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تقنية بحث جديدة
لحل تدفق تحميل شبكات التوزيع

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الخلاصة

تقترح هذه الورقة طريقة غير معتادة لجعل حل تدفق الحمل من شبكات التوزيع السائدة أكثر كفاءة. لأنه يقوم على دراسة متعمقة تنطوي على تقنية بحث جديدة للعثور على الرابط بين جميع العقد في المغذي، الجانبي والجانبي الثانوي بهدف تجنب البحث المتكرر. والطريقة المقترحة لا تحتاج إلى أي ترميز يدوي لعقدة المصدر الخاصة بالمغذي، سواء الجانبي أو الجانبي الثانوي. وتقنية البحث القوية تقوم تلقائيا بتكوين صفوف من العقد في المغذي، سواء الجانبية أو الجانبية الثانوية. وتشتق معادلة الجهد لحساب الجهد في كل عقدة جنبا إلى جنب مع معادلة عن زاوية الجهد لحساب زاوية الجهد في كل عقدة. وقد تمت تجربة الطريقة المقترحة على ثماني شبكات توزيع دائرية معيارية بما في ذلك شبكة هندية عملية واحدة لإظهار قدرتها على التقارب. ويتم فحص الطريقة المقترحة أيضا على أنواع مختلفة من نماذج الحمل للنظام العملي الحالي. وقد ارتبطت التقنية المقترحة أيضا بالطرق الأخرى المتاحة في مجال شبكات التوزيع الدائرية. وقد تم أيضا وضع التوليد الموزع في 69 عقدة لإظهار قدرته على التوزيع. كما تم توسيع التقنية المقترحة لتشمل شبكة توزيع الشبكات وأيضا لشبكة التوزيع غير المتوازنة.

A novel search technique to solve load flow of distribution networks

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ABSTRACT

This paper suggests an unaccustomed way to make the load flow solution of the prevailing distribution networks (DNs) more efficiently. It is based on an in-depth study involving a novel search technique to find the link between all nodes in the feeder, lateral(s), and sublateralals(s) with the aim of avoiding the repetitive search. The suggested method does not need any manual coding for source node of the feeder, lateral(s), and sublateral(s). The powerful search technique automatically forms arrays of nodes of the feeder, lateral(s), or sublateral(s). An expression of voltage equation is derived to compute the voltage of each node along with an expression of voltage angle to compute the angle of the voltage of each node. The suggested method has been tried out on eight standard radial distribution networks (RDNs) including one practical Indian RDN to show its capacity of convergence. The proposed method is also examined on different types of load modelling of the existing practical system. The suggested technique has been also correlated with the other methods available in the field of RDNs. Distributed generation (DG) placement in 69-node RDN has also been done to show its capacity for handling DG. The suggested technique has also been extended to mesh distribution network (MDN) and also for to unbalanced distribution network (UDN).

KeywWords: Distribution network; Convergenceconvergence; Load load flow; Load load modelling; Radialradial.

INTRODUCTION

The load flow has the most significant role in computing the node voltage of each node along with the losses of the distribution systems. Its improvement in the distribution system is an ongoing process. Distribution planners are always in search of more effective, accurate load flow solutions so that the planning of the distribution systems can be made efficiently. The load flow of any distribution network needs rigorous coding compared to that of transmission systems due to its topology. The distribution networks have a high ratio of resistance to reactance. However, this ratio is low for transmission networks because the transmission networks are of mesh type in practice. The available power flow techniques like Gauss-Seidel and Newton-Raphson methods, already popular for transmission systems, hardly converge in the RDN. During the last three decades, an intensive work has been done by researchers in this area. The following studies highlights the techniques available in the literature for load flow solution of DNs.

