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Distribution Loss Reduction using Distributed Generation

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Abstract—*Technical and commercial loss in primary and secondary distribution networks contribute a huge proportion to the total loss in a power system. Many causes are already identified and investigated into by the various researchers. Poor voltage profile, low power factor, conductors not of proper size, transformers not at load centre etc are some frequently encountered causes. Improvement of voltage profile and power factor, reconductoring, bringing transformer to load centre etc may be considered as remedial measures. With the coming up of various Distributed Generators(DG) the scenario is changing rapidly. In this paper, investigation is carried out for fruitful use of DG with a view to reducing loss with reference to simple 15 Bus distribution system. Two methods are used for finding size and suitable location of selected DG. MATLAB environment is used and comparison is done.*

Keywords*: Distributed Generation(DG); Load Centroid Identification Algorithm; Performance Index, Voltage Stability Index, Backward Forward Sweep Method etc*

1. INTRODUCTION

The power systems are composed of three main networks namely generation, transmission and distribution network along with loads. Loss is inherent of any electrical network. Considerable amount of loss occurs in T&D networks. Both technical and commercial losses contribute to such loss. Length of secondary distribution network is tremendous and hence loss is heavy in this particular part of the system requiring use of loss reduction techniques.

2. DISTRIBUTION SYSTEM

The distribution system supplies electrical power to loads. In earlier days, distribution was in DC. Loss was more when feeder was long resulting in low voltage condition. High voltage transmission could reduce loss but step up/ step down problem was there. On the other hand AC power has the advantage of voltage transformation from one level to another without any change in power and frequency. Thus AC gradually replaced DC in power transmission. The installation of transformer sub-stations became very common.

The distribution system is divided into two categories viz primary distribution system and secondary distribution system. In India for primary distribution, voltage is generally stepped down to 11 kV or 6.6 kV from 33 kV level. For economic benefit, primary distribution is carried out by 3-phase, 3-wire system.

In secondary distribution voltage is generally stepped down from 11kV to 400V and power is delivered through 3-phase 4-wire system.

1.1 Losses in a distribution system

There are two types of losses in a distributed system viz technical losses and non-technical losses

The technical losses are due to the physical properties of the distribution network. Fixed losses take place in the form of heat and noise and its magnitude does not vary with the variation of current through the conductor. The fixed losses in a distribution network may be dielectric loss, corona loss, leakage current loss etc. Variable losses are mainly the I^2R loss which varies as the square of current in the conductors. Non-Technical losses occur due to external action on the distribution system mainly due to human behavior.

1.2 Some causes for technical and non-technical losses in a distribution system

i) Long distance of distribution feeder.
ii) Erroneous placement of Distribution Transformer at secondary/primary level.
iii) Low power factor
iv) Inadequate size of transformers
v) Unbalanced load, overloading, undervoltage, harmonic distortion etc
vi) Power theft by illegal connections or by bypassing the meters etc.

A. Ways to reduce technical and non-technical losses

i) Converting LV lines to HV lines.
ii) Re-conductoring of distribution lines using high cross-sectional area.
iii) Installing DG to reduce technical loss.
iv) Improving the power factor of the system.
v) Installing transformers at load centre etc.

3. DISTRIBUTED GENERATION (DG)

With the passage of time DG started playing vital role in the area of loss reduction both in primary and secondary distribution levels. DG involves the interconnection of small-scale distributed energy resources with the main power utility at distribution voltage level [1][2][3][9]. Solar, wind, diesel generator, dual fuel generator all these independently and in conjunction with one another may contribute a lot for the purpose. This paper aims at evaluating size of DG and also positioning these in proper place. The paper aims at using single DG as well as multiple DG in standard distribution systems e,g, a simple 15 Bus system and IEEE 33 Bus system.

4. BACKWARD FORWARD SWEEP METHOD

Backward/Forward Sweep Method is a load flow method to analyze the power flow in radial distribution systems. Due to radial structure and high R/X ratios of the distribution system, the Newton-Raphson and Fast Decoupled methods are not suitable. By using this method, power losses for each branch and voltage magnitudes for each node are determined. This method has been tested on a simple 15-bus and IEEE 33-bus radial distribution system and effective results are obtained using MATLAB

A. Backward Sweep

The backward sweep is basically a power flow solution with possible voltage updates. In this method, both real and reactive power loss at the branches in the last layer is first calculated and then that in the branches connected to the root node. The updated effective power flows in each branch are obtained in the backward propagation computation by considering the node voltages of previous iteration.

