branch currents in Figure 1 can be expressed as:

$$\begin{bmatrix} V_i^{ag} - V_j^{ag} \\ V_i^{bg} - V_j^{bg} \\ V_i^{cg} - V_j^{cg} \end{bmatrix} = \begin{bmatrix} V_{ij}^a \\ V_{ij}^b \\ V_{ij}^c \end{bmatrix} = \begin{bmatrix} z_{ij}^{aa} & z_{ij}^{ab} & z_{ij}^{ac} \\ z_{ij}^{ba} & z_{ij}^{bb} & z_{ij}^{bc} \\ z_{ij}^{ca} & z_{ij}^{cb} & z_{ij}^{cc} \end{bmatrix} \begin{bmatrix} I_{ij}^a \\ I_{ij}^b \\ I_{ij}^c \end{bmatrix}$$

(1)

Where

V_i^{ag} = Voltage of phase a at node i with respect to ground

V_i^{ab} = Voltage drop between two phases a and b at node i.

V_{ij}^a = Voltage Drop between nodes i and j in phase a.

I_{ij}^a = Current through phase a between nodes i and j.

z_{ij}^{aa} = Self impedance between nodes i and j in phase a.

z_{ij}^{ab} = Mutual impedance between phase a and b between nodes i and j.

Pi^a, Qi^a , Si^a = Real, reactive and complex power loads at phase a at ith bus.

Sij^{phase} = Complex power at phase (a, b and c) between nodes i and j.

$PLij^{phase}$ = Real power loss in the line between node i and j.

$QLij^{phase}$ = Reactive power loss in the line between node i and j.

$SLij^{phase} = PLij^{phase} + jQLij^{phase}$

riting (1)

$$\begin{bmatrix} V_j^a \\ V_j^b \\ V_j^c \end{bmatrix} = \begin{bmatrix} V_i^a \\ V_i^b \\ V_i^c \end{bmatrix} - \begin{bmatrix} z_{ij}^{aa} & z_{ij}^{ab} & z_{ij}^{ac} \\ z_{ij}^{ba} & z_{ij}^{bb} & z_{ij}^{bc} \\ z_{ij}^{ca} & z_{ij}^{cb} & z_{ij}^{cc} \end{bmatrix} \begin{bmatrix} I_{ij}^a \\ I_{ij}^b \\ I_{ij}^c \end{bmatrix}$$

owing equations gives the branch currents n the nodes i and j:

$= (P_{ij}^a+jQ_{ij}^a) / V_j^a$

$: (P_{ij}^b+jQ_{ij}^b) / V_j^b$

$I_{ij}^c = (P_{ij}^c+jQ_{ij}^c) / V_j^c$

The real and reactive power losses in the line between buses i and j are written as;

$SL_{ij}^a = PL_{ij}^a + jQL_{ij}^a = Vi^a * (I_{ij}^a) - V_j^a*(I_{ji}^a)$

$SL_{ij}^b = PL_{ij}^b + jQL_{ij}^b = Vi^b * (I_{ij}^b) - V_j^b*(I_{ji}^b)$

$SL_{ij}^c = PL_{ij}^c + jQL_{ij}^c = Vi^a * (I_{ij}^c) - V_j^c*(I_{ji}^c)$

The program computes the real & reactive power and uses the formula given in equation no. (2) Receiving end power at any phase, say phase a, of line between the nodes i and j is expressed as:

$$P_{ij}^{a}+jQ_{ij}^{a} = \left[\sum_{K=\text{index of all nodes fed through the line between nodes i and j}} [\,P_{kj}^{a}+jQ_{k}^{a}\right] + \left[\sum_{\text{index of all lines connected between nodes m and n fed through the line between no}} PL_{mnj}^{a}+j(\right]$$

(2)

For modeling and simulation purpose this paper uses an input data for a 19 bus distribution system shown in Figure 2 [13]. Load data for the feeders are given in Appendix 1. Figure 3 shows the flow chart for simulation.

