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A Simple Approach of Three phase Distribution System Modeling for Power Flow Calculations

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***Abstract*—**This paper presents a simple three phase power flow method for solution of three-phase unbalanced radial distribution system (RDN) with voltage dependent loads. It solves a simple algebraic recursive expression of voltage magnitude, and all the data are stored in vector form. The algorithm uses basic principles of circuit theory and can be easily understood. Mutual coupling between the phases has been included in the mathematical model. The proposed algorithm has been tested with several unbalanced radial distribution networks and the results are presented in the article. 8-bus and IEEE 13 bus unbalanced radial distribution system results are in agreements with the literature and show that the proposed model is valid and reliable.

***Keywords*—**radial distribution networks, load flow, circuit model, three-phase four-wire, unbalance.

I. Introduction

LOAD flow technique is very important tool for analysis of power systems and used in operational as well as planning stages. Certain applications, particularly in distribution automation and optimization require repeated load flow solutions. As the power distribution networks become more and more complex, there is a higher demand for efficient and reliable system operation. Consequently, the most important system analysis tool, load flow studies, must have the capability to handle various system configurations with adequate accuracy and speed. In many cases, it is observed that the radial distribution systems are unbalanced because of single-phase, two-phase and three-phase loads. Thus, load flow solution for unbalanced case and, hence special treatment is required for solving such networks.

Due to the high R/X ratios and unbalanced operation in distribution systems, the Newton-Raphson and ordinary Fast Decoupled Load Flow method may provide inaccurate results and may not be converged. Therefore, conventional load flow methods cannot be directly applied to distribution systems. In many cases, the radial distribution systems include untransposed lines which are unbalanced because of single phase, two phase and three phase loads. Thus, load flow analysis of balanced radial distribution systems [1-3] will be inefficient to solve the unbalanced cases and the distribution systems need to be analyzed on a three phase basis instead of single phase basis.

There have been a lot of interests in the area of three phase distribution load flows. A fast decoupled power flow method has been proposed in [4]. This method orders the laterals instead of buses into layers, thus reducing the problem size to the number of laterals. Using of lateral variables instead of bus variables makes this method more efficient for a given system topology, but it may add some difficulties if the network topology is changed regularly, which is common in distribution systems because of switching operations. In [5], a method for solving unbalanced radial distribution systems based on the Newton-Raphson method has been proposed. Thukaram *et al*. [6] have proposed a method for solving three-phase radial distribution networks. This method uses the forward and backward propagation to calculate branch currents and bus voltages. A new three-phase decoupled power flow method has been proposed in [7]. This decoupled power flow method method uses traditional Newton-Raphson algorithm in a rectangular coordinate system.

In recent years the three-phase current injection method (TCIM) has been proposed [8]. TCIM is based on the current injection equations written in rectangular coordinates and is a full Newton method. As such, it presents quadratic convergence properties and convergence is obtained for all but some extremely ill-conditioned cases. Further TCIM developments led to the representation of control devices [9], [10]. Miu et al., [11] have also proposed method for solving three-phase radial distribution networks.

A fast decoupled G-matrix method for power flow, based on equivalent current injections, has been proposed in [12] .This method uses a constant Jacobian matrix which needs to be inverted only once. However, the Jacobian matrix is formed by omitting the reactance of the distribution lines with the assumption that R>>X; and fails if X>R. In [14], a method has been suggested for three phase power flow analysis in distribution networks by combining the implicit Z-bus method [13] and the Gauss-Seidel method. This method uses fractional factorization of Y-bus matrix. Thus, large computational time is necessary for this method. The Network Topology method uses two matrices, viz. bus injection to branch current (BIBC) and branch-current to bus-voltage (BCBV) matrices, to find out the solution [15]. The Ladder Network theory [16], [17] based on approaches trace the network to and fro from its load end to source end. However, methods proposed by researchers reviewed above are very cumbersome and large computation time is required.

