Heuristic Based Placement Technique for Distributed Generation

O. Aliman[1], I. Musirin, M. M. Othman and M. H. Sulaiman

***Abstract*—In this paper, a heuristic DG optimization technique for radial distribution feeders is proposed. Significant search space reductions obtained through a small number of DG tests is offered. A sufficient sensitivity test analysis applicable for DG applications is proposed. Sample test system is examined using the proposed technique and the results are compared with those obtained via other method. The suggested technique succeeds in solving different test cases. A comparative study validates the practical concerns of the proposed method.**

***Index Terms*—Distributed Generation, Optimization, Power Loss, Sensitivity Index.**

I. Introduction

FUNDAMENTALLY, a Distributed Generation (DG) is employed to compensate distribution feeder systems. Studies indicate that up to 13% of the total power generated is consumed as active power loss at distribution level [1]. Real power loss depends on the line current and the line resistance, and that current consists of active and reactive components. Voltage improvement, deferral of future expansion, extending apparatus life time, reducing environmental impact and increasing overall energy efficiency are main advantages of power loss reductions. All these merits can be achieved if the location and size of DGs are optimally employed.

Various optimization techniques have been employed seeking optimal placement, size and operating mode for Distributed Generation (DG) interconnection. DG application is very complex multi-objective nonlinear optimization problem. Typically, the DG problem aims at determining the optimal location to achieve optimality for some objective functions [2]-[4]. Usually, it includes maximizing power loss reductions and minimizing the cost.

Therefore, solution criteria may vary from one application to another. Also, achievement of one of the previous objectives does not guarantee satisfying the remaining ones. In addition, future changes in the solved system will alter the obtained results significantly. Therefore, as more objectives and constraints are considered by the algorithm, more data is required, which tends to add difficulty to implementation [5]-[6].

Many optimization tools have been tested and employed to solve different DG problems. Tools such as Genetic Algorithm, Tabu Search and Particle Swamp Optimization are promising and still evolving in this field. In each tool, a large number of results are retained to search for the optimal result. Here is where time and memory consume space. Thus, some of those techniques have been modified and hybrid with another to enhance their solution performances [7].

In this paper, a heuristic optimal placement technique for 14-Bus DISCONET distribution system is proposed. The outcomes from the test results will be further examined and compared with a sensitivity analysis technique index-based for comparable results. Results obtained from the study outperformed other technique in terms of its simplicity algorithm.

II. Power Loss in Distribution System

A. Power Loss Reduction

Normally, shunt capacitors and DGs are employed to aid in reducing power loss in distribution system. However, the latter is a better option in terms of feeder systems compensation. From a line current perspective, shunt capacitor reduces a portion of the reactive line current only. However, DG reduces portions of both active and reactive line currents. Thus, the latter decision is superior under optimal solution achievements.

B. Real Power Loss and Bus Voltage

The real power loss in *n*-bus system is given by [8].

$$P_{Loss} = \sum_{i=1}^{n}\sum_{j=1}^{n}\frac{z_{ij}}{V_iV_j}\left[cos\left(\delta_i-\delta_j\right)\left(P_iP_j+Q_iQ_j\right)+ sin\delta i - \delta j Qi Pj + Pi Qj \right. \quad (1)$$

For *n* connected lines to *j*-bus, the bus voltage can be determined by,

$$V_j = \sum_{j\neq i}^{n} 0.5\left[V_i + Z_{ij}\sqrt[2]{\left(\frac{V_i}{Z_{ij}}\right)^2 - \frac{S_{Load}}{0.25Z_{ij}}}\right] \quad (2)$$

where V_j is affected by the total power load , S_{Load} connected directly to *j*-bus.

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C. DG Impacts on Line Losses

Once DG is connected at the system, j-bus voltage would consider the power deliver by the DG, S_{DG}. Therefore, Eq.(2) will change to

$$V_j = \sum_{j \neq i}^{n} 0.5 \left[V_i + Z_{ij} \sqrt[2]{\left(\frac{V_i}{Z_{ij}}\right)^2 + \frac{S_{DG} - S_{Load}}{0.25 Z_{ij}}} \right] \quad (3)$$

At this time, several different situations may take place.