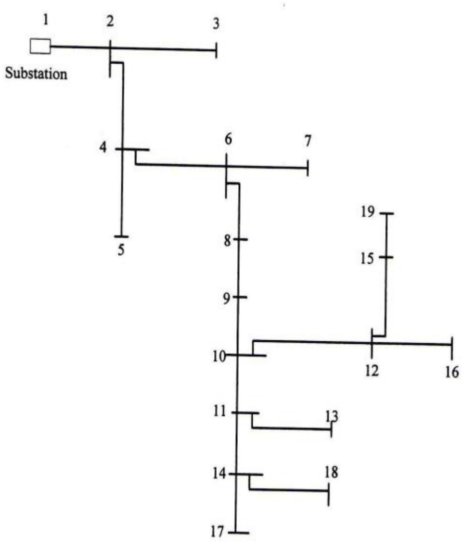


Fig. 2. - A practical 19 bus distribution feeder used for the modeling and simulation purpose.

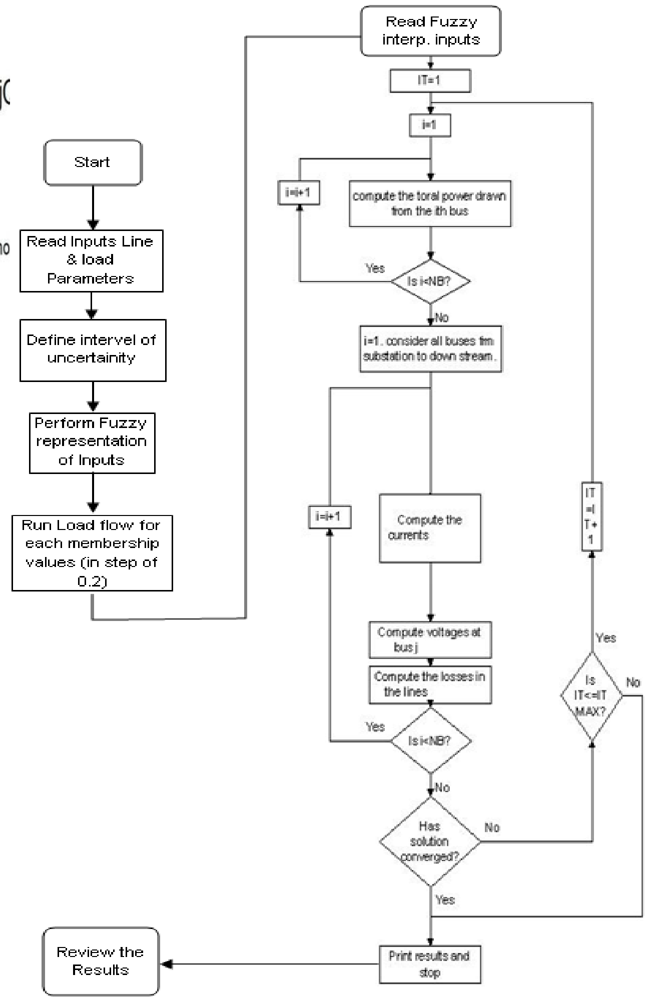


Fig. 3 - Typical Fuzzy Load Flow calculation chart used

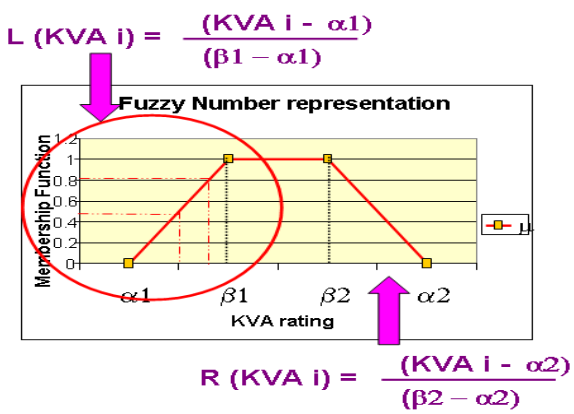


Fig. 4 - Fuzzification of kVA rating
Where, α_1 =20%, α_2 = 135%, β_1 = 95%, β_2 = 105%

For evaluation purpose, the feeder parameters are assumed unchanged and uncertainties are assumed only to the connected load parameters. An uncertain load can be represented by a fuzzy number that is in fact a membership function over the real set. Fuzzy numbers may have variety of shapes but here trapezoidal membership function is chosen. This shape is chosen from the fact that there are several points whose membership degree is maximum (μ=1).