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In this article, a simple algorithm is developed which is based on basic systems analysis method and circuit theory. The purpose of this paper is to develop a new computation model for unbalanced radial distribution network, which requires lesser computer memory and is computationally fast. The proposed method involves only recursive algebraic equations to be solved to get the following information:

- Status of the feeder line, and overloading of the conductor and feeder line currents.
- Whether the system can maintain adequate voltage level for the remote loads.
- The line losses in each segment.
- It can also suggest the necessity of re-routing or network reconfiguration for the existing distribution network.

The algorithm has been developed considering that all loads draw constant power. However, the algorithm can easily accommodate composite load modeling, if the composition of load is known. The algorithm has good convergence property for practical unbalanced radial distribution networks.

II. SYSTEM MODELING

For the purposes of power flow studies, we model a radial distribution system as a network of buses connected by distribution lines, switches, or transformers to a voltage specified source bus. Each bus may also have a corresponding load, shunt capacitor, and or cogenerator connected to it. The model can be represented by a radial interconnection of copies of the basic building block shown in Figure 2. The dotted lines from the cogenerator, shunt capacitor, and load to ground are to indicate that these elements may be connected in an ungrounded delta-configuration. Since a given branch may be single-phase, two phase, or three-phase, each of the labeled quantities is respectively a scalar, 2 x 1, or **3** x 1 complex vector. For the simplicity of presentation we will occasionally assume everything is three-phase, although both single and two phase laterals are handled by our program.

A. Distribution system line Model

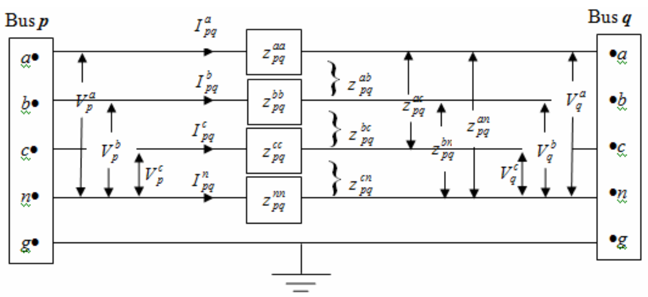

Fig. 1 Model of the three-phase four-wire distribution line

For instance a four-wire grounded wye overhead distribution line shown in fig. 1 results in a 4×4 impedance matrix. The corresponding equations are

$$\begin{bmatrix} V_p^a \\ V_p^b \\ V_p^c \\ V_p^n \end{bmatrix} = \begin{bmatrix} V_q^a \\ V_q^b \\ V_q^c \\ V_q^n \end{bmatrix} + \begin{bmatrix} z_{pq}^{aa} & z_{pq}^{ab} & z_{pq}^{ac} & z_{pq}^{an} \\ z_{pq}^{ba} & z_{pq}^{bb} & z_{pq}^{bc} & z_{pq}^{bn} \\ z_{pq}^{ca} & z_{pq}^{cb} & z_{pq}^{cc} & z_{pq}^{cn} \\ z_{pq}^{na} & z_{pq}^{nb} & z_{pq}^{nc} & z_{pq}^{nn} \end{bmatrix} \begin{bmatrix} I_{pq}^a \\ I_{pq}^b \\ I_{pq}^c \\ I_{pq}^n \end{bmatrix} \quad (1)$$

Also representable in matrix form as

$$\begin{bmatrix} \mathbf{V}_p^{abc} \\ V_p^n \end{bmatrix} = \begin{bmatrix} \mathbf{V}_q^{abc} \\ V_q^n \end{bmatrix} + \begin{bmatrix} \mathbf{Z}_{pq}^{abc} & \mathbf{z}_{pq}^{n} \\ \mathbf{z}_{pq}^{n\,T} & z_{pq}^{nn} \end{bmatrix} \begin{bmatrix} \mathbf{I}_{pq}^{abc} \\ I_{pq}^{n} \end{bmatrix} \quad (2)$$

