Power Factor Correction in a Distribution System:
An Optimization Approach

S.Neelima#1 IEEE Member, IEEE Member,
#1 *Associate Professor, Department of Electrical and Electronics Engineering, VBIT, Ghatkesar, Hyderabad-501301, India*
[1]neelimarakesh@gmail.com

Dr P.S.Subramanyam, Senior IEEE Member,
*2 *Professor, Department of Electrical and Electronics Engineering, VBIT, Ghatkesar, Hyderabad-501301, India*
[2]subramanyamps@gmail.com

Abstract- **This paper presents an efficient algorithm to solve the radial distribution power flow problem in complex mode. The relationship between the complex branch powers and complex bus powers is derived as a non singular square matrix known as element incidence matrix. The power flow equations are rewritten in terms of a new variable as linear recursive equations. The linear equations are solved to determine the bus voltages and branch currents in terms of new variable as complex numbers. The advantage of this algorithm is that it does not need any initial value and easier to develop the code since all the equations are expressed in matrix format. It is tested on the distribution systems available in the literature. This proposed method could be applied to distribution systems having voltage-controlled buses also. The results prove the efficiency of the proposed method. In this paper a new method is proposed to improve the power factor of the buses having low power factor.**

Keywords- **Dimension reducing distribution load flow algorithm, Electrical Distribution Network, Power factor.**

I. INTRODUCTION

The distribution systems are characterized by their prevailing radial nature and high R/X ratio. This renders the load flow problem ill conditioned. So many methods [1-8] have been developed and tested ranging from sweep methods, to conic programming formulation. Early research indicated that standard load flow methods fail to converge for ill-conditioned test systems [9]. The basis for the all the sweep methods is that they need an initial value (normally flat) for the voltages and the updating is done in forward and backward way implementing the kirchoff's equations. Expósito and Ramos [8] have proposed a radial load flow technique based on solving a system of equations in terms of new variables and using the Newton approach. Conic programming formulation is [9] to model the power flow problem as a conic optimization problem in terms of new variables. Both the methods the number of variables to be determined is 3N for an N bus radial system. This paper exploits the radial structure of the distribution network and the relationship between the bus powers andbranch powers is expressed as a non-singular square matrix known as element incidence matrix.

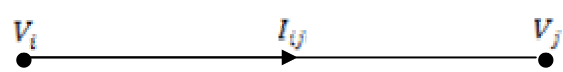
The paper is organized into four sections. The first section describes the conventional radial distribution power flow problem, the second section derives the proposed method for PQ buses, third section deals with treatment of voltage-controlled buses and the fourth section discusses the simulation results. Radial
systems of 12, In [10] the power factor of the buses having low power factor is not improved.

II. DISTRIBUTION POWER FLOW

The distribution power flow is different from the transmission power flow due to the radial structures and high R/X ratio of transmission line. Because of this conventional transmission power flow algorithms does not converge for distribution systems. In this dimension reducing power flow [11] is implemented to determine the power factor and to improve the power factor of the buses of low power factor. The distribution power flow algorithm is the heart of this method.

A. Dimension reducing load Flow Algorithm

The basis for the proposed method is that an n-bus radial distribution network has only $n-1$ lines (elements) and the branch currents (powers) can be expressed in terms of bus currents (powers). For an element 'ij' connected between nodes 'i' and 'j' the bus current of node j can be expressed as a linear equation. In terms of branch current.



$$I_j = I_{ij} - \sum_{k(j)} I_{j,k(j)} \qquad (1.1)$$

$k(j)$ is the set of nodes connected to node j. For the slack bus the power is not specified, so it is excluded and the relationship between remaining bus currents and branch currents are derived as a non-singular square matrix.

$$I_{bus} = K \ X \ I_{branch} \qquad (1.2)$$

$$I_{bus} = [I_{b2}, I_{b3} ... I_{bn}] \qquad (1.3)$$

The matrix K is named element incidence matrix. It is a non-singular square matrix of order $(n-1)$. I_{bus} is the column matrix of size n-1. The elemental incidence matrix is constructed in a simple way same like bus incidence matrix. In this matrix K each row is describing the element incidences. The elements are numbered in conventional way i.e. the number. of element 'ij' is ($j-1$).

