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A Weighted Multi-Objective Index Based Optimal Distributed Generation Planning in Distribution System

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Abstract

Distributed Generation (DG) sources have been popular due to their potential solution for some issues, like the deregulation in power system and improving the performance of Distribution System. The optimal placement of DG is needed for maximizing the DG benefits in power system such as improving reliability and stability. There are several similar works have been done to find the optimal DG site by their imposed constraints and objectives. In this paper, the siting and sizing of Distributed Generators (DG) in distribution networks are determined using multi-objective indices. The objective is to minimize the real power loss and to improve the voltage profile of the system. To minimize power losses, it is important to find the location and size of local generators to be located in power distribution systems. Best location of the DG is determined by using multi-objective voltage index analysis and size of DG is computed by finding its optimal power factor using Fast Approach. This paper presents the results of simulations for standard Civanlar16-bus and 12 bus Practical Distribution systems.

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*Keywords:*DG;Fast Approach and Real Power Loss Reduction.

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1. Introduction

With restructured environment, electric utilities are seeking new technologies to serve their customers with acceptable range of power quality and reliability. Utilities are continuously planning the expansion of their electrical networks in order to face the load growth and to properly supply their consumers. The traditional solution is the construction of new substations or the expansion of those already exists. From that moment, Distributed Generation

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(DG) started to retake its importance. Distributed Generation can be defined as an electrical power source connected directly to the distribution network or on the consumer side of the meter. There are a number of approaches developed for placement and sizing of DG units in distribution system. Chiradeja and Ramkumar [3] presented a general approach and set of indices to assess and quantify the technical benefits of DG in terms of voltage profile improvement, line loss reduction and environmental impact reduction. Khan and Choudhry [4] developed an algorithm based on analytical approach to improve the voltage profile and to reduce the power loss under randomly distributed load conditions with low power factor for single DG as well as multi DG systems. Hung et al. [5] used an improved analytical method for identification of the best location and optimal power factor for placing multiple DGs to achieve loss reduction in large-scale primary distribution networks. For optimal placement of DG, Mithulanathan et al. [6] presented a genetic algorithm based approach to minimize the real power loss in the system and found a significant reduction in the system loss. The optimal sizing and siting of DGs was investigated by Ghosh et al. [7] to minimize both cost and loss with proper weighing factors using Newton-Raphson (NR) load flow method. Ziari et al. [8] proposed a discrete particle swarm optimization and genetic algorithm (GA) based approach for optimal planning of DG in distribution network to minimize loss and improve reliability. Kamel and Karmanshahi [9] proposed an algorithm for optimal sizing and siting of DGs at any bus in the distribution system to minimize losses and found that the total losses in the distribution network would reduce by nearly 85%, if DGs were located at the optimal locations with optimal sizes.[16] and [17] proposed an algorithm for optimal sizing and siting of DGs at any bus in the distribution system to minimize losses. This paper presents a simple method for voltage profile improvement and real power loss reduction and is based on Weighted Multi-objective Voltage Index evaluation. The proposed method is tested on standard Civanlar16-bus and 12 bus Practical Distribution systems.

Nomenclature

DG	Distributed Generation
CNVI	Critical Node Voltage Index
TNVI	Tail End Node Voltage Index
WMOI	Weighted Multi-Objective Index

2. Power Loss Calculation

The real power loss in a system is given by (1). This is popularly referred to as "exact loss" formula [11]. The losses can also be calculated by using any conventional load flow techniques.

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}[\alpha_{ij}(P_iP_j + Q_iQ_j) + \beta_{ij}(Q_iP_j - P_iQ_j)] \qquad (1)$$

Where

$$\alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos(\delta_i - \delta_j)$$

$$\beta_{ij} = \frac{r_{ij}}{V_iV_j}\sin(\delta_i - \delta_j)$$

P_i and Q_i are active and reactive power at bus i.
The above equation is used in power loss calculation in the proposed work which is also the exact loss formula.