If the neutral is grounded, the voltage $\mathbf{V}_p^n$ and $\mathbf{V}_q^n$ can be considered to be equal. In case, from the l[st] row of eqn. (2), it is possible to obtain

$$I_{pq}^{n} = -z_{pq}^{nn\,-1}\,\mathbf{z}_{pq}^{n\,T}\,\mathbf{I}_{pq}^{abc} \quad (3)$$

and substituting eqn.(3) into eqn. (2), the final form corresponding to the Kron's reduction becomes

$$\mathbf{V}_p^{abc} = \mathbf{V}_q^{abc} + \mathbf{Ze}_{pq}^{abc}\,\mathbf{I}_{pq}^{abc} \quad (4)$$

Where

$$\mathbf{Ze}_{pq}^{abc} = \mathbf{Z}_{pq}^{abc} - \mathbf{z}_{pq}^{n}\,z_{pq}^{nn\,-1}\,\mathbf{z}_{pq}^{n\,T} = \begin{bmatrix} ze_{pq}^{aa} & ze_{pq}^{ab} & ze_{pq}^{ac} \\ ze_{pq}^{ba} & ze_{pq}^{bb} & ze_{pq}^{bc} \\ ze_{pq}^{ca} & ze_{pq}^{cb} & ze_{pq}^{cc} \end{bmatrix} \quad (5)$$

I_{pq}^{abc} is the current vector through line between bus *p* and *q*, can be equal to, the sum of the load currents of all the buses beyond line between bus *p* and *q* plus the sum of the charging currents of all the buses beyond line between bus *p* and *q*, of each phase.

Therefore the bus *q* voltage can be computed when we know the bus *p* voltage, mathematically, by rewriting eqn. (4)

$$\begin{bmatrix} V_q^a \\ V_q^b \\ V_q^c \end{bmatrix} = \begin{bmatrix} V_p^a \\ V_p^b \\ V_p^c \end{bmatrix} - \begin{bmatrix} ze_{pq}^{aa} & ze_{pq}^{ab} & ze_{pq}^{ac} \\ ze_{pq}^{ba} & ze_{pq}^{bb} & ze_{pq}^{bc} \\ ze_{pq}^{ca} & ze_{pq}^{cb} & ze_{pq}^{cc} \end{bmatrix} \begin{bmatrix} I_{pq}^a \\ I_{pq}^b \\ I_{pq}^c \end{bmatrix} \quad (6)$$

B. Load Model

The loads generally available in the three phase unbalanced distribution systems are spot and distributed loads. All the loads are assumed to draw complex power $\left(SL_q = PL_q + jQL_q\right)$. It is further assumed that all three-phase loads are star and delta connected and all double- and single-phase loads are connected between line and neutral and line to line respectively.

Figs. 2 and 3 show the three phase unbalanced spot load model of star and delta connected three-phase loads at bus *q*, SL_q^a, SL_q^b and SL_q^c can be of different values or even zeroes. In fact, two-phase and single-phase loads are modeled by setting the values of the complex power of the non-existing phases to zero.

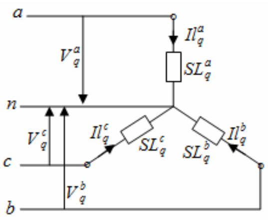

Fig. 2 Star Load Model

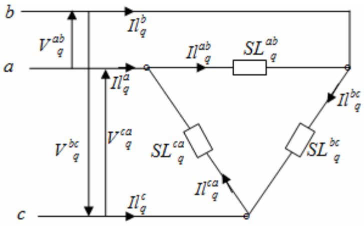

Fig. 3 Delta Load Model

In the case of three phase loads connected in start or single phase loads connected line to neutral, the load current injections at the qth bus can be given by:

