Load Flow analysis for Radial Distribution Network with Network Topology Method

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Abstract- **Voltage stability has become an important issue of power system stability. This paper work concentrated on simple and efficient load flow analysis of radial distribution system for finding voltage magnitudes without trigonometric equations. Various methods are identified in literature survey for indication of voltage magnitude. The proposed analysis will be implemented on any IEEE standard test systems for composite load modeling. This feature enables us to set an index threshold to monitor and predict system stability online so that a proper action can be taken to prevent the system from collapse.**

Keywords: ***Distribution load flow, Branch Injection and Branch Current (BIBC), mathematical techniques, stability index.***

1. INTRODUCTION

The transmission system is distinctly different, in both its operation and characteristics, from the distribution system. Whereas the latter draws power from a single source and transmits it to individual loads, the transmission system not only handles the largest blocks of power but also the system.

The main difference between the transmission system and the distribution system shows up in the network structure. The former tends to be a loop structure and the latter generally, a radial structure. The modern power distribution network is constantly being faced with an ever-growing load demand. Distribution networks experience a distinct change from low to high load level every day.

Literature survey shows that a lot of work has been done on the voltage stability analysis of transmission systems [2].

Power transmission systems may include sub transmission stages to supply intermediate voltage levels. Sub-transmission stages are used to enable a more practical or economical transition between transmission and distribution systems. It operates at the highest voltage levels (typically, 230 kV and above). The generator voltages are usually in the range of 11 kV to 35 kV. There are also a few transmission networks operating in the extremely high voltage class (345 kV to 765 kV). As compared to transmission system sub-transmission system transmits energy at a lower voltage level to the distribution substations. Generally, sub-transmission systems supply power directly to the industrial customers. The distribution system is the final link in the transfer of electrical energy to the individual customers. Between 30 to 40% of total investment in the electrical sector goes to distribution systems, but nevertheless, they haven’t received the technological improvement in the same manner as the generation and transmission systems. The distribution network differs from its two of siblings in topological structure as well as its associated voltage levels. The distribution networks are generally of radial or tree structure and hence referred as Radial Distribution Networks (RDNs). Its primary voltage level is typically between 4.0 to 35 kV, while the secondary distribution feeders supply residential and commercial customers at 120/240/440 volts. It generally consists of feeders, laterals (circuit- breakers) and the service mains.

According to these studies, power flow analysis of RDNs may be divided into two categories. The first group of methods includes: ladder network methods for radial structure distribution systems using basic laws of circuit theories like Kirchhoff's Current Law (KCL) and Kirchhoff's Voltage Law (KVL) [1]. On the other hand, the second category includes Gauss- Seidel, Newton- Raphson and Decoupled Newton- Raphson methods for transmission systems and is usually based on nodal analysis method. The characteristics of RDNs are dynamic in nature and general features of RDS are

1. Uncertainties and Imperfection of network parameters.
2. High R/X ratio
3. Extremely large number of nodes and branches.
4. Dynamic change in imposed load.

2. MATHEMATICAL MODEL OF A RDN

In RDNs, the large R/X ratio causes problems in convergence of conventional load flow algorithms. For a balanced RDN, the network can be represented by an equivalent single-line diagram. The line shunt capacitances at distribution voltage level are very small and thus can be neglected. The base values taken for calculation of voltages in the system are 11 KV and 200 KVA. The simplified mathematical model of a section of a RDN is shown in Fig.1.

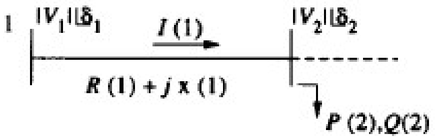
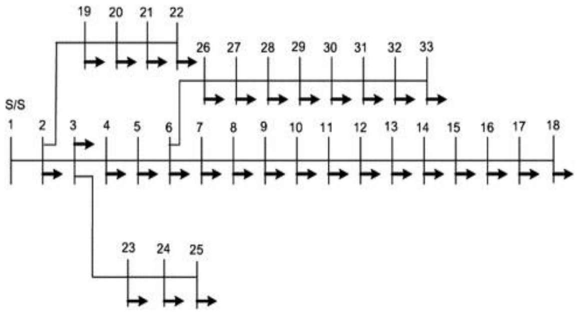