- The diagonal elements of matrix K are one. The variable j is denoting the element number.

$$K\,(\mathrm{i},\mathrm{j}) = 1 \qquad (1.4)$$

- For each 'j'the element let $m\,(j)$ is the set of element numbers connected at its receiving end.

$$K\,(\mathrm{i},\mathrm{m(j)}) = -1 \qquad (1.5)$$

- All the remaining elements are zero. It can be observed that all the elements of matrix K below the main diagonal are zero.

$$I_{branch} = K^{-1} \ X \ I_{bus} \qquad (1.6)$$

The relationship between the branch currents and bus currents can be extended to complex branch powers and bus powers. The sending end power and the receiving end powers are not same due to transmission loss. The transmission loss is included as the difference between the sending end/receiving end powers derived. The relationship between branch powers and bus powers is established in same way of bus/branch currents. Multiplying both sides by element incidence matrix K.

$$S_{bus} = K[S_{branch}{}^{sending} - \mathrm{TL}_{\mathrm{branch}}] \qquad (1.7)$$

$$S_{branch} = K^{-1} S_{bus} + \mathrm{TL}_{\mathrm{branch}} \qquad (1.8)$$

The power flow equations are complex multi variable quadratic equations .A new variable R_{ij} is introduced for each element 'ij' and the equations becomes recursively linear.

$$R_{ij} = V_i (V_i^* - V_j^*) \qquad (1.9)$$

The branch power of 'ij' th element is expressed in terms of R_{ij}

$$S_{ij} = P_{ij} + jQ_{ij} = R_{ij} Y_{ij}{}^* \qquad (1.10)$$

$$R_{ij} = S_{ij} Z_{ij}{}^* \qquad (1.11)$$

The dimension reducing power flow method is summarized as following steps.

Step 1 For the first iteration transmission losses are initialized as zero for each element.

From the bus powers specified the branch powers are determined as per equation (1.7 & 1.8).

Step 2 The variable R_{ij} is determined for each element using equation (1.9).

The bus voltage, branch current and bus current are determined from R_{ij}.

$$V_j = V_i - \left(\frac{R_{ij}}{V_i}\right)^* \qquad (1.12)$$

$$I_{ij} = \left(\frac{R_{ij}}{V_{ij}}\right)^* Y_{ij} \qquad (1.13)$$

Step 3 The bus currents are determined from (1.1) and bus powers are calculated. Since the transmission losses are neglected in the first iteration there will be mismatch between the specified powers and calculated powers. The mismatch is a part of the transmission loss. TL_{ij}^{r} is the transmission loss part for 'ij'th element for 'r'th iteration. Transmission loss of each element is the summation of the transmission loss portions of all previous iterations.

$$TL_{ij} = \sum_{1}^{r} TL_{ij}{}^{r} \qquad (1.14)$$

Where r is the iteration count

$$TL_{ij}{}^{r} = K^{-1}\left(S_j{}^{spec} - V_j{}^{r-1} I_j{}^*\right) \qquad (1.15)$$

$$S_{ji} = S_{ij} - TL_{ij} \qquad (1.16)$$

$$S_{branch}{}^{sending} = S_{branch}{}^{receving} - TL_{ij} \qquad (1.17)$$

It can be concluded that the power flow solution always exists for a distribution system irrespective of the R/X ratio if it is having connectivity from the source (slack bus) to all the nodes. For system having less transmission loss the algorithm will perform faster. The convergence criteria is that during the 'r'th iteration the mismatch of power should be less than the tolerance value.

B. Distribution load flow Software Development

After studying and rewriting the power flow equations, a new solution methodology has been developed to determine the voltage profile and power losses in radial distribution system.

The algorithm for Distribution Power Flow summarized as follow.

Step 1*:* Assume base MVA, base KV, slack bus voltage, and initial transmission losses

Step 2*:* Read the data.

Step 3: Form the bus incidence matrix K.

Step 4*:* Determine the inverse of bus incidence matrix K.

Step 5*:* Form the complex power matrix 'S' for the remaining buses (from 2 to n) from the data.

Step 6: Store the specified bus powers in a new matrix $S_{spec} = S$.

Step 7: Find out the branch power using the equation (1.8).

