Selection of Load Buses for DG placement Based on Loss Reduction and Voltage Improvement Sensitivity

A. K. Singh and S. K. Parida
Indian Institute of Technology Patna
amit@iitp.ac.in, skparida@iitp.ac.in

***Abstract*- Distributed generation (DG) has emerged as a key option for promoting energy efficiency and use of renewable energy sources in alternative to the traditional generation. The DG sources are generally integrated to the network mainly to reduce the power losses, avoid congestion, improve voltage profile and provide electricity during peak load. This paper presents a method to select the load buses for the placement of DGs based on loss reduction and voltage improvement sensitivity of the system. The strategic placement of DGs can help in reducing power losses and improving voltage profile. The proposed work discusses some factors that can be useful for selecting the locations. Benefits of employing DGs are analyzed using voltage performance index (VPI) and loss sensitivity factor (LSF). The method has the potential to be used for integrating the available DGs by identifying the best locations in a power system. The proposed method has been demonstrated on standard 5-bus test system and IEEE 24-bus Reliability Test System (RTS).**

I. INTRODUCTION

The basic objective of an electric power system is to meet the demand imposed on it in an optimal, secured and efficient manner. Deregulation of Electricity industry has brought in the culture of competition among multiple players in generation, transmission and distribution under varied constraints. Within a restructured electricity industry, the trade of electrical energy is commoditized using an economic model that is an abstraction of the underlying physical process. The network effects such as network losses and network congestion, which are subject to important physical realities and limitations, have also played an important cause for market inefficiencies. DG is a feasible alternative for new capacity, and plays key role due to their economic viability and small size especially in the competitive electricity market environment, and has immense benefits. DG includes the application of small generators or storage systems, typically ranging in capacity from 5kW to 10MW, at or near to the end-user to provide the required electric power and thermal energy. In [1], the allocation and sizing of DGs for social welfare maximization and profit maximization using Locational marginal price (LMP) is proposed. Optimal location and sizing of distributed generation in a distribution networks using Genetic Algorithm (GA) is discussed in [2]. Optimal location for the placement of DGs with minimization of losses using gradient and second order methods is demonstrated in [3]. In [4], the benefits of voltage scheduling are studied on the reduction in active power output of swing machine, for three different load levels and voltage magnitudes of all PV buses in which tap positions on all transformers are determined by optimization. Optimal placement of distributed generation for profit maximization, reduction of losses and improvement in voltage regulation at various load buses in the distribution network were carried out in [5].

DG will play significant role in the electric power system of the near future. These are generating stations providing support to a distribution network. In [6], a hybrid GA-OPF approach was proposed for finding the network capacity to connect a predefined numbers of DGs in a distribution network. A GA based methodology for optimal DG allocation and sizing in distribution systems, in order to minimize network losses, and guarantee high level of reliability and voltage improvement was proposed in [7]. A method to allocate and determine the size of DG for minimization of the active losses of the feeders using tabu search algorithm is proposed in [8]. A linear programming approach to determine optimal allocation of embedded generation on distribution networks is presented in [9]. Penetration of DG enhances the reliability and security of electrical power system in terms of preventing blackout and also to reduce the losses and improve voltage profiles at various buses in an efficient manner.

In the present work, the procedure for finding the most prominent bus location to integrate the DGs with respect to loss and system voltage sensitivity has been developed. Loss sensitivity factors (LSF) and Voltage performance index (VPI) have been defined to analyze the impact of DG integration on system loss and voltage profile. From the analysis, the ranking of various locations has been determined the effectiveness of the proposed approach has been tested on standard 5-bus Test System and IEEE 24-bus Reliability Test System (RTS) [11], [12].

II. PROPOSED METHODOLOGY FOR LOAD BUS SELECTION

In a wide area power system network, the identification of most suitable area for DG penetration is very important. Each of the load bus in a power system indicates the sub transmission/distribution zone of electricity end users. Two different methods, based on Loss reduction and voltage

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improvement, have been proposed for selection of load buses to place the DGs. These methods can be named as (i) loss reduction sensitivity method, and (ii) voltage improvement sensitivity method. In these methods, Loss sensitivity factor (LSF) and voltage performance index (VPI) have been utilized to obtain the suitable locations for DG placement. The location having higher VPI and lesser LSF indicate a suitable choice of DG placement. The methods are elaborated as following.

A. Loss Reduction Sensitivity Method

The impact of DG on losses is site and time specific, depends on the technology used and control of reactive power. There is a trend for losses to follow the U-shaped trajectory with respect to increase in DG capacity as shown in Fig. 1 [6]. It shows the plot of typical power loss versus capacity of DG at a particular bus in a distribution system. From the figure, it is obvious that for that particular bus, as the size of DG is increased, the total system loss is reduced to a minimum value and increased beyond certain size of DG (i.e. the optimal DG size) at that location. The size at most should be such that it is consumable within the distribution substation boundary. Any attempt to install high capacity DG with the purpose of exporting power beyond the substation (reverse flow of power though distribution substation), will lead to very high losses. So, the size of distribution system in terms of load (MW) will play important role in selecting the size of DG. Also, it has been noticed that the location of DGs plays an important role in minimizing the losses.

