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A New Method of Load–Flow Solution of Radial Distribution Networks

Jaydeep Chakavorty and Mukul Gupta

Assistant Professor, Department of Electrical & Electronics,
University of Petroleum and Energy Studies, India

Abstract

In order to solve the load flow problem under uncertainty a novel algorithm is presented in this paper. The proposed method applies fuzzy arithmetic and fuzzy logic principle to solve the load flow problem. The proposed method has also been compared with other existing methods in the literature like Das *et al.* [19], Ghosh and Das [24] Ranjan and Das [25]. The proposed method has been tested with 29–node radial distribution networks. Constant power (CP), constant current (CI), constant impedance (CZ), composite and exponential load modellings for each of these examples are considered. The initial voltage of all nodes is taken $1+j0$ and initial power loss of all branches are also taken zero.

Terms: Distribution system, Fuzzy arithmetic Fuzzy logic.

Introduction

The load flow problem is an important tool for designing and operation of distribution systems. At the design stage it is applied to ensure that the voltage and the current standards are fulfilled under various conditions all over the network. At the operating stage, load flow is used to ensure that voltages and currents are within the predefined ranges for expected loads.

The variables for the load–flow analysis of distribution systems are different from that of transmission systems. This is because distribution network is radial in nature having high R/X ratio, whereas, the transmission system is loop in nature having high X/R ratio. The conventional Gauss–Seidel and Newton–Raphson method do not converge for the distribution networks. A number of efficient load–flow methods for transmission systems are available in literature. The analysis of distribution systems is an important area of activity as distribution systems is the final link between a bulk power system and consumers.

Representation of Network

Network topology is an important aspect in distribution system analysis. One of the characteristics of the proposed algorithm is the fact that does not require of a numbering of nodes and branches by layers. For this algorithm the nodes and the branches can be numbered without a predetermined order, characteristic that does it more flexible and strong. In the revised algorithms in the literature the numbering of the nodes and branches should be performed for layers, in a similar way of the model proposed by Shirmohammadi, *et al* [26], being had that renumbering the nodes and the branches in the systems whose dates not possess this structure. For example Fig.1 shows a radial distribution system with sequential numbering

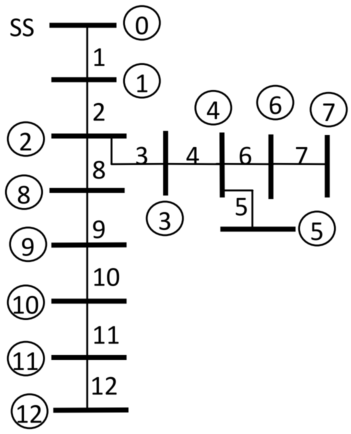

Figure 1: Sequential Numbering of the network.

Similarly, Fig.2 shows a radial distribution system where the node and branch numbering scheme are not sequential.

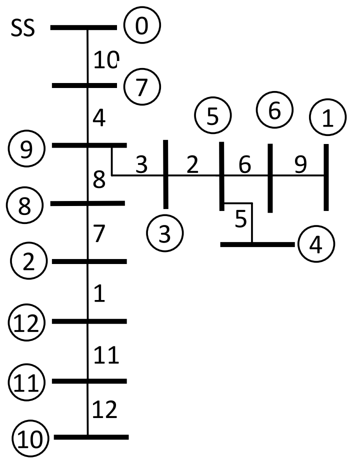

Figure 2: Non Sequential Numbering of the network.

Solution of the Network

The mathematical model of radial distribution system is derived from Fig.3.

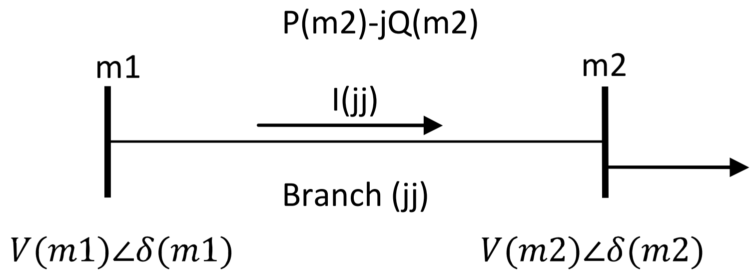

Figure 3: Mathematical model of radial distribution system.