There is very little awareness regarding load flow methods with variables expressed in rectangular form. Commonly used in polar form, a large amount of computation is required (Borivoje, 1983). Kersting & Philips (1987) suggested an approach to work out load flow of UDN using Carson's equations and they demonstrated their method on a 34-node UDN. Shirmohammadi et al. (1988) also proposed a way to compute the load flow of RDNs with the concept of a tree. They had also extended their method for mesh distribution networks using the two-port compensation theory as suggested by [[Tinney (1971)]]. Baran & Wu (1989a) also introduced an approach for the load flow solution of RDNs with the aid of three simple equations. Chinag & Baran (1990) acknowledged that, for transmission networks, various load flow solutions prevail, but, for distribution networks, a distinctive load flow solution prevails. Chiang (1991) had also suggested a method for load flow solution with the aid of three equations as suggested by [[Baran & Wu (1989a)]]. Thukaram et al. (1991) proposed a robust load flow technique for UDNs. They executed their method on different UDNs. Goswami and Basu (1991) suggested a technique for the load flow solution of RDNs with an assumption that a node can handle only three branches, i.e.that is, one entering and two leaving. Goswami and Basu (1992) suggested a technique for network reconfiguration of distributionof distribution networks to minimise the loss of theof the system. They proposed a load flow of an MDN in that paper. A power flow methodology termed as "forward sweeping method" for solving RDNs, requiring only the performance of elementary algebraic voltage expressions, was developed by Das et al. (1994). A load flow methodology, which is bare and effective, using only algebraic expressions of voltage magnitudes was developed by Das et al. (1995). Their efforts resulted in the emergence of the manual coding for the clients of a feeder from the clients of both lateral and sublateralemerged. Cheng & Shrimohammadi (1995) extended the method developed by [[Shrimohammadi et al. (1988)]]. Lin & Teng (1996) employed branch current based N-R method in their phase decoupled based load flow method. It was customized for distribution networks of radial or weakly meshed type. The Jacobian method was decoupled into three sub-Jacobians, one for each phase. It was not only insensitive to line parameters but wasalsorobust as well. A simple and efficient method was presented by Ghosh & Das (1999) to solve distribution networks, which were radial, using simple algebraic expressions to compute the receiving-–end voltages. The method had better convergence characteristics as compared to previously existing methods. Teng & Chang (2002) suggested a novel load flow technique for UDNs. A topology based method involving forward and backward sweep using the depth first search strategy was used to exploit the social formation of the RDN by Li et al. (2002).

Venkatesh & Ranjan (2003) formulated dynamic data structure (DDS) of RDN. The authors developed Pseudo pseudocodescodes for DDS algorithm and overall recursive algorithm for distribution network load flow. A load flow technique planted on simple algebraic equations was developed by Ranjan & Das (2004). The study resulted in satisfactory convergence for composite load modellinging. Ranjan et al. (2004) presented a way for load flow solution of UDNs based on Carson's equations, which were used by [Kersting and Philips (1987)]. They demonstrated their method on 34-node UDN. Eminoglu & Hocaoglu (2004) proposed a load flow method for RDN with different types of load modelling. Khodr et al. (2006) proposed load flow solution of balanced as well as unbalanced RDN considering the unbalance that exists among the phases. This aspect was neglected in earlier studies. Satyanarayana et al. (2007) introduced a novel method of load flow for ill-conditioned systems with fast convergence characteristics. Prakash & Sydulu (2007) used loss sensitivity factor to determine the optimum capacitor placement to enhance the voltage profile and to reduce the active power loss of RDNs. Ghosh & Sherpa (2008) suggested a new method based on simple equations for the load flow solution of RDN with minimum data preparation. According to the authors, the node and branch numbering are required, but need not being sequential like the case in other feasible techniques. Dharmasa et al. (2008) formulated an algorithm in which input data were sorted to compute power injections, losses, currents flowing through the branch, and complex voltages. An amended variant of the minimum data preparation method for load flow solution of RDN was suggested by Ghosh (2009) that needed lesser data arrangement. The author used the feeder, lateral(s), and sublateral(s) set of nodes for the developed algorithm. Chen & Yang (2010) suggested a three three-phase load flow method involving loop frame reference for UDNs. Dilek et al. (2010) proposed power flow algorithm applying Kirchoff's equations for heavily loaded systems (radial subsystems assembled together with mesh equations). Hamouda & Zehar (2011) introduced a refined iterative method based on electric circuit laws to solve power flow problems of balanced RDN with laterals. Singh & Ghosh (2011) pitched an effective and simple methodology based on the forward sweep method to solve load flow of RDN without any continuous node numbering, taking into account the issue of charging capacitance. Janecek & Georgiev (2012) developed analytical probabilistic load flow method that included the multivibrate normal distribution. For execution, the authors used the backward/ forward algorithm. A technique to solve load flow of RDN based on network topology [Abul' Wafa (2011)] was extended to fulfill the requirement of distribution automation by Abul' Wafa (2012). Singh & Ghose (2013) used a matrix transformation technique, which was grounded on the forward /backward sweep to make it efficient. Yuntao et al. (2014) proposed a novel method for administrating PV nodes based on loop analysis integrated with the backward/forward sweep framework. Eltantawy & Salama (2014) presented a novel algorithm for calculating load flow of distribution grids. Nikmehr & Najafi (2015) discussed that traditional power flow methods might not be useful for active distribution networks. Authors modelled the loads by the heuristic method. Nguyen & Flueck (2015) used multi-agent communication system to develop a power flow to solve UDN. Narayan & Kumar (2015) modelled loads and wind power as probability density functions using the Cholesky factorization method.