In any conditions where: $\left(|S_{DG}|\right)_j \leq \left(|S_{load}|\right)_j$ or the injection of P_{DG} and Q_{DG} may reduce the P_j and Q_j drawn from bus j. In other words, the DG reduces the load's value at bus j. However, if $\left(|S_{DG}|\right)_j > \left(|S_{load}|\right)_j$, it acts as the previous situation, but reverses a portion of the injected P_{DG} or Q_{DG} or both back to bus j. Reducing the power loss and maintaining the voltage within acceptable limits are vital in DG applications. Although the results from both situations in some cases are significant, situation where $\left(|S_{DG}|\right)_j > \left(|S_{load}|\right)_j$ leads to better results if the optimal DG size and location are employed.

III. Optimal Placement Technique

Reliability, accuracy and flexibility of the DG solution algorithm are influenced by the power flow analysis used. Therefore, the overall algorithm accuracy is highly reliant on that analysis. It can be said that the power flow analysis is the heart of the DG solution algorithm.

A. Proposed Heuristic Technique

The designated objective function is to minimize the total system real power loss. It is learned that, load at bus may affect the value of P_{Loss}. Thus, by considering this factor, a *Load Factor Sensitivity* (LFS) is proposed.

B. LFS Algorithm

The proposed technique attempts to find the optimal DG placement based on the load effect connected at the particular bus. The total power connected to the respective bus will directly contribute to the total power loss of the network system. Thus, total power loss is load-dependent connected to the bus.

The procedure is initially started by determining the total power loss as the base case of the system. Normally the first bus acts as the slack bus and no load being connected at this point. It follows to the next bus by disconnecting all connected loads to it. In other words, zero load should be applied at this bus. At this stage, running the load flow program will eventually determine the total power loss of the network system.

The process is continuously repeated by applying zero load at the particular bus and simultaneously the total power loss being recorded after running the load flow. The process will stop until the n^{th} bus result being recorded. Eventually, if initially there is no load connected at the bus, the total power loss is definitely the same as the base case result.

The recorded results are then being sort in ascending orders. Therefore, the highest rank represents the potential bus for DG placement. The above procedure is simplified in a flow chart illustration depicted in Fig. 1.

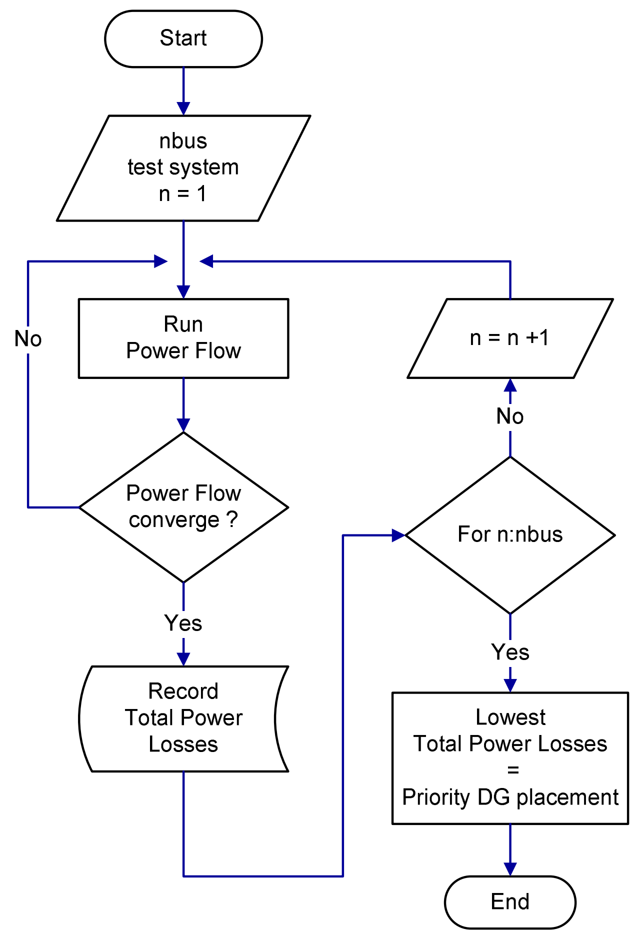

Fig. 1. LFS Algorithm

C. Sensitivity Index (SI)

A sensitivity index was developed by [9] to determine the potential placement for a DG to be installed. The formulation was based on the change in voltage stability index at a load bus with respect to changes of the load at the respective bus.

