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An Efficient Distribution Load Flow Method for Radial Distribution Systems with Load Models

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Abstract

In this paper a novel efficient approach is modelled for load flow problem in distribution systems based on the distinctive topological characteristics of radial distribution networks and have been fully studied to make the direct solution possible. Due to the direct solution of the proposed method, the usage of time-consuming decomposition or bus admittance matrix in the traditional load flow methods are no longer necessary. The Branch Path Distribution Load Flow (BPDLF) algorithm needs less memory for any size of the distribution network because it uses only branch path matrix in its algorithm. Due to this it has faster convergence with less iterations. The effectiveness of the proposed method is validated on various standard IEEE test systems for different load models and compared with existing algorithms. The future load growth on various IEEE systems are also studied. Test results reveal that the proposed method is better when compared with existing algorithms.

Keywords*: Load flow, Radial distribution system, primitive impedance, Branch path matrix, Load modelling*

1. Introduction

Load flow studies are performed in distribution systems to obtain the voltage, real and reactive power flows through the distribution lines. Many applications like reactive power control, reconfiguration, loss estimation *etc.*, require this data for analyzing various conditions in the power system. The load flow problem was solved by many methods [1-39] by exploiting the radial structure of the distribution systems available in the literature. The efficiency of the solution methods plays a vital role in all the applications which require the load flows.

The invention of digital computers made the load flow solution easy with the development of conventional methods like Gauss Seidal method, Newton Raphson method, and Decoupled and Fast Decoupled methods. However, reasons like high R/X ratio and radial structure of distribution systems make the conventional methods unsuitable for load flow solution in distribution systems and very often the solution diverges as these are designed for mesh structures. The ac power flow problem can be solved efficiently by Newton's method. Only five iterations, each equivalent to about seven of the widely used Gauss-Seidel method, are required for an exact solution [1]. A computerized method of calculating unbalanced load flow [2] or fault currents on multi-grounded radial distribution circuits. The basic concept employed is that the electrical characteristics of any portion of an unbalanced 3-phase circuit can be represented by a 6-element wye-delta network. The proposed algorithm [3] is attractive for accurate or approximate off-and on-line routine and contingency calculations for networks of any size, and can be implemented

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efficiently on computers with restrictive core-store capacities. A survey is presented [4] on the currently available numerical techniques for power-system load-flow calculations using the digital computer. Attention is given to the problems and techniques of adjustments in load-flow solutions, and the suitability of various methods for modern applications such as security monitoring and optimal load flow problems. The proposed method in [5] is very simple, has no mathematical approximations, and requires almost no additional storage and computation time incorporated into the normal Newton-Raphson program. K.M Brown's method [6] is used also to solve load-flow problems. The method is particularly effective for solving ill-conditioned nonlinear algebraic equations. The method proposed in [7] is efficient method for calculating the load flow solution of weakly meshed transmission and distribution systems. Its essential advantages over a previous approach are the following :(a) It uses active and reactive powers as flow variables rather than complex currents. (b) It uses an efficient tree-labeling technique which also contributes to the computational efficiency of the procedure. Proposed methods in [8-9] involves only the evaluation of a simple algebraic expression of voltage magnitude and no trigonometric functions as opposed to the standard load flow case. The classical constant-power load model is usually used to solve the load flow problem [10] of a transmission or distribution system. However, the actual load of a system is not independent of voltage magnitude. Incorporation of voltage dependent load models in the load flow algorithm is essential to get better and accurate results.

