AN EFFICIENT ALGORITHM FOR LOSSES REDUCTION OF RADIAL DISTRIBUTION SYSTEM

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ABSTRACT

This paper present an efficient algorithm for losses reduction of radial power distribution system, in which the choice of the switches to be opened / close is based on the calculation of voltage at the buses, real and reactive power flowing through lines, real power losses and voltage deviation, using distribution load flow (DLF) program.

I. INTRODUCTION

An efficient algorithm that analyzes distribution systems for losses reduction is described. The electric power distribution systems consist of groups of interconnected radial circuits and have a number of constraints like radial configuration, all loads are served, co-ordinated operation of over current protective devices, and voltage drop within limits etc. Each feeder in the distribution system has a different mixture of commercial, residential and industrial type loads, with daily load variations. The process of reconfiguration; by operating switches to change the circuit topology of the network to reduce the operating costs and meeting the constraints listed above is now the demand of the era for quality power supply to the consumers.

Losses reduction of radial distribution system is a matter of actual interest. In effect, recent papers are dedicated to several topics in this field among which:

- Losses reduction to reduce overall system power loss.
- Load balancing to relieve network overloads.
- Co-ordination of the protection scheme of the new configuration.
- The final network configuration is independent on the initial states of network switches.
- Maximum reliability.
- Don't demand continuous maintenance.
- On line reconfiguration.
- Minimize number of switching operation
- Easy fast solution to the problem.

But losses reduction is big challenge for distribution engineers. Several load flow algorithms specially designed for distribution systems have been proposed and published so far time to time. In [1-5] optimal load flow methods for losses reduction in distribution system are proposed.

This paper proposes an efficient algorithm for losses reduction of radial distribution system on 33 bus.

II. MATHEMATICAL ANALYSIS

In order to obtain load flow solutions for losses reduction, first objective is to obtain voltages at the buses.

COMPUTATION OF VOLTAGES AT THE BUSES

If V^k is the voltages of the buses after k^{th} iteration, then voltages at the buses after $(k+1)^{th}$ iteration is given by

$$V^{k+1} = V^k - \Delta V^k \qquad (1)$$

Here ΔV^k is change in bus voltages after two successive iterations.

REAL POWER FLOW

$$P_{ij} = \mathrm{Real}[V_i\{(V_i - V_j)y_{ij}\}^*] \qquad (2)$$

Here P_{ij} is the real power flowing through the line connecting i^{th} and j^{th} buses, Vi and V_j are the voltages of i^{th} and j^{th} bus respectively and y_{ij} is the admittance of the line between i^{th} and j^{th} buses.

REACTIVE POWER FLOW

$$Q_{ij} = \mathrm{Imag}[V_i\{(V_i - V_j)y_{ij}\}^*] \qquad (3)$$

Here Q_{ij} is the real power flowing through the line connecting i^{th} and j^{th} buses.

REAL POWER LOSS

$$\text{Loss} = \text{Real}\left\{V_{ss}\sum_{j\in ss}\left[(V_{ss} - V_j)y_{ss,j}\right]^* - \sum_{j=1}^{N} PD_j\right\} \qquad (4)$$

Where V_{ss} and V_j in Eq. (2.4) refers to the voltages at main substation and bus j, respectively, $y_{ss,j}$ refers to the line admittance between the main substation bus and bus j, PD_j refers to the real power load at bus j and N the number of buses in the RDS.

VOLTAGE DEVIATION INDEX (VDI)

In order to quantify the extent of violation of limits imposed on voltages at buses in a RDS, the following Voltage Deviation Index (VDI) has been defined.

$$VDI = \sqrt{\frac{\sum_{i=1}^{NVB}(V_{Li} - V_{LiLIM})^2}{N}} \quad (5)$$

Subject to $V_{jMIN} \leq V_j \leq V_{jMAX} \quad j \in 1 \text{ to N}$

Where NVB is the number of buses that violates the prescribed voltage limits and V_{LiLIM} is the upper limit of the I^{th} load bus voltage if there is upper limit violation or lower limit if there is a lower limit violation.

III. EXPERIMENTAL

A sample distribution system drawn bellow is taken here to illustrate the methodology [2].