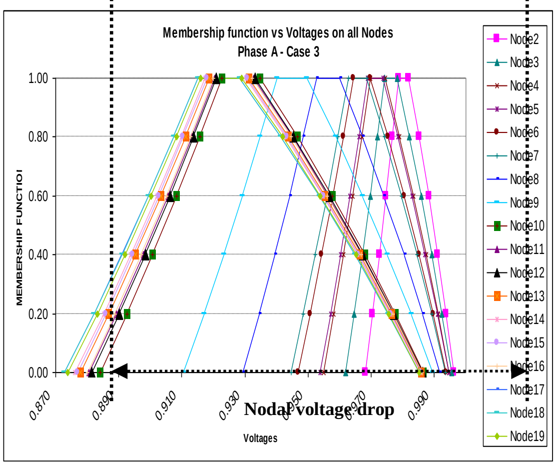
A linguistic declaration such as "peak values of load will not occur below 20 Percentage or above 135 Percentage, and the least estimation is, say between 95 Percentage and 105 Percentage of the rated capacity" can be translated into a fuzzy number as shown in Figure 4 as per [14].

For each value of μ (KVA), two different values of KVA loads can be obtained i.e. the L (KVA) & the R (KVA). Therefore, for each membership value, two load flow runs are required. Membership function μ (KVA) is taken in steps of 0.2. Table 1 shows the calculated nodal voltages for loads at μ(KVA) of 0.4 (Left) & 0.6 (Left).

TABLE 1.
CALCULATED NODAL VOLTAGES FOR μ (KVA) OF 0.4 (LEFT) & 0.6 (LEFT)

Node no.	μ Membership function of voltage magnitude					
	0.4			0.6		
	Ph A	Ph B	Ph C	Ph A	Ph B	Ph C
1	1	1	1	1	1	1
2	0.991	0.992	0.997	0.988	0.989	0.995
3	0.989	0.991	0.992	0.986	0.988	0.989
4	0.987	0.988	0.991	0.983	0.984	0.987
5	0.987	0.988	0.988	0.983	0.984	0.984
6	0.985	0.986	0.987	0.980	0.981	0.983
7	0.985	0.985	0.986	0.980	0.981	0.981
8	0.980	0.981	0.985	0.974	0.975	0.979
9	0.975	0.975	0.980	0.967	0.967	0.973
10	0.968	0.968	0.974	0.958	0.957	0.965
11	0.967	0.967	0.968	0.956	0.956	0.957
12	0.967	0.967	0.968	0.957	0.956	0.957
13	0.966	0.966	0.967	0.955	0.955	0.956
14	0.966	0.966	0.967	0.955	0.955	0.956
15	0.966	0.965	0.967	0.955	0.954	0.956
16	0.967	0.966	0.967	0.956	0.955	0.956
17	0.965	0.965	0.966	0.954	0.954	0.955
18	0.965	0.965	0.966	0.954	0.953	0.955
19	0.965	0.965	0.965	0.954	0.953	0.954

Figure 5 shows the calculated nodal voltages for all KVA membership functions for Phase A. One can notice that for certain group of nodes, nodal voltages are more sensitive to load variation and drops sharply. Similarly, fuzzy modeled load flow algorithm is used to calculate the nodal voltage trend and subsequently calculating the nodal ranking.



IV. Fuzzy Modeled Load Flow Algorithm to Calculate Voltage Stability Index (SI)

Voltage stability is the ability of a power system to maintain steadily acceptable bus voltage at each node under normal operating conditions, following load increases, system configuration changes or a disturbance. The progressive and uncontrollable drop in voltage eventually results in a wide spread voltage collapse.

This section calculates the voltage stability index (SI) for all the nodes of the radial distribution system using the load flow results. There are several methods to estimate or predict the voltage stability condition of a power system. This study utilizes the voltage stability index [15] in order to indicate the voltage stability condition at each bus of the system.

For a typical RDS, any line between the bus 'i' and 'j' can be represented by an equivalent single line represented as given in Figure 6.

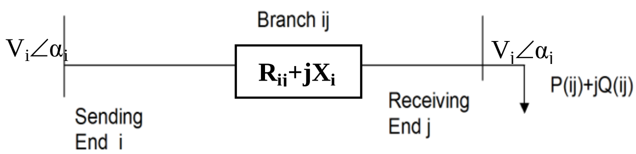


Fig. 6 - Electrical equivalent of one branch

The complex power flowing into the receiving end will be $P_{ij}+jQ_{ij}$, where P & Q stand for real and reactive power.