Fig 1: Single Line of an Existing Distribution Feeder



$I(i)=S(J)/V^*(J)$ ----------------------(1)

$I(i)=P(J)-Q(J)/V^*(J)$ -----------------------(2)

Fig 2: 33-bus Radial Distribution Network single line diagram

and also

$I(i)=|V(i)|\llcorner \quad (i)-|V(j)| \quad (j)/(R(i)+X(j))$-----(3)

$|V(2)|=\{[(P(j)*R(i)+Q(j)*X(i)-0.5|V(i)|^2)^2-(R^2(i)+X^2(i))(P^2(j)+Q^2(j))]^{1/2}-(P(j)*R(i)+Q(j)*X(i)-0.5|V(i)|^2)\}^{1/2}$ -----------(4)

The real and reactive power losses in branch ij are given by:

$LP(j)=R(j)*[P^2(m2)+Q^2(m2)]/|V(m2)|^2$ -------(5)

$QP(j)=X(j)*[P^2(m2)+Q^2(m2)]/|V(m2)|^2$ ------(6)

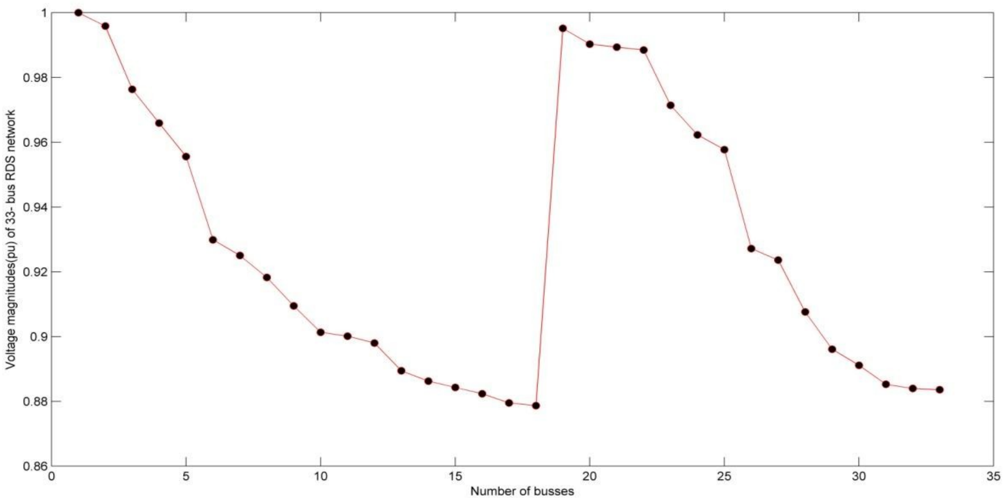


Fig 3: Voltage magnitudes of 33-bus Radial Distribution Network

Initially, if LP(j) and LQ(j) are set to zero for all j, then initial estimates of P(m2) and Q(m2) will be the sum of the loads of all the nodes beyond node m2 plus the load of the node m2 itself.

3. NETWORK TOPOLOGY FOR MATRIX FORMATION

The branch current B is calculated with the help of "Bus-Injection to Branch-Current matrix" (BIBC)[4]. The BIBC matrix is the result of the relationship between the bus current injections and branch currents.The elements of BIBC matrix consists of '0's or '1's.

$[B]_{Nnb*1}=[BIBC]_{nb*(n-1)*}[I]_{(n-1)*1}$----------------------(7)

Where nb is the number of branches, [I] is the vector of the equivalent current injection for each bus except the reference bus. This produced matrix is used for calculation of voltage magnitudes. The building Step for the BIBC matrix is shown in Fig .1.

