# A NOVEL APPROACH TO RECONFIGURE RADIAL DISTRIBUTION NETWORKS FOR VOLTAGE PROFILE IMPROVEMENT

**P.J.R.Vaishnavi[1], Dr. V.Bapi Raju[2]**

[1]PG Student, A.U. College of Engineering (A), Dept. Electrical Engg., A.P, India, pjrvaishnavi1@gmail.com.
[2]Professor, A.U. College of Engineering (A), Dept. Electrical Engg., A.P, India, drbapibv @yahoo.com.

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*Abstract— Electricity distribution is the penultimate process in the delivery of electric power. With the available resources, proper planning and utilization of the resources, should lead to an effective and efficient distribution system. One characteristic of the distribution networks is their high r/x ratios. This leads to misbehavior of many analytical models, especially in the case of power flow analysis. In this paper, an attempt is made to explore the possibility of adapting the so called general purpose FDLF model [4] for distribution systems. However, a power flow model [10], particularly suitable for radial distribution systems is applied. The sensitivity of the above methods for initial guess solution and for high r/x ratios is explored and an alternative approach for the initial guess solution is proposed.*

*In this paper, an approach for Network Reconfiguration for the improvement in voltage profile and reduction in system real power losses is explored. In radial distribution networks, the improvement in voltage profile is realizable by tie line placement resulting in re-routing of powers. An attempt is made in this paper to determine the buses between which the tie line should be placed and also the importance for the consideration of the circuit breaker ratings for the tie line placement. A tie line placement results in the creation of a loop. This process results in a weakly meshed distribution network. However an attempt is made to determine which line to be switched out in the loop, to maintain radiality to the possible extent and also to improve system performance.*

***Key Words*: Alternative to FDLF, Complex Distribution networks, Network Reconfiguration, Anchoring Node, Landing Node.**

## 1. INTRODUCTION

Electric power distribution system is an integral part of an electric power system in delivering electric power to the consumers. The utilities are switching to computer-aided monitoring, control and management for efficient operation to increase revenues. In view of the increased importance, a systematic analysis of these networks is a must for both planning and operational purposes. For steady state analysis, Gauss-Seidel, Newton-Raphson and Fast-decoupled Load Flow models and their variants suffered from poor convergence characteristics as these networks grew with high r/x ratio power lines.

Very few papers are published dealing with power flow models relevant to distribution networks. The distribution networks are mostly radial in nature and in order to enhance the reliability, weak enmeshing is being done. It is widely reported in the literature [5][6][7] that the existing power flow models suitable for transmission networks proved to be either unreliable or do not work for both radial and enmeshed type of configurations. Hence, researchers are trying to develop appropriate power flow models with an objective for strong convergence characteristics suitable for all classes of distribution networks. The literature suggests that there is no single power flow model suitable for both radial distribution networks and enmeshed distribution networks [10] [11] [5].

Kersting [6] and Kersting and Mendive [7] have developed a load flow technique for solving radial distribution networks using ladder network theory. They have developed the ladder technique from basic ladder-network theory into a working algorithm, applicable to the solution of radial load flow problems. Stevens *et al* [8] have shown that the ladder technique is found to be fastest but did not converge in five out of 12 cases studied. Goswami and Basu [9] have presented a direct method for solving radial and mesh distribution networks. However, the main limitation of this method is that no node in the network is the junction of more than three branches .A simple power flow method for radial distribution networks proposed by Das *et al* [10] is considered. It proved to be an efficient method for the solution of radial distribution networks in particular. It involves the evaluation of simple algebraic expressions of the receiving-end voltages. In this method, the loads have been presented as 'constant power' loads. No importance is given for initial guess solution in Das *et al* [10] and other related research works [7][8][9].

In the light of the paper by Bapi Raju *et al* [4] wherein, a general purpose FDLF model was envisaged and the authors claimed, it works for high r/x ratio transmission networks also. In this paper, an attempt is made to explore the possibility of adapting the so called general purpose FDLF model proposed by Bapi Raju *et al* [4] for both radial as well as for enmeshed distribution networks.