A detailed analysis of onthe effects of the methodologies used in the above studies, indicated gaps such as manual coding to identify nodes of the feeder, lateral(s), and sublateral(s), longer execution time, high Ohmic losses, etcand so forth. These gaps needed to be addressed for further improvement of load flow of RDN, MDN, and UDN. In this paper, a novel search algorithm is proposed, which finds out the nodes in the feeder, lateral(s), and sublateral(s) form the available line data. The suggested method does not need any manual coding of the node from whom tich the lateral and sublateral are emanating emanatingout.. An equation for computing the voltage of receiving-end node is derived along with computationwith ofcomputation of voltage angle. The paper is organized as follows: Problem formulationFormulation, Simulation results Results and dDiscussion,s and Conclusions followed by References.

PROBLEM FORMULATION

A simplified diagram of a RDN is shown in Fig.ure 1.

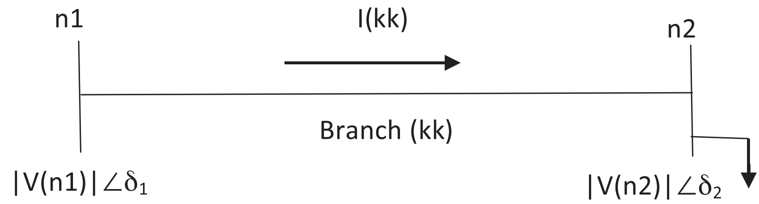


Fig.ure 1. Mathematical model of RDN.

From Fig.ure 1, the current and power can be computed using (1) and (2).

$$I(kk) = \frac{V(n1)\angle\delta(n1) - V(n2)\angle\delta(n2)}{Z(kk)} \tag{1}$$

$$P(n2) - jQ(n2) = V^{*}(n2) \times I(kk) \tag{2}$$

Wherewhere Z(kk) = R(kk) + jX(kk), 'n1' and 'n2' are the respective source and sink nodes of branch kk, 'P(n2)' is the summation of active power loads of all the nodes beyond branch kk plus the summation of the active power losses of all the branches beyond node n2, 'Q(n2)' is the summation of reactive power loads of all the nodes beyond branch kk plus the summation of the reactive power losses of all the branches beyond node n2, 'I(kk)' is the current passing through the branch kk, 'V(i)' is the voltage magnitude of the i th node, 'd(n1)' is the voltage angle of node n1, 'd(n2)' is the voltage angle of node n2, and 'R(kk)' and 'X(kk)' are the resistance and reactance of the branch kk, respectively.

From (1), we have

$$\begin{aligned}|V(n1)|\angle\delta(n1) &= |V(n2)|\angle\delta(n2) + I(kk)Z(kk)\\ &= |V(n2)|\angle\delta(n2) + |I(kk)|\angle\theta|Z(kk)|\angle\phi\\ &= |V(n2)|\angle\delta(n2) + |I(kk)||Z(kk)|\angle(\theta+\phi)\end{aligned}$$

where $\theta = \tan^{-1}\frac{I_m(kk)}{I_r(kk)}$, $\phi = \tan^{-1}\frac{X(kk)}{R(kk)}$, $I(kk) = I_r(kk) + j\,I_m(kk) = |I(kk)|\angle\theta$,

$Z(kk) = R(kk) + j\,X(kk) = |Z(kk)|\angle\phi$ and $I_m(kk)$ and $I_r(kk)$ are the imaginary and real parts of

I(kk).

$$|V(n2)|\angle\delta(n2) = |V(n1)|\angle\delta(n1) - |I(\text{kk})||Z(\text{kk})|\angle(\theta+\phi)$$

$$\begin{aligned}|V(n2)|\cos\delta(n2) + j|V(n2)|\sin\delta(n2) &= |V(n1)|\cos\delta(n1) + j|V(n1)|\sin\delta(n1)\\ &\quad - |I(kk)||Z(kk)|\cos(\theta+\phi) - j|I(kk)||Z(kk)|\sin(\theta+\phi)\end{aligned}$$

$$|V(n2)|\cos\delta(n2) = |V(n1)|\cos\delta(n1) - |I(kk)||Z(kk)|\cos(\theta+\phi) \tag{3}$$

$$|V(n2)|\sin\delta(n2) = |V(n1)|\sin\delta(n1) - |I(kk)||Z(kk)|\sin(\theta+\phi) \tag{4}$$

From (3) and (4),

$$|V(n2)|^2 = |V(\mathrm{n}1)|^2 - 2|V(n1)||I(kk)||Z(kk)|\cos\{\delta(n1)-\theta-\phi\} + |I(kk)|^2|Z(kk)|^2$$

$$|V(n2)| = \sqrt{\left\{|V(\mathrm{n}1)|^2 - 2|V(n1)||I(kk)||Z(kk)|\cos\{\delta(n1)-\theta-\phi\} + |I(kk)|^2|Z(kk)|^2\right\}} \tag{5}$$

$$\delta(n2) = \tan^{-1}\left\{\frac{|V(n1)|\sin\delta(n1) - |I(kk)||Z(kk)|\sin(\theta+\phi)}{|V(n1)|\cos\delta(n1) - |I(kk)||Z(kk)|\cos(\theta+\phi)}\right\} \tag{6}$$

From (5), the magnitude of voltage will be obtained and from (6), the angle of voltage will be obtained.