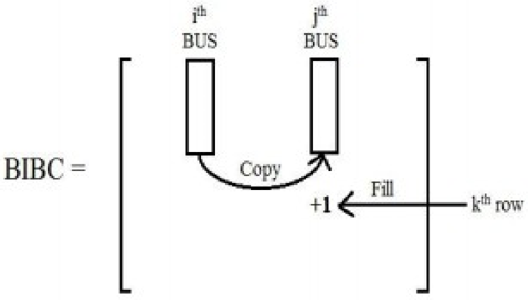


Fig 4: Graphical view of BIBC matrix

Step (1): For a distribution system with nb branch sections and n buses, the dimension of the BIBC matrix is nb × (n–1)

Step (2): If a line section (B_k) is located between Bus i and Bus j, copy the column of the ith bus of the BIBC matrix to the column of the jth bus and fill +1 in the position of the jth bus column as shown below. Step (3): Repeat Step (2) until all the line sections are

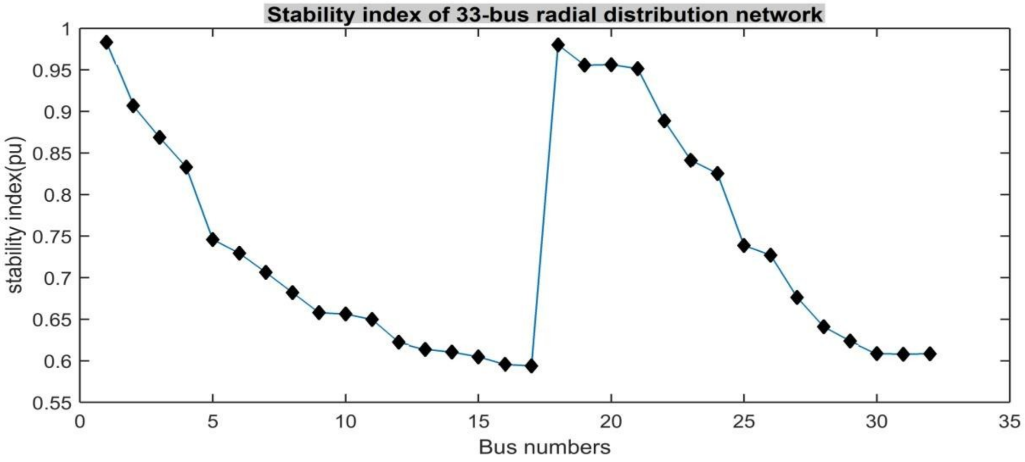


Fig 5: stability index of 33-bus Radial Distribution Network

included in the BIBC matrix. The building Step (2) for the BIBC matrix is shown in Fig. 4.

The BIBC matrix is responsible for the relations between the bus current injections and branch currents. (iii) The corresponding variation of the branch currents, which is generated by the variation at the current injection buses, can be found directly by using the BIBC matrix.

4. MATHEMATICAL MODEL OF STABILITY INDEX

For a distribution line model, given in fig.1, the quadratic equation which is mostly used for the calculation of the line sending end voltages in load flow analysis can be written in general form as

$$V_r^4+2\,V_r^2(PR+QX)-V_r^{2}\;{}^{2}\quad V_r^{2}+(P^{2}+Q^{2})|Z|=0\text{-------}(8)$$

and from this equation a feasible solution has considered , line receiving end active and reactive power can be written

$$2V_r^2\,V_r^2-Vr^4-2Vr^2(PR+QX)-|Z|^2(P^2+Q^2)\geq 0\text{--------}(9)$$

The above equation is most feasible of Eq (8).From the last equation, it is clearly seen that the value of the Eq.9 is decrease with the increase of the transferred power and impedance of the line, and it can be used as a bus stability index for a distribution networks as

$$SI(m2)=|V(m1)|^4-4\{P(m2)r(jj)-Q(m2)x(jj)\}^2-4\{P(m2)r(jj)+Q(m2)x(jj)\}|V(m1)|^2\text{------------------}(10)$$

In this study the above simple stability criterion, given in eq. 10, is used to find the stability index for each line receiving end bus in radial distribution networks. After the load flow study, the voltages of all nodes and the branch currents are known, therefore P and Q at the receiving end of each line can easily be calculated and hence using Eq. 5 the voltage stability index of each node can easily be calculated. The node, at which the value of the stability index is at minimum, is the most sensitive to the voltage collapse.