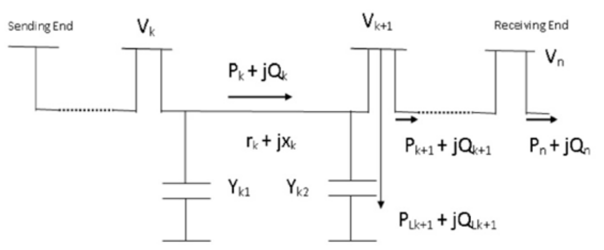

Fig. 1: A simple single line diagram

The following equations are used to obtain real and reactive power loss of the system:

$$P_j = P_{j+1} + P_{loss,}(j,j+1) + P_{Lj+1} \quad ...(4.1)$$

$$Q_j = Q_{j+1} + Q_{loss,}(j,j+1) + Q_{Lj+1} \quad ...(4.2)$$

$P_,$ Q being real and reactive power and P_{loss} , Q_{loss} are real and reactive power loss.

The total real power loss ($P_{T,loss}$) and reactive power loss ($Q_{T,loss}$) can be expressed as:

$$P_{Tloss} = \sum_{j=1}^{n} P_{loss}(j, j+1) \quad ...(4.5)$$

$$Q_{Tloss} = \sum_{j=1}^{n} Q_{loss}(j, j+1) \quad ...(4.6)$$

B. Forward Sweep

The forward sweep is basically a voltage drop calculation with power flow updates. Nodal voltages are updated in a forward sweep starting from branches in the first node toward those in the last.

The voltage magnitude and angle at bus ‘j+1’ can be determined from that of bus ‘j’ from the given equations:

$$I_{b1} = \frac{V_j\angle\delta_j - V_{j+1}\angle\delta_{j+1}}{r_j + jx_j} \quad ...(4.7)$$

$$P(n2) - jQ(n2) = V^*(n2) \times I_{b1} \quad ...(4.8)$$

Solving equations (4.7) and (4.8), we get

$$V_{j+1} = \frac{[\{V_j^2 - (P_j r_j + Q_j x_j)\}^2 + (P_j r_j - Q_j x_j)^2]^{0.5}}{V_j}$$

And

$$\delta_{j+1} = \delta_j + \tan^{-1}\left\{\frac{P_j x_j - Q_j r_j}{V_j^2 - P_j r_j - Q_j x_j}\right\}$$

The above two methods are carried out alternately again and again until

$V_j(n+1) - V_j(n) \leq$ Acceptable Error

$V_j(n+1)$ is the value of voltage magnitude at j^{th} node after ‘n+1’ iterations.

$V_k(n)$ is the value of voltage magnitude at k^{th} node after ‘n’ iterations.

5. VOLTAGE STABILTY INDEX

Voltage Stability Index (VSI) is a numerical parameter to identify the sensitivity of each nodes of a radial distribution system. It also gives an idea to the operator that during any instability in the system, which node is subjected to collapse first. The node with minimum value of VSI is selected as the most vulnerable node.

The mathematical procedure for determining the VSI[] of each nodes is explained below:

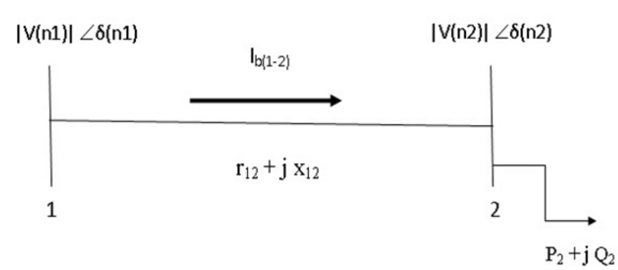

Fig. 2: A simple 2 bus system

From fig 2,

$$I_{b(1-2)} = \frac{|V(n1)|\angle\delta(n1) - |V(n2)|\angle\delta(n2)}{r_{12} - jx_{12}} \quad ...(5.1)$$

$$P(n2) - jQ(n2) = V^{*}(n2) \text{ x } I_{b(1-2)} \quad ...(5.2)$$

P(n2) is the sum of all real power loads at all nodes beyond node n2 and at node n2 itself and sum of the real power losses of all branches beyond node n2.

Q(n2) is the sum of all reactive power loads at all nodes beyond node n2 and at node n2 itself and sum of the real reactive losses of all branches beyond node n2. Other symbols carry usual meaning.

