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Implementations of Sweep Algorithm For Load Flow Analysis in Radial Distribution Networks

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Power system is the most complex man made inter connected system with the combination of power generation, transmission and distribution to the consumer loads. In order to determine the behavior of the entire system i.e., planning and design, economic operation, stability. etc of the power system the power flow or load studies plays vital role. By using this power flow solution we obtain magnitude and phase angle of voltage at each bus, real and reactive power flowing through the branches by using conventional iterative techniques like Gauss-seidal, Newton Raphson method, Fast decoupled methods. This paper gives the complete load flow analysis of a radial distribution network with a proposed simple backward/forward sweep algorithm method which gives better convergence and takes full advantage of the radial structure of distribution systems tested for the IEEE 33 bus and IEEE 69 bus system implemented in MATLAB™ code.

Keywords: *Distribution systems, radial distribution systems, power flow analysis, algorithm.*

1.0 INTRODUCTION:

Electrical energy is the essential ingredient for the development of industrial, domestic and all for the existence of the civilized world today. As the power demand is increasing day by day it is necessity to generate the power sufficiently from all the sources and transmit to the distributed system with the help of inter connected tie lines. Distribution system is the part of the power system gives the necessary information helps for the reliable power supply to consumers. Distribution of electric power is done by distribution networks and distribution networks consist of following main parts distribution substation, Primary distribution feeder, Distribution Transformer, Distributors, and Service mains. There are three basic types of distribution system designs: 1. Radial distribution system: The radial distribution is the cheapest to build, and is widely used in sparsely populated areas (Figure 1). A radial system has only one power source for a group of customers. 2. Loop distribution system: A loop system, as the name implies, loops through the service area and returns to the original point (Figure 2). The loop is usually tied into an alternate power source. By placing switches in strategic locations, the utility can supply power to the customer from either direction. If one source of power fails, switches are thrown (automatically or manually), and power can be fed to customers from the other source. The loop system is more expensive than the radial because more switches and conductors are required, but the resultant improved system reliability is often worth the price. 3. Network distribution system: Network systems are the most complicated and are interlocking loop systems (Figure 3). A given customer can be supplied from two, three, four, or more different power supplies. Obviously, the big advantage of such a system is added reliability. However, it is also the most expensive.

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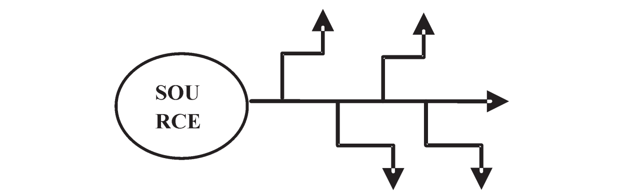

FIG. 1. RADIAL DISTRIBUTION SYSTEM

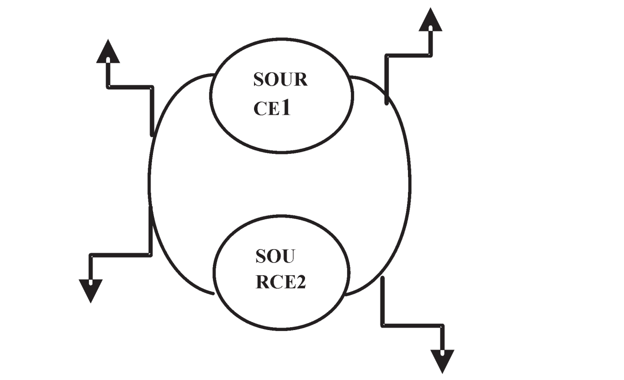

FIG. 2. LOOP DISTRIBUTION SYSTEM

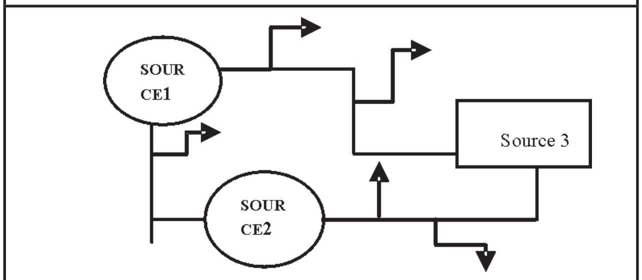

FIG. 3. NETWORK DISTRIBUTION SYSTEM LOAD FLOW

A feeder brings power from substation to load centers in Radial Distribution System (RDS). Single or multiple radial feeders are used in this development approach. Basically, the RDS entire power losses can be reduced by reducing the branch power flow or transported electrical power from transmission systems (i.e. some percentage of loads is locally meeting by local DG). To find the total power loss of the system or each feeder branch and the maximum voltage difference are found by performing load flow. The forward/backward sweep load flow analysis is used in this case. The impedance of a feeder is calculated by the specific resistance and reactance of the conductors used in the branch construction. The forward/backward sweep load flow analysis consist two steps (i) Backward sweep and (ii) Forward sweep.