From Fig.3.3,

$$I(jj) = \frac{V(m1)\angle\delta(m1) - V(m2)\angle\delta(m2)}{Z(jj)} \quad (1)$$

$$P(m2) - jQ(m2) = V^{*}(m2) \times I(jj) \quad (2)$$

Where, $Z(jj) = R(jj) + jX(jj)$

m1 and m2 are the sending end and receiving end nodes respectively.

P(m2) is the sum of real power loads of all the nodes beyond node m2 plus real power load of the node m2 itself plus the sum of the real power losses of all the branches beyond node m2.

Q(m2) is the sum of reactive power loads of all the nodes beyond node m2 plus reactive power load of the node m2 itself plus the sum of the reactive power losses of all the branches beyond node m2.

I(jj) is the current flowing through the branch jj.

V(i) is the magnitude of the voltage of the i^{th} node.

δ(m1) is the voltage angle of node m1

δ(m2) is the voltage angle of node m2

R(jj) is the resistance of the branch jj.

X(jj) is the reactance of the branch jj.

From equation (1) and equation (2), we get

$$V(m2) = \sqrt{B(jj) - A(jj)} \quad (3)$$

Where,

$$A(jj) = P(m2) \times R(jj) + Q(m2) \times X(jj) - 0.5 \times \left(V(m1)\right)^2 \quad (4)$$

$$B(jj) = \sqrt{A^2(jj) - \left[Z^2(jj) \times \left(P^2(m2) + Q^2(m2)\right)\right]}$$

The real and reactive power loss of branch jj is given by,

$$LP(jj) = \frac{R(jj)\times[P^2(m2)+Q^2(m2)]}{V(m2)^2} \quad (5)$$

$$LQ(jj) = \frac{X(jj)\times[P^2(m2)+Q^2(m2)]}{V(m2)^2} \quad (6)$$

These calculations are carried out successively until the convergence criterion is achieved, that is, the difference in voltage between the previous iteration and the present one be smaller to a certain defined value, for each nodes. That is,

$$\max|V_i(old) - V_i(new)| < \varepsilon \quad (7)$$

Where,

$V_i(old)$ is the node i voltage in previous iteration.

$V_i(new)$ is the node i voltage in present iteration.

ε in the maximum voltage mismatch.

Although the data obtained by deterministic methods of measurement usually are reliable, the possible errors can always be expected. In order to represent these errors, all the local estimated (measured) are modeled as fuzzy variables, constrained by trapezoidal membership functions, with narrow interval of uncertainty. The fuzzification interface involves the following steps during an iterration.

Calculate in per unit the power parameter ΔF_P and ΔF_Q of each node.

The maximum power parameter determines the range of scale mapping that will transfer the input signal into the corresponding universe of discourse, at every iteration.

Then the input signal is fuzzified into corresponding fuzzy signals with several linguistic variables as shown in Fig.4

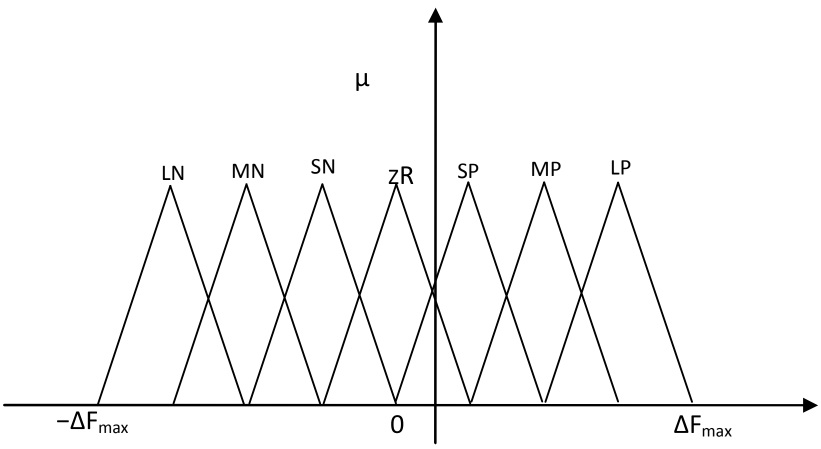

Figure 4: Membership Function.

Where,

LN denotes Large negative

MN denotes Medium negative

SN denotes Small negative
ZE denotes Zero
LP denotes Large positive
MP denotes Medium positive
SP denotes Small positive

The same interval of uncertainty is adopted for node voltages and currents. The main structure of the process has been shown in Fig.5.