5. LOAD MODELING

For the purpose of voltage stability analysis of radial distribution networks, composite load modeling is considered. The real and reactive power loads of node `i' is given as:

$PL(i) = PLo(i)(c_1+c_2|V(i)|+c_3|V(i)|^2)$ ----- (11)

$QL(i) = QLo(i)(d_1+d_2|V(i)|+d_3|V(i)|^2)$ ----- (12)

In the above equations, loads are gradually increased at every node. Constants (c_1, d_1), (c_2, d_2) and (c_3, d_3) are the compositions of constant power, constant current and constant impedance loads, respectively.

To demonstrate the effectiveness of the proposed method, a 33-bus radial distribution network [3] is considered. Fig.2 shows a 33-node radial distribution network. Line data and nominal load data (i.e. r, x, PL_o and QL_o) are given in Appendix A and Appendix B. In the present work, a composition of 40% constant power=c_1=d_1= 0:4; 30% of constant current=c_2 =d_2= 0.3; and 30% of constant impedance =c_3 =d_3 =0.3; are considered.

Table 1: Voltages at different nodes

branch	Voltage(pu)
1	1
2	0.995894
3	0.976348
4	0.96592
5	0.955601
6	0.929896
7	0.92505
8	0.918269
9	0.90949
10	0.901343
11	0.900134
12	0.898013
13	0.889443
14	0.886274
15	0.884297
16	0.882379
17	0.879547
18	0.878696
19	0.995177
20	0.990319
21	0.989363
22	0.988498
23	0.971436
24	0.962298
25	0.957741
26	0.927204
27	0.923625
28	0.907613
29	0.896112
30	0.891151
31	0.885285
32	0.883993
33	0.883593

The above table shows the voltage magnitudes (pu) for 33-bus network .The first bus voltage is as obtained to be 1pu and further it continues with respect to algorithm of proposed method. The above voltages are obtained for composite loads which are in algebraic form which are shown in Eqns (8) & (9). The Fig.3. shows how voltages are changes with respect their busses, at 19th bus the a sudden increase had obtained as this is because of the reason that the bus is nearer to substation bus and it continues.

Table 2: Line flows of P and Q of 33- bus radial distribution network

Branch number	Real Power loss(KW)	Reactive Power loss(KVAR)
1	3.29E-02	1.68E-02
2	1.28E-01	6.52E-02
3	2.06E-01	1.05E-01
4	4.69E-02	2.39E-02
5	9.21E-02	7.95E-02
6	2.65E-01	8.74E-01
7	1.01E+00	3.35E-01
8	1.18E-01	8.51E-02
9	1.21E-01	8.59E-02
10	1.67E-02	5.52E-03
11	5.26E-02	1.82E-02
12	2.08E-01	1.64E-01
13	3.32E-01	4.37E-01
14	6.47E-02	5.75E-02
15	8.85E-02	6.46E-02
16	1.53E-01	2.05E-01
17	2.11E-01	1.66E-01
18	4.18E-02	3.99E-02
19	3.85E-01	3.47E-01
20	1.05E-01	1.23E-01
21	1.82E-01	2.40E-01
22	1.29E-01	8.80E-02
23	5.28E+00	4.17E+00
24	5.29E+00	4.14E+00
25	2.42E-02	1.23E-02
26	3.40E-02	1.73E-02
27	1.22E-01	1.08E-01
28	4.53E-01	3.95E-01
29	5.96E+00	3.03E+00
30	7.89E-01	7.79E-01
31	4.97E-01	5.79E-01
32	5.25E-02	8.16E-02

The above table shows the line flow of real and reactive power 33- bus radial distribution network. The total real power loss of the system is **44.80KW** and reactive power loss is **33.82KVAR**.The stability indices are shown in Fig 5.