The active and reactive power losses of the branch kk are given in (7) and (8), respectively.

$$PL(kk) = \frac{R(kk)\times\left[P^2(n2)+Q^2(n2)\right]}{|V(n2)|^2} \tag{7}$$

$$PQ(kk) = \frac{X(kk)\times\left[P^2(n2)+Q^2(n2)\right]}{|V(n2)|^2} \tag{8}$$

The loss sensitivity factor (LSF) is used to recognize the proper position for the distributed generator (DG). The node of the RDN, which has more chance to put the DG, has the supreme value of loss sensitivity factor [Devabalaji et al. (2015)].

$$LSF = \frac{2Q(n2)R(kk)}{|V(n2)|^2} \tag{9}$$

The LSF values of all nodes are arranged in descending order, and the node having the maximum value of LSF is chosen for placement of DG.

From (5) it is clear that the knowledge of I(kk), i.e.that is, the current flowing through the branch kk, is required as the value of Z(kk), i.e.that is, the impedance of branch kk, is known to us. In order to compute the current of branch kk, the knowledge of initial voltage of each and every node is essential. Since the value of the voltage of each node except the substation is not known, a flat voltage start is considered in this technique. To compute the current in each branch, a search technique to arrange the nodes sequentially of each feeder, lateral, and sublateral is proposed. A distribution network is shown in Figure 2. The bracketed terms indicate the branch number (BN). Sending-–end node of any branch 'kk' is denoted by 'SE' (n1), whereas the receiving-end node of branch 'kk' is denoted by 'RE' (n2).

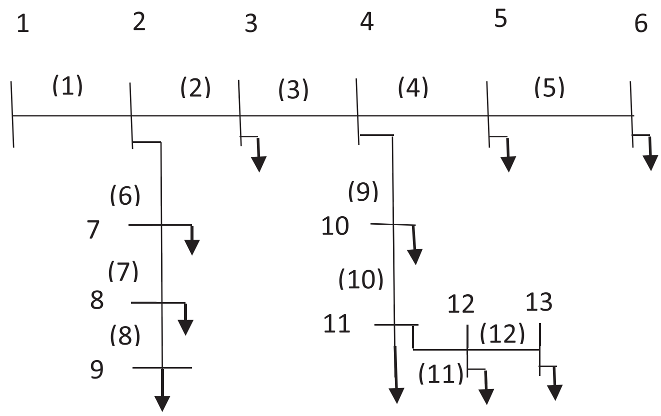


Fig.ure 2. Sample distribution network.

Table 1 shows the BN, SE, and RE of Figure 2.

Table 1. BN, SE, and RE of Figure 2

kk	n1	n2
1	1	2
2	2	3
3	3	4
4	4	5
5	5	6
6	2	7
7	7	8
8	8	9
9	4	10
10	10	11
11	11	12
12	12	13

Let the branch number, its source node, and sink node be stored in BN[i], SE[i], and RE[i], respectively, where i = 1 to 12. Figure 2 has one feeder, two laterals. Let the respective nodes of the feeder and laterals of Figure 2 be stored in F[i], LAT1 [i], and LAT2 [i], respectively. SE [1] is the source node of BN [1], i.e., branch 1. The corresponding RE [1] is 2, which is the receiving-end node of branch 1. SE [1] is stored in F [1] for i =1 and RE [1] is stored in F [2] i.e., i = 12= 1+. RE [1] is checked with all the source nodes of Table 1 for kk= 2 to kk=12. SE [2] and SE [6] are equal to RE [1]. Let us take a counter k = 1 and here j1 = 2 is taken. Here at first, we will start with SE [2] for j1 = 1.For j1 = 2, SE [6] is marked. The respective RE [2] is stored in F [3] i.e., i = 2 + 1 = 3. RE [2] is checked with all the source nodes of Table 1 for kk= 3 to kk=12. RE [2] and SE [3] are only equal. The respective RE [3] is stored in F [4] i.e., i = 3 + 1 = 4. RE [3] is checked with all the source nodes of Table 1 for kk= 4 to kk=12. Here SE [4], SE [9] and RE [3] are identical and j2=2 is put and the counter is increased by one i.e., k = 12= 1+. The respective RE [4] is stored in F [5] i.e., i = 45 = 1+ and SE [9] is marked referred to j2 =2. RE [4] is checked with all the source nodes of Table 1 for kk= 5 to kk=12. Here SE [5] and RE [4] are identical. The respective RE [5] is stored in F [6] i.e., i = 56 = 1+. RE [5] is checked with all the source nodes of Table 1 for kk= 6 to kk=12 and no SE[kk] for kk = 6 to 12 are is equal to RE[5]. The search is stopped for this feeder.

