Impact of Distribution Generation on Voltage Levels in Radial Distribution Systems

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Abstract

The power distribution network is constantly experiencing an ever growing load demand. The load on the system is not constant and varies over a wide range within the same day. Hence, the system stability is of great concern under severe loading conditions in the distribution system. System stability is characterized by an initial slow variation in system operating point until a sharp accelerated change occurs with load increase. If the system loading increases beyond this point then the distribution system will experience a voltage collapse. In this thesis, load flow solution is obtained for radial distribution systems using a network topology based algorithm and an approach for enhancement of voltage profile of radial distribution system employing Distributed Generators (DG) and Dynamic Voltage Restorer (DVR). The Voltage profiles were compared in between Dynamic Voltage Restorer (DVR) and Distribution Generation (DG) on 6 bus and 15 bus radial distribution systems using the software program developed in MATLAB environment.

Keywords- **Distributed Generation (DG), Dynamic Voltage Restorer (DVR), DG placement, Radial Distribution system.**

I.INTRODUCTION

Distribution load flow is important for distribution automation systems, and distribution management systems. Network optimization, VAR planning, switching, state estimation etc. need the support of robust and efficient load flow solution. Traditional transmission system load flow methods Gauss-Siedel and Newton Raphson techniques, cannot be used for distribution systems as R/X ratio is high. Kresting and Mendive [3] have presented a load flow technique based on the ladder network theory. Teng and Lin(1994) proposed solution for meshed topology. In India, all the 11KV rural distribution feeders are radial and too long.

The voltages at the far end of many such feeders are very low with very high voltage regulation. D.Das and D. P. Kothari have proposed a load flow solution method by writing a algebraic equation for bus voltages [4].

Topology based technique for three phase un-balanced systems is developed by J.H. Teng [5]. Equivalent current injection at each node is considered for the analysis in their work. Shirmohamadi *et al* [5] have presented a compensation based power flow for weakly meshed transmission and distribution systems. Baran and Wu [7] and Chiang [8] have obtained the load flow solution in a distribution system by iterative solution of three fundamental equations representing real power, reactive power and voltage magnitude. In many developing countries, the 11KV rural distribution feeders are radial and too long. The voltages at the far end are very low with very high regulation.

In this thesis, the proposed method involves only evaluation of a simple algebraic expression of voltage magnitude [4] and no trigonometric terms. Topology based approach is used for evaluating equivalent load at every node. This eliminates the complex process of identifying nodes connected beyond a particular node as described in [4]. The two developed matrices, '*bus injection to node power matrix*' and '*line loss to node power matrix'* are very easy to form. The features of this method are robustness and computer economy. Convergence is always guaranteed. The assumption is that shunt capacitance is negligible at the distribution voltage level.

The location of DG and DVR units that should be placed in the system to minimize loss. The sizes of DG units for all nodes are determined for base case and best one is chosen based on the maximum loss saving. This process is repeated if multiple DG locations are required by modifying the base system by inserting a DG unit into the system one-by-one.

II. PROBLEM FORMULATION

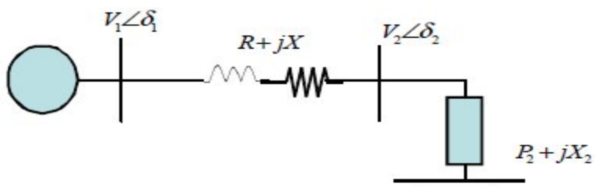

Fig.2.1 Formulation of Distribution Systems

P_2 and Q_2 are effective active and reactive powers supplied beyond node 2. Formulae have been derived in ref [4]. This model of calculating voltages is termed in [4] as simple and efficient method of load flow by Das and Kothari. The same equations are used along with the matrices developed from network topology. This model also requires less memory and rapid. The load flow equations used are,

$$A[j]=P_2R[j]+Q_2X[j]-\frac{V_1^2}{2} \tag{1}$$

$$B[j]=\sqrt{[A[j]^2-(P_2^2+Q_2^2)(R[j]^2+X[j]^2]} \tag{2}$$

$$V_2=\sqrt{[B[j]-A[j]]} \tag{3}$$

$$P_{loss}[j]=R[j]*\left[\frac{P_2^2+Q_2^2}{V_2^2}\right] \tag{4}$$

$$Q_{loss}[j]=X[j]*\left[\frac{P_2^2+Q_2^2}{V_2^2}\right] \tag{5}$$

A. Bus-Injection to Node Power matrix: (BINP)

For distribution systems, the models which are based on the effective load at every node is very convenient. At each bus 'i' the complex power S is specified by,

$$S_i=P_i+jQ_i \tag{6}$$

Pi and Qi are the real power and imaginary powers at i^{th} node. The set of equations can be written by applying Kirchhoff's current law (KCL) to the distribution network. The KCL equations will equally hold good for powers also. For example, consider a simple 6 bus system. N_2, N_3, N_4 , N_5 and N_6 are the equivalent powers at each node.

$$N_2= S_3+ S_4 + S_5 + S_6$$
$$N_3 = S_3 + S_5$$
$$N_4 = S_4+ S_6 \tag{7}$$

Where S_3, S_4, S_5 and S_6 are complex load powers respectively at buses 3,4,5 and 6. Effective load at Node [N] can be obtained by,

$$[N] = [BINP] [S] \tag{8}$$

The constant BIBP matrix has entries of 1 and 0 only. For a distribution system with m-branch sections and n-load buses, the dimension of the BIBC is m X n. The bus where there is no load need not enter into matrix [S].

