Research Inventy: International Journal of Engineering And Science
Vol.6, Issue 6 (July 2016), PP -28-34
Issn (e): 2278-4721, Issn (p):2319-6483, www.researchinventy.com

An Approach for Power Flow Analysis of Radial Distribution Networks

[1]Ujjavala Singla, [2]Rajni Bala
[1]M.Tech. (Power Engg.) Student BBSBEC Fatehgarh Sahib-140407 (Pb.)
[2]AP (EE Dept.) BBSBEC Fatehgarh Sahib -140407 (Pb.)

Abstract: *This paper provides an easy and effective approach to the load flow solution of Radial distribution networks. As compared to the various methods proposed in the past, this work presents a new technique consisting of load flow solution of the network, facilitated by the identification of all the nodes beyond a particular branch. The proposed method is quite accurate and reliable for the system having any number of nodes. The primary target of this work is to evaluate the results with high precision and convergence.*
Keywords: *Convergence, load currents, nodes beyond branch, Radial Distribution network.*

I. Introduction

Load-Flow is defined as the computational procedure required to determine the steady state operating characteristics of a power system network. The aim of power flow calculations is to determine the steady state operating characteristics of a power transmission/generation system for a given set of loads. There are a number of efficient and reliable load flow solution techniques, such as; Gauss-Seidel, Newton-Raphson and Fast Decoupled Load Flow [1,2,3,4,5,6,7].

In 1967, Tinney and Hart [1] developed the classical Newton based power flow solution method. Later work by Stott and Alsac [2] made the fast decoupled Newton method. The algorithm made by [2] remains unchanged for different applications. Even though this method worked well for transmission systems, but its convergence performance is poor for most distribution systems due to their high R/X ratio which deteriorates the diagonal dominance of the Jacobian matrix. For this reason, various other types of methods have been presented. Those methods consist of backward/forward sweeps on a ladder system.

Baran and Wu [8], proposed a methodology for solving the radial load flow for analyzing the optimal capacitor sizing problem. In this method, for each branch of the network three non-linear equations are written in terms of the branch power flows and bus voltages. The number of equations was subsequently reduced by using terminal conditions associated with the main feeder and its laterals, and the Newton- Raphson method is applied to this reduced set. The computational efficiency is improved by making some simplifications in the jacobian. Chiang [9] had also proposed three different algorithms for solving radial distribution networks based on the method proposed by Baran and Wu .He had proposed decoupled, fast decoupled & very fast decoupled distribution load-flow algorithms. Goswami and Basu [10] had presented a direct method for solving radial and meshed distribution networks. However, the main limitation of their method is that no node in the network is the junction of more than three branches, i.e. one incoming and two outgoing branches. Jasmon and Lee [11] had proposed a new load-flow method for obtaining the solution of radial distribution networks. They have used the three fundamental equations representing real power, reactive power and voltage magnitude derived in [10].

Das et al. [12] had proposed a load-flow technique for solving radial distribution networks by calculating the total real and reactive power fed through any node using power convergence with the help of coding at the lateral and sub lateral nodes for large system that increased complexity of computation. This method worked only for sequential branch and node numbering scheme. Haque [13] presented a new and efficient method for solving both radial and meshed networks with more than one feeding node.

Eminoglu and Hocaoglu [14] presented a simple and efficient method to solve the power flow problem in radial distribution systems which took into account voltage dependency of static loads, and line charging capacitance. Prasad et. al. [15] proposed a simple and efficient scheme for computation of the branch currents in RDN. The proposed load flow algorithm exploits the tree- structure property of a RDN and claims the efficient implementation of LFA algorithm. Ghosh and Sherpa [16] presented a method for load-flow solution of radial distribution networks with minimum data preparation. This method used the simple equation to compute the voltage magnitude and has the capability to handle composite load modeling. But in order to implement this algorithm, a lot of programming efforts are required. Sivanagaraju et al. [17] proposed a distinctive load flow solution technique which is used for the analysis of weakly meshed distribution systems. A branch-injection to branch current matrix is formed (BIBC) and this matrix is formed by applying Kirchhoff's current law for the distribution network.