Let us consider k = 1. For k =1, j1 = 2.For j1=2, SE [6] will be considered. It is stored in LAT1 [1] i.e., i =1, which is starting value of this array. The respective RE [6] is checked with all SE [kk] for all kk = 7 to kk = 12. RE [6] and SE [7] are identical only. The respective RE [7] is stored in LAT1 [2] i.e., 'i' is increased by 1 i.e., i = 12= 1+. RE [7] is checked with all SE [kk] for all kk = 8 to kk = 12. SE (8) = RE[7] only and the respective RE[8] is stored in LAT1[3] i.e., 'i' is increased by one i.e., i = 23= 1+. RE [8] is checked with all SE [kk] for all kk = 9 to kk = 12. Any SE (kk) for kk = 9 to 12 is not equal to RE [8]. Hence the search for k =1 and j1=2 is stopped.

Let us consider k = 2. For k =2, j2 = 2.For j2=2, SE [9] will be considered. It is stored in LAT2 [1] i.e., i =1, which is starting value of this array. The respective RE [9] is stored in LAT2 [2] i.e., i = 12=1+ and RE [9] is checked with all SE [kk] for all kk = 10 to kk = 12. RE [9] and SE [10] are identical only. The respective RE [10] is stored in LAT2 [3] i.e., 'i' is increased by 1 i.e., i = 23= 1+. RE [10] is checked with all SE [kk] for all kk = 11 to kk = 12. SE [11] = RE [10] only and the respective RE[11] is stored in LAT1[4] i.e., i is increased by one i.e., i = 34= 1+. RE [11] is checked with all SE [kk] for all kk = 12 to kk = 12. Any SE [12] =RE [11] and here RE [12] is stored in LAT2 [5] i.e., i = 45 = 1+.

The above search technique makes the process much simpler as compared to the method of [Ghosh & Das (1999)] and other proposed methods. No manual precoding of nodes from which lateral or sublateral are emanated as proposed in the method of[Das et al. (1995)] are is required. General data preparation is required only..

The above search techniques produces the following:

F [1] = 1, F [2] = 2, F [3] = 3, F [4] =4, F [5] =5, F [6] =6

LAT1 [1] = 2, LAT1 [2] = 6, LAT1 [3] =7, LAT1 [4] =9

LAT2 [1] = 4, LAT2 [2] = 10, LAT2 [3] =11, LAT2 [4] =12, LAT2 [5] =13

LAT1 [1] is checked with F[i] for i = 1 to 5 and LAT1 [1] = F [2] for i =2.

LAT2 [1] is checked with F[i] for i = 1 to 5 and LAT2 [1] = F [4] for i =4.

An array K[i] is considered to map F[i]. The elements of K[i] for i=1, 3, 5 are put to zero whereas K[i] for i=1,4 are put to one.

The load modelling proposed by Eminoglu, & Hocaoglu, (2004) is used in this paper.

The steps of an algorithm for the proposed load flow solution are given below.

Step-1	:	START
Step-2	:	Read the system data
Step-3	:	Read base values of the system, convergence factor (esp=0.000001) and ITMAX (IT = 100).
Step-4	:	Convert the line data and load data into its per unit value
Step-5	:	Make V (i) = 1 + j0 for all i =1, 2,3, ……, NN.
Step-6	:	Compute VV(i) = |V(i)| and VV1(i) = VV(i)
Step-7	:	IT=1
Step-8	:	Use the search technique to form the array of the feeder, lateral and sublateral and to link them.
Step-9	:	Compute the current in each branch
Step-10	:	Compute the voltage magnitude VV(i) of each and every node using (5)
Step-11	:	Calculate the voltage angle of each and every node using (6).
Step-12	:	Calculate DV(i) = |VV(i) – VV1(i)| for each and every node.
Step-13	:	Find the max value of DV(i).
Step-14	:	If DV(i)|max £ eps, GO TO Step-18.
Step-15	:	Make VV1(i) = VV(i) for all i.
Step-16	:	IT = IT+1
Step-17	:	If (IT£ ITMAX), GO TO Step-9, Else Display Not Converged and GO TO Step-24.
Step-18	:	Compute active and reactive power losses of each and every onebranch using (7) and (8).
Step-19	:	Compute the total active and total reactive power losses of the system.
Step-20		Display the base case results.
Step-21	:	Compute LSF (n2) using (9) for each node n2 where n2 = 2, 3,4,.……,NN and find the highest value of LSF(n2).
Step-22	:	Put the DG at the node n2 having the highest value of LSF and start the DG value with 10 kW and increase gradually until the loss becomes minimum. Take this DG value.
Step-23	:	Display all the RESULTS after DG placements
Step-24	:	STOP

The proposed method has been extended to MDN using the two-port compensation techniques as suggested by [Tinney (1971)] and had also been extended to UDN using Carson’s equations available in [Kersting and Philips (1987)].