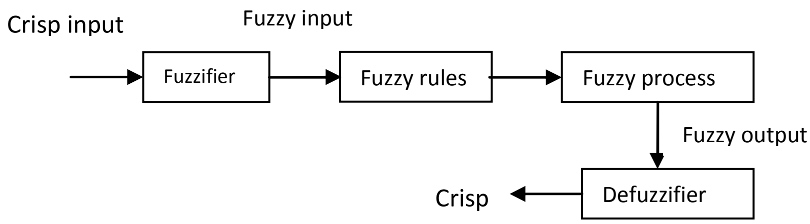

Figure 5: Structure of the proposed method.

Algorithm for Computation of Load–Flow

Assumptions: To calculate the node voltages and branch currents and the total system loss, the real and reactive power losses of all the branches is assumed to be zero. Also flat voltage start is used. The convergence criteria is such that if Max|V_{old}[FN(i,j)] − V_{New}[FN(i,j)] | < ε, for i = 1,2,..,TN and j = 1,2,….,N(i) where, j = total number of nodes of FN(i).

The following are the steps for load flow calculation:

Step 1	:	Get the number of Feeder (A), lateral(s) (B) and sub–lateral(s) (C).
Step 2	:	TN = A + B + C
Step 3	:	Read the total number of nodes N(i) of feeder, lateral(s) and sub–lateral(s) for i = 1,2,…,TN
Step 4	:	Read the nodes and branch numbers of feeder, lateral(s) and sub–lateral(s) i.e., FN(i,j) for j =1,2,…,N(i) and i = 1,2,….,TN if these are not sequential..
Step 5	:	Read real and reactive power load at each node i.e., PL[FN(i,j)] and QL[FN(i,j)] for j = 2,3,..,N(j) and i = 1,2,..,TN.
Step 6	:	Initialize PL[FN(1,1)] = 0.0 and QL[FN(1,1)] = 0.0
Step 7	:	Read the branches of feeder, lateral(s) and sub–lateral(s) *i.e.*, FB(I,j) for j =1,2,…,N(i) – 1 and i = 1,2,….,TN.
Step 8	:	Read resistance and reactance of each branch *i.e.*, R[FB(i,j)] and X[FB(i,j)] for j = 2,3,..,N(j) –1 and i = 1,2,..,TN.
Step 9	:	Read base kV and base MVA, Total number of iteration (ITMAX), ε (0.00001)

Step 10	:	Compute the per unit values of PL[FN(i,j)] and QL[FN(i,j)] for j = 2,3,..,N(j) and i = 1,2,..,TN as well as R[FB(i,j)] and X[FB(i,j)] for j = 1,2,3,..,N(j) −1 and i = 1,2,..,TN.
Step 11	:	Set PL1[FN(i,j)] = PL[FN(i,j)] and QL1[FN(i,j)] = QL[FN(i,j)] for j = 2,3,..,N(j) and i = 1,2,..,TN
Step 12	:	Set LP[FB(i,j)] = 0.0 and LQ[FB(i,j)] = 0.0 for all j = 1,2,…,N(i) −1 and i = 1,2,….,TN.
Step 13	:	Set V[FN(i,j)] = 1.0 + j0.0 for j =1,2,…,N(i) and i = 1,2,….,TN and set V1[FN(i,j)] = V[FN(I,j)] for j =1,2,…,N(i) and i = 1,2,….,TN.
Step 14	:	Use the step 7 to step 11 to calculate the branch currents of each feeder, lateral(s) and sub–lateral(s) respectively.
Step 15	:	Set IT = 1
Step 16		Construct the membership functions for node voltages, load current, real and reactive power.
Step 17	:	Set PL[FN(i,j)] = PL1[FN(i,j)] and QL[FN(i,j)] = QL1[FN(i,j)] for j = 2,3,..,N(j) and i = 1,2,..,TN
Step 18	:	Use proper load modelling.
Step 19	:	Compute voltage |V[FN(I,j)]| using the fuzzy rules. for j = 2,3,..,N(j) and i = 1,2,..,TN.
Step 20	:	Compute |ΔV[FN(i,j)]| = |V1[FN(i,j)]| – |V[FN(i,j)]| for j = 2,3,..,N(j) and i = 1,2,..,TN.
Step 21	:	Compute current |I[FB(i,j)]| using the fuzzy rules for j = 1,2,3,..,N(j)–1 and i = 1,2,..,TN.
Step 22	:	Set |V1[FN(i,j)]| = |V[FN(i,j)]| for j = 1,2,3,..,N(j) and i = 1,2,..,TN.
Step 23	:	Compute LP[FB(i,j)] and LQ[FB(i,j)] for all j = 1,2,…,N(i)–1 and i = 1,2,….,TN.
Step 24	:	Find ΔV_{max} from |ΔV[FN(i,j)]| for j = 2,3,..,N(j) and i = 1,2,..,TN.
Step 25	:	If $\Delta V_{min} \leq 0.00001$ go to step 26 else go to step 24.
Step 26	:	IT = IT + 1
Step 27	:	If IT ≤ ITMAX go to step 16 else write "NOT CONVERGED" , go to step 27.
Step 28	:	Write "SOLUTION HAS CONVERGED" and display the results: Total Real and Reactive Power Losses, Voltages of each node, minimum value of voltage and its node number and total real and reactive power load for CP, CI, CZ, Composite and Exponential Load Modelling.
Step 29	:	Stop