The derivation of the SI from the voltage stability index is as the following. The voltage stability index at a load bus i is given by

$$L_i = \frac{4\left[V_O V_L \cos\theta_i - V_{L_i}^2 \cos\theta_i^2\right]}{V_{O_i}^2} \quad (4)$$

where;

V_{L_i} = load voltage at bus *i*

V_{O_i} = no load voltage at bus *i*

θ_i = $(\theta_{O_i} - \theta_{L_i})$

θ_{L_i} = load angle at bus *i*

θ_{O_i} = no lad angle at bus *i*

The sensitivity index was formulated from the change in L_i with respect to the change in injected P_i at bus *i* and it is given by

$$\frac{\partial L_i}{\partial P_i} = \begin{bmatrix} \frac{\partial L_i}{\partial V_{L_i}} & \frac{\partial L_i}{\partial \theta_{L_i}} \end{bmatrix} \begin{bmatrix} \frac{\partial V_{L_i}}{\partial P_i} \\ \frac{\partial \theta_{L_i}}{\partial P_i} \end{bmatrix} \tag{5}$$

The element of the row matrices in Eq. (5) is derived from Eq. (4) as follows,

$$\frac{\partial L_i}{\partial V_{L_i}} = 4\frac{(V_{O_i} - 2V_{L_i})}{V_{O_i}^2} \tag{6}$$

$$\frac{\partial L_i}{\partial \theta_{L_i}} = \frac{4}{V_{O_i}^2}\left[-V_{O_i}V_{L_i}\sin\theta_i + 2V_{L_i}^2\cos\theta_i\sin\theta_i\right] \tag{7}$$

$\frac{\partial V_{L_i}}{\partial P_i}$ and $\frac{\partial \theta_{L_i}}{\partial P_i}$, are obtained from the inverse of load flow jacobian matrix.

The sensitivity criterion was determined from the values of the sensitivity indices evaluated at each load bus in a system. Buses with highest sensitivity values are selected for the suitable location for the distributed generators.

D. SI Algorithm

The following procedures were implemented in the sensitivity analysis to determine the suitable location of distributed generator in the test systems.

I. Run the load flow at the base case
II. Compute the no load voltage and no load angle for bus i
III. Compute the sensitivity indices for injected active power and injected reactive power using equation A and B respectively.
IV. Record the highest sensitivity index by taking the magnitude of the index.
V. Select the bus with the highest sensitivity index value as the suitable location for the distributed generator.

From the analysis, the bus that gives the highest value index will be chosen as the potential location for the DG placement. The above procedure is simplified in a flow chart illustration depicted in Fig. 2.