SIMULATION RESULTS AND DISCUSSION

In this paper, a total, of eight RDNs have been studied. These are 13-node, 24-node, 28-node, 29-node, 33-node, 34-node, 69-node, and 85-node. Out of these, 33-node and 69-node are the IEEE data bus and 24-node is the practical data bus (Jeevakona, India). The system data of 13-node and 34-node RDNs are accessible in [Suharati et al. (2014)]. The line data and load data of 28-node RDN are available in [Das et al. (1994)] and 85-node RDN are accessible in [Das et al. (1995)]. The system data of 29-node, 33-node, and 69-node distribution networks are accessible in [Ghosh and Das (1999)]. The system data of 24-node RDN are accessible in [Kumar et al. (2013)].

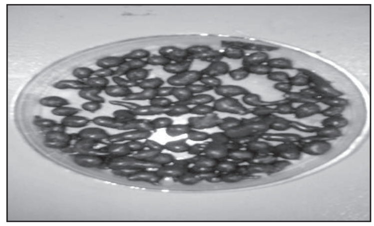
The base values are 12.66 kV and 100 MVA for 33-node and 69-node RDNs. The base values for the rest of the test systems are 11 kV and 100 MVA.

Table 2 shows the real part, imaginary part, voltage magnitude (p.u.), and voltage angle (rad.) for 13-node RDN, and Table 3 presents the value of $DV(i)|_{max}$ iteration-wise for the eight networks.

Table 2. Real part of the voltage, iImaginary part of the voltage, the voltage magnitude (p.u.), and voltage angle (rad.) of each node of 13-node RDN.

Node number	Real part of the voltage (p.u.)	Imaginary part of the voltage (p.u.)	Voltage magnitude (p.u.)	Voltage angle (rad.)
1	1.000000	0.000000	1.000000	0.000000
2	0.997122	0.003838	0.997130	0.003849
3	0.996619	0.004621	0.996630	0.004637
4	0.996327	0.004871	0.996339	0.004889
5	0.995401	0.006669	0.995424	0.006700
6	0.994755	0.008153	0.994789	0.008196
7	0.994319	0.009958	0.994369	0.010014
8	0.995243	0.006802	0.995266	0.006835
9	0.996211	0.006294	0.996231	0.006318
10	0.995736	0.007691	0.995766	0.007724
11	0.994757	0.007820	0.994788	0.007861
12	0.994641	0.008069	0.994673	0.008112
13	0.994626	0.007837	0.994657	0.007879

In 13-node RDN, a minimum voltage is observed at node 7.

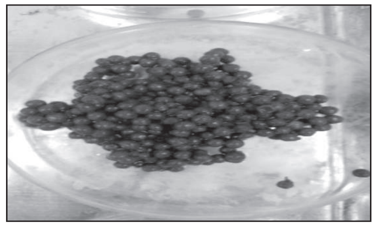
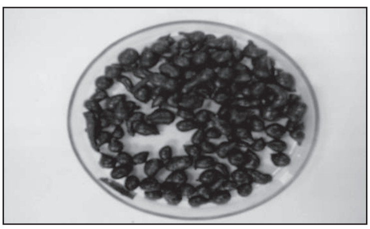
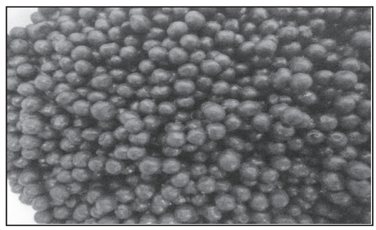




Table 3. Value of $DV|_{max}$ iteration-wise for eight different RDNs by the proposed technique for constant power load model.

Iteration-wise $\Delta V|_{max}$ values of distribution networks **[convergence criteria $\Delta V|_{max} \leq 0.000001$]**

13-node	24-node	28-node	29-node	33-node	34-node	69-node	85-node
0.005519	0.020951	0.080540	0.297414	0.080348	0.060149	0.082973	0.113750
0.000112	0.000365	0.006422	0.018737	0.005896	0.003561	0.007141	0.013183
0.000000	0.000006	0.000519	0.001395	0.000453	0.000192	0.000631	0.001539
	0.000000	0.000044	0.000315	0.000035	0.000011	0.000059	0.000195
		0.000004	0.000023	0.000003	0.000001	0.000005	0.000023
		0.000000	0.000016	0.000000		0.000000	0.000003
			0.000004				0.000000
			0.000001				
			0.000001				

Table 4. Load flow results of eight different types of RDNs by the proposed techniques for constant power load model.