In radial distribution networks, the improvement in voltage profile is realizable by tie line placement resulting in re-routing of powers. An attempt is made in this paper to determine the buses between which the tie line should be placed and also the importance for the consideration of the circuit breaker ratings for the tie line placement. A tie line placement results in the creation of a loop. This process results in a weakly meshed distribution network. However an attempt is made to determine which line to be switched out in the loop, to maintain radiality to the possible extent and also to improve system performance.

## 2. PROBLEM FORMULATION

As compared to the classical approaches of voltage profile improvement and loss minimization, with the advent of Information Technology associated with GIS/GPS, one of the most important tools for the improvement in voltage profile and reduction in system losses is considered to be Reconfiguration approach. In literature several methods have been proposed for reconfiguration. Wagner *et al* [12] have used a linear programming method using transportation techniques and a new heuristic search method was proposed. Baran and Wu [13] have used the network reconfiguration for loss reduction and load balancing. Ying-Tung Hasio [14] proposed a multiobjective evolution programming method for distribution feeder reconfiguration. Venkatesh *et al* [15] have proposed a fuzzy evolutionary programming technique for optimal reconfiguration of radial distribution systems.

In all the above methods, the networks considered are such that there are tie lines already present in the network. A question arises for the criterion followed as – why the tie lines are considered between those buses only? Clear cut criterion/strategies are not presented in the above referred works. This is an important issue in the context of network reconfiguration.

Distribution networks are not always radial in nature. From the reliability point of view they will be configured as meshed networks. A meshed distribution network inherently contains loops. To convert these networks to radial networks, one of the lines present in that particular loop is being switched out. The number of lines to be switched out depends on the number of loops. There is no criterion followed to switch out the line. *However, an attempt is made here to switch out a line keeping the objective of voltage profile improvement as the criterion.* Also emphasis is to determine which line to be switched out so that the voltage profile of the system is improved and also reduction in system losses.

In radial distribution networks, the improvement in voltage profile is done by tie line placement.In such networks, the bus which is farthest away from the substation will have the least voltage. This bus is taken as the ***'Anchoring Node'*** and the reconfiguration studies are made via this node to identify the ***'Landing Node'*** between which tie line has -to be established. A very important aspect which should be considered during placement of a tie line are the circuit breaker ratings located at the buses.

Initially, for the radial distribution network under consideration, the load flow is performed. From the load flow results, the voltage profile of the network is obtained. The bus which is having the least voltage is considered as the ***'Anchoring Node'***. This ***'Anchoring Node'*** is connected to the most suitable node in the network based on the criterion of minimum loss/ improvement of voltage profile. For each such individual connection, the network performance is obtained. During such an interconnection of the ***'Anchoring Node'*** with another node of the network, a loop is formed. To maintain the radial nature of the network one of the lines from that loop should be switched out. The factors which are considered for such a study are voltage profile, real power losses of the network and short circuit MVA of the buses

During reconfiguration, the network topology changes. A new interconnection between the buses comes into picture for each configuration. During such interconnections, due to re-routing of powers, there may be conditions where high currents flow in the lines. This reduces the reliability and the circuit breaker would tend to be burdened with unreliable operations. This stress, to which a breaker is subjected, is directly related to the short circuit capacity of the breaker. The short circuit MVA (SCMVA) is evaluated as: $SCMVA = \frac{BaseMVA}{Z_{th}(pu)}$

Where, $Z_{th}$ (p.u) is the per unit Thevenin's impedance at that bus.

For the original network, the Thevenin's impedances are calculated at all the buses and the SCMVA capacity of the breakers are calculated. These values are considered as the base values and the limit values are determined with +20% tolerance. SUL is the limit of the SCMVA with +20% tolerance at that bus. Such a limit is determined at all the buses. During reconfiguration, as the network topology changes, for each such network topology the following calculations are done:

- Initially, the load flow is performed. From the load flow results, the voltage profile of the network is obtained. The total losses of the network are also determined.
- The Thevenin's impedances are calculated at all the buses from which the SCMVA of the circuit breakers are calculated. The SCMVA of the buses are checked whether they are within limits or not.

From the above, further discussions are made to examine the validity of the reconfiguration.