Backward sweep: In this step, the load current of each node of a distribution system having *N* number of nodes is calculated as:

$$\bar{I}_L(m) = \left\{ \frac{P_L(m) - jQ_L(m)}{\bar{V}^*(m)} \right\} \quad [\, m = 1,2,3 \ldots \ldots \ldots N \,] \qquad \ldots(1)$$

Where, P_L (m) and Q_L (m) represent the active and reactive power demand at node *m* and the phasor quantities, such as $\bar{I}_L$, □*then, the current in each branch of the system is determined as:

$$\bar{I}(mn) = \bar{I}_L(n) + \sum_{m\in\Gamma} \bar{I}_L(m) \qquad \ldots(2)$$

Where, the set Γ consists of all nodes which are placed beyond the node *n*.

***Forward sweep*:** This step is used after the backward sweep so as to calculate the voltage at each node of a distribution system as follows:

$$\bar{V}(n) = \bar{V}(m) - \bar{I}(mn)Z(mn) \qquad \ldots(3)$$

Where, nodes *n* and *m* represent the receiving and sending end nodes respectively for the branch *mn* and Z(mn) is the impedance of the branch.

2.0 BACKWARD/FORWARD SWEEP ALGORITHM

This analysis includes two steps: the backward sweep and the forward sweep. In backward sweep, voltage and currents are calculated using KVL and KCL from the outermost node. In forward sweep, the downstream voltage is computed starting from source node. The input data of this algorithm is given by node-branch oriented data. Basic data required are, active and reactive powers, nomenclature for sending and receiving nodes. Listed below summarize main steps of the proposed solution algorithm with suitable equations.

1) Assume the source voltage is load end voltage.

2) Determine branch currents and node voltages by using Kirchhoff's current and Kirchhoff's voltage laws respectively. I = (S/V)*: Node Voltage = (V + IZ)

3) In Back sweep starting from last node and determine all branch currents and node voltages.

4) Compute new voltage with rated voltage.

5) If node voltage is in tolerance limits and print results else forward sweep.

6) Now in forward sweep calculate voltages i.e. $V_{new} = (V - IZ)$.

7) Compute the calculated end voltage with rated voltage.

8) If the difference exceed tolerance again starts backward sweep.

9) Thus forward and backward sweep continues till within the tolerance.

10) Print the voltage magnitude at all the nodes, the real and reactive power losses at all the nodes.

3.0 SIMULATION RESULTS

The first test case for the proposed method is a 33-bus radial distribution system. The single line diagram is shown in Figure 4 The base values of the system are taken as 12.66 kV and 100MVA.

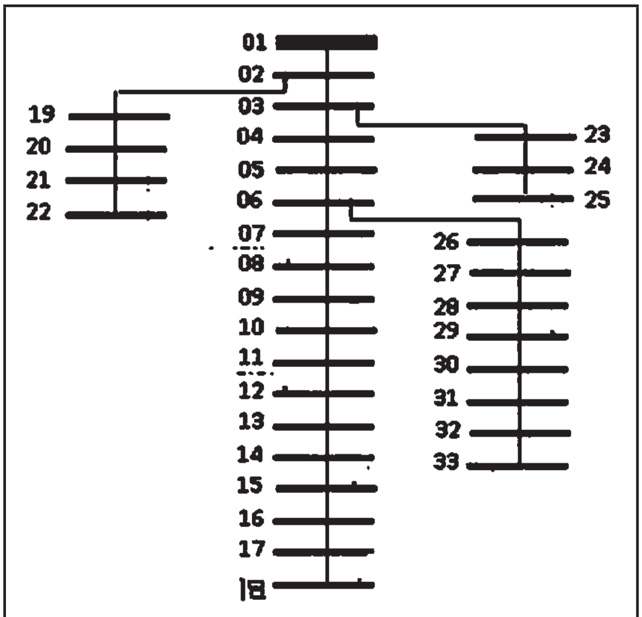

FIG. 4: 33 BUS RADIAL DISTRIBUTION SYSTEM 33 BUS SYSTEM OUTPUT DATA:

Voltage magnitude and phase angle, active and Reactive line losses of 33 bus system