The proposed method [11] can be applied for both radial and mesh networks and a mesh network is converted to a radial network by breaking the loops through adding some dummy buses. Unlike other methods, the shunt admittances are considered in the proposed load flow algorithm and effect of admittance is also incorporated in the calculation of power injections at the LBPs. Two novel methods –sequence decoupling-compensation Newton-Raphson(SDCNR) and sequence decoupling-compensation fast–decoupled(SDCFD) methods-used for three-phase load flow studies are proposed in [12], which can be used to analyze both normal and abnormal three-phase power system steady state operation. A new algorithm [13] that is used for the solution of three-phase (or unsymmetrical) power flow analysis of both transmission and distribution systems under unsymmetrical operating conditions and power quality problems, is presented. A simple and efficient method [14] for solving radial distribution networks and involves only the evaluation of a simple algebraic expression of receiving end voltages and it is very efficient computational method. The method proposed in [15] in distribution system is first converted to an equivalent source network with radial configuration so that the conventional branch equations can be used to solve load flow problem [15]. An efficient methods for radial distribution network have been proposed [16-20]. The efficiency makes it suitable for distribution applications and fast three-phase load flow analysis. It will increase the convergence speed and bus voltages are considered as state variables. The proposed load flow algorithm[19] requires formation of bus-injection to branch current (BIBC) matrix with 1's & 0's as elements and branch-current to bus voltage(BCBV) matrix with primitive impedances as elements & distribution load flow (DLF) matrix. DLF matrix is obtained as product of (BCBV) and (BIBC) matrices. These three matrices require large memory space

Owing to the radial nature and high R/X ratio, radial distribution systems (RDS) employ a special recursive technique for distribution load flow (DLF) [21-22]. The DLF plays a critical role in automation algorithms of RDS whose scope encompasses fault isolation, network reconfiguration and service restoration. An improved backward/ forward sweep algorithm [23] for three-phase load-flow analysis of radial distribution systems. In the backward sweep, Kirchhoff's Current

Law and Kirchhoff's Voltage Law are used to calculate the upstream bus voltage of each line or a transformer branch. Network topology [24-25] is exploited to build two matrices. One is to the sum of all active and reactive powers connected to nodes beyond a particular node. Other one is the power loss in all the lines connected beyond the node under consideration. In this method, simple algebraic expression of voltage magnitude is used. This method is very efficient and requires very less computer memory. An improved method have been proposed [26] based on electric circuit laws, this method is iterative and allows the evaluation of both, voltage (rms) values and phase angles. A novel matrix transformation technique [27-28], which directly solves the determination of branch flows in radial distribution network, consequently it makes forward backward sweep based load flow method, more effective and fast. Mekhamer *et al.* [29] described a method for radial distribution feeder load flow solution which is accurate and relatively fast and can be implemented for different systems. Afsari *et al.* [30] developed an algorithm called backward sweep algorithm for finding the load flow solution by using two methods to estimate the terminal voltages at the nodes at the start and the advantages and limitations of both the methods have been discussed.

Ranjan and Das [31] proposed a simple and efficient algorithm for solving the load flow problem in radial distribution networks by developing and solving the simple algebraic expressions involving magnitudes of the voltage with difference of real and reactive power as convergence criteria. Ghosh [32] described a simple method for solving the load flow problem for different load models in radial distribution systems which has advantages of handling the arbitrary node numbering scheme and reduced data preparation by exploiting structure. AlHajri and El-Hawry [33] developed and demonstrated a fast and flexible radial power flow technique with reduced memory and execution time based on one single building block matrix known as radial configuration matrix that uses forward or backward iterations for solving the balanced and unbalanced three phase networks by exploiting the structure. Semi definite programming is one of the most promising modeling techniques for this propose [34]. Other analytical approaches were presented in [35] and [36].

In this paper, the main objective function is to form the BPDLF matrix without the use of BCBV and BIBC matrices. This can be achieved by using branch path matrix (K). The proposed algorithm is tested on various IEEE systems for different load models.

2. Building of Branch Path Matrix in Proposed Load Flow Algorithm

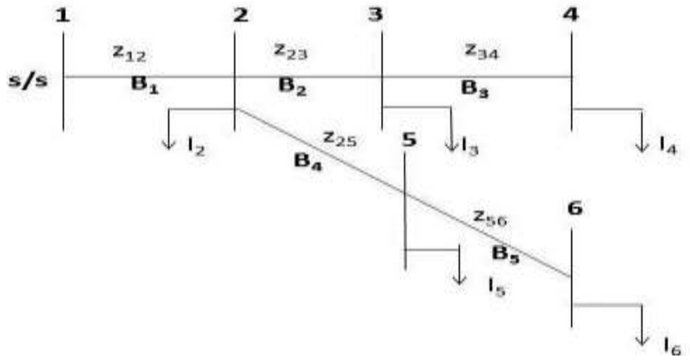

Figure 1. Simple 6 bus Radial System

The DLF impedance matrix can be obtained by multiplication of BIBC and BIBV matrices is as shown in Equation 1. Consider a simple radial distribution network as shown in the Figure 1 for formation of proposed load flow algorithm.