## 3. METHOD OF APPLICATION

The following illustration network, shown in Figure 1, is considered as an example to explain the method of reconfiguration for the radial network.

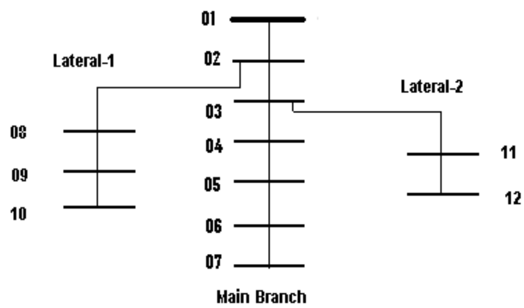


**Fig 1.12 Node Example for Illustration**

The above radial network consists of 12 nodes with 2 laterals. Initially the load flow is performed for this network and the voltage profile is obtained. The bus which is having the least voltage is determined. Bus 7 is having the least voltage of 0.992011 p.u.

In order to form the tie line, for an improved performance such as minimum loss condition and /or improved voltage profile condition are chosen as criterion of goodness to connect the ***'Anchoring Node'*** with any other node in the whole system. With this objective in mind an exhaustive search is needed to be carried out to identify the node to which the ***'Anchoring Node'*** has to be connected via suitable line parameters. This node to which the anchoring node is connected is referred to as the ***'Landing Node'*** in the entire thesis.

Loops are formed and one of the lines within the loops must be switched out, other than the line connecting the anchoring node, to maintain the radial nature. The lines are numbered as in accordance to the nodes. For example, bus 7 is connected with bus 2 and so a loop is formed in the network. The lines in the loop are (2,3,4,5,6). When bus 2 is connected with bus 7 and line 3(line between node 2 and 3) is switched out, the network topology is obtained and the network conditions (such as voltage profile, real power losses and SCMVA) are obtained. Similarly, when bus 2 is connected with bus 7 and line 3 is switched out, all the network conditions are obtained. Similar study is continued when bus 2 is connected with bus 7 and line 6 is switched out. In this process, switching out of all the lines one after the other is considered and the performance of the network is compared.

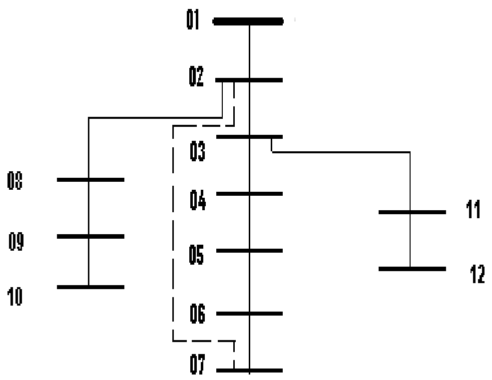


**Fig 2. Tie line illustration for 12 node example network**

Next, bus 7 is connected with bus 3 and the lines in that loop are (3,4,5,6). When each of these lines are switched out, for such an interconnection, the network conditions are obtained. Continuing in the same fashion as outlined above, bus 7 is connected with bus 5 and a similar exercise is repeated. The reconfiguration process is continued with other laterals also as is being done with the main branch.

Initially, consider lateral-1. Bus 7 is connected with bus 8 and the loop formed contains the lines (7,2,3,4,5,6). Line 7 cannot be switched out because the main aim of such an exercise is improvement in voltage profile. For such a network topology, the main branch interconnection remains the same and bus 8 is connected to bus 7 down the line. For such a network topology there is no improvement in voltage profile.

The above mentioned exercise is repeated for bus 7 connected with bus 8 and lines (2,3,4,5,6) switched out individually. The same exercise is repeated for the interconnection of bus 7 with lateral-1 and lateral-2. So now as a whole for each network topology the network conditions are obtained and are analyzed.

The above methodology is implemented on a digital computer as per the discussed algorithm, and is tested on a 33 node distribution network which is a frequently referred test example in the literature [10] [13] [15].

## 4. RESULTS AND DISCUSSSION

The feeder voltage profile for a 33 node test radial distribution network is obtained from load flow studies and showed graphically in the below figure.