Solving equations (5.1) & (5.2), we get

$$\frac{|V(n1)|\angle\delta(n1) - |V(n2)|\angle\delta(n2)}{r_{12} - jx_{12}} = \frac{P(n2) - jQ(n2)}{V^{*}(n2)} \quad ...(5.3)$$

By solving eq. (5.3), we get the expression given below,

$$|V(n2)|^4 - [|V(n1)|^2 - 2\{P(n2)\, r_{12} + Q(n2)\, x_{12}\}]\, |V(n2)|^2 + \{P^2(n2) + Q^2(n2)\}\{r_{12}^2 + x_{12}^2\} = 0 \quad ...(5.4)$$

$$b(1\text{-}2) = |V(n1)|^2 - 2\{P(n2)\, r_{12} + Q(n2)\, x_{12}\} \quad ...(5.5)$$

$$c(1\text{-}2) = \{P^2(n2) + Q^2(n2)\}\{r_{12}^2 + x_{12}^2\} \quad ...(5.6)$$

From equations (5.4),(5.5),(5.6) we get,

$$|V(n2)|^4 - b(1\text{-}2)|V(n2)|^2 + c(1\text{-}2) = 0 \quad ... (5.7)$$

From Eq. (5.7), voltage of receiving end V(n2) has 4 solutions and out of these only one solution is feasible because two are null and one is negative.

From Eq. (5.8), it is seen that, a feasible load flow solution of Radial Distribution System (RDS) will exist only if

$$b^2(kk) - 4c(kk) \geq 0 \quad ...(5.8)$$

$$|V(n1)|^4 - 4\{P(n2)\, r_{12} - Q(n2)\, x_{12}\}^2 - 4\{P(n2)\, r_{12} - Q(n2)\, x_{12}\}|V(n1)|^2 \geq 0 \quad ...(5.9)$$

SI(n2) = Voltage Stability Index of Node n2. (n2=2, 3, 4....., n) and is given by expression (5.10)

For stable operation of the RDS,

SI(n2) ≥0;   for n2=2, 3, 4.....,n   {n=Total No. of Bus}

By using VSI, stability level of radial distribution networks can be measured and a suitable action can be taken. Node with minimum VSI is more sensitive to voltage collapse.

The effectiveness of this technique has been explained using standard-15 bus RDS.

A. Results for 15 bus system

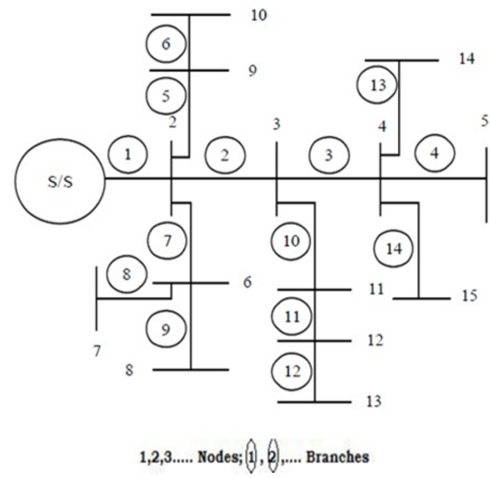

Fig. 3 A 15 bus system

Table 1: VSI for 15 Bus System at each node (N_i)

N_i	SI	N_i	SI	N_i	SI	N_i	SI
1	-	5	0.814	9	0.878	13	**0.796**
2	0.885	6	0.842	10	0.880	14	0.810
3	0.837	7	0.845	11	0.814	15	0.809
4	0.818	8	0.849	12	0.800		

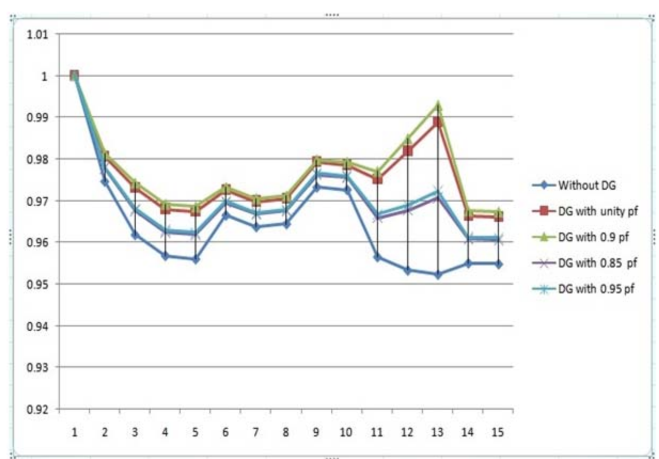

Fig. 4: Voltage profile for 15 bus system with DG for different pf

Table 2: Size of optimal DG for 15 Bus RDS

CASE	DG SIZE	TOTAL P_{LOSS}
1	0.2 MVA at unity power factor	51.8730 kW
2	0.2 MVA at 0.95 power factor lag	51.8623 kW
3	0.2 MVA at 0.9 power factor lag	51.8848 kW
4	0.2 MVA at 0.85 power factor lag	51.8851 kW