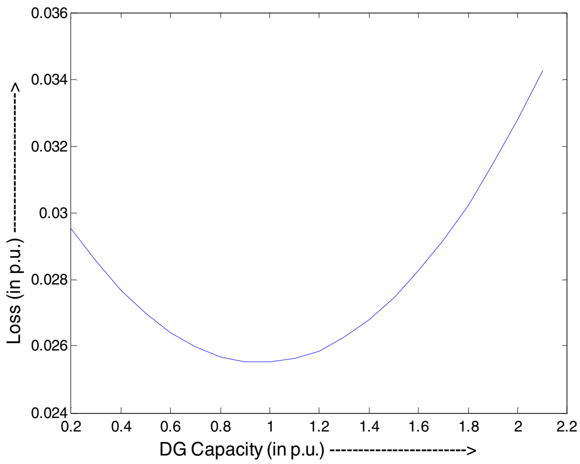

Fig. 1. Impact of DG capacity on losses.

By installing DG, line currents can be reduced, thus helping to reduce electrical line losses. The proposed loss sensitivity factor (LSF) due to injection by DG at bus i can be defined as,

$$LSF_i = \frac{\Delta P_{loss}}{\Delta P_i} = \frac{P^i_{loss} - P^b_{loss}}{P^{inc}_{dg,i}} \quad (1)$$

where, P^i_{loss} is the system loss with increment in DG capacity at i^{th} load bus, P^b_{loss} is the total system loss for base case, and $P^{inc}_{dg,i}$ is the increment in DG capacity at i^{th} bus.

Based on the above formulation, the following attributes have been observed. $LSF > 0$, $LSF = 0$ and $LSF < 0$ indicates that injection by DG has the impact of increased, zero and reduced system loss, respectively. The minimum value of LSF corresponds to the best DG location in terms of loss reduction.

B. Voltage Improvement Sensitivity Method

The integration of DGs can lead to improved voltage profile at various buses. As shown in Fig. 2, with increase in DG capacity up to certain level the bus voltage improves, then beyond this it degrades. This figure is obtained by observing the voltage profile at a particular bus when increasing the DG capacity gradually at any of the load buses.

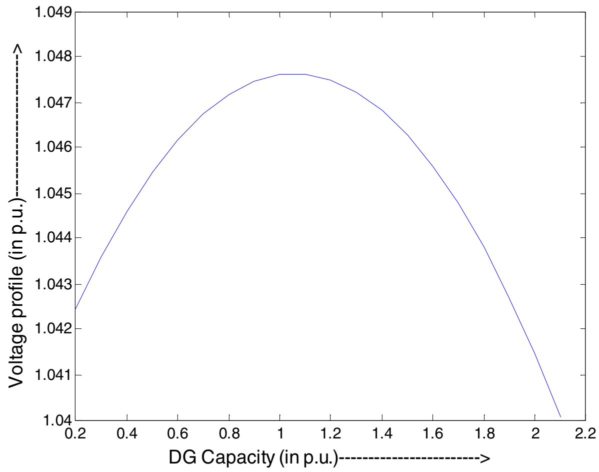

Fig. 2. Impact of DG capacity on voltage profile.

Similar expression equivalent to the voltage performance index (VPI) for voltage security based ranking has been used here for the selection of load buses [10],

$$(VPI)^{(i)} = \sum_{j=1}^{N} \frac{\omega_j}{2n} \left(\frac{\Delta V_j^{(i)}}{\Delta V_j^{\lim}} \right)^{2n} \quad (2)$$

$$\Delta V_j^{(i)} = V_j^{(i)} - V_j^{\lim} \quad (3)$$

$$V_j^{\lim} = V_j^{\max}, \ \forall \ V_j^{(i)} \geq 1.0 \quad (4)$$

$$V_j^{\lim} = V_j^{\min}, \ \forall \ V_j^{i} < 1.0 \quad (5)$$

$$V_j^{(i)} = V_j^{\max}, \ \forall \ V_j^{(i)} > V_{\max} \quad (6)$$

$$V_j^{(i)} = V_j^{\min}, \ \forall \ V_j^{(i)} < V_{\min} \quad (7)$$

$$\Delta V_j^{\lim} = \frac{V_j^{\max} - V_j^{\min}}{2} \quad (8)$$

where, w_j is the weighing factor of bus j that is decided by the system operator depending upon the operating condition of the system, N is the total number of buses in the system, $2n$ represents the order of performance index, $V^{(i)}_j$ is the voltage at bus j with incremental change in DG capacity at ith bus.