The governing circuit equations are:

$$V_i\angle\alpha_i - V_j\angle\alpha_j = I_{ij}(R_{ij}+jX_{ij}) \quad (3)$$

$$(V_i\angle\alpha_i)^* I_{ij} = P_{ij} - jQ_{ij}\,; \quad (4)$$

$*$ = complex conjugate operation

By solving the above two equations and with the assumption that for a typical radial distribution system ($\angle\alpha_i - \angle\alpha_j$) is typically very small value, hence the assumption

$$\cos(\angle\alpha_i - \angle\alpha_j) \approx 1 \;\;\&\;\; \sin(\angle\alpha_i - \angle\alpha_j) \approx 0$$

With the above assumption, it is derived that

$$V_j^2 - V_i V_j + (P_{ij} R_{ij} + Q_{ij} X_{ij}) = 0 \quad (5)$$

Therefore,

$$V_j = \{V_i \pm \sqrt{V_i^2 - 4(P_{ij} R_{ij} + Q_{ij} X_{ij})}\} / 2 \quad (6)$$

Eq (6) results in two possible solutions for the receiving end voltage V_j. However, the feasible solution is the minimum of the two as the voltage towards the receiving end is typically lower than its sending end voltage.

Thus, V_j can be taken as,

$$V_j = \{V_i - \sqrt{V_i^2 - 4(P_{ij} R_{ij} + Q_{ij} X_{ij})}\} / 2 \quad (7)$$

Since the voltage magnitude is always the real quantity, hence;

V_i^2 ... $R_{ij}+jQ_{ij} X_{ij}) \geq 0$ (8)

..., the stability index for the bus j ...ived as

... $4(P_{ij} R_{ij} + Q_{ij} X_{ij})$ (9)

The value of SI varies from 0 to 1. For stable operation of the RDS, stability Index should be nearing one. If the SI is nearing 0, this reflects an unstable bus.

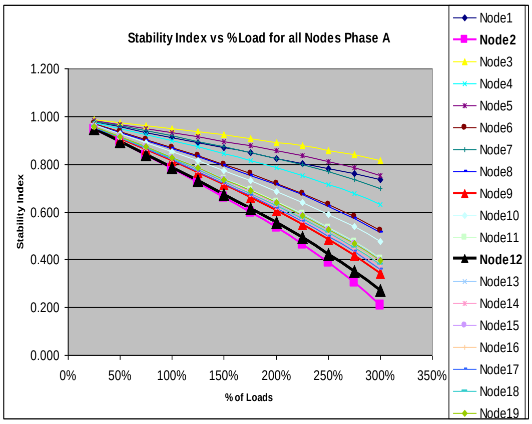


Fig. 7. - Stability Index variation with Load Changes

Figure 7 shows the typical variation of stability index based on load variation for all the nodes. One can note that for few nodes (e.g. Node 2, 12) stability index value dips sharply at higher loads tending towards instability.

V. FUZZY 'IF-THEN' RULES TO CALCULATE PERCENTAGE RELIABILITY OF A NODE.

This paper proposes fuzzy approach and uses voltage and SI of each node to calculate the percentage reliability and reliability ranking of the node. The bus voltage and the SI are selected as the crisp input parameters and expressed as fuzzy set notation.

The fuzzy 'If-Then' rules are used to evaluate the percentage-reliability of each node. Finally after defuzzufication the crisp value of the output mentioning the percentage reliability of a node is calculated. Using the same methodology, individual impact of voltages and SI on the percentage reliability can also be calculated. For calculation purpose a trapezoidal membership functions is assumed for bus voltage and SI profile and are represented in fuzzy set notation. The bus voltage profiles are divided into five triangular membership functions, as indicated in Figure 8.

terpretation of voltage (V);
25, then 'Unstable (UN)'
-0.95, then 'Less Stable (LS)'
25-0.975, then 'Moderately Stable

5-1.0, then, 'Stable (S)' &
75, then, 'Over range (Over)'.