Kumar and Arvindhababu [18] presented an approach for power flow solutions to obtain a reliable convergence in distribution systems. The method was simpler than existing approaches and solved iteratively similar to Newton-Raphson (NR) technique. Augugliaro et al. [19] had proposed a method for the analysis of radial or weakly meshed distribution systems supplying voltage dependent loads. Advantages of this method are: its possibility to take into account of any dependency of the loads on the voltage, very reduced computational requirements and high precision of results.

Due to the ill conditioned nature of the distribution systems the conventional methods of load-flow analysis used for transmission systems failed to converge. Unlike transmission networks, distribution networks are radial in nature. The distribution networks have high R/X ratio compared to the transmission networks because X>>R in distribution systems as compared to the transmission systems. So therefore arises a need to develop new load-flow techniques of load-flow analysis which can assure convergence for distribution systems. This paper aims to develop a new load-flow technique which requires lesser data preparation. This method shows good and fast convergence for any kind of numbering scheme of the nodes and laterals.

II. Assumptions

While implementing the calculations it was assumed that:

a. Three-phase radial distribution networks were balanced and represented by their single-line diagrams.
b. Charging capacitances are neglected at the distribution voltage level (medium level).

III. Method for load flow calculation

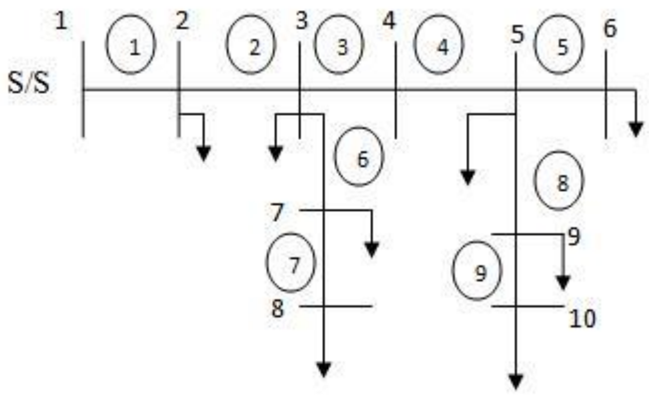

Figure 1. Single line diagram of a distribution feeder.

Figure 1 shows the single line diagram of a distribution feeder. Consider branch 1. The node voltage of receiving-end node can be written as:

V(2) = V(1) - I(1)Z(1) (1)

Similarly, for branch 2,

V(3) = V(2) - I(2)Z(2) (2)

Substation voltage is taken as 1.00 pu

Since the voltage at the substation V(1) is known, so if I(l) is known, i.e. current of branch 1, V(2) can be easily calculated from eqn.(1). Once V(2) is known, it is easy to calculate V(3) from eqn. (2), if the current through branch 2 is known. Similarly, voltages of nodes 4,5,.....10 can easily be calculated if all the branch currents are known. Therefore, a generalized equation of receiving-end voltage, sending-end voltage, branch current and branch impedance can be defined as

V(m2) = V(m1) - I(jj)Z(jj) (3)

where jj is the branch number

m2 = IR(jj) (4)

m1 = IS(jj) (5)

Current through branch 1 is equal to the sum of the load currents of all the nodes beyond branch 1 plus the sum of the charging currents of all the nodes beyond branch 1, but since charging capacitances are neglected, hence vanishing charging currents, the current through branch 1 is equal to the sum of only the load currents of all the nodes beyond branch 1, i.e.