$$[\Delta v] = [DLF][I] \tag{1}$$

Where, $[DLF]$ represents distribution load flow matrix given as

$$\begin{bmatrix} z_{12} & z_{12} & z_{12} & z_{12} & z_{12} \\ z_{12} & z_{12}+z_{23} & z_{12}+z_{23} & z_{12} & z_{12} \\ z_{12} & z_{12}+z_{23} & z_{12}+z_{23}+z_{34} & z_{12} & z_{12} \\ z_{12} & z_{12} & z_{12} & z_{12}+z_{25} & z_{12}+z_{25} \\ z_{12} & z_{12} & z_{12} & z_{12}+z_{25} & z_{12}+z_{25}+z_{56} \end{bmatrix}$$

From the above DLF matrix, the following useful observations are used in developing the proposed topological and primitive based distribution load flow method

1) All elements of DLF matrix of (n-1)x(n-1) size are complex non-zero and symmetric.
2) Diagonal elements are given by the sum of the primitive impedances of all those lines in the path connecting the substation bus and any selected bus.
3) Each bus-p of the network can have one unique path from substation bus.
4) Off-diagonal p-q elements are given by the sum of the primitive impedances of those lines which appear common to the paths of p and q buses from substation bus.

These observations are effectively used in proposing the algorithm with the help of branch path (k) matrix that exploits the topological structure of the network

3. Proposed Solution Technique

The proposed method directly determines the Radial distribution load flow solution by simply using primitive impendence of lines and Branch path (K) matrix. There by need of formation of BIBC and BCBV matrix can be avoided. This new algorithm determines the elements of the DLF matrix by comparing rows and columns of the branch path (K) matrix .Thus [Δv] elements of the Equation [1] can be determined easily. The proposed approach offers very significant saving in computational burden as it avoids the formation of BIBC and BCBV matrix with exact results at the end.it also requires less iterations for convergence criteria when compared with other solution techniques.

3.1. Formation of DLF Matrix Elements using Branch path (K) matrix

A Typical 6-bus radial distribution network as shown in Figure1 is considered in order to explain the DLF matrix elements formation by using Branch path (K)matrix. The K -matrix can be formed from reduced incidence matrix (A). K=transpose(inverse(A)). The K–matrix for stated 6-Bus radial distribution network is given by

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 \\ 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 1 & 1 \end{bmatrix}$$

The k matrix is a combination of 0's and 1's. The 1's representation in a row of a Branch path matrix gives information about connecting path between node-1 and any selected node. Thus, diagonal elements of DLF matrix can be formed.

For example, the fourth row in above k matrix has 1's in first column and fourth column therefore diagonal element in fourth row is summation of z_{12} and z_{25} $i.e., Z_{44} = z_{12} + z_{25}$. Similarly, when rows of the K matrix are compared, if there exists a common 1's in respective columns then summation of those primitive impedance will gives respective off diagonal elements of the DLF matrix. For example, Z_{23} of DLF matrix can be formed by comparing second row and third row which gives summation of z_{12} and z_{23} $.i.e., Z_{23} = z_{12} + z_{23}$.

