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Clustering Based Load Flow for Three Phase Unbalanced Distribution System with Voltage Sensitive Component Models

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Abstract

This paper presents a novel distribution power flow algorithm to estimate losses and analyze unbalanced distribution systems. An unbalanced distribution network is decomposed into clusters. The unbalanced laterals are solved using the backward/forward sweep method in each phase. The clustering of total network makes faster computation. The three phase modeling of all the distribution transformers, feeders, shunt capacitors and loads compile efficient algorithm. Load modeling is voltage dependent which makes up the load as voltage sensitive. The proposed method is tested on the IEEE 13 Node test system and the results are verified.

Index terms— clustering, load flow, backward/forward sweep, radial distribution system, distribution system modeling, voltage sensitive components

1 Introduction

ower flow analysis is essential for power system planning and operation. With the use of digital computing since 1960 and its rapid development, various power flow algorithms based on modern computing methods have been introduced. Certain applications, particularly in distribution automation and optimization require repeated load flow solutions. The load flow algorithm is used to determine the voltages and line flows for a large-scale power system from a given load and generation data. Conventionally, most of the distribution systems are radial or weakly meshed types. The power flow analysis in such distribution systems becomes more complex because of different characteristic features of distribution networks, such as radial structure and high R/X ratio [1]. Hence distribution system load flow analysis differs significantly from transmission systems. The single-phase power flow methods are normally used in the systems by neglecting unbalance in the system.

In distribution systems, the three-phase balanced statement cannot be practical. Therefore, a three-phase load flow algorithm with complete three-phase modeling is required. The radial distribution structure is also exploited in developing a fast and flexible radial power flow for unbalanced three-phase networks [2]. Several load flow algorithms specially designed for distribution systems have been proposed in the literature [3]- [10]. Those formulations can be divided into two categories. The first category was based on the distribution system general topology and uses the bus voltages as state variables to solve the load flow problem [3]. In this type, the most timeconsuming load flow method is the Gauss implicit Y-Bus method [4], [5]. A fast decoupled load flow algorithm based on Newton Raphson, using rectangular voltage state variables is proposed which improves the execution time of the three-phase load flow [5]. The second category was based on the special network structures of distribution systems [6]- [8]. A compensation-based technique for weakly meshed distribution networks has been proposed [6]. By emphasizing on modeling of dispersed generation (PV nodes), unbalanced and distributed loads, and voltage regulators an algorithm was proposed [7]. Large weakly mesh connected distribution networks are solved by using an efficient tree-labeling technique which enhances computational efficiency as in [8]. The radial parts are solved by a two-step procedure in which the branch currents are first calculated (backward sweep) and then, the bus voltages are updated (forward sweep). Branch power flows rather than branch currents were later used in the improved version [9]. In recent times probabilistic load flows were also proposed considering distributed generation to obtain load flow variations with DG variation through backward forward sweep [10]. A decoupled method in which each phase is modeled in a decoupled way and therefore can be solved independently and the solution method is based on the Zbus Gauss approach, with implicit factorization of the Ybus matrix for each phase [11].

The algorithm proposed in this paper is basically a backward and forward sweep method. The approach used is based on clustering the total network which makes faster computation and also gives accurate results as it considers the three phase models of all the transformers, feeders, shunt capacitors and loads.

2 II.

3 Distribution System Modeling a) Distribution line modeling

The feeder line modeling and the line parameters can be obtained by the method developed by Carson and Lewis [12].

Figure **??** : Three phase transmission line model Fig. **??** shows a three-phase line section between bus 'n'and 'm'. A 4 x 4 matrix, which takes into account the self and mutual coupling effects, can be expressed as (1) Applying Kron's reduction [12], the matrix dimension will reduce to 3 x 3, whereas the effects of the neutral or ground wire are still included in this model, as shown below in (2) For any phase failed to present, the corresponding row and column in this matrix will contain null-entries. The relationships between bus voltages and branch currents as shown in Fig. **??** can be expressed as (3) (1) I nm abc is the current vector through line between bus 'n' and 'm', can be equal to, the sum of the load currents of all the buses beyond line between bus 'n' and 'm' plus the sum of the charging currents of all the buses beyond line between bus 'n' and 'm', of each phase. Therefore, voltage of bus 'm' can be computed if bus 'n' voltage is known, as shown in (4). Year ? n nmZ Z Z Z Z Z Z Z Z Z Z Z Z Z Z Z Z V V V V V V V V V ? n cc nm n cb nm n ca nm n bc nm n bb nm n ba nm n ac nm n ab nm n aa nm abc nm br Z Z Z Z Z Z Z Z Z Z , ? ? ? ? ? ? abc nm br abc nm br abc nm br I Z V , , , ? ? (4) ? c ij I b ij I a ij I abc ij br Z c i V b i V a i V c j V b j V a j V , ? ? ? ? ? ? ? ? ? ? ? ? 1 0 0 0 1 0 0 1 1 t I y Y (7) (2) (3)