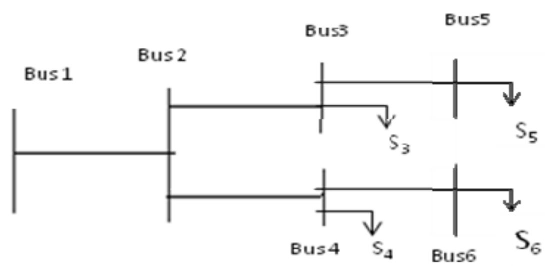

Fig.2.2 Sample Distribution System.

$$\begin{bmatrix} N_2 \\ N_3 \\ N_4 \\ N_5 \\ N_6 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} S_3 \\ S_4 \\ S_5 \\ S_6 \end{bmatrix} \tag{9}$$

B. Line Loss to Node Power matrix: (LLNP)

The relation between the line losses and node power can be obtained by following equations.

$$N_2' = S_{l1} + S_{l2} + S_{l3} + S_{l4} + S_{l5}$$

similarly,

$$N_3' = S_{l4}$$
$$N_4' = S_{l5} \tag{10}$$

Complex power losses associated with lines 1,2,3,4,5 are given by S_{l1}, S_{l2}, S_{l3}, S_{l4} and S_{l5} respectively. Sum of the line losses appearing at Node 2, 3, 4, 5 and 6 are given by N_2, N_3,N_4, N_5, N_6. Total Line loss supplied by node2, N_2.

End nodes will not have to supply and line loss component. So, they will have all zeros in their corresponding rows. Node 2 will have to supply all the line losses except branch -1 loss.S_L is the column matrix containing all line losses.

$$[N'] = [LLNP][S_L]$$

$$\begin{bmatrix} N_2' \\ N_3' \\ N_4' \\ N_5' \\ N_6' \end{bmatrix} = \begin{bmatrix} 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} * \begin{bmatrix} S_{l1} \\ S_{l2} \\ S_{l3} \\ S_{l4} \\ S_{l5} \end{bmatrix} \quad (11)$$

Effective load at each node = N + N' (12)

After calculating the effective load at each node, recalculate the receiving end voltages using the above equations (1) – (3).

Calculate power losses using equations (4) and (5). The voltage values at all nodes change after adding losses.

III. DG PLACEMENT

This algorithm determines the optimal size and location of DG units that should be placed in the system to minimize loss. First optimum sizes of DG units for all nodes are determined for base case and best one is chosen based on the maximum loss saving. This process is repeated if multiple DG locations are required by modifying the base system by inserting a DG unit into the system one-by-one.

3.1 Methodology

Assume that a single-source radial distribution system with *n* branches and a DG is to be placed at bus *m* and α be a set of branches connected between the source and bus m. The DG produces active current I_{DG}, and for a radial network it changes only the active component of current of branch set α. The currents of other branches are unaffected. Thus new active current I_{ai}^{new} of the i_{th} branch is given by

$$I_{ai}^{new} = I_{ai} + D_i I_{DG} \quad (13)$$

where Di = 1; if branch i□α = 0; otherwise, The loss P_{La}^{com} associated with the active component of branch currents in new system (when DG is connected) is given by

$$P_{La}^{com} = \sum_{i=1}^{n} (I_{ai} + D_i I_{DG})^2 R_i \quad (14)$$

The saving S is the difference between equation 2 and 5 and is given by

$$S = P_{La} - P_{La}^{com} = -\sum_{i=1}^{n} (2 D_i I_{ai} I_{DG} + D_{DG} I_c^2) R_i \quad (15)$$

The DG current I_{DG} that provides maximum saving can be obtained from

$$\frac{\partial S}{\partial I_{DG}} = -2\sum_{j=1}^{n} (D_i I_{ai} + D_i I_{DG}) R_i = 0 \quad (16)$$

The DG current for maximum saving is

$$I_{DG} = -\frac{\sum_{i=1}^{n} D_i I_{ai} R_i}{\sum_{i=1}^{n} D_i R_i} = -\frac{\sum_{i \in \alpha} I_{ai} R_i}{\sum_{i \in \alpha} R_i} \quad (17)$$

The corresponding DG size is

$$P_{DG} = V_m I_{DG} \quad (18)$$

V_m is voltage magnitude of bus-*m*. The optimum size of DG at each bus is determined using eqn (4.25). Then saving for each DG is determined using eqn (4.22).