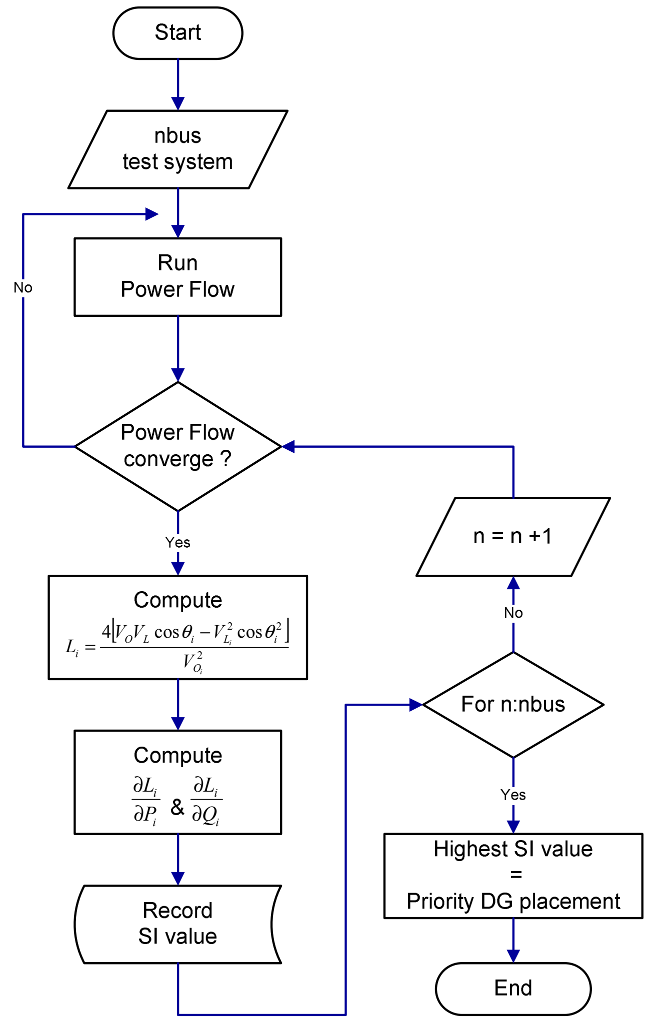

Fig. 2. SI Algorithm

IV. COMPARATIVE STUDY

A. 14-Bus DISCONET

In testing the effectiveness of the proposed technique, experimental works have been conducted on a 14-Bus DiscoNet test system as depicted in Fig. 3.

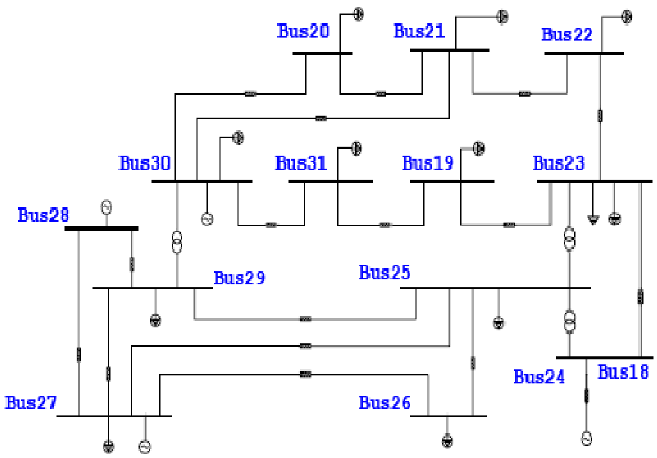

Fig. 3. 14-Bus DiscoNet test system

B. Simulation Results

The LFS as explained in section D was evaluated at every bus of the test system. Each bus's results are depicted in Table 1(a) and sorted in descending orders as tabulated in Table 1(b). The bus with lowest power loss value is selected as the most suitable place for the DG.

TABLE I
LFS SIMULATION RESULTS

BUS NO.	P_{Loss} (kW)
1	13,821.12
2	12,867.34
3	5,632.37
4	9,386.52
5	13,155.44
6	13,107.61
7	13,821.12
8	13,821.12
9	11,015.06
10	12,874.76
11	13,477.06
12	13,262.41
13	12,050.72
14	12,050.72

(a)

RANK	BUS NO.
1	3
2	4
3	9
4	13
5	14
6	2
7	10
8	6
9	5
10	12
11	11
12	1
13	7
14	8

(b)

The above results show that bus 3 with the lowest power loss value is chosen as the suitable placement for the DG. Next, the test system is further tested with SI technique. Each bus's results are depicted in Table 2(a) and sorted in descending orders as tabulated in Table 2(b). The bus with highest SI value is selected as the optimal place for the DG.

TABLE II
SI SIMULATION RESULTS

BUS NO.	$\frac{\partial L_i}{\partial P_i}$
1	0.0000
2	0.0364
3	8.0494
4	0.9814
5	0.0200
6	0.2871
7	0.0000
8	0.0000
9	2.0280
10	0.2851
11	0.0554
12	0.2883
13	0.8401
14	1.5253

(a)

RANK	BUS NO.
1	3
2	9
3	14
4	4
5	13
6	12
7	6
8	10
9	11
10	2
11	5
12	1
13	7
14	8

(b)

The above results show that bus 3 with the highest index value is chosen as the optimal placement for the DG.

In order to check and analyze the effectiveness of the result, a 50 MW DG has been installed at the specified bus; bus 3. As a result, the test system shows a reduction of 5.53 MW (40.02%) of the existing (without DG) total power losses.

For comparison purposes, the 50 MW DG is installed and tested at bus 14 and bus 2, each at a time. The comparisons of the total losses reduction are illustrated in Table 3.