Table 3: Stability Index of 33- bus radial distribution network

Branch number	Stability Index
1	0.983272583
2	0.906940845
3	0.868636821
4	0.832999639
5	0.745868785
6	0.729374704
7	0.706288905
8	0.682070313
9	0.657896675
10	0.656196014
11	0.649589051
12	0.622415428
13	0.613741796
14	0.61041852
15	0.604740201
16	0.595537497
17	***0.593828343***
18	0.980141808
19	0.955548193
20	0.95627273
21	0.951432533
22	0.888761294
23	0.841258052
24	0.825358375
25	0.7386677
26	0.72715612
27	0.67629338
28	0.640883659

29	0.623765846
30	0.60857052
31	0.607974998
32	0.608448922

The 17th bus in the system is nearer to collapse, so that we must take care of that node by optimal using of distributed generators or shunt capacitors [5].

6. RESULTS

The rate of convergence of the proposed approach is tested using IEEE 33 node radial distribution systems with varying load conditions ranging from 0.5 to 3.0 times of the given load condition. The voltages had been plotted in Fig 3.and Fig 5. Voltage magnitude and stability index values are obtained from RDS network which is shown in Table 1.The total real power loss of the system is **44.80KW** and reactive power loss is **33.82KVAR.**

7. CONCLUSION

It has been shown that the load flow solutions of radial distribution networks are unique. The power system issues Distributed Generation for optimally placed and sized at Radial Distribution Feeder where the voltage stability index value are minimum and most sensitive to voltage collapse. Optimal sizing of Distributed Generation can be calculated using analytical expression and an efficient approach is used to determine the optimum location for distributed generators. The effectiveness of the proposed technique has been demonstrated through a 33- bus radial distribution network and it can be evaluated for any IEEE test system.

8. REFERENCES

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Appendix A

Line data of 33-bus radial distribution network

BRANCHNUMBE	SENDINGNODE	RECEIVINGNODE	RESISITANCE	REACTANCE
1	1	2	0.000152388	7.77E-05
2	2	3	0.00081483	0.000415018
3	3	4	0.000604925	0.000308082
4	4	5	0.000629882	0.000320808
5	5	6	0.001353643	0.00116853
6	6	7	0.000309404	0.001022753
7	7	8	0.001175802	0.000388573
8	8	9	0.001702384	0.001223072
9	9	10	0.001725523	0.001223072
10	10	11	0.00032494	0.000107432
11	11	12	0.000618808	0.000214533
12	12	13	0.00242631	0.001908984
13	13	14	0.000895156	0.001178281
14	14	15	0.000976805	0.000869373
15	15	16	0.001233485	0.000900776
16	16	17	0.002130459	0.002844469
17	17	18	0.00120985	0.000948707
18	2	19	0.000271059	0.000258663
19	19	20	0.002486142	0.002240205
20	20	21	0.000676822	0.0007907
21	21	22	0.00117167	0.001549169
22	3	23	0.000745743	0.000509558
23	23	24	0.001484214	0.001171835
24	24	25	0.001480909	0.001158778
25	6	26	0.000335518	0.0001709
26	26	27	0.000469726	0.00023916
27	27	28	0.001750315	0.001543219
28	28	29	0.001329182	0.001157952
29	29	30	0.000838796	0.000427249
30	30	31	0.001610488	0.001591646
31	31	32	0.000513194	0.000598148
32	32	33	0.000563605	0.000876315

Appendix B

Bus data of 33-bus radial distribution network

Node number	PL(composite load)pu	QL(composite load)pu
1	0	0
2	0.511344	0.306806
3	0.460209	0.204538
4	0.613613	0.409075
5	0.306806	0.153403
6	0.306806	0.102269
7	1.022688	0.511344
8	1.022688	0.511344
9	0.306806	0.102269
10	0.306806	0.102269
11	0.230105	0.153403
12	0.306806	0.17897
13	0.306806	0.17897
14	0.613613	0.409075
15	0.306806	0.051134
16	0.306806	0.102269
17	0.306806	0.102269
18	0.460209	0.204538
19	0.460209	0.204538
20	0.460209	0.204538
21	0.460209	0.204538
22	0.460209	0.204538
23	0.460209	0.255672
24	2.147644	1.022688
25	2.147644	1.022688
26	0.306806	0.127836
27	0.306806	0.127836
28	0.306806	0.102269
29	0.613613	0.357941
30	1.022688	3.068063
31	0.767016	0.357941
32	1.073822	0.511344
33	0.306806	0.204538