The DG with highest saving is candidate location for single DG placement. When the candidate bus is identified and DG is placed, the process is repeated to identify subsequent buses for DG placement.

Algorithm for the Topology based Method

Step 1: The system data is taken as, V_1= 1.0 pu. Line losses are assumed to be zero in the first iteration.

Step 2: BINP matrix and LLNP matrix are build.

Step 3: Peffective + j*Qeffective, at each node using equation (4.10) were obtained. N represents the part of load powers in the effective load at various nodes.

where, S is the column matrix of all loads.

Step 4: Initialize iteration count =1.

Step 5: The receiving end voltages using simple formulae, from the equation (3)

Step 6: Power loss on all lines was calculated using the formulae from the equations(4) and (5).

$$S_{loss} = P_{loss} + jQ_{loss}$$

Step 7: The power loss column matrix, S_L are multiplied with LLNP matrix to get N' matrix from the equation (11). N' represents the part of line losses in the effective load at various nodes.

Step 8: The total effective load at various nodes are calculated by adding the N and N' matrix from the equation (12).

Step 9: Increment the iteration count Repeat the steps from step (5) using new effective loads at every node.

Step 10: If the difference in the voltages between present iteration and previous iteration is greater than 0.001 pu, then increment the iteration count and repeat from step(5), otherwise, print the result.

Algorithm for Single DG Placement

Step 1: Conduct load flow analysis for the original system.
Step 2: Calculate I_{DG} and DG size using equations 8 & 9 for buses i=2…n.
Step 3: Determine saving using equation (15), for buses i=2…n.
Step 4: Identify the maximum saving and the corresponding DG size.
Step5: The corresponding bus is candidate bus where DG can be placed. Modify the active load at this bus and conduct the load flow again.
Step 6: Check whether the saving obtain is more than 1kW. If yes, go to step 2. Otherwise, go to next step.
Step 7: Print all the candidate locations to place DG sources and the sizes.

Since the DGs are added to the system one by one, the sizes obtained by single DG placement algorithm are local optima not global optimum solution.

IV.RESULTS

The Voltage profiles were compared in between the Dynamic Voltage Restorer (DVR) and Distribution Generation (DG) on 6 bus and 15 bus radial distribution systems.

The Line diagrams for a 6-Bus Distribution Systems are represents along with the line data and load data.
The corresponding results without and with compensation are represented in Table 1.

Table 1: Distribution Voltages for 6-Bus systems when compensation devices are kept at Bus 4.

VOLTAGE	Without Compensation	With Compensation	
		DVR	DG
V1	0	0	0
V2	1.0291	1.0182	1.0632
V3	0.5253	1.0052	1.0160
V4	0.7203	1.0368	0.9731
V5	0.5258	1.0361	0.9350
V6	0.5271	1.0458	0.9125

The Line diagrams for a 15-Bus Distribution Systems are represented along with the line data and load data.
The corresponding results without and with compensation are represented in Table 2.

Table 2: Distribution Voltages for 15-Bus systems when compensation devices are kept at Bus 10.

VOLTAGE	Without Compensation	With Compensation	
		DVR	DG
V1	0	0	0
V2	1.0008	1.0016	1.0016
V3	1.0046	1.0056	1.0056
V4	1.0293	1.0233	1.0225
V5	0.1004	1.0018	1.0030
V6	0.5319	1.0199	1.0308
V7	0.5319	1.0199	1.0308
V8	0.1713	1.0044	1.0075
V9	0.1713	1.0044	1.0075
V10	0.1004	1.0023	1.0030
V11	0.5319	1.0199	1.0308
V12	0.1713	1.0044	1.0075
V13	0.1004	1.0018	1.0030
V14	0.1713	1.0044	1.0075
V15	0.5319	1.0199	1.0308

V.CONCLUSION

In this thesis, load flow solution is obtained for radial distribution systems using a network topology based algorithm and this network topology is used to build two matrices which are Bus- Injection to Node Power Matrix and Line Loss to Node Power Matrix. This method is very efficient and requires very less computer memory.

Also an approach for enhancement of voltage profile of radial distribution system employing distributed generators (DG) and Dynamic Voltage Restorer (DVR) . By observing the Voltage profiles which are obtained, the quality of the power can be maintained by using DG.

The Voltage profiles were compared in between the Dynamic Voltage Restorer (DVR) and Distribution Generation (DG) on 6 bus and 15 bus radial distribution systems using the software program developed in MATLAB environment.

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BIOGRAPHIES

K.Sri Chandan did his B.Tech in Electrical Engineering from ANITS college of Engineering, Visakhapatnam, india in 2005 and M.Tech in Power Systems and Automation from Gitam Institute of Technology, Gitam University, Visakhapatnam, India in 2008.He had Two and Half years of Teaching experience. He is currently employed as Assistant Professor in Electrical Engineering department in Gitam Institute of Technology, Gitam University, Visakhapatnam, India. His research interests are in the Distribution Generation, Smart Grids and Machine Designing.

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