6. LOAD CENTROID IDENTIFICATION ALGORITHM

In the previous algorithm capacity and optimal place for installing a DG unit was determined for a 15 Bus system. But the VSI method has the following limitations:

- Multiple DG units could not be installed in a particular system.
- It does not take into account the size constraint of the type of DG unit that is to be installed.

The above drawbacks were overcome by a new algorithm called Load Centroid Identification (LCI) Algorithm. The concept of load centroid is addressed as a helpful tool in distribution system expansion planning studies.

A distribution system contains a number of load of different power requirement at different nodes. The load centroid is defined as that node where the resultant load of the distribution system tends to act.

The idea behind LCI algorithm is that if the main source supplies only one load, then the best location for the DG should be the load point itself. When many loads are supplied then the best location for the DG should be the load centre of gravity (centroid). As a concept, the load centroid is equivalent to the point of action of the resultant force of a group of forces in mechanics. Alternatively, it is similar to center of gravity of a big object formed from a number of parts. The centroid is selected as the optimal location of the concerned DG unit. The method assumes a simple radial network fed at one end. A systematic simple approach to allocate multiple DG units in any distribution network is applied. The concept of equivalent load is introduced and extended to identify the load centroid precisely. A complete straightforward procedure for sizing and locating multiple DG units to optimize the defined performance index is developed.

The proposed algorithm

The equivalent aggregated load is calculated as follows:

$$P_e = \sum_{n=1}^{N} P_n$$

$$Q_e = \sum_{n=1}^{N} Q_n$$

Where,

P_e is the equivalent active power component of the aggregated load;

P_n is the active power component of the load at bus number n;

Q_e is the equivalent reactive power component of the aggregated load;

Q_n is the reactive power component of the load at bus number n;

N is the total number of buses

The power system Performance Index (PI) combines two terms to express both total active power loss (Ploss) and the average node voltage deviation (ANVD). It is always required to get the least value of PI. It is formed as follows:

$$PI = Ploss + K * ANVD$$

$$ANVD = |1 - \frac{\sum_n V_n}{N}|$$

Where K is selective weighting factor;

V_n is the voltage of nth node in p.u.

Load centroid identification algorithm

Load centroid is specified by the following steps:

i) The PI for the base case system without DG is computed and saved as PI0.

ii) All loads are disconnected.

iii) A load of Pe and Qe is put at bus 2 and then the PI is estimated and it is saved in a vector called PIE.

iv) The load Pe and Qe is then moved to bus 3 and step (iii) is repeated.

v) Step (iv) is repeated for every bus until bus N.

vi) The absolute difference between each value in the vector PIE of N -1 elements and PI0 is saved in a vector called DPIE.

vii) The element with the least absolute value in DPIE is determined and is saved as ‘g’.

viii) The load centroid is at bus number ’busDG’ such that busDG = g +1.

Therefore ‘busDG’ is the best location to install a DG unit of a proper size.

DG unit allocation algorithm

i) To get the optimal DG size, a direct search technique is applied. For base case system, with all loads connected, a DG at ‘busDG’ is placed of active power size as 1% of P_e. Under this condition the PI is calculated and is saved in a vector called PIS.

ii) Step (i) is repeated for different DG sizes from 2% to 100% of P_e with 1% incremental step.

iii) The DG size corresponding to the minimum value in vector PIS is specified .It is considered as the total optimal DG size ‘P_{DGT}’.

iv) A first DG unit of the total optimal size or maximum available size is installed at

v) 'busDG1' such that busDG1 =busDG.

vi) $P_{DGr} = P_{DGT} - P_{DG}$ is computed. P_{DG} is the total DG active power that has been actually added. Let $P_{DG,min}$ is the minimum available standard DG size. If $P_{DGr} < P_{DG,min}$, no more DG units can be added. Otherwise, the first (previous) DG unit is treated as a negative load and new value of Pe and Qe is calculated.

vii) The LCI algorithm as described above is repeated to determine the new load centroid that is the location of the second (next) DG unit and is saved as busDG2.

viii) The above steps are repeated until $P_{DG2} < P_{DGr}$.