Where, y t is the transformer leakage admittance. It is disclose to say that Y II and Y III are the singular matrix and this is valid if tap ratio is 1 on both sides of transformer else the coefficient of the matrix will as follows Where '?' and '?' are the primary and secondary side tap ratios.

The nodal admittance matrices for nine common connections of three-phase transformers were presented in **??**19] and tabulated in Table 1.

The nodal admittance matrix model for a three phase distribution transformer can be represented by (10) Where, The load model equations from [7] are used and the proportions of the loads are given in a arbitrary way for solving the system. Loading of the system is done with the standard loadings but in the ratio load equations considered i.e., the load equations are assumed instead of total assumption of the single load. For example, if the load at a node is 100 KW then 46% (46 KW) of the load is assumed as consumed by refrigerator loads, 22% (22 KW) by fans and air conditioned loads, 18% (18 KW) by the incandescent lights, 8% (8 KW) by dryer loads and 6% (6 KW) by heaters.Ip? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? 2 1 1 1 2 1 1 1 2 3 t II y Y ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? 1 0 1 1 1 0 0 1 1 3 t III y Y YI = 2 ? t y ; YII = 2 3? t y ; YIII = 3 ?? t y ? s p ss sp ps pp s p V V Y Y Y Y I I

4 i. Wye Connected Loads

The notation for the specified complex powers and voltages are as follows:(8)**(9)**

A method for accommodating load compositions may vary by hour, day, season, etc. based on the usage. A pictorial representation showing percentages of the total load is used and is termed as a "load window" as illustrated in Fig. 3.

5 (11)

Where, i-represents a, b and c Phases.

a. Constant Power Load

The line currents for constant real and reactive power loads (PQ loads) are given by: (12) Here, line-to-neutral voltages will change during each iteration until convergence is achieved.

6 b. Constant Impedance Load

The constant impedance load is first determined from the specified complex power and assumed line-to-neutral voltages: (13) The load currents as a function of the constant load impedances are given by: (14) In this model the line-to-neutral voltages will change during each iteration, but the impedance computed in the equation will remain constant.

7 c. Constant Current Load

In this model the magnitudes of the currents are computed according to Constant power equations and are then held constant while the angle of the voltage (?) changes, resulting in a changing angle on the current so that the power factor of the load remains constant: (15) ii. Delta Connected Loads As similar to wye connected loads delta can also expressed as (16) n=0, for constant power loads n=1, for constant current loads n=2, for constant impedance loads

8 III. Solution Methodology

The solution procedure starts using a clustering technique applied to a radial distribution system as shown in figure 4. The basic rules followed for cluster formation are: ? There should be no further bifurcation in the cluster.

? The cluster will start from a branch but not from the node (except first cluster). ? The cluster will have only one parent node and one terminal node.

The clusters are solved by following different notations as shown in Table 2. After the clusters are formed currents are determined in the backward direction i.e., the evaluation starts from the last cluster. Each cluster is passed to the backward sweep function and then the current through each branch is determined. Then the last cluster i.e., here 9 th cluster is passed through the backward sweep it checks whether the terminal node of the cluster is end node or not, if it is the end node then it is taken as the current that flowing out of the node is zero and the current at that nodes is calculated by using the equations given above for respective load type. If there is no transformer in the branch, the branch current is determined by using equation (17).