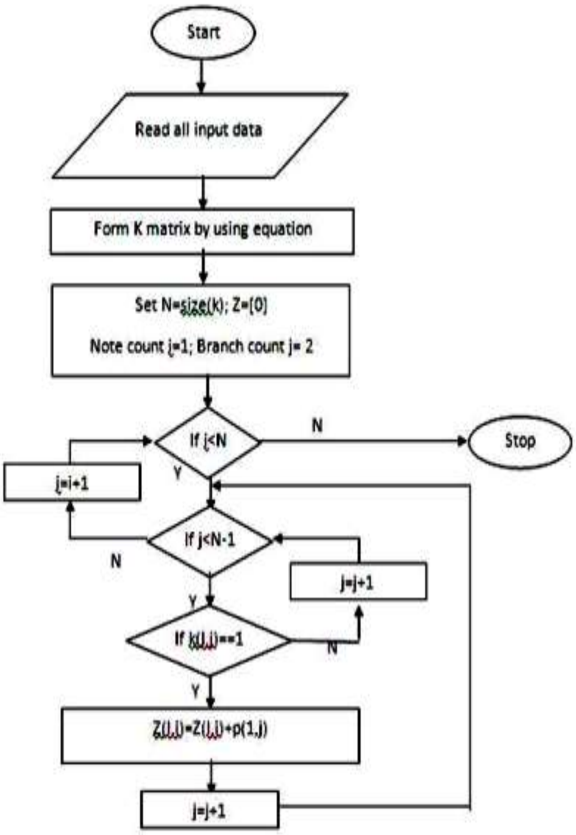

Figure 2. Flow Chart for Formation of DLF Matrix

4. Proposed Distribution Load Flow Algorithm

1. Read the distribution system data and Initialize the Bus Voltages to 1+*j*0 p.u.
2. Form the Branch path matrix using Equation (1).
3. Add all the primitive impedances of all those lines by direct comparison of 1's in K matrix as shown in Figure 2.
4. Calculate the Power Injections and Current Injections $I[i]$ at all the buses
5. Assign $I\left[i\right]^{old} = I\left[i\right]$ for all the buses.
6. As discussed in Figure 2 calculate the Δv elements of the Equation $[\Delta v] = [DLF][I]$
7. Choose proper load model. Update the bus voltages at all the buses.
8. Calculate the current Injections $I[i]$ with the updated bus voltages.

9. If max ($|I\left[i\right]^{k+1} - I\left[i\right]^{k}|$) >tolerance, then advance the iteration count and go to step 7.
10. Print the converged load flow solution for different load models and Stop.

5. Load Modelling

Distribution load flow studies have been intensely impacted by Load modelling. Load flow solutions and convergence ability are greatly affected by load characteristics.

Load models are usually classified into two main categories *i.e.,* static and dynamic load models.

1 **Static load model:** Static load model expresses the active and reactive power at any instant of time as functions of the bus voltage magnitude and frequency at the same instant. Static load models are used for essentially static load components such as resistive and lighting loads, and as an approximation for dynamic load components, such as, motor driven loads.

2 **Dynamic load model:** Dynamic load model expresses the active and reactive powers at any instant of time as functions of the bus voltage magnitude and frequency at past instants of time and, usually, including the present instant. These types of models are represented by using differential equations.

As load flow analysis is mainly performed for static states of power systems only static load model is considered. Load that can be modelled either as constant power, constant current, constant impedance and composite load or as an exponential load is considered here. The general expression of load is shown below.

$$PL = PL_0 \left(\frac{V}{V_0} \right)^{np} \tag{3}$$

$$QL = QL_0 \left(\frac{V}{V_0} \right)^{nq} \tag{4}$$

Where np and nq stand for load exponents, V and V_0 stand for load bus voltage and load nominal voltage, respectively. PL_0 and QL_0 stand for the values of the active and reactive powers at the nominal voltages. The load can be represented as constant power, constant current, or constant impedance models by setting the exponents to 0, 1, or 2 respectively. The aggregate effect of different types of load components can be represented by using other exponents. Common values for the exponents for different static loads are given in following Table 1.

Polynomial load model: It is a static load model where the voltage magnitude is related to the power as a polynomial equation, usually in the following form

$$PL = PL_0 \left[a_1 + a_2 \left(\frac{V}{V_0} \right)^1 + a_3 \left(\frac{V}{V_0} \right)^2 \right] \tag{5}$$

$$QL = QL_0 \left[b_1 + b_2 \left(\frac{V}{V_0} \right)^1 + b_3 \left(\frac{V}{V_0} \right)^2 \right] \tag{6}$$

The coefficients a_1 to a_3 and b_1 to b_3 are the parameters of this model. This model is sometimes referred to as the “ZIP” model as it consists of the sum of constant impedance (Z), constant current (I), and constant power (P) terms.