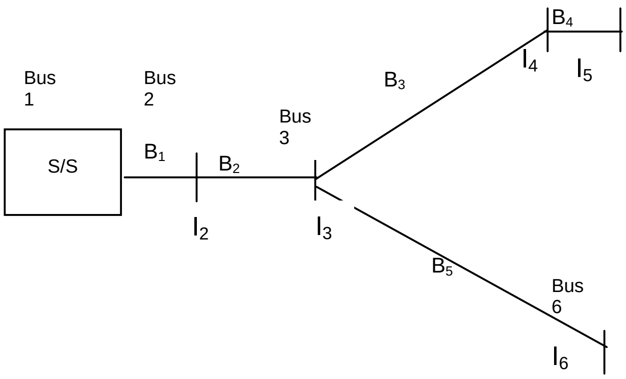

Figure 1. Equivalent current injection based model of distribution network.

The distribution Networks, the equivalent-current-injection-based model is more practical as shown in figure 1.

For bus i, the complex load Si is expressed by

$$Si = (Pi + jQi) \quad i=1\ldots\ldots N \quad (6)$$

Corresponding equivalent current injection at the k^{th} iteration of solution is

$$Ii^k = Ii^k(Vi^k) + j\, Ii^i(Vi^k) = \left(\frac{Pi + jQ_i}{V_i k}\right)^* \quad (7)$$

Where Vi^k and Ii^k are the bus voltage and equivalent current injection of bus I at the k^{th} iteration, respectively. Ii^r and Ji^i are the real and imaginary parts of the equivalent current injection of bus i at the k^{th} iteration respectively.

RELATIONSHIP MATRIX DEVELOPMENT

A sample distribution system shown in fig. 1 is used as an example here. The power injection can be connected to the equivalent current injections by using equation 7 and relationship between the bus current injections and branch current can be obtained by applying Kirchoff's current law (KCL) to the distribution network. The branch currents can then be formulated as functions of equivalent current injections. For example the branch currents B_1, B_2 and B_5 can be expressed by equivalent current injections

$$B_1 = I_2 + I_3 + I_4\, I_5 + I_6$$
$$B_3 = I_4 + I_5$$
$$B_5 = I_6 \quad (8)$$

Therefore the relationship between the bus current injections and branch currents can be expressed as

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{bmatrix} \quad (9.1)$$

Above can be expressed in general form as

$$[B] = [BIBC]\,[I] \quad (9.2)$$

The relationship between branch currents and bus voltages can be obtained as follows:

$$V_2 = V_1 - B_1 Z_{12} \quad (10.1)$$
$$V_3 = V_2 - B_2 Z_{23} \quad (10.2)$$
$$V_4 = V_3 - B_3 Z_{34} \quad (10.3)$$

Substituting (10.1) and (10.2) into (10.3), the equation (10.3) can be written as

$$V_4 = V_1 - B_1 Z_{12} - B_2 Z_{23} - B_3 Z_{34} \quad (11)$$

From (11), it can be seen that the bus voltage can be expressed as a function of branch currents, line parameters and the substation voltage. Similar procedures can be performed another buses; therefore the relationship between branch currents and bus voltages can be expressed as

$$\begin{bmatrix} V_1 \\ V_1 \\ V_1 \\ V_1 \\ V_1 \end{bmatrix} - \begin{bmatrix} V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \end{bmatrix} = \begin{bmatrix} Z_{12} & 0 & 0 & 0 & 0 \\ Z_{12} & Z_{23} & 0 & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & Z_{45} & 0 \\ Z_{12} & Z_{23} & 0 & 0 & Z_{36} \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} \quad (12.1)$$

Above equation (12.1) can be expressed in general form as DeltaV=[BCBV][B] (12.2)

BUILDING FORMULATION DEVELOPMENT

Observing equation. (9), a building algorithm for BIBC matrix can be developed as follows:

1. For a distribution system with m branch sections and n buses, the dimension of the BIBC matrix is $m^x(n-1)$.
2. If a line section B_k is located between bus I and bus j, copy the column of the I^{th} bus of the BIBC matrix to the column of the j^{th} bus and fill a +1 to the position of the k-th row and the j^{th} bus column.
3. Repeat procedure (2) until all line sections are included in the BIBC matrix. From equation (12), a building algorithm for BCBV matrix can be developed as follows.