9 XIII Issue IX Version I

10 ( )

Year i in i i i i V and jQ P S i Phase ? ? ? ? ? ? ? ? c c c c cn c cn c c b b b b bn b bn b b a a a a an a an a a IL V S V S IL IL V S V S IL IL V S V S IL ?) ( ) (S V S V Z Z S V S V Z Z S V S V Z ?V Z V IL IL Z V Z V IL IL Z V Z V IL ?) ( ) ( ) (c c c c b b b b a a a a IL IL IL IL IL IL ? n bc q bc q bc q n ca q ca q ca q n ab q ab q ab q n bc q bc q bc q n ca q ca q ca q n ab q ab q ab q c q b q a q V V SL V V SL V V SL V V SL V V SL V V

11 Where i = cluster number; k = node number

If the terminal node is not the end node then the current through that cluster terminal branch is given by equation (18). (18) Else, if there is a transformer then the core power loss of the transformer is added as the load to node that connected to secondary of the transformer and node current is determined. The intermediate primary voltages V p,m are only to calculate the power injections on the primary side. These are the primary voltages calculated in backward sweeps, which can be found by V V V V ? ? ? 0 , , , ? ? ? c m p b m p a m p V V V ? 0 0 0) 2 1 (,) 2 1 (,) 2 1 (, , p p p c m p b m p a m p m p V V V V V V V

The power injections on the primary side can be calculated by **??**25) Where, (

Then the primary side current injection is calculated as Where x, y are the branches that connect the terminal node of the cluster.Vp,m=[Yps] -1 [Iss] [Iss]=[Is]-[Yss]*[Vs] ?

While calculating the branch currents, the proposed software checks the node numbers with the nodes stored in the array. If there is no transformer in the before branch then the voltages at the nodes are given by equation (30) if the node is not the start node of the cluster.

(30) VN abc (i,k)=VN abc (i,k-1)+IB abc (i,k-1)*Z abc-n (i,k-1)

If the node is the start node then the voltage is given by equation (**??**1 (i,k)=VN abc (i-1,k-1)+IB abc (i,k-1)*Z abc-n (i,k-1) ? ? p pp p ps s V Y I Y V ? ? ?1 ? ? 3 , , , 0 c m s b m s a m s s V V V V ? ? ? VN abc (i, k)=Vs abc LP abc (i, k) = [IB 2] abc (i, k) *R abc-n (i, k Lq abc (i,k)=[IB 2] abc (i, k) *X abc-n

Clustering Based Load flow for Three Phase Unbalanced Distribution System with Voltage Sensitive Component Models

If Y ps is singular then we have to follow the similar approach that stated for V p,m calculation by which we get sum of positive and negative sequence values, for the zero sequence we use following expression.

Step 1 : Active and Reactive loads at each node are to be given in the proportions of the load models, based on the load window in the chronological order.

Step 2 : Branch impedance values for each branch along with its starting and ending nodes is to be given in the chronological order.

Step 3 : Cluster the branches to implement backward forward sweep methodology

Step 4 : Based on the number of times a particular node repeats itself as starting node, the number of clusters emanating from that particular node is obtained.

Step 5 : After detection of parent node by traversing through sending end node, final node of cluster is obtained at the end of chronological order.

Step 6 : By implementing similar steps to the entire system all cluster sets formed are arranged as an array of structures for better computational ability.

Step 7 : Each structure element tracks the requisite data to calculate voltage and current profiles of the constituents of a cluster.

Step 8 : Based on the cluster order, backward sweep is executed which involves calculation of branch currents from voltage profile of previous iteration or initial conditions.

Step 9 : Forward sweep is executed in the forward direction which updates the voltages and the loads based on the deviation of voltage as per load models

Step 10 : Repeat the process until the system is converged.

V.

12 Flow Chart

The proposed method is applied to an IEEE-13 Bus unbalanced Radial Distribution System and the results are tabulated as in Table 3. The results are verified with the standard test results [18]. The results are also compared with the Node Admittance method proposed in [15] as shown in Table 4 . Both methods were executed on a Microcomputer with 2.6 GHz Intel i5 Processor. [1]

Figure 1:

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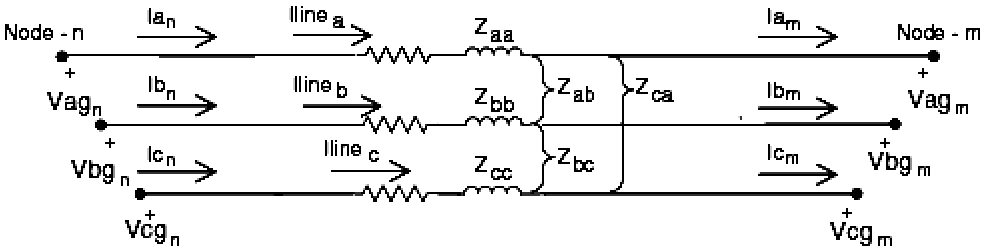