I(1) = IL(2) + IL(3) + IL(4) + IL(5) + IL(6) + IL(7) + IL(8) + IL(9) + IL(10)

Therefore, if it is possible to identify the nodes beyond all the branches, it is possible to compute all the branch currents. Identification of the nodes beyond all the branches is realized through a method as explained in next section.
The load current at node m2 is expressed by

$$IL(m2) = \frac{PL(m2) - j\,QL(m2)}{V^*(m2)} \qquad (6)$$

where PL(m2) is the real power load at node m2 and QL(m2) is the reactive power load at node m2.
The real and reactive power losses of branch jj are given by :

$$LP(jj) = |I(jj)|^2 R(jj) \qquad (7)$$

$$LQ(jj) = |I(jj)|^2 X(jj) \qquad (8)$$

IV. Determination Of The Nodes Beyond All The Branches

For jj = 1 (first branch of Fig. 1) , IR(jj) = IR(1) = 2; check whether IR(1) = IS(i) or not for i = 2, 3, 4, ...,10. It is seen that IR(1) = IS(2) = 2; the corresponding receiving-end node is IR(2) = 3.

Note that there should not be any repetition of any node while identifying nodes beyond a particular branch [20], and this logic has been incorporated in the proposed algorithm.

From the above discussion, it is seen that node 2 is connected to node 3. Similarly, the proposed logic will identify the nodes which are connected to node 3. Firstly, it will check whether node 3 is connected to any other node. It is seen that node 3 is connected to nodes 4 and 7. Similarly, the proposed logic will check whether nodes 4 and 7 are connected to any other nodes. This process will continue unless all nodes are identified beyond branch 1. This will help to obtain load flow solution by summation of load currents of all the nodes beyond a particular branch.

The total current flowing through branch 1 is equal to the sum of the load currents of all nodes beyond branch 1.

Note that, if the receiving-end node of any branch in Fig. 1 is an end node of a particular lateral, the total current of this branch is equal to the load current of this node itself.

V. Convergence Criterion

The maximum voltage mismatches at the network nodes is used as convergence criterion. The nodal current injections, at each iteration, are calculated using the scheduled nodal power injections and node voltages from the previous iteration. The node voltages at the same iteration are then calculated using these nodal current injections. The voltage magnitudes at each node in present iteration are compared with their values in previous iteration. If the error is within the tolerance limit, the procedure is stopped. Otherwise the steps of calculation and check for convergence are repeated. At k_{th} iteration, the voltage mismatch at node i can be calculated as

$$\Delta V(i)_k = V(i)_k - V(i)_{k-1} \quad ; i = 1,2,3,.......NB$$

VI. Load Modeling

In distribution systems, because of the voltage-dependent characteristics of load, the constant load model is no longer suitable for accurate power flow analysis. Load models usually can be classified into two main categories: static and dynamic. Since power flow analysis is mainly performed for static states of power systems, only static load is considered here.

Normally, Static Load Can Be Described Using One Of The Following Models:
(i) Constant power model (constant P and Q), i.e., the load power doesn’t vary with the voltage magnitude;
(ii) Constant impedance model (constant Z), i.e., the load power varies with the square of the voltage magnitude;
(iii) Constant current model (constant I), i.e., the load power varies with the voltage magnitude only;

Here the load is modeled as polynomial load as:

$$P = P_0(a_0 + a_1V + a_2 V^2) \qquad (9)$$

$$Q = Q_0(b_0 + b_1V + b_2 V^2) \qquad (10)$$

where V is the pu value of the node voltage;
P_0, Q_0 are the real power and reactive power consumed at the specific node under the reference voltage;
a_0, b_0 are the parameters for constant power (constant P and Q) load component i.e. $a_0 = b_0 = 1$ and $a_i = b_i = 0$ for i = 1,2,3;
a_1,b_1 are the parameters for constant current (constant I) load component i.e. $a_1 = b_1 = 1$ and $a_i = b_i = 0$ for i = 0,2,3;
a_2, b_2 are the parameters for constant impedance (constant Z) load component i.e. $a_2 = b_2 = 1$ and $a_i = b_i = 0$ for i = 0,1,3;
Composite load modeling is combination of CP, CI and CZ.