Distribution networks	Total real power load (kW)	Total reactive power load (kvar)	Total real power loss (kW)	Total reactive power loss (kvar)	Minimum voltage in p.u. (node number)	Total number of iterations
13-node	1115.00	4430.00	38.236	12.744	0.994369 (7)	3
24-node	2955.59	1342.70	39.366	25.121	0.978677 (14)	4
28-node	761.04	776.41	68.81	46.04	0.912471(26)	6
29-node	1654.25	928.830	371.51	149.63	0.682150 (18)	9
33-node	3715.00	2300.00	202.522	135.128	0.913265(18)	6
34-node	4636.50	3633.50	262.702	98.315	0.936087(27)	5
69-node	3801.90	2692.60	224.936	102.130	0.909191(65)	6
85-node	2570.28	2622.21	316.13	198.61	0.871308 (54)	7

Table 4 shows the total real power load, total reactive power load, total real power loss, total reactive power loss, minimum voltage magnitude (p.u.) along with the node number, and number of iterations to converge for the constant power load model.

Table 5. Load flow results for 24-node RDN for different types of load modelling.

Distribution networks	Total real power load (kW)	Total reactive power load (kvar)	Total real power loss (kW)	Total reactive power loss (kvar)	Minimum voltage in p.u. (node number)	Total number of iterations
Battery charge	2854.27	1271.34	36.052	23.006	0.979697 14	4
Fluorescent lamps	2873.58	1285.42	36.675	23.404	0.979501(14)	4
Constant impedance	2875.93	1306.50	36.968	23.591	0.979390(14)	4
Fluorescent lighting	2915.11	1288.37	37.730	24.077	0.979203(14)	4
Air conditioner	2935.11	1296.89	38.324	24.457	0.979027(14)	3
Constant current	2914.82	1324.17	38.128	24.331	0.979042(14)	3
Resistance space heater	2875.37	1342.70	37.370	23.848	0.979229(14)	3
Pumps, fans, other motors	2952.27	1312.93	38.938	24.848	0.978836(14)	4
Incandescent lamps	2893.26	1342.70	37.809	24.128	0.979106(14)	3
Compact fluorescent lamps	2914.73	1336.16	38.264	24.418	0.978988(14)	3
Small industrial lamps	2951.43	1331.41	39.129	24.970	0.978758(14)	4
Large industrial motors	2953.50	1333.27	39.203	25.017	0.978735(14)	4

Table 5 shows the load flow results for 24-node RDN for various types of load modelling to ensure the convergence capacity of the proposed load flow technique.

Table 6. Relative CPU tTime/ IT nNumber/$\Delta V(1)|_{max}$ of the suggested technique with the available techniques [Satyanarayana et al. (2007), Singh & Ghosh (2011), and Singh & Ghose(2013)].

	Relative CPU time/ IT number/$\Delta V(1)|_{max}$			
Distribution networks	Proposed method	Satyanarayana *et al.* (2007)	Singh & Ghosh (2011)	Singh & Ghose (2013)
13-node	1/3/0.005519	1.27/3/0.005548	1.21/3/0.005537	1.31/3/0.005598
24-node	1/4/0.020951	1.39/4/0.020971	1.32/5/0.020972	1.45/5/0.021037
28-node	1/6/0.080540	1.43/6/0.080590	1.37/5/0.080593	1.51/6/0.080658
29-node	1/9/0.297414	1.87/11/0.297439	1.72/10/0.297430	1.95/11/0.297492
33-node	1/6/0.080348	1.51/6/0.080375	1.43/6/0.080368	1.57/6/0.080391
34-node	1/5/0.060149	1.56/5/0.060185	1.47/5/0.060176	1.64/6/0.060195
69-node	1/6/0.082973	1.83/6/0.083011	1.71/6/0.082988	1.92/7/0.083029
85-node	1/7/0.113750	1.97/8/0.113786	1.77/8/0.113768	2.10/9/0.113810

Table 6 shows the comparison of the relative CPU time/iIteration number (IT no.)/$\Delta V(1)|_{max}$ by the proposed technique and the available techniques [Satyanarayana et al. (2007), Singh & Ghosh (2011), and Singh & Ghose (2013)] under the same platform.

Table 7. Load flow results of 69-node RDN , before and after DG placement.