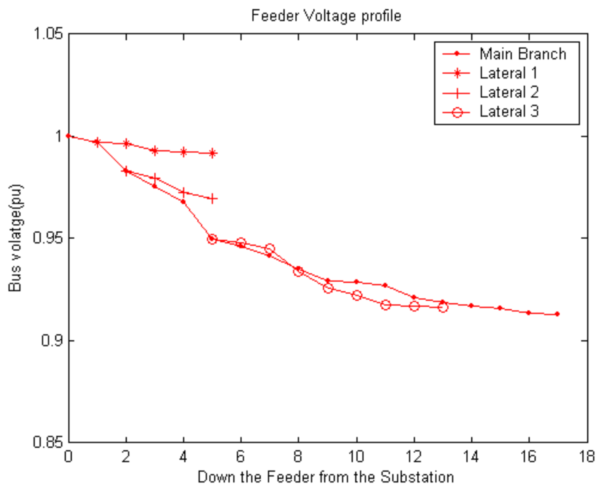


**Fig 3. Feeder Voltage Profile of a 33 bus test radial distribution system**

For the 33 node test radial distribution network, bus-18 has the least voltage, as shown in Fig 3. The losses for this network, which is considered as the 'base-case' network, are 202.67 KW and the least voltage of the network is at bus 18 and is equal to 0.91309 Pu.

Consider the tie line 7-18 with line 13 switched out. The losses are 187.144394 KW and the least voltage is at bus 33 and is equal to 0.916880 p. u. This case is one such where the losses have decreased from 202.67 KW to 187.144394 KW. The voltage at bus 18 has increased from 0.91309 p.u to 0.946214 p.u. The least voltage for such a network topology is 0.916880 p.u. And also the circuit breaker ratings are within the limits. For the brevity of space, a typical result in the form of table 1 is presented. From the table it is observed that the voltage profile has improved, the losses have decreased and the circuit breaker ratings are within limits. Hence, such a case of reconfiguration can be considered for the improvement of voltage profile.

| Tie-Line | Line switched out | Losses(KW) | Least voltage | Anchoring node voltage | SCMVA |
|---|---|---|---|---|---|
| 7-18 | 8 | 193.037155 | V[33]=0.916734 | V[18]=0.945817 | Within limits |
| | 9 | 190.676285 | V[33]=0.916791 | V[18]=0.945928 | Within limits |
| | 10 | 188.931717 | V[33]=0.916832 | V[18]=0.946020 | Within limits |
| | 11 | 187.882126 | V[33]=0.916857 | V[18]=0.946088 | Within limits |
| | 12 | 187.162323 | V[33]=0.916876 | V[18]=0.946160 | Within limits |
| | 13 | 187.144394 | V[33]=0.916880 | V[18]=0.946214 | Within limits |
| | 14 | 189.353500 | V[33]=0.916842 | V[18]=0.946271 | Within limits |
| | 15 | 191.066574 | V[33]=0.916809 | V[18]=0.946274 | Within limits |
| | 16 | 193.514984 | V[33]=0.916762 | V[18]=0.946262 | Within limits |
| | 17 | 196.580048 | V[33]=0.916701 | V[18]=0.946235 | Within limits |
| 8-18 | 9 | 195.571884 | V[33]=0.916704 | V[18]=0.941020 | Within limits |
| | 10 | 193.550400 | V[33]=0.916752 | V[18]=0.941132 | Within limits |
| | 11 | 192.247543 | V[33]=0.916782 | V[18]=0.941213 | Within limits |