VII. Example

A 69-node (shown in figure 2) example has been considered to show the effectiveness of the proposed method. Base values are 12.66 kV and 100 MVA. Line data and load data for 69-node radial distribution network is shown in Table 1(as available in [21]).

Table 2 shows the results of voltage magnitude at each node for all of the load models discussed above.

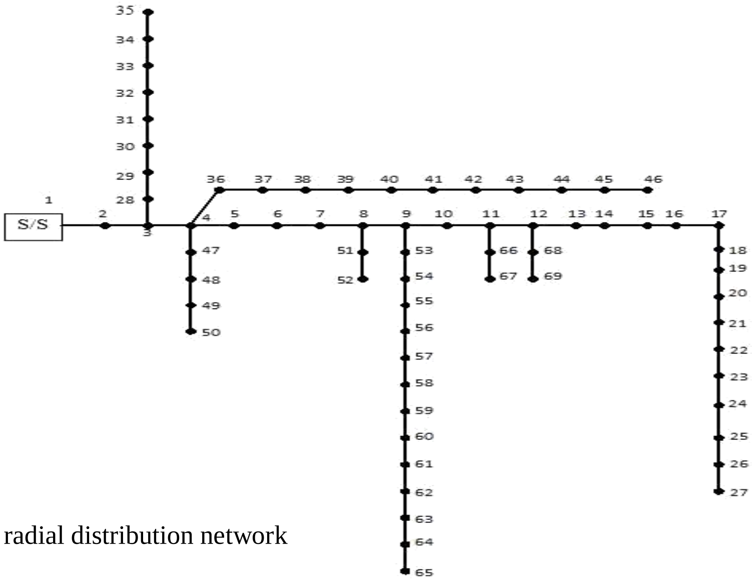

Figure 2. 69-node radial distribution network

VIII. Conclusion

The main target of this work was to provide a new and efficient load flow method for Radial Distribution systems. The proposed method utilized simple and flexible algorithm steps to evaluate the results. The performance of the method has been tested on a 69-node system wherein, it provides excellent convergence characteristics. It takes full advantage of the radial structure of the distribution systems, to achieve high speed and low memory requirements.

References

[1] W.Tinney and C.Hart, “Power Flow Solution by Newton's Method”, IEEE Transactions on Power Apparatus and Systems, Vol.PAS-86, no.11, pp.1449- 1460, November. ‘1967.

[2] B.Stott and O.Alsac, “Fast Decoupled Load-flow”, IEEE Transactions on Power Apparatus and Systems, Vol.PAS-93, no.3, pp.859-869, May 1974.

[3] F. Zhang and C. S. Cheng, “A Modified Newton Method for Radial Distribution System Power Flow Analysis”, IEEE Transactions on Power Systems, Vol.12, no.1,pp.389-397, February 1997.

[4] G.B. Jasmon, L.H.C. Lee, Distribution Network Reduction for Voltage Stability Analysis and Load Flow Calculations, Electrical Power & Energy Systems, Vol.13, no:1, pp. 9-13, 1991.

[5] T. H. Chen, M. S. Chen, K. J. Hwang, P. Kotas, and E. A. Chebli, “Distribution System Power Flow Analysis- A Rigid Approach”, IEEE Transactions on Power Delivery, Vol.6, no.3, pp.1146-1153, July1991.

[6] Whei-Min Lin, Jen-HaoTeng, “Three-Phase Distribution Network Fast-Decoupled Power Flow Solutions”, Electrical Power and Energy SystemsVol.22, pp.375-380, 2000.

[7] J. H. Teng, “A Modified Gauss-Seidel Algorithm of Three-phase Power Flow Analysis In Distribution Networks”, Electrical Power and Energy Systems Vol.24, pp.97-102, 2002.

[8] M.E. Baran, F.F. Wu, Optimal Sizing of Capacitors Placed on a Radial Distribution System, IEEE Transactions on Power Delivery, Vol.4, no:1, pp.735-743, 1989.