TABLE III
IMPACT ON POWER LOSSES DUE TO PROPER DG PLACEMENT

BUS NO.	TOTAL LOSS (kW)	REDUCED LOSS (kW)	REDUCED LOSS (%)
Base Case	13,821.12		
3	8,290.30	5,530.81	40.02%
14	10,306.16	3,514.96	25.43%
2	11,632.14	2,188.97	15.84%

Apparently, the selection of proper placement of DG could significantly reduce the total losses of the network system. However, the increment of the DG size may not linearly reduce the total losses. It has the limitation that be called as an optimal size of DG. Figure 4 illustrates that upon reaching the optimal size, further increment of DG size may increase the total power loss. Thus, the oversize of DG ultimately may increase the capital cost of the system.

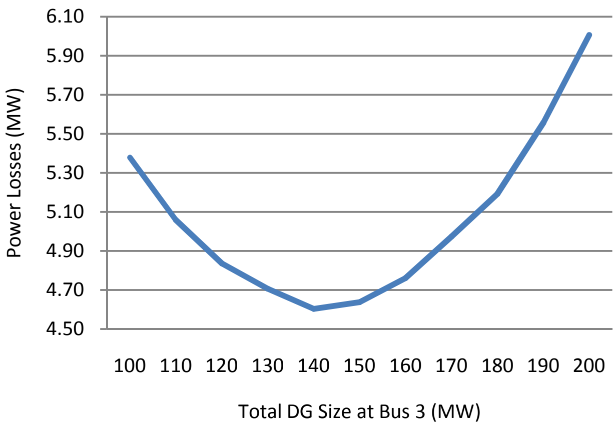

Fig. 4. DG Size vs Power Loss

V. CONCLUSION

In conclusion, the interconnection of DG at the optimal placement is a vital point to be considered upon integrating to the distribution network system. Total losses of the network system could be reduced and optimized by considering this matter. The suggested technique of LFS based is one of many techniques being developed by other researchers. In terms of the outcome, the results show that the proposed technique was capable to minimize the system losses. Apart of the important to place at the right bus, another important point that might effect to the investment cost is the DG size factor.

VI. REFERENCES

[1] H.N. Ng, M.M.A. Salama, A.Y. Chikhani, Classification of Capacitor Allocation Techniques, IEEE Transaction on Power Delivery, Vol. 15(1), Jan 2000, pp. 387-392.

[2] D. Thukaram, H.M. Wijekoon Banda, Jovtha Jerome, *A Robust Three Phase Power Flow Algorithm for Radial Distribution Systems*, Electric Power Systems Research, Vol. 50(3), 1999, pp. 227-236.

[3] Jen-Hao Teng, Tain-Syh Luor, Yi-Hwa Liu, Strategic Distributed Generator Placements for Service Reliability Improvements, IEEE Power Engineering Society Summer Meeting, Vol. 2, 2002, pp. 719-724.

[4] An D.T. Le, M.A.Kashem, M.Negnevitsky, G.Ledwich, *Optimal Distributed Generation Parameters for Reducing Losses with Economic Consideration*, IEEE Power Engineering Society General Meeting, June 2007, pp. 1-8.

[5] P.P. Barker, R.W. De Mello, Determining the Impact of Distributed Generation on Power Systems, Part 1. Radial Distribution Systems, IEEE power Engineering Society Summer Meeting, Vol 3, 16-20 July 2000, pp. 1645-1656.

[6] D.K. Khatod, V. Pant, J. Sharma, A Novel Approach for Sensitivity Calculations in the Radial Distribution System, IEEE Transaction on Power Delivery, Vol. 21(4), Oct. 2006, pp. 2048-2057.

[7] S.F. Mekhamer, M.E. El-Hawary, M.M. Mansour, M.A. Moustafa, S.A. Soliman, Fuzzy and Heuristic Techniques for Reactive Power Compensation of Radial Distribution Feeders : A Comparative Study, Electrical and Computer Engineering, IEEE CCECE 2002. Canadian Conference, Vol. 1, 12-15 May 2002, pp. 112-121.

[8] Naresh Acharya, Pukar Mahat, N. Mithulananthan, *An Analytical Approach for DG Allocation in Primary Distribution Network*, Journal of Electrical Power and Energy Systems, Vol. 28, 2006, pp. 669-678.

[9] S.R.A. Rahim, T.K.A. Rahman, I. Musirin, *Optimal Allocation and Sizing of DG in Distribution System Using Evolutionary Programming Technique*, 2nd International Power Engineering and Optimization Conference (PEOCO), Shah Alam, 4-5 June 2008, pp. 200-2004.