TABLE 1

VOLTAGE MAGNITUDE AND PHASE ANGLE, ACVTIVE AND REACTIVE LINE LOSSES OF 33 BUS SYSTEM

S no	Voltage magni-tude	Phase angle	Send-ing End	Re-ceiv-ing End	Active loss KW	Reac-tive loss KVAR
1	1.0000	0	1	2	12.2404	6.2397
2	0.9970	0.0145	2	3	51.7912	26.3789
3	0.9829	0.0960	3	4	19.9005	10.1351
4	0.9755	0.1617	4	5	18.6989	9.5237
5	0.9681	0.2283	5	6	38.2486	33.0180
6	0.9497	0.1339	6	7	1.9145	6.3285
7	0.9462	-0.0965	7	8	4.8380	1.5988
8	0.9413	-0.0604	8	9	4.1805	3.0035
9	0.9351	-0.1335	9	10	3.5609	2.5240
10	0.9292	-0.1960	10	11	0.5537	0.1831
11	0.9284	-0.1888	11	12	0.8811	0.2914
12	0.9269	-0.1773	12	13	2.6662	2.0978
13	0.9208	-0.2686	13	14	0.7292	0.9598
14	0.9185	-0.3473	14	15	0.3570	0.3177
15	0.9171	-0.3850	15	16	0.2815	0.2055
16	0.9157	-0.4082	16	17	0.2516	0.3360
17	0.9137	-0.4855	17	18	0.0531	0.0417
18	0.9131	-0.4951	18	19	0.1610	0.1536
19	0.9965	0.0037	19	20	0.8322	0.7499
20	0.9929	-0.0633	20	21	0.1008	0.1177
21	0.9922	-0.0827	21	22	0.0436	0.0577
22	0.9916	-0.1030	22	23	3.1816	2.1740
23	0.9794	0.0651	23	24	5.1437	4.0617
24	0.9727	-0.0237	24	25	1.2875	1.0074
25	0.9694	-0.0674	25	26	2.6009	1.3248
26	0.9477	0.1733	26	27	3.3290	1.6950
27	0.9452	0.2295	27	28	11.3009	9.9637
28	0.9337	0.3124	28	29	7.8333	6.8242
29	0.9255	0.3903	29	30	3.8957	1.9843
30	0.9220	0.4956	30	31	1.5936	1.5750
31	0.9178	0.4112	31	32	0.2132	0.2485
32	0.9169	0.3881	32	33	0.0132	0.0205
33	0.9166	0.3804	Total losses		202.6771	135.1410

The second test case for the proposed method has been tested on 69 bus Radial Distribution System, using MATLAB. 69 bus systems are shown in Figure 5. This system is consisting of 69 nodes and 65 branches, 1 reference node, KVA is 100. The tolerance is 0.00001 p.u. Results are shown in Table 2. Bus voltage magnitude in p.u. and phase angle in degree at each bus and real and reactive line losses in each branch in KW and KVAR are shown in Table 2.

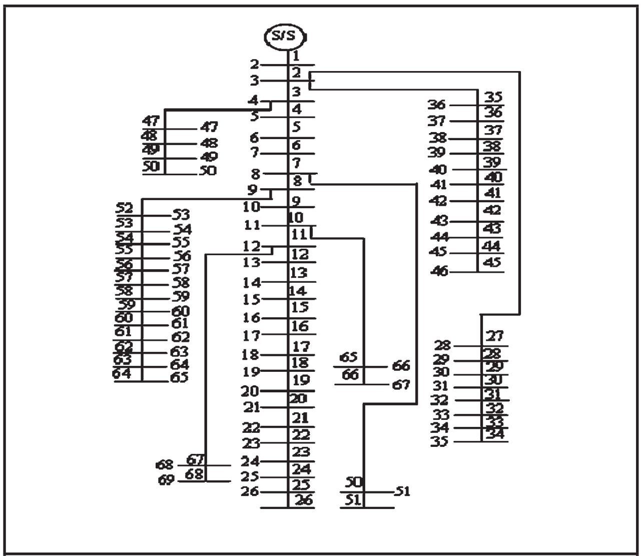

FIG. 5. 69 BUS RADIAL DISTRIBUTION SYSTEM

69 BUS SYSTEM OUTPUT DATA:

Voltage magnitude and Phase angle, Active and Reactive line losses of 69 bus system