[9] CHIANG, H.D.: ‘A decoupled load flow method for distribution power network algorithms, analysis and convergence study”, Electrical Power and Energy Systems,13 (3), 130-138,1991.

[10] GOSWAMI, S.K., and BASU, S.K.: ‘Direct solution of distribution systems’, IEE Proc. C. , 188, (I), pp. 78-88, 1991.

[11] G.B. Jasmon, L.H.C. Lee, Distribution Network Reduction for Voltage Stability Analysis and Load Flow Calculations, Electrical Power & Energy Systems, Vol.13, no:1, pp. 9-13, 1991.

[12] D.Das, H.S.Nagi an D.P.Kothari, “Novel Method for Solving Radial Distribution Networks”, IEE Proceedings on Generation Transmission and Distribution ,Vol.141 , no.4, pp.291-298, July 1994.

[13] M.H.Haque, “Efficient Load-flow Method for Distribution Systems with Radial or Mesh Configuration”, IEE Proceedings on Generation, Transmission, Distribution,Vol.143, no.1, pp.33-39, January 1996.

[14] U.Eminoglu and M.H.Hocaoglu, "A New Power Flow Method For Radial Distribution Systems Including Voltage Dependent Load Models", Electric Power Systems Research Vol.76 pp.106-114, 2005.
[15] Prasad K., Sahoo N. C., Chaturvedi A. and Ranjan R, "A Simple Approach In Branch Current Computation In Load Flow Analysis Of Radial Distribution Systems", International Journal for Electrical Engineering Education, Vol.44/1, pp.1,2007.
[16] Ghosh S. and Sherpa K., "An Efficient Method for Load−Flow Solution of Radial Distribution Networks,'' Proceedings International Journal of Electrical Power and Energy Systems Engineering, 2008.
[17] S. Sivanagaraju, J. Viswanatha Raoand M. Giridhar,"A loop based loop flow method for weakly meshed distribution network", ARPN Journal of Engineering and Applied Sciences ISSN 1819-6608, Vol.3,no.4,August 2008.
[18] Kumar A. and Aravindhababu, "An Improved Power Flow Technique for Distribution Systems", Journal of Computer Science, Informatics and Electrical Engineering ,Vol.3, Issue 1, 2009.
[19] Augugliaro A, Dusonchet L, Favuzza S, Ippolito MG, Riva Sanseverino E,"A Backward sweep method for power flow solution in distribution networks", Electrical Power and Energy Systems 32 ,271-280 ,2010.
[20] S. Ghosh and D. Das, 'Method for load-flow solution of radial distribution networks', IEEE Proc.-Gener Transm. Distrib., Vol. 146, No. 6., Nov 1999.
[21] M.E.Baran and F.F.Wu, "Optimal Sizing of Capacitor Placed on Radial Distribution Systems," IEEE Transaction on Power Delivery, Vol.2, pp.735–743, January 1989.