Table 1. Common Values for the Exponents for Different Static Loads

S.No	Load components	*np*	*nq*
1	Constant Power	0.00	0.00
2	Constant current	1.00	1.00
3	Constant impedance	2.00	2.00
4	Incandescent light	1.55	0.00
5	Fluorescent light	0.96	7.38
6	Air conditioner	0.20	2.30
7	Dryer	2.04	3.27
8	Freezer	0.77	2.50
9	Heater	2.00	0.00
10	Pumps,fans *etc*	0.08	1.60
11	Computer,T.V. *etc*	2.00	5.20

4.1. The Effect of Change of Operating Voltage on Different Types of Load Models

The effect of change of operating voltage with respect to load current for constant power, constant current, constant impedance types of loads is shown in Figure 3.

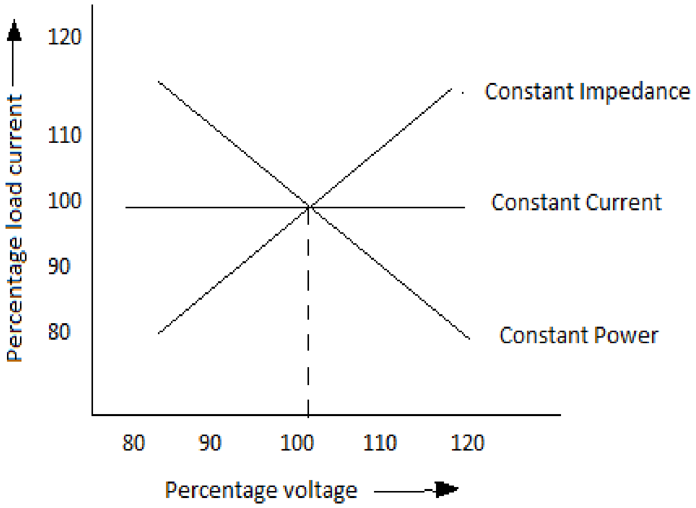

Figure 3. Behaviour of Constant Current, Constant Power and Constant Impedance Loads with Respect to Current Loading as a Function of Voltage Variations

The effect of change of operating voltage with respect to load MVA on constant power, constant current, constant impedance types of loads is shown in Figure 4.

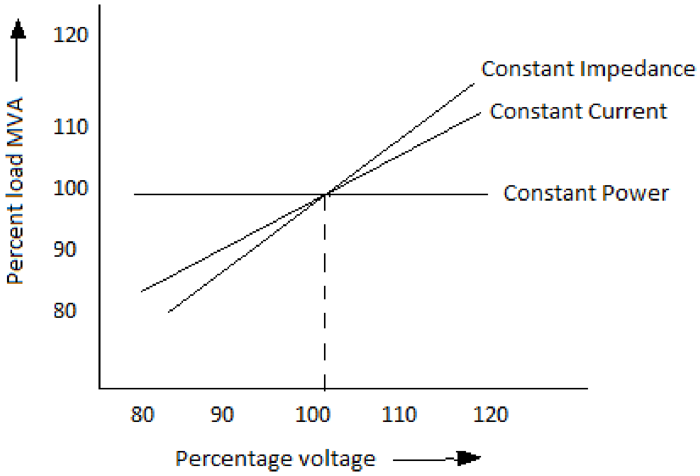

Figure 4. Behaviour of Constant Current, Constant Power and Constant Impedance Loads with Respect to MVA Loading as a Function of Voltage Variations

6. Load Growth

In a geographical area, load growth is the most important factor influencing the expansion of a distribution system. Therefore, the future estimate of the system must be known to a system engineer for planning, expansion and efficient operation of the distribution systems.

By knowing the load growth rate, the real and reactive power loads at end of the nth year is given by

$$PL_n = PL_0\left(1+ {}^{g}\!/_{100}\right)^n \tag{7}$$

$$QL_n = QL_0\left(1+ {}^{g}\!/_{100}\right)^n \tag{8}$$

Where PL_n is the real power load at the end of the nth year. QL_n is the reactive power load at the end of the nth year . PL_0 is the initial real power load. QL_0 is the initial reactive power load. g is the annual load growth rate. n is the number of years.

Here, the following load growth scenarios are considered for a period of n = 5 years in the load flow calculations.