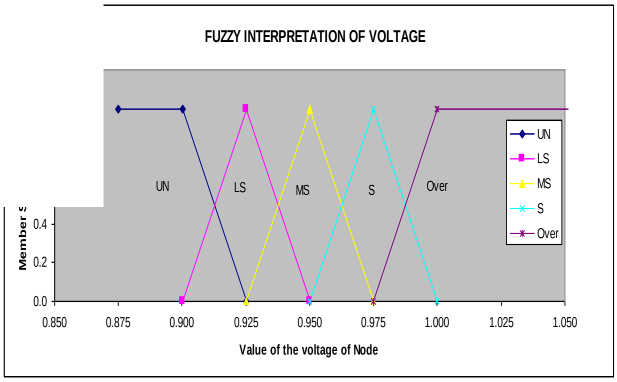


Fig. 8 - Fuzzy number representation

Similarly the 'SI' profiles are divided into five triangular membership functions using fuzzy set notations, as given in Figure 9.

Fuzzy Interpretation of SI;
If SI<0.85, then 'Unstable (UN)'
If SI=0.8-0.9, then 'Less Stable (LS)'
If SI=0.85-0.95, then 'Moderately Stable (MS)'
If SI=0.9-1.0, then, 'Stable (S)'
If SI>0.975, then, 'Over range (Over)'

Using fuzzy 'If-Then' rules overall percentage reliability is calculated based on both the voltage and SI profiles.

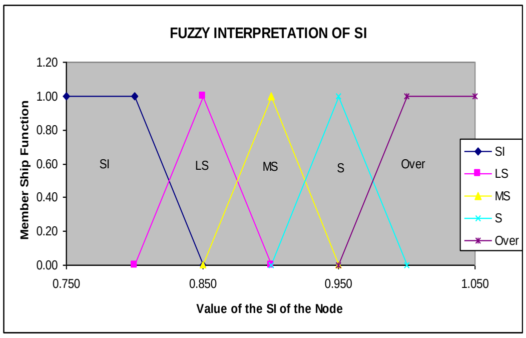


Fig. 9 - Fuzzy number representation

Fuzzy 'If then' rules shown in table 3 are used for calculation purpose;

Let for a node; Voltage = V and Stability Index = SI
Then the corresponding membership values for each zone of the five triangular membership functions can be defined as given in table 2.

TABLE 2.
CALCULATED NODAL VOLTAGES FOR µ (KVA) OF 0.4 (LEFT) & 0.6 (LEFT)

	Menbership Values	
	Voltage	SI
UN	Av	SIa
LS	Bv	SIb
MS	Cv	SIc
Stable	Dv	SId
Over	Ev	SIe

TABLE 3
'IF THEN' RULES

R1	If	V<0.925	AND	SI<0.85	Then	'UN'	Min
R2	If	V=0.9-0.95	AND	SI<0.85	Then	'UN'	Min
R3	If	V=0.925-0.975	AND	SI<0.85	Then	'UN'	Min
R4	If	V=0.95-1.0	AND	SI<0.85	Then	'LS'	Min
R5	If	V>0.975	AND	SI<0.85	Then	'LS'	Min
R6	If	V<0.925	AND	SI=0.8-0.9	Then	'UN'	Min
R7	If	V=0.9-0.95	AND	SI=0.8-0.9	Then	'LS'	Min
R8	If	V=0.925-0.975	AND	SI=0.8-0.9	Then	'LS'	Min
R9	If	V=0.95-1.0	AND	SI=0.8-0.9	Then	'MS'	Min
R10	If	V>0.975	AND	SI=0.8-0.9	Then	'S'	Min
R11	If	V<0.925	AND	SI=0.85-0.95	Then	'UN'	Min
R12	If	V=0.9-0.95	AND	SI=0.85-0.95	Then	'MS'	Min
R13	If	V=0.925-0.975	AND	SI=0.85-0.95	Then	'MS'	Min
R14	If	V=0.95-1.0	AND	SI=0.85-0.95	Then	'S'	Min
R15	If	V>0.975	AND	SI=0.85-0.95	Then	'S'	Min
R16	If	V<0.925	AND	SI=0.9-1.0	Then	'UN'	Min
R17	If	V=0.9-0.95	AND	SI=0.9-1.0	Then	'MS'	Min
R18	If	V=0.925-0.975	AND	SI=0.9-1.0	Then	'S'	Min
R19	If	V=0.95-1.0	AND	SI=0.9-1.0	Then	'S'	Min
R20	If	V>0.975	AND	SI=0.9-1.0	Then	'S'	Min
R21	If	V<0.925	AND	SI>0.975	Then	'UN'	Min
R22	If	V=0.9-0.95	AND	SI>0.975	Then	'MS'	Min
R23	If	V=0.925-0.975	AND	SI>0.975	Then	'S'	Min
R24	If	V=0.95-1.0	AND	SI>0.975	Then	'S'	Min
R25	If	V>0.975	AND	SI>0.975	Then	'O'	Min

The strengths for five triangular membership functions are
shown in equation no (10).