Step 8: Determine the impedance matrix from the data and express in a per unit impedance matrix.

Step 9: Find out nodal voltage at each nodes using the equation (1.12).

Step 10: Find out the branch and bus currents for the network using the equations (1.2 to1.16).

Step 11: Find out the calculated bus power for all nodes. (1.7)

Step 12: Find out the transmission losses using equation (1.17) and add it to specified bus and repeat for 'r' iterations till convergence.

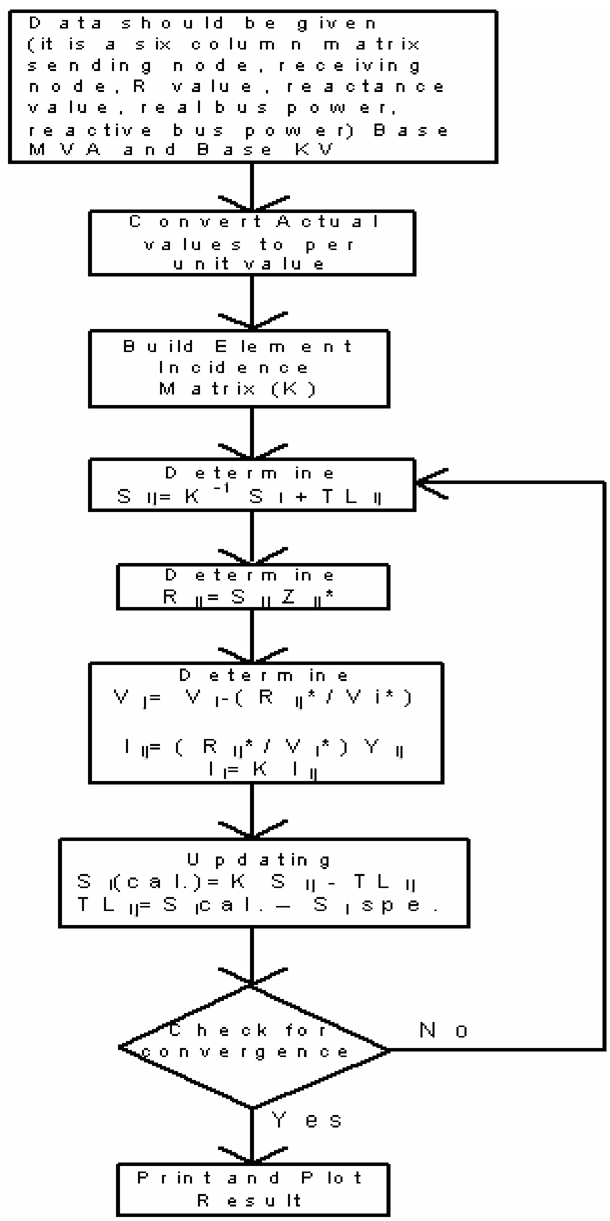


Fig. 1: Flow chart for DRD load flow

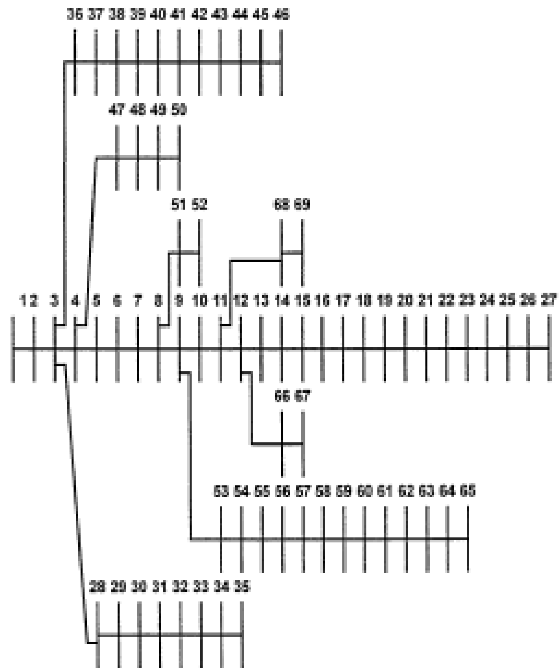


Fig. 2: IEEE 69 bus system

In this the power factor of all the 69 buses is determined, after that the buses having low power factor is found out and then the power factor of the buses having low power factor is set to unity and then by running the load flow is conducted.