Case (i)	No load growth	(0% annual load growth)
Case (ii)	Slight load growth	(2% annual load growth)
Case (iii)	Average load growth	(5% annual load growth)
Case (iv)	Fast load growth	(7% annual load growth)

7. Test Results

In load flow studies of distribution systems, the classical constant power load model is usually used. The Branch path Distribution load flow (BPDLF) algorithm is applied on various IEEE standard systems. The BPDLF algorithm requires less number of iterations due to direct comparisons of 1's in Branch path matrix which leads to the faster convergence. The proposed algorithm converges in less iterations when compared with existing algorithms in Table 2.

Table 2. Comparative Study of Various Algorithms

S.NO	Type of algorithms	Various standard IEEE systems				
		IEEE 15 bus	IEEE 34 bus	IEEE 69 bus	IEEE 85 bus	IEEE 118 bus
		Iterations	Iterations	Iterations	Iterations	Iteration
1	Ghosh and Das [17]	7	7	8	10	-
2	Renato method [11]	4	4	4	-	-
3	Kersting [6]	4	4	4	-	-
4	AbulWafa [39]	4	4	4	-	-
5	Proposed method	3	3	4	4	4

7.1. Load Modelling Results

The Brach Path Distribution Load Llow(BPDLF) method is used for performing Load flow analysis for different static loads shown in Table 1, such as Constant power load, Constant current load, Constant impedance load, Incandescent light load, Fluorescent light load, Air conditioner load, Dryer load, Freezer load, Heater load, Pumps & Fans load and Computer & T.V. load.

In the load flow analysis, the real and reactive power loads are modified using the Equations (3) and (4), after each update of bus voltages.

7.1.1. Case 1: Each static load is considered separately to perform load flow analysis. Load flow results of 15-bus system for different static loads are shown in Table 3 and Load flow results of different test systems for different static loads are shown in Table 4 below.

7.1.2. Case 2: Composite load of (40% constant power load + 30% constant impedance load + 30% constant current load) is considered for performing load flow analysis. Load flow results of different test systems for the composite load are shown in Table 5.

Table 5. Load Flow Results of Different Test Systems for the Composite Load

S.No	System	TPL(kW)	TQL(kVAr)	Iterations
1	15 bus	56.74	52.60	2
2	34 bus	204.36	60.10	2
3	69 bus	195.16	89.40	3
4	85 bus	260.26	163.76	2

7.1.3. Case 3: Industrial load of (30% incandescent light + 49% fluorescent light + 21% air conditioner load) is considered to perform load flow analysis for different test systems. Load flow results of different test systems for the industrial load are shown in Table 6.

Table 6. Load Flow Results of Different Test Systems for the Industrial Load

S No	System	TPL(kW)	TQL(kVAr)	Iterations
1	15 bus	50.17	46.52	4
2	34 bus	189.69	55.0935	4
3	69 bus	170.23	78.04	5
4	85 bus	206.23	129.95	6

Table 3. Load Flow Results of 15-Bus System for Different Static Load

Constant current	Constant Impedance	Incandescent light	Fluorescent light	Air conditioner	Dryer	Freezer	Heater	Pumps, Fans *etc*	Computer TV *etc..*
Voltage magnitudes in p.u.									
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.00000	1.0000	1.0000
0.9726	0.9737	0.9722	0.9754	0.9729	0.9744	0.9733	0.9725	0.9724	0.9753
0.9587	0.9605	0.9581	0.9630	0.9591	0.9615	0.9599	0.9585	0.9584	0.9629
0.9532	0.9553	0.9526	0.9582	0.9537	0.9565	0.9545	0.9530	0.9529	0.9580
0.9523	0.9544	0.9516	0.9573	0.9528	0.9556	0.9536	0.9521	0.9519	0.9571
0.9601	0.9617	0.9596	0.9639	0.9604	0.9627	0.9611	0.9600	0.9597	0.9638
0.9580	0.9597	0.9575	0.9620	0.9583	0.9607	0.9590	0.9579	0.9576	0.9619
0.9589	0.9606	0.9584	0.9630	0.9592	0.9615	0.9599	0.9588	0.9585	0.9627
0.9694	0.9706	0.9690	0.9728	0.9697	0.9713	0.9702	0.9693	0.9691	0.9723
0.9684	0.9696	0.9680	0.9714	0.9686	0.9704	0.9691	0.9682	0.9681	0.9713
0.9524	0.9544	0.9517	0.9572	0.9528	0.9556	0.9536	0.9522	0.9519	0.9571
0.9485	0.9507	0.9478	0.9537	0.9489	0.9520	0.9498	0.9483	0.9480	0.9536
0.9472	0.9496	0.9465	0.9529	0.9477	0.9509	0.9486	0.9471	0.9467	0.9525
0.9511	0.9532	0.9504	0.9562	0.9516	0.9544	0.9524	0.9508	0.9507	0.9560
0.9509	0.9531	0.9502	0.9560	0.9514	0.9543	0.9523	0.9507	0.9505	0.9559
56.14	51.45	57.89	45.71	55.03	48.79	53.11	56.97	56.98	45.74
52.05	47.69	53.67	42.38	51.02	45.20	49.23	52.82	52.83	42.40
1	3	3	5	3	4	3	3	3	4