Formula	Outp
UNs	(R1^2+R2^2+R3^2+R6^2+R11^2+R16^2+R21)^
LSs	(R4^2+R5^2++R7^2R8^2)^0.5
MSs	(R9^2+R12^2+R13^2+R17^2+R22^2)^0.5
Ss	(R10^2+R14^2+R15^2+R18^2+R19^2+R20^2+F +R24^2)^0.5
Over (s)	(R25^2)^0.5

(10)

TABLE 4
OUTPUT RANGE CONSIDERED FOR RANKING & PERCENTAGE RELIABILITY CALCULATION.

Output Range

Unr	=	0	=	0%
LSr	=	0.3	=	30%
MSr	=	0.5	=	50%
Sr	=	0.9	=	90%
Over®	=	1	=	100%

Table 4 shows the output ranges for percentage reliability assumed and uses defuzzification calculations given in equation (11) to find the crisp value of percentage reliability of each node.

$$OUTPUT = \frac{(UNr*UNs+LSr*LSs+MSr*MSs+ \; Sr*Ss+Over(r)*Over(s))}{(Unr+LSr+MSr+MSr+Over(r))} \quad (11)$$

The above procedure is repeated for all the buses to calculate the output percentage reliability of the nodes.

According to the output range shown in table 4 the cut-off level below 20 percentage (i.e 0.2) is assumed as unreliable node and prone for voltage collapse. Further ranking of nodes is done on the basis of their percentage reliability calculated after defuzzification. The higher rank (i.e rank 1, 2, 3…) indicates unstable nodes.

The result based on above methodology is shown in table 5, which gives percentage reliability of each node for 19 bus system. The results shown are for two loads i.e. 82 percent and 111 percent of base loads. One can notice that as the load increases, the percentage reliability generally decreases. However certain nodes become more stable as the load increases. In reference example all the nodes from 10 to 19 tends to become unstable (below 20 percent) at higher loads. The percentage reliability depends on the output range assumed. A different output range will shift the reliability windows for nodes. One can run this simulation for various load combination.

Table 6 shows the nodal stability ranking. The ranking is based on the percentage reliability values. Table 6 depicts the rounded values; however for nodal ranking the actual percentage values are used. Values with lower percentage indicates a higher rank showing nodes towards instability. One can notice that ranking of various nodes are different at different loads. Figure 10, shows the typical changes to nodal rankings based on load changes. The figure gives a snap shot of nodal ranking changes based on load variations. It may be noted that the loads connected away from the substation (Node 12, 13, 14, 16 & 17) tends to get unstable on higher loads. For Certain nodes (e.g node 2) ranking actually improves.

TABLE 5
'PERCENTAGE RELIABILITY AS VOLTAGE & SI

	82% Load			111% Load		
Node	Phase A	Phase B	Phase C	Phase A	Phase B	Phase C
1	51%	51%	51%	51%	51%	51%
2	90%	90%	90%	51%	51%	51%
3	51%	51%	51%	90%	90%	86%
4	91%	90%	90%	50%	50%	50%
5	89%	87%	83%	79%	76%	73%
6	90%	89%	87%	50%	50%	50%
7	65%	50%	50%	66%	63%	59%
8	83%	76%	73%	47%	31%	30%
9	50%	47%	47%	51%	51%	51%
10	35%	30%	30%	28%	9%	11%
11	41%	35%	35%	8%	1%	3%
12	37%	33%	34%	0%	0%	0%
13	30%	30%	30%	1%	0%	0%
14	32%	31%	31%	1%	0%	0%
15	31%	30%	30%	1%	0%	0%
16	33%	32%	33%	2%	0%	2%
17	30%	30%	30%	0%	0%	0%
18	30%	30%	29%	0%	0%	0%
19	30%	30%	30%	0%	0%	0%
	Un stable Zone					