| | | | | | |
|---|---|---|---|---|---|
| | 12 | 191.164154 | V[33]=0.916807 | V[18]=0.941298 | Within limits |
| | 13 | 190.739914 | V[33]=0.916818 | V[18]=0.941363 | Within limits |
| | 14 | 191.962357 | V[33]=0.916797 | V[18]=0.941433 | Within limits |
| | 15 | 193.215637 | V[33]=0.916772 | V[18]=0.941438 | Within limits |
| | 16 | 195.125275 | V[33]=0.916734 | V[18]=0.941427 | Within limits |
| | 17 | 197.60.3836 | V[33]=0.916683 | V[18]=0.941398 | Within limits |
| 9-18 | 10 | 198.202805 | V[33]=0.916656 | V[18]=0.934761 | Within limits |
| | 11 | 196.718826 | V[33]=0.916691 | V[18]=0.934864 | Within limits |
| | 12 | 195.349258 | V[33]=0.916722 | V[18]=0.934972 | Within limits |
| | 13 | 194.572021 | V[33]=0.916740 | V[18]=0.935057 | Within limits |
| | 14 | 194.839462 | V[33]=0.916739 | V[18]=0.935154 | Within limits |
| | 15 | 195.615952 | V[33]=0.916724 | V[18]=0.935166 | Within limits |
| | 16 | 196.945587 | V[33]=0.916700 | V[18]=0.935162 | Within limits |
| | 17 | 198.775574 | V[33]=0.916660 | V[18]=0.935132 | Within limits |
| 10-18 | 11 | 200.728531 | V[12]=0.915542 | V[18]=0.915542 | Within limits |
| | 12 | 199.135498 | V[33]=0.916646 | V[18]=0.916646 | Within limits |
| | 13 | 198.065201 | V[33]=0.916670 | V[18]=0.916670 | Within limits |
| | 14 | 197.492188 | V[33]=0.916685 | V[18]=0.916685 | Within limits |
| | 15 | 197.840149 | V[33]=0.916679 | V[18]=0.916679 | Within limits |
| | 16 | 198.640808 | V[33]=0.916664 | V[18]=0.916664 | Within limits |
| | 17 | 199.870117 | V[33]=0.916637 | V[18]=0.916637 | Within limits |
| 11-18 | 12 | 199.743500 | V[33]=0.916634 | V[18]=0.928179 | Within limits |
| | 13 | 198.630646 | V[33]=0.916660 | V[18]=0.928290 | Within limits |
| | 14 | 197.928955 | V[33]=0.916678 | V[18]=0.928433 | Within limits |

| | | | | | |
|---|---|---|---|---|---|
| | 15 | 198.209091 | V[33]=0.916672 | V[18]=0.928461 | Within limits |
| | 16 | 198.923645 | V[33]=0.916659 | V[18]=0.928471 | Within limits |
| | 17 | 200.052750 | V[33]=0.916637 | V[18]=0.928459 | Within limits |
| 12-18 | 13 | 199.572952 | V[33]=0.916642 | V[18]=0.926758 | Within limits |
| | 14 | 198.671982 | V[33]=0.916665 | V[18]=0.926914 | Within limits |
| | 15 | 198.840759 | V[33]=0.916662 | V[18]=0.926947 | Within limits |
| | 16 | 199.411118 | V[33]=0.916651 | V[18]=0.926961 | Within limits |
| | 17 | 200.371109 | V[33]=0.916631 | V[18]=0.926953 | Within limits |
| 13-18 | 14 | 201.223145 | V[33]=0.916612 | V[18]=0.920689 | Within limits |
| | 15 | 201.034958 | V[33]=0.916616 | V[18]=0.920743 | Within limits |
| | 16 | 201.122696 | V[33]=0.916614 | V[18]=0.920780 | Within limits |
| | 17 | 201.498871 | V[33]=0.916606 | V[18]=0.920796 | Within limits |
| 14-18 | 15 | 201.733490 | V[33]=0.918427 | V[18]=0.918427 | Within limits |
| | 16 | 201.675827 | V[33]=0.918475 | V[18]=0.918475 | Within limits |
| | 17 | 201.867783 | V[17]=0.918505 | V[18]=0.918505 | Within limits |
| 15-18 | 16 | 202.024307 | V[33]=0.916593 | V[18]=0.917041 | Within limits |
| | 17 | 202.112839 | V[17]=0.915626 | V[18]=0.917072 | Within limits |
| 16-18 | 17 | 202.342773 | V[17]=0.915002 | V[18]=0.915695 | Within limits |
| 21-18 | 10 | 148.092072 | V[33]=0.927678 | V[18]=0.980906 | Within limits |
| | 11 | 149.813461 | V[33]=0.926738 | V[18]=0.981963 | Within limits |
| | 12 | 152.843384 | V[33]=0.925524 | V[18]=0.983292 | Within limits |
| | 13 | 156.837433 | V[33]=0.924299 | V[18]=0.984607 | Within limits |
| | 14 | 168.334534 | V[33]=0.921712 | V[18]=0.987338 | Within limits |
| | 15 | 173.807175 | V[33]=0.920696 | V[18]=0.988303 | Within limits |