Energy Rate = \$4.08 per KWH
Demand Charge = \$2.16 per KW
PF Penalty = \$0.15 per KVARH

TABLE 1: POWER FACTOR CORRECTION

Bus No	Original Power factor	Corrected Power factor	KVAR required
5	0.7633	1	2.2
9	0.7791	1	3.5
40	0.768	1	1
Total KVAR required			6.7

TABLE 2: SAVINGS AT BUS 5 DUE TO PF CORRECTION

Bus No	5
Savings in Energy usage in \$/month	161.575
Saving in demand charge	0.11717

in $/month	
Savings due to power factor penalty in $/month	**240.9**

TABLE 3: SAVINGS AT BUS 9 DUE TO PF CORRECTION

Bus No	**9**
Savings in Energy usage in $/month	**254.563**
Saving in demand charge in $/month	**0.18461**
Savings due to power factor penalty in $/month	**383.25**

TABLE 4: SAVINGS AT BUS 40 DUE TO PF CORRECTION

Bus No	**40**
Savings in Energy usage in $/month	**73.268**
Saving in demand charge in $/month	**0.05313**
Savings due to power factor penalty in $/month	**109.5**

TABLE 5: ANNUAL SAVINGS DUE TO PF CORRECTION

Saving/Cost	**With power factor correction**
Savings at Bus No 5 in $/month	**402.59**
Savings at Bus No 9 in $/month	**637.99**
Savings at Bus No 40 in $/month	**182.82**
Total cost of capacitor in $	**20.1**
Total Savings/month in $	**1203**
Total Savings/year in $	**14,436**

III. CONCLUSION:

This study presents DRD load flow method to solve the IEEE 69 Bus Problem regarding power factor correction in the distribution system. Using this method Energy savings, savings in demand and savings in power factor penalty are obtained.

As the KVAR required is small to correct the power factor, cost of the capacitor required for power factor correction is also very less. By using this method the overall system performance can also be improved. Because of the improvement in the power factor at the buses having low power factor the voltage profile of the system also improves. Finally this method is useful for the consumers who requires the power factor nearer to unity.

REFERENCES

1. Baran ME and Wu FF (1989) Network reconfiguration in distribution systems for loss reduction and load balancing. IEEE Trans. Power Del. 4, 1401–1407.
2. Cespedes R (1990) New method for the analysis of distribution networks. IEEE Trans. Power Del. 5, 391–396.
3. Chakravorty M and Das D (2001) Voltage stability analysis of radial distribution networks. Elect. Power Energy Syst. 23, 129–135.
4. Danaraj RMS (2007) An efficient software to solve distribution power flow in complex mode. Research report, ATRI/R&D/DPF1, Electrical department, Aurora's Technological Research Institute, Hyderabad.
5. Das D, Kothari DP and Kalam A (1995) Simple and efficient method for load flow solution of radial distribution networks. Elect. Power Energy Syst. 17, 335–346.
6. Das D, Nagi HS and Kothari DP (1994) Novel method for solving radial distribution networks. Proc. Inst. Elect. Eng., Gen., Transm. Distrib. 141, 291–298.
7. Expósito AG and Ramos ER (1999) Reliable load flow technique for radial distribution networks. IEEE Trans Power Syst. 14, 1063–1069.
8. Rabih AJ (2006) Radial distribution load flow using conic programming. IEEE transactions on power systems, 21, 1458-1459.
9. Tripathy SC, Prasad GD, Malik OP, and Hope GS (1982) Load-flow solutions for ill-conditioned power systems by a Newton-like method. IEEE Trans. Power App. Syst.. PAS-101, 3648–3657.
10. Reactive Power Loss & Efficiency Calculation Using LoadFlow Technique In Distribution System For Pune City, International Journal of Computer Science and Informatics ISSN (PRINT): 2231 –5292, Vol-1, Iss-4, 2012.
11. An algorithm for radial distribution power flow in Complexmode including voltage controlled buses, Indian Journal of Science and Technology, Vol.1 No.2 (Dec. 2007)