3. Proposed Algorithm

The aim of this paper is to find the best location and size of a DG unit in order to decrease the power losses of the system. The proposed algorithm of this paper gives the most optimum location and size of a DG unit in a distribution system based on a weighted multi-objective index which considers the voltage deviation at critical nodes and tail end nodes simultaneously.

3.1 To find Location of DG Placement

The location of DG is chosen as the one that gives the best voltage profile. This could be done by injecting the DG at each node calculating the voltage index by using equation. (2). the best location is selected as the node with least voltage index.

$$VI_i = \sum_{k}^{nbus} (1 - V_k)^2 \qquad (2)$$

Where k=1 to nbus and i=1 to nbus. Where V_k is voltage at kth node and nbus is the number of nodes. The voltage index is calculated for different levels of DG penetration. The above index can be calculated by considering voltage deviations at all nodes or considering only critical nodes. In this work, the DG is placed by considering the Voltage Deviations of critical nodes. Critical nodes can be those having high connectivity, high voltage nodes, nodes those connected to highly dedicated nodes etc. Here, in this work the high connectivity nodes are considered as critical nodes and DG siting is done based on the voltage deviation index of such nodes. The location of DG which gives least voltage deviation of critical nodes is the optimal location. Here, the work is also extended considering the voltage deviations of very important tail end nodes. Hence, the work comprised of optimally siting and sizing of DGs based on the critical node voltage deviations and tail end node voltage deviations simultaneously. Therefore, certain weights are assumed for both critical node voltage index (CNVI) and tail end node voltage index (TNVI). The weighting factor of CNVI and TNVI are assumed to be w1 and w2 respectively whose values are chosen based on requirement of the system such that sum of the weights must be equal to unity. Hence, the composite index Weighted Multi-Objective Voltage Index is formed by combining both CNVI and TNVI using appropriate weights as shown below in equation (3) .

$$\text{WMOVI} = (w1 * \text{CNVI}) + (w2 * \text{TNVI}) \qquad (3)$$

The node with least WMOVI is the optimal location of DG and its size is found by Fast approach as discussed in next section as the least WMOVI signifies lesser voltage deviations at critical and tail end nodes.

3.2 To find Optimal Power Factor [14]

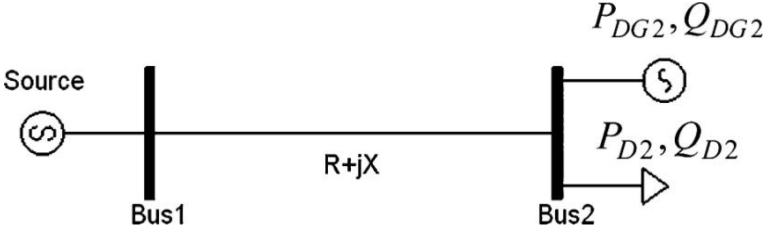

Fig 1. Two bus distribution system

Consider a simple distribution system with two buses, a source, a load and DG connected through a transmission line as shown in Fig. 1. The power factor of the single load (PF_{D2}) is given by (4)

$$PF_{D_2} = \frac{P_{D2}}{\sqrt{P^2_{D2} + Q^2_{D2}}} \qquad (4)$$

It can be proved that at the minimum loss occur when power factor of DG is equal to the power factor of load as given by (5).

$$PF_{D_2} = PF_{DG_2} = \frac{P_{DG_2}}{\sqrt{P^2_{DG_2} + Q^2_{DG_2}}} \qquad (5)$$

To find the optimal power factor of DG for a radial complex distribution system, fast and repeated methods are proposed. It is interesting to note that in all the three test systems the optimal power factor of DG (Type 3) placed for loss reduction found to be closer to the power factor of combined load of respective system.