Fuzzy Rules

The fuzzy rules are tabulated in the Table.1 and Table.2

Table 3.1: Fuzzy rules for calculation of voltage.

V(fuz) \ I(fuz)	LN	MN	SN	ZR	SP	MP	LP
LN	LN	LP	SP	MP	MN	SN	ZR
MN	SP	MN	ZR	LN	MP	LP	SN
SN	MP	ZR	SN	MN	LP	SP	LN
ZR	MN	SP	LP	ZR	SN	LN	MP
SP	LP	MP	LN	SN	SP	MN	ZR
MP	ZR	SN	LP	SP	LN	MP	MN
LP	SN	LN	SP	MN	MP	ZR	LP

Table 3.2: Fuzzy rules for calculation of current.

V(fuz) \ S(fuz)	LN	MN	SN	ZR	SP	MP	LP
LN	SN	SP	LN	LP	ZR	MP	MN
MN	LP	ZR	SP	MN	SN	LN	MP
SN	SP	SN	MP	ZR	LN	MN	LP
ZR	LN	LP	MN	SP	MP	ZR	SN
SP	MN	LN	LP	MP	ZR	SN	SP
MP	MP	LP	ZR	SN	MN	SP	LN
LP	ZR	SP	SN	LN	LP	MN	MP

An Example

To demonstrate the effectiveness of the proposed method, the following example has been considered here:

A 29–node radial distribution network (nodes have been renumbered with Substation as node 1) shown in Figure 6. Data for this system is given in Table A1 and Table A2. The voltage magnitude of each node for CP, CI, CZ, Composite and Exponential load modelling as well as the minimum voltage and its node number are shown in Table 3.3, Table 3.4, Table 3.5, Table 3.6 and Table 3.7 respectively. Base values for this system are 11.00 kV and 100 MVA respectively. Composite Load = 40%CP + 30%CI + 30% CZ has been considered in this example.

Table 3.3: Voltage (pu) of Each Node of 29–Node Radial Distribution Network for Constant Power (CP) Load Modelling at Substation Voltage of 1.0 (pu).

Node Number	Voltage in (pu)
1(S/S)	1.000000
2	0.948817
3	0.894629

4	0.865232
5	0.846434
6	0.776218
7	0.731741
8	0.709771
9	0.671963
10	0.626105
11	0.596746
12	0.583914
13	0.550833
14	0.524335
15	0.508877
16	0.498557
17	0.488797
18	0.485532
19	0.942728
20	0.937642
21	0.936342
22	0.935212
23	0.886007
24	0.881791
25	0.879809
26	0.765959
27	0.762208
28	0.761026
29	0.760534

Table 3.4: Voltage (pu) of Each Node of 29–Node Radial DistributionNetwork for Constant Current (CI) Load Modelling at Substation Voltage of 1.0 (pu).