Load type	**Constant power**
Bus No	
1	1.0000
2	0.9713
3	0.9567
4	0.9509
5	0.9499
6	0.9582
7	0.9560
8	0.9570
9	0.9680
10	0.9669
11	0.9500
12	0..9458
13	0.9445
14	0.9486
15	0.9484
TPL(KW)	61.79
TQL(KVAr)	57.29
Iterations	3

Table 4. Load Flow Results Different Bus System for Different Static Load

Constant Impedance	**Incandescent light**	**Fluorescent light**	**Air conditioner**	**Dryer**	**Freezer**	**Heater**	**Pumps, Fans** ***etc***	**Computer TV** ***etc..***
15-Bus system								
51.45	57.89	45.71	55.03	48.79	53.11	56.97	56.98	45.74
47.69	53.67	42.38	51.02	45.20	49.23	52.82	52.83	42.40
3	3	5	3	4	3	3	3	4
34-bus system								
186.09	204.61	173.79	202.99	178.76	195.22	200.60	208.80	170.59
54.82	60.02	51.25	59.68	52.70	57.45	59.02	61.37	50.335
7	3	4	3	4	3	3	3	4
69-bus system								
167.16	198.09	155.61	192.46	156.55	180.08	192.70	201.65	146.67
77.364	90.61	72.42	88.28	72.81	88.28	88.28	92.22	68.57
7	4	6	4	5	4	4	4	6
85-bus system								
212.28	282.95	176.85	238.36	221.55	277.75	257.17	257.17	168.41
133.78	178.10	111.54	150.11	139.60	174.60	161.66	161.66	106.21
3	3	4	4	4	4	4	3	5

Load type	**Constant power**	**Constant current**
TPL(KW)	61.79	56.14
TQL(KVAr)	57.29	52.05
Iterations	3	1
TPL(KW)	221.724	202.2897
TQL(KVAr)	65.110	59.5035
Iterations	3	5
TPL(KW)	224.99	191.5024
TQL(KVAr)	102.20	87.8353
Iterations	4	6
TPL(KW)	315.70	253.3816
TQL(KVAr)	198.35	159.3571
Iterations	4	2

7.1.4. Case 4: Industrial load of (30% incandescent light + 49% fluorescent light + 21% air conditioner load) is considered to perform load flow analysis for different test systems. Load flow results of different test systems for the industrial load are shown in Table 7.

Table 7. Load Flow Results of Different Test Systems for the Industrial Load

S No	System	TPL(kW)	TQL(kVAr)	Iterations
1	15 bus	50.17	46.52	4
2	34 bus	189.69	55.0935	4
3	69 bus	170.23	78.04	5
4	85 bus	206.23	129.95	6

7.1.5 Case 5: Commercial load of (13% incandescent light + 39% fluorescent light + 40% air conditioner + 8% pumps & fans load) is considered to perform load flow analysis for different test systems. Load flow results of different test systems for the commercial load are shown in Table 8.

Table 8. Load Flow Results of Different Test Systems for the Commercial Load

S No	System	TPL(kW)	TQL(kVAr)	Iterations
1	15 bus	51.12	47.39	4
2	34 bus	190.57	56.11	4
3	69 bus	175.49	81.09	5
4	85 bus	211.7	133.39	6

7.1.6. Case 6: Residential load of (8% incandescent light + 31% air conditioner load + 23% dryer load + 13% freezer load + 25% heater load) is considered to perform load flow analysis for different test systems. Load flow results of different test systems for the residential load are shown in Table 9.