1) Fast Approach: Power factor of combined total load of the system (PFD) can be expressed by (5). In this condition, the total active and reactive power of the load demand are expressed as The “possible minimum” total loss can be achieved if the power factor of DG (PFDG) is quickly selected to be equal to that of the total load as in (6).

$$PF_{DG} = PF_{D} \tag{6}$$

2) Repeated Approach: In this method, the optimal power factor is found by calculating power factors of DG (change in a small step of 0.01) near to the power factor of combined load. The sizes and locations of DG at various power factors with respect to losses are identified from (5). The optimal power factor of DG for which the total loss is at minimum is determined.

3.3 Computational Procedure for DG Placement and Sizing

- Identify Critical nodes and tail end nodes and Run the base case load flow.
- Calculate the optimal power factor of DG by using Fast Approach.
- Compute the WMOVI at each node using equation (3) by penetrating the DG at respective node and rank the indices of all nodes in ascending order to form priority list.Select the bus with least value of index and that is the optimal location of DG.
- Repeat the above steps for another penetration level of DG.

The above algorithm computes the WMOVI index and based on the index value the location of DG is determined, i.e., the connection of DG to a bus which yields least WMOVI is the best location in regard to the best voltage profiles of specified critical buses in a given system. Through this novel method we can have controlled or less voltage deviations across specified critical buses and hence as a result we can ensure better voltages at critical buses.

4. Results and Discussions

The proposed method is tested on standard Civanlar16-bus and 12 bus Practical Distribution systems and results were tabulated. A computer program has been written using MATLAB Ver. R2010b to evaluate the algorithm. In this work, the weights are chosen as w1=0.4 and w2=0.6.

4.1.Case Study 1

The proposed method is applied to a practical radial network of 12 Buses as in Fig. 2. It is a 11 kV rural feeder situated at a distance of 40 Km from Bangalore, Karnataka, India. The parameters of this system are in appendix. Table 1 shows the list of critical nodes and tail end nodes whose voltage deviations are considered in the present work. The node 3 is the highest connectivity node and therefore it is chosen as the critical node.