Table 1. Line Data and Load Data of 69 Node Radial Distribution Network

Branch No.	Sending end	Receiving end	Branch Resistance (□)	Branch Reactance (□)	PL (kW)	QL (kVAr)
1	1	2	0.0005	0.0012	00.00	00.00
2	2	3	0.0005	0.0012	00.00	00.00
3	3	4	0.0015	0.0036	00.00	00.00
4	4	5	0.0251	0.0294	00.00	00.00
5	5	6	0.3660	0.1864	2.600	2.200
6	6	7	0.3811	0.1941	40.40	30.00
7	7	8	0.0922	0.0470	75.00	54.00
8	8	9	0.0493	0.0257	30.00	22.00
9	9	10	0.8190	0.2707	28.00	19.00
10	10	11	0.1872	0.0619	145.0	104.00
11	11	12	0.7114	0.2351	145.0	104.00
12	12	13	1.0300	0.3400	8.000	5.000
13	13	14	1.0440	0.3450	8.000	5.500
14	14	15	1.0580	0.3496	00.00	00.00
15	15	16	0.1966	0.0650	45.50	30.00
16	16	17	0.3744	0.1238	60.00	35.00
17	17	18	0.0047	0.0016	60.00	35.00
18	18	19	0.3276	0.1083	00.00	00.00
19	19	20	0.2106	0.0696	1.000	00.60
20	20	21	0.3416	0.1129	114.0	81.00
21	21	22	0.0140	0.0046	5.000	3.500
22	22	23	0.1591	0.0526	00.00	00.00
23	23	24	0.3463	0.1145	28.00	20.00
24	24	25	0.7488	0.2475	00.00	00.00
25	25	26	0.3089	0.1021	14.00	10.00
26	26	27	0.1732	0.0572	14.00	10.00
27	3	28	0.0044	0.0108	26.00	18.60
28	28	29	0.0640	0.1565	26.00	18.60
29	29	30	0.3978	0.1315	00.00	00.00
30	30	31	0.0702	0.0232	00.00	00.00
31	31	32	0.3510	0.1160	00.00	00.00
32	32	33	0.8390	0.2816	14.00	10.00
33	33	34	1.7080	0.5646	19.50	14.00
34	34	35	1.4740	0.4873	6.000	4.000
35	3	36	0.0044	0.0108	26.00	18.55
36	36	37	0.0640	0.1565	26.00	18.55
37	37	38	0.1053	0.1230	00.00	00.00
38	38	39	0.0304	0.0355	24.00	17.00
39	39	40	0.0018	0.0021	24.00	17.00
40	40	41	0.7283	0.8509	1.200	1.000
41	41	42	0.3100	0.3623	00.00	00.00
42	42	43	0.0410	0.0478	6.000	4.300
43	43	44	0.0092	0.0116	00.00	00.00
44	44	45	0.1089	0.1373	39.22	26.30
45	45	46	0.0009	0.0012	39.22	26.30
46	4	47	0.0034	0.0084	00.00	00.00
47	47	48	0.0851	0.2083	79.00	56.40
48	48	49	0.2898	0.7091	384.7	274.0
49	49	50	0.0822	0.2011	384.7	274.0
50	8	51	0.0928	0.0473	40.50	28.30
51	51	52	0.3319	0.1114	3.600	2.700

52	9	53	0.1740	0.0886	4.350	3.500
53	53	54	0.2030	0.1034	26.40	19.00
54	54	55	0.2842	0.1447	26.00	17.20
55	55	56	0.2813	0.1433	00.00	00.00
56	56	57	1.5900	0.5337	00.00	00.00
57	57	58	0.7837	0.2630	00.00	00.00
58	58	59	0.3042	0.1006	100.0	72.00
59	59	60	0.3861	0.1172	00.00	00.00
60	60	61	0.5075	0.2585	1244.0	888.0
61	61	62	0.0974	0.0496	32.00	23.00
62	62	63	0.1450	0.0738	00.00	00.00
63	63	64	0.7105	0.3619	227.0	162.0
64	64	65	1.0410	0.5302	59.00	42.00
65	11	66	0.2012	0.0611	18.00	13.00
66	66	67	0.0047	0.0014	18.00	13.00
67	12	68	0.7394	0.2444	28.00	20.00
68	68	69	0.0047	0.0016	28.00	20.00

Table 2. Voltage Magnitude(pu) at each node for 69 Node Radial Distribution Network