$$\begin{bmatrix} SL_q^a \\ SL_q^b \\ SL_q^c \end{bmatrix} = \begin{bmatrix} (PL_q^a + jQL_q^a) \\ (PL_q^b + jQL_q^b) \\ (PL_q^c + jQL_q^c) \end{bmatrix} = \begin{bmatrix} (SL_{q0}^a)\left(\frac{|V_q^a|}{|V_0^a|}\right)^n \\ (SL_{q0}^b)\left(\frac{|V_q^b|}{|V_0^b|}\right)^n \\ (SL_{q0}^c)\left(\frac{|V_q^c|}{|V_0^c|}\right)^n \end{bmatrix} = \begin{bmatrix} (PL_{q0}^a + jQL_{q0}^a)\left(\frac{|V_q^a|}{|V_0^a|}\right)^n \\ (PL_{q0}^b + jQL_{q0}^b)\left(\frac{|V_q^b|}{|V_0^b|}\right)^n \\ (PL_{q0}^c + jQL_{q0}^c)\left(\frac{|V_q^c|}{|V_0^c|}\right)^n \end{bmatrix}$$

$$\begin{bmatrix} Il_q^a \\ Il_q^b \\ Il_q^c \end{bmatrix} = \begin{bmatrix} \left(\frac{SL_q^a}{V_q^a}\right)^* \\ \left(\frac{SL_q^b}{V_q^b}\right)^* \\ \left(\frac{SL_q^c}{V_q^c}\right)^* \end{bmatrix} = \begin{bmatrix} \left(\frac{PL_q^a + jQL_q^a}{V_q^a}\right)^* \\ \left(\frac{PL_q^b + jQL_q^b}{V_q^b}\right)^* \\ \left(\frac{PL_q^c + jQL_q^c}{V_q^c}\right)^* \end{bmatrix} \quad (7)$$

The current injections at the q^{th} bus for three phase loads connected in delta or single phase loads connected line to line can be expressed by:

$$\begin{bmatrix} SL_q^{ab} \\ SL_q^{bc} \\ SL_q^{ca} \end{bmatrix} = \begin{bmatrix} (PL_q^{ab} + jQL_q^{ab}) \\ (PL_q^{bc} + jQL_q^{ba}) \\ (PL_q^{ca} + jQL_q^{ca}) \end{bmatrix} = \begin{bmatrix} (SL_{q0}^{ab})\left(\frac{|V_q^{ab}|}{|V_0^{ab}|}\right)^n \\ (SL_{q0}^{bc})\left(\frac{|V_q^{bc}|}{|V_0^{bc}|}\right)^n \\ (SL_{q0}^{ca})\left(\frac{|V_q^{ca}|}{|V_0^{ca}|}\right)^n \end{bmatrix} = \begin{bmatrix} (PL_{q0}^{ab} + jQL_{q0}^{ab})\left(\frac{|V_q^{ab}|}{|V_0^{ab}|}\right)^n \\ (PL_{q0}^{bc} + jQL_{q0}^{ba})\left(\frac{|V_q^{bc}|}{|V_0^{bc}|}\right)^n \\ (PL_{q0}^{ca} + jQL_{q0}^{ca})\left(\frac{|V_q^{ca}|}{|V_0^{ca}|}\right)^n \end{bmatrix}$$

$$\begin{bmatrix} Il_q^a \\ Il_q^b \\ Il_q^c \end{bmatrix} = \begin{bmatrix} \left(\frac{SL_q^{ab}}{V_q^{ab}}\right)^* - \left(\frac{SL_q^{ca}}{V_q^{ca}}\right)^* \\ \left(\frac{SL_q^{bc}}{V_q^{bc}}\right)^* - \left(\frac{SL_q^{ab}}{V_q^{ab}}\right)^* \\ \left(\frac{SL_q^{ca}}{V_q^{ca}}\right)^* - \left(\frac{SL_q^{bc}}{V_q^{bc}}\right)^* \end{bmatrix} = \begin{bmatrix} \left(\frac{PL_q^{ab} + jQL_q^{ab}}{V_q^{ab}}\right)^* - \left(\frac{PL_q^{ca} + jQL_q^{ca}}{V_q^{ca}}\right)^* \\ \left(\frac{PL_q^{bc} + jQL_q^{bc}}{V_q^{bc}}\right)^* - \left(\frac{PL_q^{ab} + jQL_q^{ab}}{V_q^{ab}}\right)^* \\ \left(\frac{PL_q^{ca} + jQL_q^{ca}}{V_q^{ca}}\right)^* - \left(\frac{PL_q^{bc} + jQL_q^{bc}}{V_q^{bc}}\right)^* \end{bmatrix} \quad (8)$$