Table 1.List of critical and tail end nodes of practical 12 bus system

Critical Nodes			3		
Tail end Nodes	5	6	7	10	12

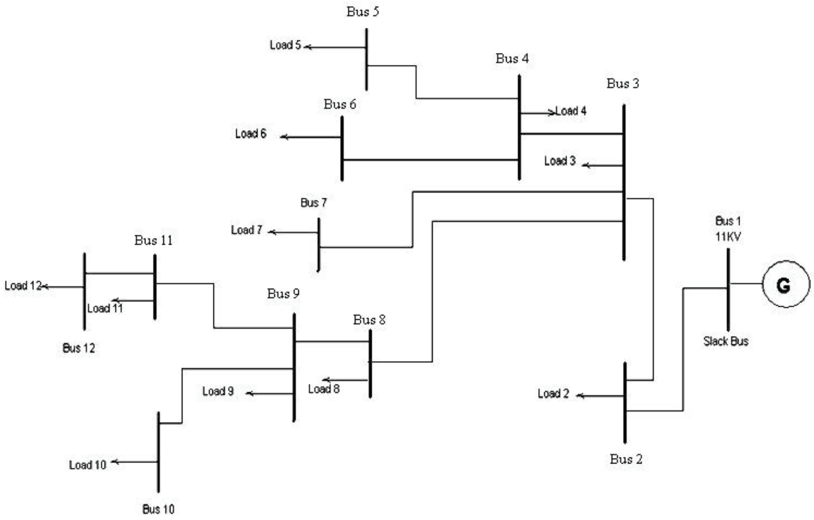

Fig. 2 Practical 12 bus System

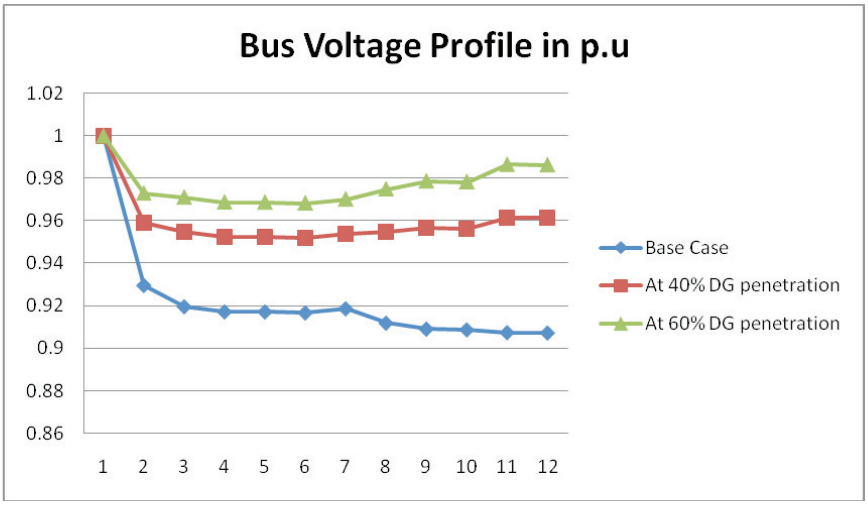

Fig. 3. Voltage profile of practical 12 bus System

Table 2. Summary of Results of practical 12 bus System

12 BUS TEST SYSTEM			
DG PENETRATION LEVEL		40%	60%
OPTIMAL LOCATION		9	8
OPTIMAL POWER FACTOR		0.85	0.85
OPTIMAL DG SIZE	PDG IN MW	0.684	1.026
	QDG IN MVAR	0.423	0.6354
REAL LOSS BEFORE DG PLACEMENT in MW		0.161	0.161
REAL LOSS AFTER DG PLACEMENT in MW		0.053	0.033
% REAL LOSS REDUCTION		67.0807453	79.5031056

Table 2 shows the summary of the results of the proposed algorithm for practical 12 bus System. The optimal location of DG has been found by WMOVI shown in Table 3. The least value of the index is at bus no 11 for both 40% and 60% DG penetration levels and hence it is chosen as the best location and optimal size of DG is chosen by finding the optimal power factor of the DG using the proposed two approaches. From Fig. 3, it is evident that the DG placement through the proposed method improves the voltage profile and from Table 2 it is seen that it gives percentage power loss reduction at two different DG penetration levels.

Table 3.WMOVI of practical 12 bus System

WMOVI					
Nodes	40%	60%	Nodes	40%	60%
1	0	0	7	0.0081267	0.003657858
2	0.0107708	0.006053439	8	0.0076433	0.002966294
3	0.0087127	0.003935026	9	0.0071466	0.002594992
4	0.007837	0.003247343	10	0.0069069	0.002492735
5	0.0077926	0.00322667	11	**0.0068643**	**0.002452985**
6	0.0076398	0.003172709	12	0.0067984	0.002435507
			Optimal Node	11	11

4.2 Case Study 2

The method has been applied to a radial system of sixteen buses with three feeders and three tie switches as shown in Fig. 4. The line data is taken from [13] without any DG injection. The branches S15, S21and S26 are the tie branches. Table 4 shows the list of critical nodes and tail end nodes whose voltage deviations are considered in the present work. The nodes 4, 8, 9 and 13 have the highest connectivity and therefore they are chosen as the critical nodes.