Parameters	Without DG	With DG		
Location	---	61	61	61
DG size (kW)	---	1820	1830	1840
Real power loss (kW)	224.936	80.17	80.16	80.22
Reactive power loss (kvar)	102.130	39.18	39.17	39.21
Min. voltage (Node no.)	0.909191 (65)	0.968618 (27)	0.968678 (27)	0.968598 (27)

Table 7 shows the results obtained by the proposed technique before and after DG placement in 69-node RDN. The node number 61 has the highest value of LSF calculated with the help of equation 9 and it is selected for the placement of DG. Three results with DG size 1820 kW, 1830 kW, and 1840 kW has have been presented. The DG size with 1830 kW gives the better results in terms of losses and minimum voltage compared to that of with sizes 1820 kW and 1840kW. Hence, this DG size is the most suitable one.

Table 8.: Comparison of the speed of the proposed technique with the other two, already existing techniques for 33-node MDN.

Methods	Relative CPU time (sec.)	Iteration no.
Proposed method	1.00	12
Shirmohammadi *et al.* (1988)	1.42	16
Goswami and Basu (1992)	1.97	16

Table 8 shows the power flow results for 33 node mesh distribution system with five tie-lines. The system data is available in [Baran & Wu (1989b)]. Total active and reactive power losses of this system are 146.27 kW and 105.42 kvar, respectively. The minimum voltage occurs at node 32, having a value of 0.94958 p.u. The relative CPU time and iteration number have been correlated with [Shirmohammadi et al. (1988)] and [Goswami & Basu (1992)].

Table 9. Load flow outcomes of 19-node UDN.

Node no.	Voltage magnitude (p.u.)		
	Phase A	**Phase B**	**Phase C**
1	1.000000	1.000000	1.000000
2	0.987394	0.989098	0.987893
3	0.985198	0.988598	0.986296
4	0.982295	0.983899	0.983089
5	0.981999	0.983548	0.982763
6	0.979198	0.980692	0.980029
7	0.978592	0.980196	0.979437
8	0.972784	0.973783	0.973385
9	0.965894	0.965895	0.965623
10	0.956195	0.955394	0.955000
11	0.954899	0.954287	0.953210
12	0.954679	0.953693	0.953487
13	0.954286	0.953378	0.952093
14	0.954392	0.953782	0.952790
15	0.952698	0.951198	0.951130
16	0.953299	0.951393	0.952034
17	0.953579	0.953280	0.952289
18	0.953698	0.953176	0.952008
19	0.951497	0.949690	0.950389

Table 9 shows the results for 19-node UDN. The system data is available in [Vulasara et al. (2009)]. The real power losses are 4.4542 kW, 4.538 kW, and 4.5644 kW for Phase A, Phase B, and Phase C, respectively. The reactive power losses are 1.9402 kvar, 1.8965 kvar, and 1.9587 kvar for Phase A, Phase B, and Phase C, respectively. Table 10 shows the juxtaposition of the relative CPU time and iIteration number of the proposed technique with the available methods [Thukarm et al. (1999), Teng & Chang (2002), and Ranjan et al. (2004)].

Table 10. Relative CPU time and iIteration number of the proposed technique of 19-node UDN with the available methods [Thukarm et al. (1999), Teng & Chang (2002), and Ranjan et al. (2004)]

	Relative CPU time/ IT number/$\mathbf{\Delta V(1)}\|_{max}$			
Distribution networks	Proposed method	Thukarm *et al*. (1999)	Teng & Chang (2002)	Ranjan *et al*. (2004)
19-node UDN	1/6	1.46/8	1.34/7	1.26/7

From above results, it can be observed that the proposed technique converges the load flow of distribution networks efficiently. The suggested method takes short CPU time as well as iteration number, in contrast to the methods of [Satyanarayana et al. (2007), Singh & Ghosh (2011), and Singh & Ghose(2013)] for the RDNs as shown in Table 6 . Table 8 shows the comparison of between the proposed method, when extended to MDN, with and that of [Shirmohammadi et al. (1988) and Goswami & Basu (1992),] and it has been foundis better in terms of CPU time and iteration number. From Table 10, it is clear that it also takes lesser CPU time as well as iterations number as compared to [Thukarm et al. (1999), Teng & Chang (2002), and Ranjan et al. (2004)] when extended to UDN.

CONCLUSIONS

A novel search technique is proposed to solve load flow of RDNs, which has been extended to MDN and UDN also. Voltage magnitudes of each node and its voltage angle are computed using the derived equations. The proposed search technique does not require to store the nodes beyond each branch and does not need for repetitive search. The voltage convergence criteria are used and this method examined eight examples, including one practical Indian test feeder. The proposed technique takes lesser CPU time as compared to the three methods reported in the literature and has converged for different types of load modelling. The suggested method has been extended for MDN and UDN. The suggested technique is found to be superior as compared to other available methods in terms of relative CPU time and iteration number.

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