Eqns. (7) and (8) represents a generalized model for star and delta load models respectively. Where n is defined as follows:

n=0, constant power
n=1, constant current
n=2, constant impedance

C. *Line Shunt charge model*

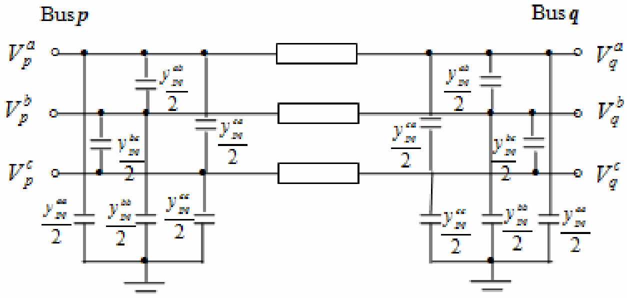

Fig. 4 Shunt capacitance of line sections

The previous line section model can be improved by the inclusion of line charging representation. The shunt capacitances phase to phase and phase to ground, depicted in Fig. 4, can be taken into account through additional current injections.

These current injections for representing line charging, which should be added to the respective compensation current injections at buses p and q, are given by

$$\begin{bmatrix} Ish_q^a \\ Ish_q^b \\ Ish_q^c \end{bmatrix} = \frac{1}{2}\begin{bmatrix} -(y_{pq}^{aa}+y_{pq}^{ab}+y_{pq}^{ac}) & y_{pq}^{ab} & y_{pq}^{ac} \\ y_{pq}^{ba} & -(y_{pq}^{ba}+y_{pq}^{bb}+y_{pq}^{bc}) & y_{pq}^{bc} \\ y_{pq}^{ca} & y_{pq}^{cb} & -(y_{pq}^{ca}+y_{pq}^{cb}+y_{pq}^{cc}) \end{bmatrix}\begin{bmatrix} V_q^a \\ V_q^b \\ V_q^c \end{bmatrix} \quad (9)$$

D. *Line Shunt charge model*

Fig. 5 shows phase a of a three-phase system where lines between buses p and q feed the bus q and all the other lines connecting bus q draw current from line between bus p and q.

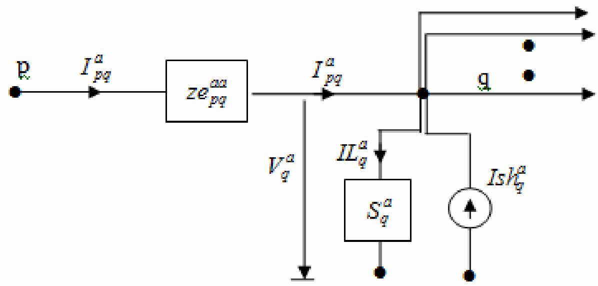

Fig. 5 Single phase line section with load connected at bus q between to phase a and neutral n

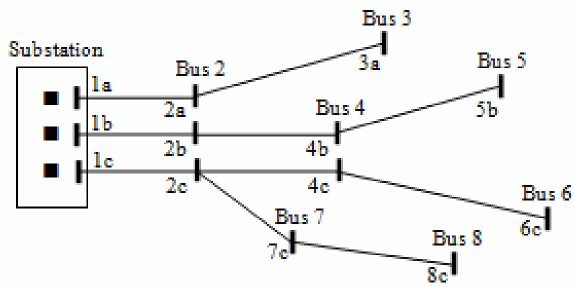

Fig. 6 An eight bus system

Consider the eight bus three-phase radial distribution system [14] shown in Fig. 6. The total line current supplied through the phase a of the line connected between buses 1 and 2 or effective current of phase a at bus 2 is

$$I_{12}^{a} = Il_{2}^{a} + Il_{3}^{a} + Ish_{2}^{a} + Ish_{3}^{a} \qquad (10)$$

Thus, in general, the line current at any phase of line between buses p and q may be expressed as