4. For distribution network with in branch section and n bus, the dimension of BC BV matrix is (n-1) x m.
5. If a line section (B_k) is located between bus i and bus j copy the row of the i[th] bus of BCBV matrix to the row of the j[th] bus and fill the line impedances (Zij) to the positions of the j[th] bus row and k[th] column.
6. Repeat procedure (5) until all line sections one included in the BCBV matrix.

The algorithm can easily be expanded to a multiphase line section or bus. It can also be seen that the building algorithm of the BIBC and BCBV matrices are similar. In fact these two matrices will be made by using same subroutine of our test program. Therefore the competition resources needed, can be saved. In addition the building algorithms are developed based on the traditional bus-branch oriented data base; thus the data preparation time can be reduced and the proposed method can be easily integrated.

SOLUTION TECHNIQUE DEVELOPMENTS

The BIBC and BCBV matrices are developed based on the topological structure of distribution systems. The BIBC matrix represents the relationship between bus current injections and branch currents. The corresponding variations at branch currents, generated by the variations at bus current injection can be calculated directly by the BIBC matrix. The BCBV matrix represents the relationship between branch current and bus voltages. The corresponding variations at bus voltage, generated by the variations at branch currents can be calculated directly by the BCBV matrix. Combining equation (9.2) and (12.2), the relationship between bus current injections and bus voltages can be expressed as

$$[\Delta V] = [BCBV]\,[BIBC]\,[I]$$
$$[\Delta V] = [DLF]\,[I] \qquad (13)$$

DLF is a multiplication matrix of BCBV and BIBC matrices and the solution for distribution load flow can be obtained by solving (8) iteratively as

$$Ii^k = Ii^k\,(Vi^k) + j\,Ii^i\,(Vi^k) = \left(\frac{Pi + jQ_i}{V_i k}\right)^*$$
$$[\Delta V^{K+1}] = [DLF]\,[I^k]$$
$$[V^{k+1}] = [V^0] + [\Delta V^{k+1}] \qquad (14)$$

According to the research, the arithmetic operation, number for LU factorization is approximately proportional to N^3. For a large value of N, the LU factorization will occupy a large portion of the computational time. Therefore if the LU factorization can be avoided, the load flow method can save tremendous computational resource. From the solution technique described in this chapter, the LU decomposition and forward backward substitution of the Jacobian matrix are the Y admittance matrices are no longer necessary. Only the DLF matrix is necessary in solving load flow problem. Therefore above discussed method can save considerable computation resources and this feature make the proposed method suitable for online operation.

IV. RESULTS AND DISCUSSION

Distribution Load Flow (DLF) program has been tested on 33-bus RDS given in Figure 2. The load data, line details and the tie lines available for switching are given in [5]. Substation voltage is 12.66 KV and base MVA has been taken as 10 MVA.

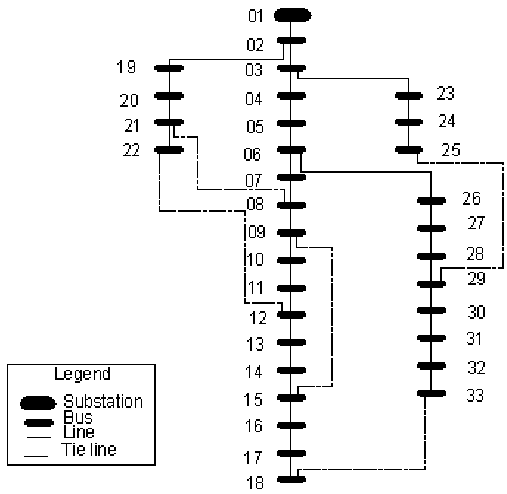

Figure 2. A 33-bus radial distribution system.

System has five tie lines. The two configurations are termed as Base Configuration and Optimal Configuration respectively. Using DLF program voltages at the buses, real and reactive powers flowing through lines, real power loss and voltage deviation index (VDI) were calculated for the two configurations.