TABLE 6
NODAL STABILITY RANKING BASED ON PERCENTAG RELIABILITY

Node	82% Load			111% Load		
	Phase A	Phase B	Phase C	Phase A	Phase B	Phase C
1	12	13	13	14	14	14
2	17	18	18	14	14	14
3	12	13	13	19	19	19
4	19	19	19	12	12	12
5	16	16	16	18	18	18
6	18	17	17	13	13	13
7	14	12	12	17	17	17
8	15	15	15	11	11	11
9	11	11	11	14	14	14
10	8	4	4	10	10	10
11	10	10	10	9	9	9
12	9	9	9	3	5	4
13	1	5	5	6	8	7
14	6	7	7	5	1	1
15	5	6	6	7	6	5
16	7	8	8	8	1	8
17	4	2	3	1	1	1
18	3	1	1	2	4	3
19	2	3	2	4	7	6

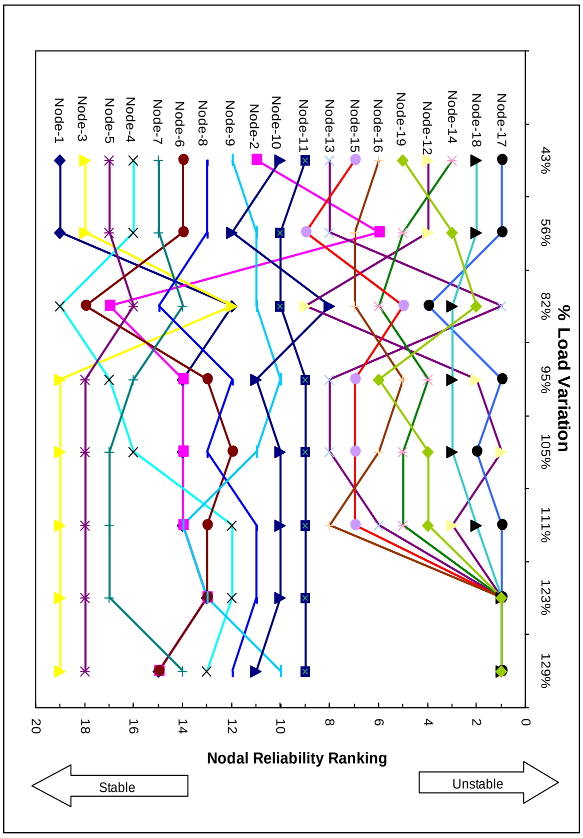


Fig. – 10 Typical changes to nodal rankings based on load changes

VI. CONCLUSION

This paper uses the application of fuzzy logic to define percentage reliability and accordingly define nodal reliability ranking for a typical RDS. The simulation uses fuzzy based load flow algorithm to calculate nodal parameters and voltage stability index, which are further used as an input to model the fuzzy based reliability ranking algorithm. The result shows the possible Nodal reliability distribution of all the nodes at glance and gives a good idea about the network as a whole.

Using the proposed methodology, all possible scenarios are modeled and comparison is drawn for a wide variation in loads. The proposed technique is useful to ensure the reliability of distribution system by predicting the nearness of voltage collapse with respect to existing load conditions and can be used as an early warning. This can also be used during initial stages of planning and design studies.

APPENDIX

Input Load & Line data table.

Table – A Load data

Node	Phase Load in KVA		
	A	B	C
2	64	32	64
3	68	32	60
4	25	35	40
5	40	32	28
6	26	19	18
7	60	50	50
8	46	33	21
9	76	92	82
10	21	26	16
11	46	46	68
12	60	50	50
13	27	33	40
14	19	19	25
15	27	30	43
16	48	64	48
17	40	30	30
18	33	33	34
19	54	62	44

Table – B Conductor data

Conductor type	Resistance PU/Km	Reactance PU/Km
1	0.008600	0.003700
2	0.012950	0.003680

Table – C Conductor Code & Distances

Sending End Node(IR)	Receiving End Node(IR)	Conductor Code	Distance in Km
1	2	1	3
2	3	2	5
2	4	1	1.5
4	5	2	1.5
4	6	1	1
6	7	2	2
6	8	1	2.5
8	9	1	3
9	10	1	5
10	11	1	1.5
10	12	1	1

Sending End Node(IR)	Receiving End Node(IR)	Conducto r Code	Distance in Km
11	13	2	5
11	14	1	3.5
12	15	1	4
12	16	2	1.5
14	17	1	6
14	18	2	5
15	19	1	4

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