$$\mathrm{I}_{pq}^{abc} = \begin{bmatrix} I_{pq}^{a} \\ I_{pq}^{b} \\ I_{pq}^{c} \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^{N(pq)} Il_{\{IE(pq,i)\}}^{a} + \sum_{i=1}^{N(pq)} Ish_{\{IE(pq,i)\}}^{a} \\ \sum_{i=1}^{N(pq)} Il_{\{IE(pq,i)\}}^{b} + \sum_{i=1}^{N(pq)} Ish_{\{IE(pq,i)\}}^{b} \\ \sum_{i=1}^{N(pq)} Il_{\{IE(pq,i)\}}^{c} + \sum_{i=1}^{N(pq)} Ish_{\{IE(pq,i)\}}^{c} \end{bmatrix} \qquad (11)$$

E. *Line Shunt charge model*

Eqn. (11) provides a method to compute the currents through the three phase of the branch between buses p and q. Power fed into the phase a of line between buses p and q at bus p is $V_{p}^{a} \cdot \left(I_{pq}^{a}\right)^{*}$. Power fed into the phase a of line between buses p and q at bus q is $V_{q}^{a} \cdot \left(I_{qp}^{a}\right)^{*}$. Therefore real and reactive power losses in the line between buses p and q may be written as:

$$\begin{bmatrix} LS_{pq}^{a} \\ LS_{pq}^{b} \\ LS_{pq}^{c} \end{bmatrix} = \begin{bmatrix} LP_{pq}^{a} + jLQ_{pq}^{a} \\ LP_{pq}^{b} + jLQ_{pq}^{b} \\ LP_{pq}^{c} + jLQ_{pq}^{c} \end{bmatrix} = \begin{bmatrix} V_{p}^{a} \cdot \left(I_{pq}^{a}\right)^{*} - V_{q}^{a} \cdot \left(I_{qp}^{a}\right)^{*} \\ V_{p}^{b} \cdot \left(I_{pq}^{b}\right)^{*} - V_{q}^{b} \cdot \left(I_{qp}^{b}\right)^{*} \\ V_{p}^{b} \cdot \left(I_{pq}^{b}\right)^{*} - V_{q}^{b} \cdot \left(I_{qp}^{b}\right)^{*} \end{bmatrix} \qquad (12)$$

III. Flow Chart for Three Phase Load Flow

The complete algorithm is presented in the flow charts are shown in Figs. 7 and 8. Fig. 7 shows the algorithm to identify the buses and branches beyond any one particular bus. Fig.8 shows the algorithm for load flow solution. In every iteration, the following steps are followed. In Fig. 5, only one line connecting the bus q to the substation bus p feeds the bus q. The total line current supplied through this line to bus q is determined using eqn. (11).

With the knowledge of current flowing between buses p and q or at the qth bus, from eqn. (11), the proposed algorithm computes the voltage at receiving end bus q by using eqn. (4). In this method, the algorithm computes the voltages at all the buses of the system starting from the substation to all the buses downstream. The algorithm stops if the change in the computed bus voltage magnitudes in successive iterations is within tolerance limit (i.e. $IT \geq ITMAX$).