Reduction in the real power loss, improved voltage deviation and increased bus voltages are the merits shown by the method used. This can be under stood by having a look on the following tables I and II:

TABLE I

Case	%Loss Reduction	% VDI Improvement	% Increment in Worst Voltage
Base	4.5	30	1.16
Optimal	11.1	4.8	0.106

TABLE II

Case	Loss(DLF/given in [5]) in KW	VDI(DLF/given in [5])	Worst Voltage(DLF/given in [5]) in p.u.
Base	201.42/211	0.0174/ 0.02489	0.9143/ 0.9038
Optimal	158.24/178	0.0039 0.0041	0.9388/ 0.9378

VOLTAGE COMPARISON

V1: Bus Voltages in per unit obtained from the DLF Program for Base Case.

V2: Bus Voltages in per unit obtained by using ETAP software.

TABLE III
COMPARISON OF DLF AND ETAP SOLUTIONS

Bus No.	V1(p.u)	V2(p.u)
2	0.997	0.996
3	0.992	0.984
4	0.985	0.975
5	0.977	0.968
6	0.959	0.951
7	0.956	0.947
8	0.942	0.934
9	0.936	0.929
10	0.93	0.923
11	0.929	0.922
12	0.928	0.921
13	0.922	0.915
14	0.919	0.913
15	0.918	0.912
16	0.917	0.911
17	0.915	0.909
18	0.914	0.908
19	0.996	0.996
20	0.993	0.992
21	0.992	0.991
22	0.991	0.99
23	0.989	0.979
24	0.982	0.972
25	0.979	0.968
26	0.957	0.949
27	0.955	0.946
28	0.943	0.936
29	0.935	0.928
30	0.932	0.924
31	0.928	0.921
32	0.927	0.92
33	0.926	0.919

COMPARISON BETWEEN THE BUS VOLTAGES

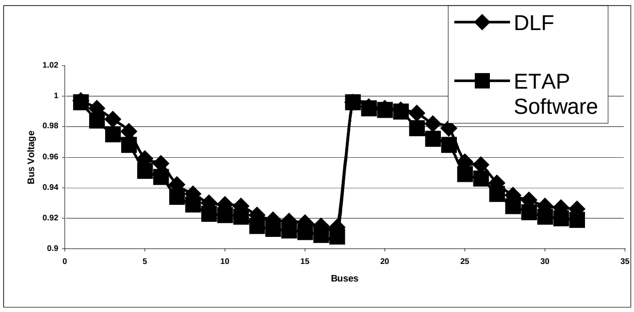

Figure 3. Voltage comparison.

Solutions to the voltages at the buses obtained show that at each bus, voltage in case DLF program is better than those in case of ETAP simulation results. Worst bus voltage in case of ETAP is 0.908 and that in case of DLF method it is 0.914.Also the best voltage is higher in case of DLF solutions. Once the voltages become higher, the losses are bound to be reduced.. For the same load, power drawn in case of ETAP solutions is higher as compared to that obtained by DLF method. This only signifies the fact that losses in latter case have been reduced.

GRAPHICAL COMPARISON OF BASE AND OPTIMAL REAL AND REACTIVE POWER

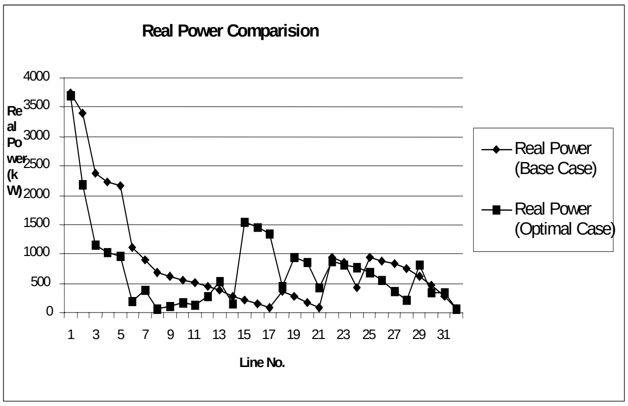

Figure 4. Real power comparison.

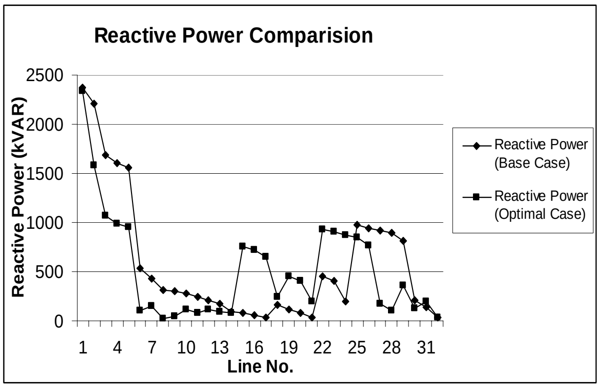

Figure 5. Reactive power comparison.