Table 4. List of Critical and tail end nodes of practical 16 bus System

Critical Nodes	4 8 9 13
Tail end Nodes	2 3 5 7 10 11 12 14 16

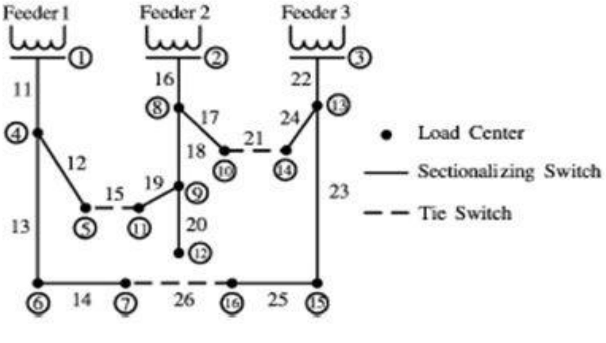

Fig. 4 Standard 16 bus test system

Table 5 shows the summary of the results of the proposed algorithm for standard 16 bus test system. The optimal location of DG has been found by WMOVI shown in Table 6. The least value of the index is at bus no 8 for 40% and 60% DG penetration levels and hence they are chosen as the best location and optimal size of DG is chosen by finding the optimal power factor of the DG using the proposed two approaches. From Fig.5, it is evident that the DG placement through the proposed method improves the voltage profile and Table 5 gives percentage power loss reduction at two different DG penetration levels.

5. Conclusions

Size and location of DG are crucial factors in the application of DG for loss minimization. This paper presents a novel approach to find optimum location of DG using multi objective index which considers voltage deviations of critical nodes and tail end nodes simultaneously. The presented work significantly contributes in determining the optimal location of DG considering the voltage profile of specified critical nodes in a given system. The size of DG is based on optimal working power factor as found in [14]. The work basically deals in identifying the suitable locations for DG installations for voltage improvement of specified critical buses irrespective of nature of load. By locating the DG using the presented method the voltage profile of specified critical nodes can be improved greatly. The work is greatly concentrated in improving the voltage profile rather than losses in a given system. This paper presents a multi-objective index based approach for optimum location and allocation of DG in distribution system in which the optimal siting of DG is determined by Voltage index for improving the voltage profiles and power loss reduction. The proposed method is tested on standard Civanlar 16 bus and practical 12 bus system RDS and results were tabulated. The work can also be further extended to system with dynamic load conditions and integrated with renewable DG resources which are intermittent in nature.

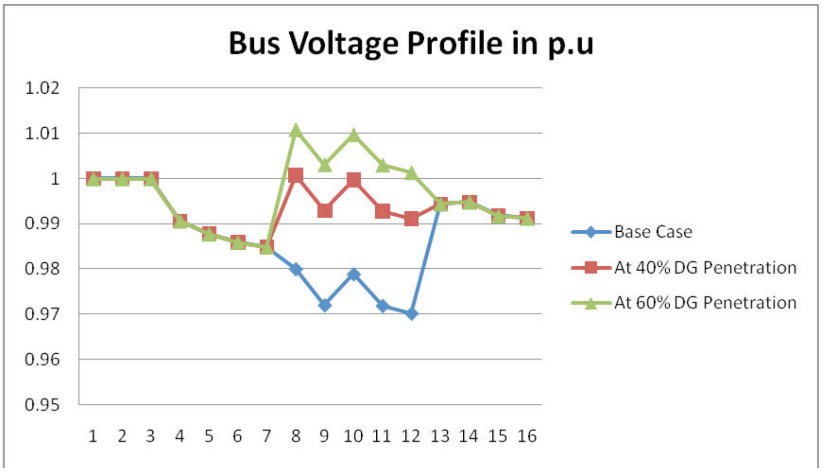

Fig. 5. Voltage profile of Standard 16 bus Test System

Table 5. Summary of results 16 bus test system

16 BUS TEST SYSTEM			
DG PENETRATION LEVEL		40%	60%
OPTIMAL LOCATION		8	8
OPTIMAL POWER FACTOR		0.856	0.856
OPTIMAL DG SIZE	PDG IN MW	11.48	17.22
	QDG IN MVAR	6.92	10.38
REAL LOSS BEFORE DG PLACEMENT IN MW		0.503	0.503
REAL LOSS AFTER DG PLACEMENT IN MW		0.265	0.238
% REAL LOSS REDUCTION		47.3161034	52.6838966

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