Table 9. Load Flow Results of Different Test Systems for the Residential Load

S.No	System	TPL(KW)	TQL(KVAR)	Iterations
1	15 bus	53.97	49.50	3
2	34 bus	193.63	57.00	3
3	69 bus	180.92	82.25	4
4	85 bus	228.77	144.08	5

7.2. Load Growth Results

The Branch path distribution load flow (BPDLF) method is used to perform the load flow analysis for different test systems to find the total real and reactive power losses, percentage increase of total real and reactive power losses and rate of increase of total real and reactive power losses for a period of 5 years, considering the four load growth rates. Load flow results of 15-bus, 34-bus, 69-bus and 85-bus systems are shown in Tables 10, 11, 12 and 13 respectively.

Table 10. Load Flow Results of 15-Bus System Considering the Load Growth

After 5 years	Base case	0% Load growth	2% Load growth	5% Load growth	7% Load growth
TPL(KW)	61.79	61.79	76.14	103.64	126.91
TQL(KVAR)	57.29	57.29	70.60	96.10	117.6846
% Increase of TPL	-	0.0000	23.23	67.72	105.37
% Increase of TQL	-	0.0000	23.23	67.73	105.39
Rate of increase of TPL	-	0.0000	4.26	10.89	15.48
Rate of increase of TQL	-	0.0000	4.2666	10.89	15.48

Table 11. Load Flow Results of 34-bus System Considering the Load Growth

After 5 years	Base case	0% Load growth	2% Load growth	5% Load growth	7% Load growth
TPL(KW)	221.72	221.72	273.1	371.42	454.54
TQL(KVAr)	65.11	65.11	80.18	109.01	133.37
% Increase of TPL	-	0.0000	23.17	67.51	105.00
% Increase of TQL	-	0.0000	23.15	67.43	104.84
Rate of increase of TPL	-	0.0000	4.25	10.86	15.43
Rate of increase of TQL	-	0.0000	4.25	10.85	15.42

Table 12. Load Flow Results of 69-Bus System Considering the Load Growth

After 5 years	Base case	0% Load growth	2% Load growth	5% Load growth	7% Load growth
TPL(KW)	225.00	225.00	279.73	386.81	479.70
TQL(KVAr)	102.20	102.20	126.92	175.17	216.91
% Increase of TPL	-	0.0000	24.32	71.91	113.19
% Increase of TQL	-	0.0000	24.18	71.39	112.23
Rate of increase of TPL	-	0.0000	4.45	11.44	16.34
Rate of increase of TQL	-	0.0000	4.427	11.37	16.24

Table 13. Load Flow Results of 85-Bus System Considering the Load Growth

After 5 years	Base case	0% Load growth	2% Load growth	5% Load growth	7% Load growth
TPL(KW)	315.70	315.70	395.90	556.31	699.25
TQL(KVAr	198.35	198.35	248.69	349.29	438088
% Increase of TPL	-	0.0000	25.40	76.21	121.49
% Increase of TQL	-	0.0000	25.37	76.09	121.25
Rate of increase of TPL	-	0.0000	4.631	11.99	17.239
Rate of increase of TQL	-	0.0000	4.62	11.98	17.21

8. Conclusions

In this paper a simple and efficient load flow algorithm is proposed by using Branch path matrix. The proposed load flow method has been tested on various IEEE test systems. The proposed algorithm has better convergence characteristics, and is reasonably accurate in obtaining the load flow solution of radial distribution systems, and also it requires less memory. The proposed algorithm uses only branch path matrix for calculations which saves the computational time. The load flow results shows that the radial distribution systems with different types of static or composite loads can be efficiently solved by using the proposed method. The future losses of distribution systems by considering the effect of load growth on various distribution systems can also be analysed efficiently by using proposed method. The proposed method is therefore capable of performing power flow analysis of radial distribution systems with any number of buses or any types of static loads. The proposed method is accurate and efficient for studies on distribution system planning problems.

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