Figure 4 and 5 are showing the comparisons between real and reactive power respectively flowing through the lines in the two cases. In optimal case lesser real power is required because the loss has been decreased. This was the objective to be achieved through reconfiguration. This discussion is equally applicable to reactive power comparison.

COMPARISON OF BASE AND OPTIMAL VOLTAGES

Figure 6 and 7 compares the results obtained for the two cases considered. It is concluded from the figure that voltages at the buses in case of optimal case is much better than that in the base case for majority of buses. Few buses have lower voltages (in case of optimal case) than that in base case. This is because of the fact that in the former case the structure of the network has been drastically changed as compared to that of later case.

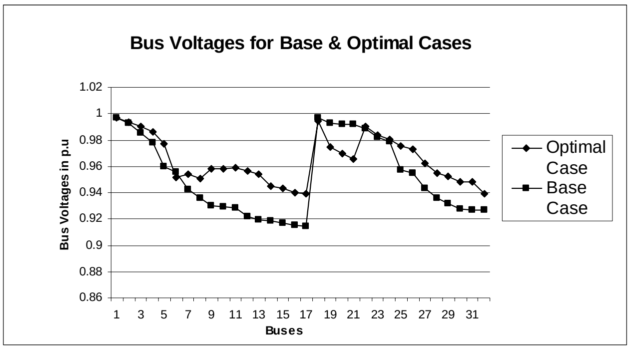

Figure 6. Base and optimal voltage comparison.

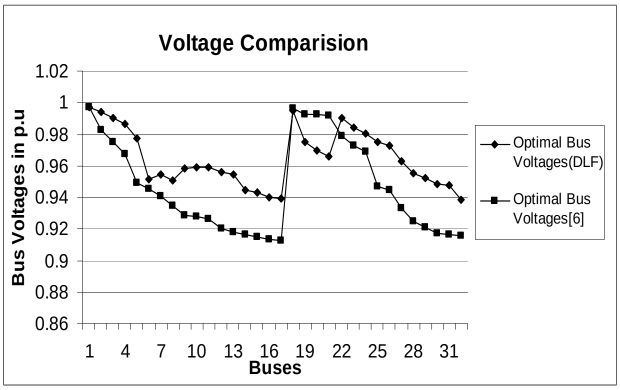

Figure 7. Voltage comparison for optimal cases.

Results obtained indicate that the approach to load flow solutions is much superior to the previous approaches such as used in [2] and ETAP software. For example even in base configuration the worst voltage is better than the worst voltage obtained through ETAP simulation. Also, voltages at the majority of buses are greater than those obtained by the other methods such as in [2] and ETAP simulation. Also, real and reactive powers drawn are lower for the same demand. This aspect leads the system to have lower losses and better voltage deviations index (VDI) as shown by the results.

Results shown and compared in table I and II. The voltage was improved by 4.5% and 11.1% in base case and optimal case respectively. Voltage deviation index was improved by 30% and 4.8% in base case and optimal case respectively. Similarly worst voltage was improved by 1.16% and 0.106% in base case and optimal case respectively.

V. CONCLUSION

In this paper, a new method for losses reduction of radial power distribution system using DLF program is proposed. Two matrices that are developed from the topological characteristics of distribution systems are used to solve distribution load flow problems. The BIBC matrix represents the relationship between bus current injections and branch currents, and BCBV matrix represents the relationship between branch current and bus voltages. These two matrices are combined to form a direct approach for solving load flow problems. The execution time is extremely smaller as compared to other recent methods reported in literature for radial distribution systems, such as fast decoupled and Gauss Implicit Z-matrix method. Here, we do not require to compute Z-matrix or jacobian.

Merit of used method is that it is very effective and solutions get conversed even in second equation there for the execution time of DLF program is quite small. This is the big advantage for distribution system where the load varies indiscriminately. Limitation of the program is that it can be used only for the radial distribution system and, not for meshed distribution systems and transmission systems.

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