TABLE 2

VOLTAGE MAGNITUDE AND PHASE ANGLE, ACTIVE AND REACTIVE LINE LOSSES OF 69 BUS SYSTEM

S no	Voltage magnitude	Phase angle	Sending End	Receiving End	Active loss (KW)	Reactive loss (KVAR)
1	1.0000	0	1	2	0	0
2	1.0000	0	2	3	3.8427e-006	9.2225e-006
3	1.0000	-0.0000	3	4	4.8788e-007	1.1709e-006
4	1.0000	-0.0000	4	5	3.5021e-004	4.1021e-004
5	1.0000	-0.0002	5	6	0	0
6	1.0000	-0.0002	6	7	0.0028	0.0015
7	0.9999	0.0006	7	8	0.4644	0.2368
8	0.9993	0.0048	8	9	0.2282	0.1162
9	0.9990	0.0070	9	10	3.4987	1.1564
10	0.9947	0.0776	10	11	0.4906	0.1622
11	0.9940	0.0900	11	12	0.9751	0.3223
12	0.9919	0.1229	12	13	1.3552	0.4473
13	0.9889	0.1699	13	14	1.3155	0.4347
14	0.9859	0.2167	14	15	1.3331	0.4405
15	0.9829	0.2644	15	16	0.1904	0.0629
16	0.9824	0.2722	16	17	0.2443	0.0808
17	0.9816	0.2850	17	18	0.0019	6.3817e-004
18	0.9816	0.2851	18	19	0.1307	0.0432
19	0.9811	0.2945	19	20	0.0832	0.0273
20	0.9808	0.3005	20	21	0.0254	0.0084
21	0.9805	0.3048	21	22	9.2379e-004	3.0353e-004
22	0.9805	0.3049	22	23	0.0105	0.0035
23	0.9804	0.3068	23	24	0.0099	0.0033
4	0.9803	0.3095	24	25	0.0214	0.0071
25	0.9799	0.3152	25	26	0.0049	0.0016
26	0.9798	0.3170	26	27	0.0012	3.7991e-004
27	0.9798	0.3177	27	28	3.4690e-004	8.5148e-004
28	1.0000	-0.0003	28	29	0.0026	0.0063
29	0.9999	-0.0029	29	30	0.0161	0.0053
30	0.9997	0.0007	30	31	0.0028	9.3670e-004
31	0.9997	0.0013	31	32	0.0142	0.0047
32	0.9995	0.0044	32	33	0.0209	0.0070

33	0.9992	0.0102	33	34	0.0164	0.0164
34	0.9988	0.0175	34	35	0.0094	0.0031
35	0.9985	0.0228	35	36	0.0010	0.0025
36	1.0000	-0.0005	36	37	0.0105	0.0257
37	0.9998	-0.0058	37	38	0.0173	0.0202
38	0.9997	-0.0082	38	39	0.0034	0.0039
39	0.9996	-0.0088	39	40	1.2035e-004	1.4041e-004
40	0.9996	-0.0089	40	41	0.0472	0.0552
41	0.9990	-0.0197	41	42	0.0201	0.0235
42	0.9987	-0.0244	42	43	0.0023	0.0027
43	0.9986	-0.0250	43	44	5.1343e-004	6.4737e-004
44	0.9986	-0.0251	44	45	0.0015	0.0019
45	0.9986	-0.0260	45	46	0	0
46	0.9986	-0.0260	46	47	0.0254	0.0627
47	0.9999	-0.0019	47	48	0.5276	1.2915
48	0.9988	-0.0447	48	49	0.4959	1.2133
49	0.9966	-0.1214	49	50	0.0013	0.0031
50	0.9966	-0.1235	50	51	5.8933e-005	3.0038e-005
51	0.9993	0.0049	51	52	6.4642e-005	2.1697e-005
52	0.9993	0.0051	52	53	4.0835	2.0793
53	0.9967	0.0255	53	54	4.6052	2.3457
54	0.9940	0.0469	54	55	6.2458	3.1800
55	0.9903	0.0764	55	56	6.1820	3.1493
56	0.9866	0.1059	56	57	34.9428	11.7289
57	0.9678	0.4333	57	58	17.2231	5.7799
58	0.9585	0.5995	58	59	5.8008	1.9184
59	0.9552	0.6610	59	60	7.3626	2.2349
60	0.9510	0.7454	60	61	0.0631	0.0321
61	0.9505	0.7499	61	62	0.0060	0.0031
62	0.9505	0.7505	62	63	0.1399	0.0712
63	0.9501	0.7541	63	64	0.0440	0.0224
64	0.9496	0.7585	64	65	0.0036	0.0018
65	0.9494	0.7601	65	66	0.0041	0.0012
66	0.9939	0.0914	66	67	3.5147e-00	1.0469e-005
67	0.9939	0.0914	67	68	0.0056	0.0018
68	0.9917	0.1258	68	69	0	0
69	0.9917	0.1258	Total losses		98.3377 KW	38.8593 KVAR

4.0 CONCLUSION

This method for solving the load flow problem for radial distribution uses simple algebraic equations to determine iteratively the outgoing powers and voltage magnitudes of various nodes and mismatches at the last nodes of main feeder and laterals and depending upon mismatches the substation injection is corrected judiciously and this process is repeated until convergence. The total active and reactive power losses for 33 KV and 69 KV system are 202.6771 KW, 135.1410 KVAR and 98.3377 KW, 38.8593 KVAR respectively. This makes the algorithm very robust and numerically efficient for convergence for wide variation of distribution network determines the behavior of the entire system.

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