2

Figure 2: Figure 2 :

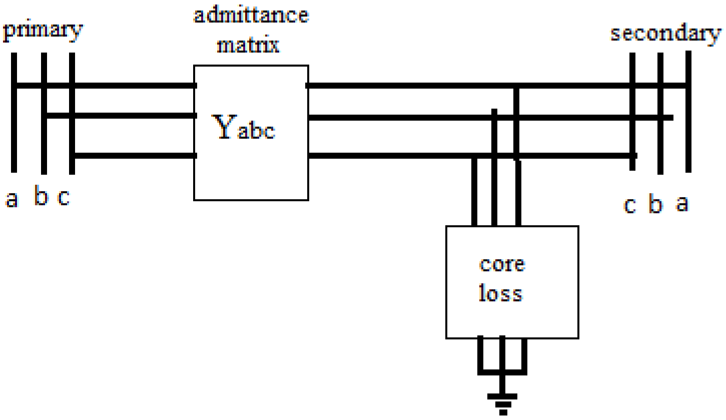


Figure 3:

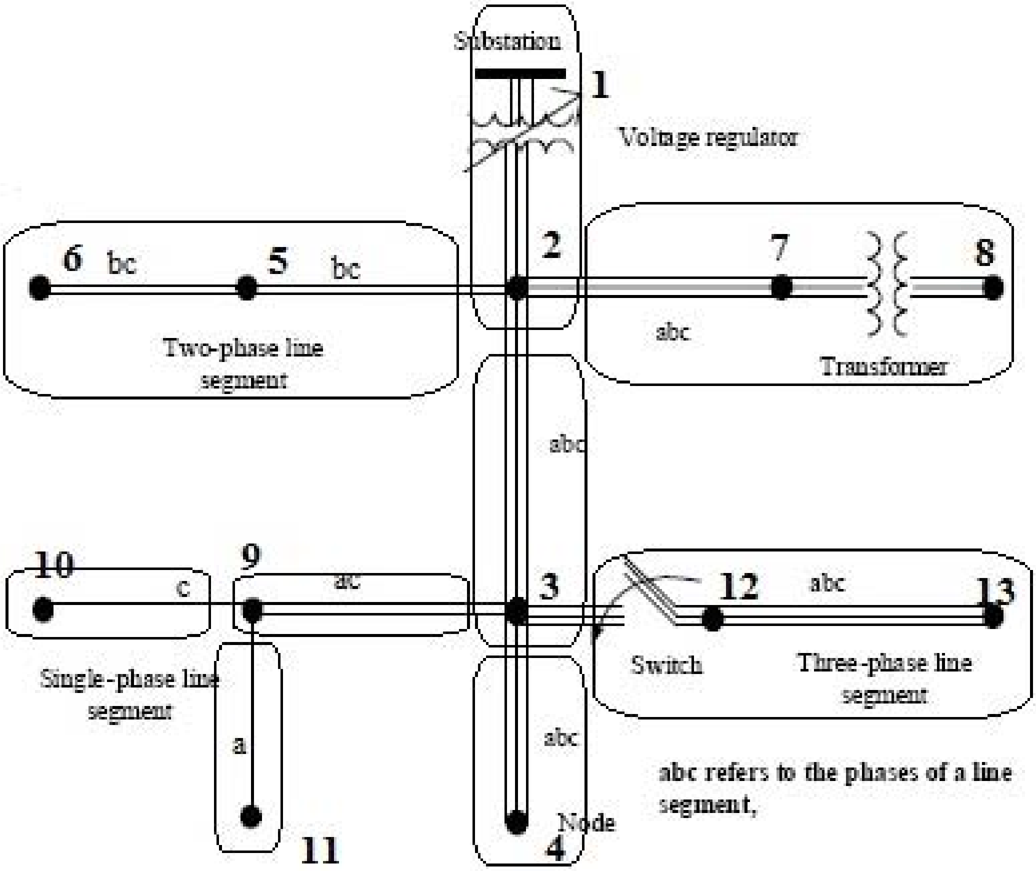
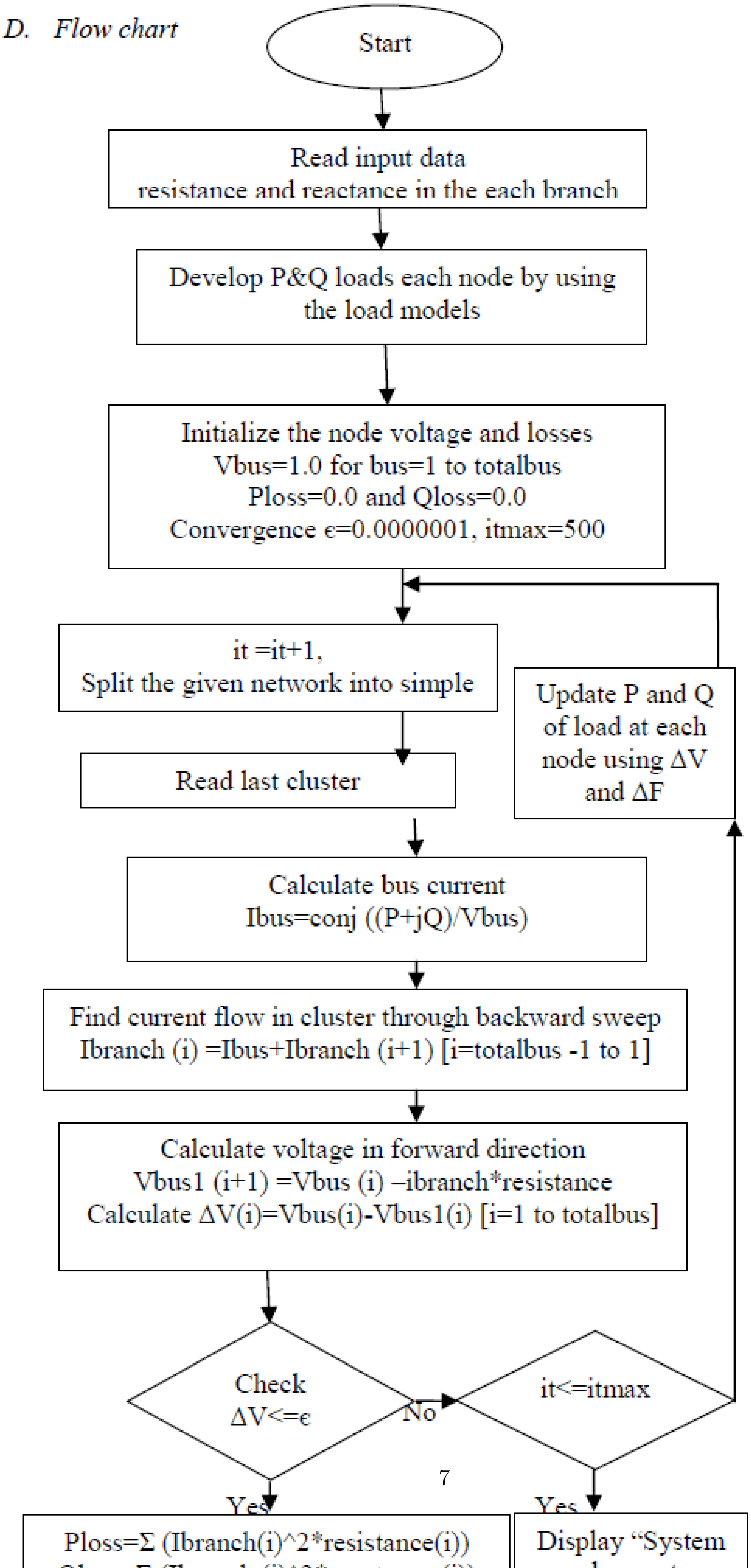

Substation
1
Voltage regulator
6
bc
5
bc
2
7
8
Two-phase line segment
abc
Transformer
abc
10
9
c
ac
3
12
abc
13
Single-phase line segment
Switch
Three-phase line segment
a
abc
abc refers to the phases of a line segment,
11
Node
4