Node No.	Voltage Magnitude (pu)			
	CP	**CC**	**CI**	**Composite**
1	1.0000000	1.0000000	1.0000000	1.0000000
2	0.9999965	0.9999965	0.9999965	0.9999896
3	0.9999930	0.9999930	0.9999930	0.9999792
4	0.9999897	0.9999897	0.9999897	0.9999692
5	0.9999411	0.9999412	0.9999413	0.9998237
6	0.9992353	0.9992377	0.9992401	0.9977137
7	0.9985005	0.9985053	0.9985101	0.9955180
8	0.9983229	0.9983283	0.9983336	0.9949873
9	0.9982323	0.9982379	0.9982435	0.9947165
10	0.9970182	0.9970289	0.9970395	0.9910919
11	0.9967408	0.9967525	0.9967642	0.9902637
12	0.9958422	0.9958573	0.9958723	0.9875807
13	0.9948647	0.9948824	0.9948999	0.9846597
14	0.9939756	0.9939952	0.9940147	0.9820022
15	0.9930746	0.9930962	0.9931178	0.9793098
16	0.9929106	0.9929323	0.9929538	0.9788188
17	0.9926052	0.9926270	0.9926486	0.9779048
18	0.9926033	0.9926244	0.9926452	0.9778969
19	0.9925044	0.9925247	0.9925449	0.9775985
20	0.9924531	0.9924725	0.9924917	0.9774421
21	0.9923898	0.9924082	0.9924265	0.9772394
22	0.9923936	0.9924107	0.9924277	0.9772367
23	0.9923979	0.9924136	0.9924293	0.9772355
24	0.9924477	0.9924620	0.9924762	0.9772356
25	0.9931518	0.9931646	0.9931773	0.9772458
26	0.9938853	0.9938963	0.9939073	0.9772559
27	0.9940641	0.9940733	0.9940824	0.9772658
28	0.9999920	0.9999920	0.9999920	0.9999760
29	0.9999793	0.9999793	0.9999792	0.9999379
30	0.9999524	0.9999525	0.9999525	0.9998575
31	0.9999523	0.9999523	0.9999523	0.9998569
32	0.9999523	0.9999523	0.9999523	0.9998569
33	0.9999523	0.9999523	0.9999523	0.9998569
34	0.9999522	0.9999523	0.9999523	0.9998569
35	0.9999522	0.9999523	0.9999523	0.9998569
36	0.9999895	0.9999895	0.9999895	0.9999685
37	0.9999536	0.9999536	0.9999536	0.9998609
38	0.9999215	0.9999215	0.9999216	0.9997648
39	0.9999140	0.9999140	0.9999140	0.9997422
40	0.9999136	0.9999136	0.9999137	0.9997411
41	0.9998645	0.9998646	0.9998646	0.9995940
42	0.9998638	0.9998638	0.9998638	0.9995917
43	0.9998638	0.9998638	0.9998638	0.9995917
44	0.9998638	0.9998638	0.9998638	0.9995917
45	0.9998638	0.9998638	0.9998638	0.9995917
46	0.9998638	0.9998638	0.9998638	0.9995917
47	0.9999897	0.9999897	0.9999897	0.9999692
48	0.9999897	0.9999897	0.9999897	0.9999692
49	0.9999897	0.9999897	0.9999897	0.9999692

50	0.9999897	0.9999897	0.9999897	0.9999692
51	0.9983230	0.9983283	0.9983336	0.9949873
52	0.9983231	0.9983283	0.9983334	0.9949873
53	0.9980842	0.9980900	0.9980958	0.9942732
54	0.9979146	0.9979207	0.9979267	0.9937657
55	0.9976824	0.9976889	0.9976953	0.9930711
56	0.9975248	0.9975314	0.9975379	0.9925992
57	0.9970405	0.9970475	0.9970545	0.9911489
58	0.9968460	0.9968530	0.9968599	0.9905660
59	0.9967859	0.9967926	0.9967994	0.9903852
60	0.9967602	0.9967666	0.9967731	0.9903073
61	0.9967593	0.9967654	0.9967714	0.9903035
62	0.9967598	0.9967654	0.9967709	0.9903036
63	0.9967603	0.9967654	0.9967704	0.9903036
64	0.9967643	0.9967688	0.9967734	0.9903036
65	0.9967682	0.9967723	0.9967763	0.9903036
66	0.9967410	0.9967525	0.9967640	0.9902637
67	0.9967413	0.9967525	0.9967637	0.9902637
68	0.9958426	0.9958573	0.9958719	0.9875807
69	0.9958430	0.9958573	0.9958715	0.9875807