Results in a 15 bus system for Solar, Wind and Dual Fuel

Table 5: Determination of the Load Centroid for installing Solar, Wind and Dual Fuel based DG unit: $PI0_1$=0.4127 $PI0_2$=0.2589

SL NO	OPTIMAL PLACE OF			
	1ST DG UNIT		2ND DG UNIT	
	PI VALUE	X	PI VALUE	Y
1	Slack	-	Slack	-
2	0.2635	0.1492	0.1370	0.1219
3	0.4046	**0.0008**	-	-
4	0.4624	0.0497	0.2242	0.0347
5	0.4985	0.0858	0.2361	0.0228
6	0.3482	0.0645	0.1676	0.0913
7	0.3830	0.0297	0.1752	0.0837
8	0.4024	0.0103	0.1788	0.0801
9	0.2954	0.1173	0.1482	0.1107
10	0.3187	0.0940	0.1543	0.1046
11	0.4882	0.0755	0.2313	0.0276
12	0.5838	0.1711	0.2523	0.0066
13	0.6414	0.2287	0.2576	**0.0013**
14	0.5165	0.1038	0.2390	0.0199
15	0.4904	0.0777	0.2347	0.0242

X= Absolute difference from $PI0_1$, Y= Absolute difference from $PI0_2$

Table 6: Optimal placement and sizing of multiple DG

DG Unit	Optimal Place (Node)	Optimal Size (kVA)	Installed DG Size (kVA)
1st DG	3	1226.4	1000
2nd DG	13	156.4	150

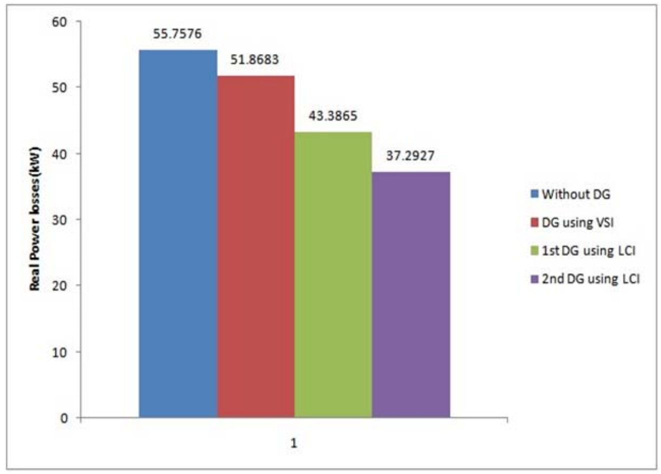

Fig. 7: Real power loss for 15 bus system with DG using different algorithms

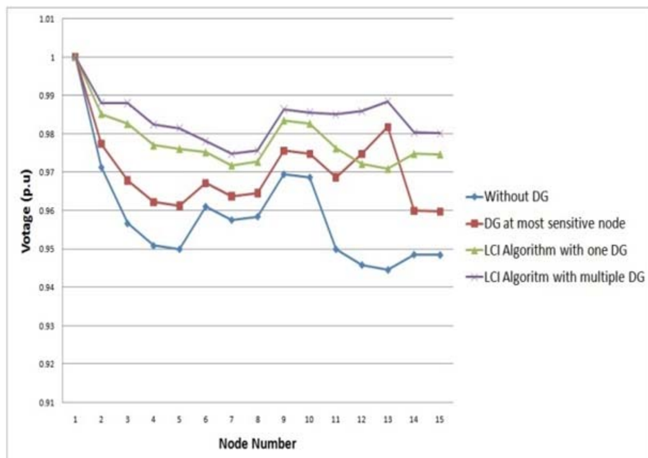

Fig. 8 :Voltage profile for 15 bus system with DG using different algorithms

7. CONCLUSION

In this paper Backward Forward Sweep method is used for determining node voltages and branch power losses of distribution systems. The capacity evaluation of DG to be used and its proper positioning is done for 15 bus system and IEEE 33 Bus system with MATLAB environment.

Using LCI Algorithm and obtaining Performance Index, the capacity evaluation and optimal placement is done for more than one DG at a time. The LCI Algorithm is found to be more suitable because it allows installation of multiple DGs. This algorithm helps to find suitable capacity of DG as per available range of DG ratings. In case the evaluated size exceeds the maximum rating, number of DGs can be increased with lower ratings. Installation of multiple DGs means more loss reduction.

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