Figure 4: F

D. *Flow chart*


Start
Read input data
resistance and reactance in the each branch
Develop P&Q loads each node by using the load models
Initialize the node voltage and losses
Vbus=1.0 for bus=1 to totalbus
Ploss=0.0 and Qloss=0.0
Convergence ϵ=0.0000001, itmax=500
it =it+1,
Split the given network into simple
Read last cluster
Update P and Q of load at each node using ΔV and ΔF
Calculate bus current
Ibus=conj ((P+jQ)/Vbus)
Find current flow in cluster through backward sweep
Ibranch (i) =Ibus+Ibranch (i+1) [i=totalbus -1 to 1]
Calculate voltage in forward direction
Vbus1 (i+1) =Vbus (i) –ibranch*resistance
Calculate ΔV(i)=Vbus(i)-Vbus1(i) [i=1 to totalbus]
Check
ΔV<=ϵ
No
it<=itmax
Yes
Yes
Ploss=Σ (Ibranch(i)^2*resistance(i))
Display “System

4

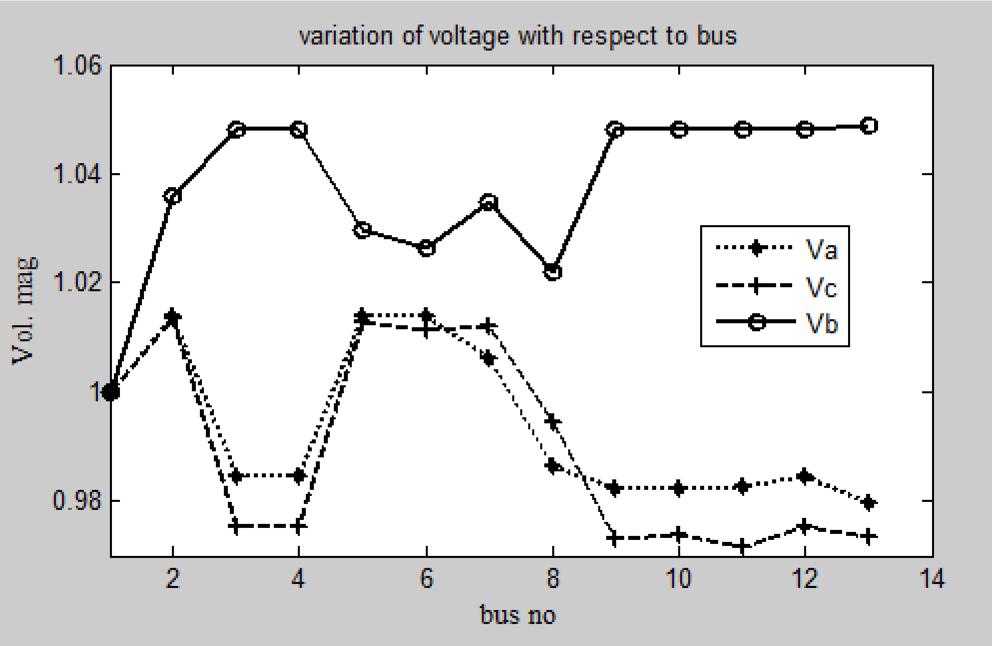


Figure 6: Figure 4 :

1

Figure 7: Table 1 :

2

Figure 8: Table 2 :

3

Figure 9: Table 3 :

4

Gl

Figure 10: Table 4 :

(17)

(31

If there is transformer in the previous branch then we calculate the voltage of the node that connected to secondary of the transformer as (32)

Here, Ip is similar to that of calculated in backward sweep of that iteration.

If Y ss is also singular then V s 0 is entirely a function of downstream grounding conditions. If the downstream sub network contains no zero sequence current paths then V s 0 is zero. The voltage of the node that connected to the secondary is given by below expression (34)

The power losses in the system are given by (35) (36) After computing the voltages at all nodes, convergence of the solution is checked. As per the method proposed in this paper, the solution converges after successive iterations if the maximum difference in voltage magnitude (Î?”V max) is equal to 0.00001.

VI. Results

modeling. An unbalanced radial distribution network is decomposed into a main three phase circuit and unbalanced laterals. An improved load flow algorithm has been used which reduces the time and iterations for the convergence. The advantage of the proposed formulation is that a complicated distribution network is decomposed to many sub systems. By considering the load models this load flow can also be easily applicable to real time system with efficient data and calculations.

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