| | | | | | |
|---|---|---|---|---|---|
| | 16 | 180.695816 | V[33]=0.919570 | V[18]=0.989387 | Within limits |
| | 17 | 188.468781 | V[33]=0.918428 | V[18]=0.990468 | Within limits |
| 24-18 | 12 | 169.459747 | V[33]=0.923570 | V[18]=0.967147 | Within limits |
| | 13 | 171.311295 | V[33]=0.922621 | V[18]=0.967963 | Within limits |
| | 14 | 178.156250 | V[33]=0.920602 | V[18]=0.969634 | Within limits |
| | 15 | 181.737717 | V[33]=0.919815 | V[18]=0.970254 | Within limits |
| | 16 | 186.500488 | V[33]=0.918935 | V[18]=0.970934 | Within limits |
| | 17 | 192.082977 | V[33]=0.918040 | V[18]=0.971608 | Within limits |
| 27-18 | 8 | 200.471740 | V[33]=0.913806 | V[18]=0.941949 | Within limits |
| | 9 | 197.226593 | V[33]=0.914122 | V[18]=0.942300 | Within limits |
| | 10 | 194.650299 | V[33]=0.914420 | V[18]=0.942634 | Within limits |
| | 11 | 192.884048 | V[33]=0.914665 | V[18]=0.942909 | Within limits |
| | 12 | 191.312408 | V[33]=0.914964 | V[18]=0.943248 | Within limits |
| | 13 | 190.506912 | V[33]=0.915245 | V[18]=0.943568 | Within limits |
| | 14 | 191.257248 | V[33]=0.915770 | V[18]=0.944177 | Within limits |
| | 15 | 192.527466 | V[33]=0.915960 | V[18]=0.944402 | Within limits |
| | 16 | 194.514374 | V[33]=0.916152 | V[18]=0.944633 | Within limits |
| | 17 | 197.165802 | V[33]=0.916329 | V[18]=0.944849 | Within limits |
| 28-18 | 13 | 200.765457 | V[33]=0.910992 | V[18]=0.927930 | Within limits |
| | 14 | 197.417847 | V[33]=0.913046 | V[18]=0.930047 | Within limits |
| | 15 | 197.351349 | V[33]=0.913780 | V[18]=0.930811 | Within limits |
| | 16 | 197.907654 | V[33]=0.914580 | V[18]=0.931637 | Within limits |
| | 17 | 199.209732 | V[33]=0.915361 | V[18]=0.932450 | Within limits |
| 29-18 | 14 | 201.999710 | V[33]=0.910937 | V[18]=0.919711 | Within limits |
| | 15 | 200.929214 | V[33]=0.912095 | V[18]=0.920895 | Within limits |
| | 16 | 200.414337 | V[33]=0.913366 | V[18]=0.922192 | Within limits |
| | 17 | 200.714661 | V[33]=0.914614 | V[18]=0.923477 | Within limits |
| 30-18 | 16 | 201.782532 | V[33]=0.912683 | V[18]=0.917939 | Within limits |
| | 17 | 201.532791 | V[33]=0.914198 | V[18]=0.919495 | Within limits |
| 31-18 | 17 | 202.443954 | V[33]=0.913284 | V[18]=0.914403 | Within limits |

**Table1: Results of 33 node system for Voltage Profile improvement**

## 5. CONCLUSION

- For improvement of voltage profile, via network reconfiguration approach, a new methodology is proposed on the Thevenin's principles wherein the least voltage node is considered as 'Anchoring Node' and the tie line is formed with a 'Landing Node' chosen such that there is an improvement of voltage profile and the radial nature is preserved for the best possible extent by opening the tie switches at either end .
- A new reconfiguration solution is suggested such that the breaker capacity violations do not take place while envisaging for a reconfiguration solution for voltage profile improvement. It is interesting to note that this solution invariably resulted in reduced-loss condition when compared to the base-case value.

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