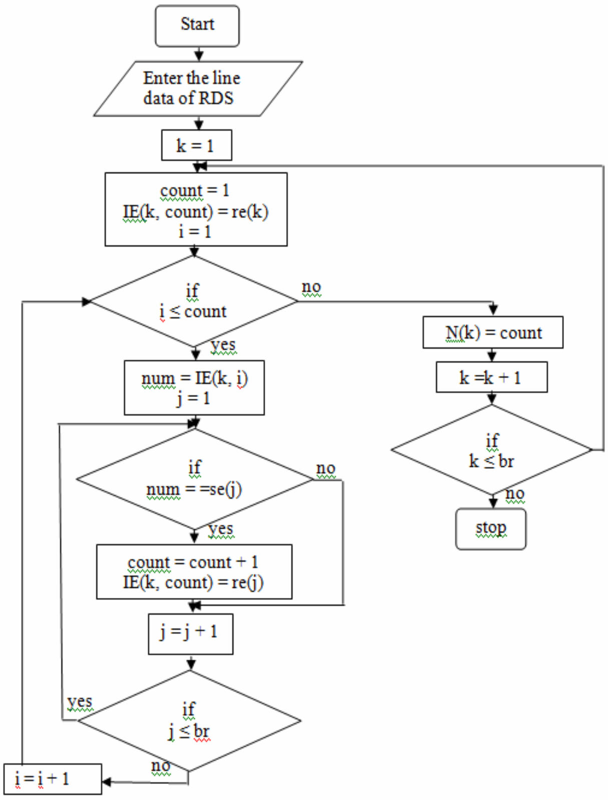

Fig. 7 Flow chart to identify the buses and branches beyond a particular bus

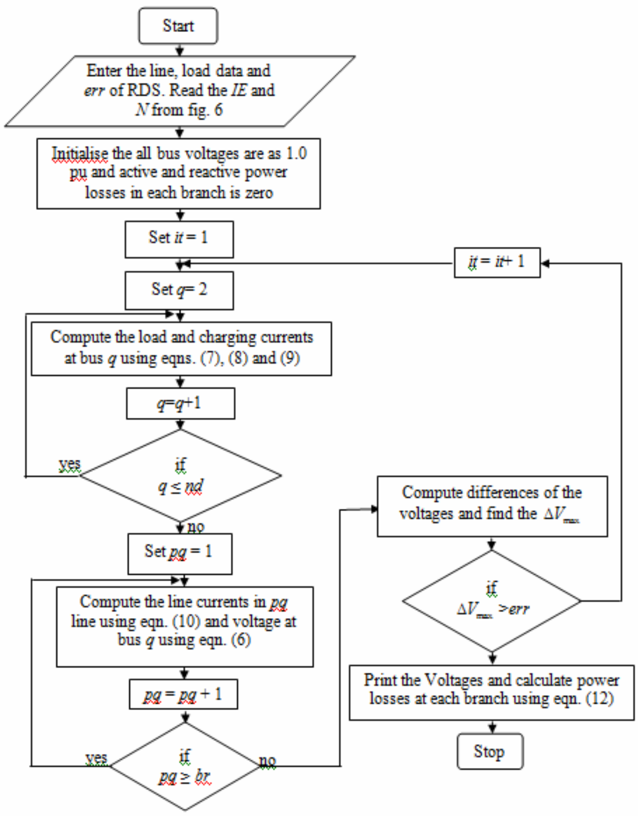

Fig. 8 Flow chart for Load Flow solution

IV. Results and Analysis

The effectiveness of the proposed method has been explained with two unbalanced radial distribution systems.

A. *Case Study 1: 8-bus URDS*

A sample 8 bus unbalanced radial distribution network is shown in Fig. 7 has been taken from the Taiwan Power Corporation [14]. The base values of the system are 14.4 kV and 100 kVA. The convergence tolerance specified is 0.001 p.u. The converged solutions (voltage magnitudes and phase angles) are given in Table 1**.**

TABLE I
VOLTAGES AND ANGLE OF THE 8-BUS UNBALANCED RDS

Bus No	**Forward backward sweep method [6]**		**Proposed Method**	
	|V| (p.u.)	**Angle (deg.)**	**|V| (p.u.)**	**Angle (deg.)**
1a	1.0000	0.00	1.0000	0.00
1b	1.0000	-120.00	1.0000	-120.00
1c	1.0000	120.00	1.0000	120.00
2a	0.9830	0.18	0.9830	0.18
2b	0.9714	-119.76	0.9714	-119.76
2c	0.9745	119.97	0.9745	119.97
3a	0.9822	0.18	0.9823	0.19
4b	0.9655	-119.73	0.9655	-119.73
4c	0.9716	119.93	0.9717	119.94
5b	**0.9643**	-119.74	**0.9644**	-119.74
6c	0.9697	119.92	0.9697	119.92
7c	0.9731	119.96	0.9731	119.96
8c	0.9719	119.95	0.9719	119.95

Table 1 shows comparison of the results obtained by Forward backward sweep method [6] and proposed method. For proposed method, the maximum deviation of voltage and its phase angle from the Forward backward sweep method is 0.0001 p.u and 0.01 deg.. Thus, the two discussed methods are quite accurate. The minimum voltages are obtained by both the methods are highlighted in Table 1.