Node Number	Voltage in (pu)
1(S/S)	1.000000
2	0.963894
3	0.927782
4	0.909062
5	0.897322
6	0.854504
7	0.828786
8	0.816378
9	0.795524
10	0.770814
11	0.755347
12	0.748715

13	0.731955
14	0.718798
15	0.711212
16	0.706194
17	0.701488
18	0.699918
19	0.958184
20	0.953424
21	0.952209
22	0.951152
23	0.920188
24	0.916482
25	0.914741
26	0.846722
27	0.843882
28	0.842986
29	0.842615

Table 3.5: Voltage (pu) of Each Node of 29−Node Radial Distribution Network for Constant Impedance (CZ) Load Modelling at Substation Voltage of 1.0 (pu).

Node Number	Voltage in (pu)
1(S/S)	1.000000
2	0.968118
3	0.937109
4	0.921449
5	0.911777
6	0.876990
7	0.856922
8	0.847543
9	0.832094
10	0.814421
11	0.803898
12	0.799556
13	0.788780
14	0.780747
15	0.776336
16	0.773509
17	0.770916
18	0.770071
19	0.962684
20	0.958170
21	0.957018

22	0.956019
23	0.930211
24	0.926861
25	0.925290
26	0.870670
27	0.868384
28	0.867666
29	0.867368

Table 3.6: Voltage (pu) of Each Node of 29−Node Radial Distribution Network for Composite (CC) Load Modelling at Substation Voltage of 1.0 (pu).

Node Number	Voltage in (pu)
1(S/S)	1.000000
2	0.962437
3	0.924554
4	0.904778
5	0.892338
6	0.846802
7	0.819226
8	0.805877
9	0.783364
10	0.756606
11	0.739817
12	0.732604
13	0.714326
14	0.699951
15	0.691659
16	0.686171
17	0.681020
18	0.679302
19	0.956691
20	0.951902
21	0.950679
22	0.949616
23	0.916862
24	0.913108
25	0.911344
26	0.838775
27	0.835845
28	0.834921
29	0.834538

Table 3.7: Voltage (pu) of Each Node of 29–Node Radial Distribution Network for Exponential (EXP) Load Modelling at Substation Voltage of 1.0 (pu).

Node Number	Voltage in (pu)
1(S/S)	1.000000
2	0.966722
3	0.933907
4	0.917135
5	0.906691
6	0.868847
7	0.846637
8	0.836159
9	0.818806
10	0.798687
11	0.786525
12	0.781438
13	0.768757
14	0.759171
15	0.753838
16	0.750381
17	0.747167
18	0.746113
19	0.961230
20	0.956665
21	0.955499
22	0.954484
23	0.926801
24	0.923332
25	0.921712
26	0.862030
27	0.859554
28	0.858773
29	0.858444

The comparison of relative CPU Time of the proposed method with the other existing methods [Das *et al.* (1991), Ghosh and Das (1999), Ranjan and Das (2003)] for constant power oad modelling has been shown in Table 3.19. All simulation works have been carried out by Celeron Processor 1GHz.

Table 3.19: Comparison of Relative CPU Time of the Proposed Method with Other Existing Methods [Das *et al.* (1991), Ghosh and Das (1999), Ranjan and Das (2003)] for Constant Power Load Modelling.

Method	CPU Time
Proposed Method	0.99
D.Das. *et al* (1995)	1.90
S. Ghosh and D. Das (1999)	1.41
Ranjan and D.Das (2003)	1.59

Conclusion

In this paper a new method of load−flow technique, using fuzzy logic concept, for a balanced radial distribution network has been presented. The proposed technique does not consider the flat voltage for all the nodes and does not reduce the network into its equivalent network. Also in the proposed method the method of sequential numbering of the network has also been eliminated. It is applicable to distribution network with any number of feeders, lateral(s) and sub−laterals having either sequential or non sequential branch or node numbering.

Effectiveness of the proposed method is presented considering 29−node, radial distribution network at different load models. The example have been considered at system voltage of 1.00 (pu) with base kV of 11 and 12.66 with base MVA of 100. The last node of the network bears the minimum voltage.

The proposed method of load−flow consume less CPU processing time. Comparative tabulation of CPU processing time with available techniques is being presented.

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Authors Biography

Jaydeep Chakravorty received his BE degree in Electrical & Electronics Engineering from Sikkim Manipal University, Sikkim, India and ME degree in Software Engineering from Birla Institute of Technology, Meshra, Ranchi, Jharkhand, India. He is currently persuing Ph.D in the field of Power System.

Mukul Gupta received his ME degree in control system (electrical engineering) from VJTI Mumbai in control system (electrical engineering).