For both the methods, load flow converged in 2 iterations for the tolerance of 0.001 p.u.. When the tolerance limit is set as 0.0001, the number of iterations required for the convergence is 3 for Forward backward sweep method and 2 for proposed method. The summary of test results is given in Table 2.

The execution time is 0.048 seconds for the Forward backward sweep method and 0.016 seconds for the proposed method on P-IV computer with 1.6 GHz frequency and 128 MB RAM.

TABLE II
SUMMARY OF TEST RESULT OF 8 BUS UNBALANCED RADIAL DISTRIBUTION NETWORK

Load Flow Method	**Tolerance 0.001**	**Tolerance 0.0001**
Forward backward sweep Method [6]	2	3
Proposed Method	2	2

From the above discussion, it is observed that the number of iterations for low tolerance and time of execution by the proposed method is superior when compared with the existing method.

B. *Case Study I1: 37-bus IEEE URDS*

Short and relatively highly loaded for a 4.16 kV feeder is very small and yet displays some very interesting characteristics.. One substation voltage regulator consisting of three single-phase units connected in wye, overhead and underground lines with variety of, phasing Shunt capacitor banks, in-line transformer and unbalanced spot and distributed loads. For a small feeder this will provide a good test for the most common features of distribution analysis software. The line data and load data of the system are given in [20-21]. It is assumed that the transformer at the substation is balanced, voltage regulators and capacitors at various buses is neglected. For the load flow, base voltage and base MVA are chosen as 4.16 kV and 100 MVA respectively. The load flow results are presented in Table 3.

TABLE III
TEST RESULTS OF THE IEEE 13-BUS UNBALANCED RDS

Bus	**$\|V_a\|$ p.u.**	**$\angle V_a$ deg.**	**$\|V_b\|$ p.u.**	**$\angle V_b$ deg.**	**$\|V_a\|$ p.u.**	**$\angle V_a$ deg.**
1	1.00000	0.00	1.00000	-120.00	1.00000	120.00
2	0.95376	-2.12	0.97153	-122.63	0.94217	117.46
3	0.92698	-5.24	0.97167	-122.77	0.87823	115.04
4	0.92698	-5.24	0.97167	-122.77	0.87823	115.04
5	0.95064	-2.20	0.96953	-122.68	0.93937	117.45
6	0.95064	-2.20	0.96953	-122.68	0.93937	117.45
7	-	-	0.95528	-123.27	0.94730	117.42
8	-	-	0.94965	-123.62	0.94944	117.43
9	0.92698	-5.24	0.97167	-122.77	0.87823	115.04
10	0.91870	-5.41	0.97289	-122.86	0.87424	115.15
11	0.92527	-5.29	-	-	0.87492	115.01
12	-	-	-	-	0.87163	114.93
13	0.92005	-5.22	-	-	-	-

The total system losses were found to be the following in each phase of the radial system:

- Phase A: 34.70 kW, 150.49 kVAr
- Phase B: 18.67 kW, 87.26 kVAr
- Phase C: 95.90 kW, 197.25 kVAr

V. Conclusions

In this paper, a simple and efficient computer algorithm has been presented to solve unbalanced radial distribution networks. The proposed method has good convergence property for any practical distribution networks with practical *R/X* ratio. Computationally, this method is extremely efficient, as it solves simple algebraic recursive equations for voltage phasors. Another advantage of the proposed method is all the data is stored in vector form, thus saving enormous amount of computer memory when tested for large systems. The proposed algorithm can be used effectively with Supervisory Control and Data Acquisition (SCADA) and Distribution Automation and Control (DAC) as the algorithm quickly gets the voltage solution and efficient operation of the system.

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