The value of VPI in this case will be high when the voltage at various buses is tending towards its nominal value i.e. 1.0 p.u. and it will have a low value when, the voltage tends to vary from its nominal value. This method selects the buses for DG placement, which help to maintain the voltage nearer to its nominal value. The higher value of VPI implies the best locations for installing DG in terms of improving voltage profile.

III. CASE STUDIES

The proposed method has been demonstrated and analyzed on standard 5-bus test system and IEEE 24-bus RTS. 5-bus test system consists of 3 generators, 5 buses, and 7 lines. IEEE 24-bus consists of 10 generators, 24 buses, and 38 lines.

A. Standard 5 Bus Test System

Case I: Loss sensitivity factor is calculated at each load bus and plotted with the DG capacity as shown in the Fig. 3. The load buses with minimum LSF have been selected for optimal placement of distributed generator. The LSF has been determined for two DGs at two different location .The values of LSF for different load buses with their ranking are given in the Table I. The value of LSF is minimum for load bus 5 than load bus 4, hence bus 5 will preferred first for DG placement than the bus 4.

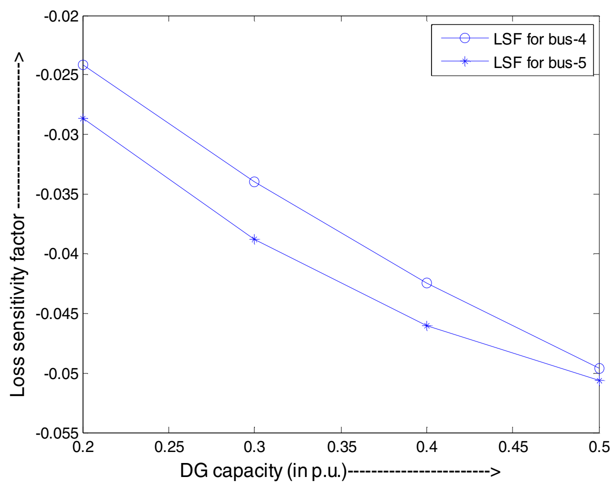

Fig. 3. Loss sensitivity factor with DG capacity.

The system loss has been determined for the base case is found to be 0.0319 p.u. The total system loss without and with DG placed at bus 5 and then bus 5 and 4 respectively, are given in the Table II. It can be observed from Table II and Fig.4 that the total loss of the system decreases with the increase in number of DG. For a DG capacity of 0.5 p.u. the plot of total system loss versus number of DGs is shown in Fig.4.

As shown in Table III, the line flows without and with DGs can be observed. It has been found from the table that the line flows with DGs are uniformly distributed throughout the system.

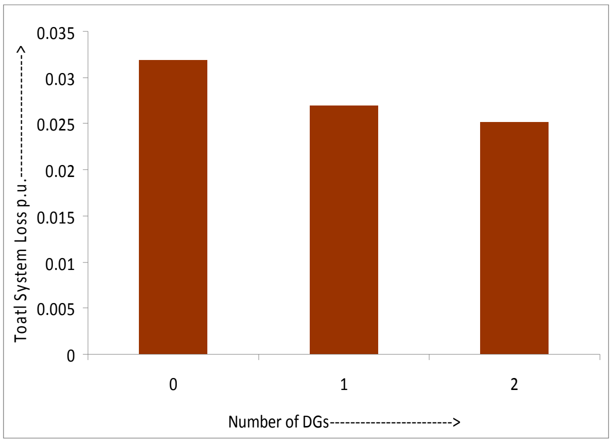

Fig. 4. System loss without and with DGs.

Case II: VPI is calculated at each load bus and the variation with respect to change in DG capacity is shown in the Fig. 5. The DG at a load bus with higher VPI value has been selected for optimal placement of DGs. Load buses 4 and 5 have been considered for optimal location of distributed generation. The values of VPI for different load buses are given in the Table IV. The value of VPI for load bus 4 is higher than load bus 5, hence the former will preferred first for DG placement than the later.

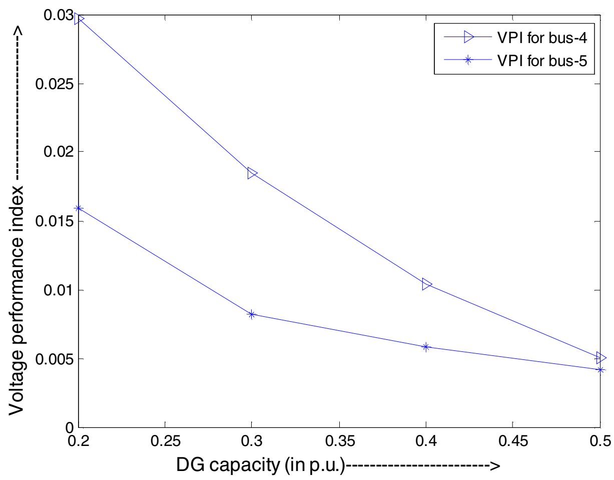

Fig. 5. Voltage performance index with DG capacity.

The voltage variation at load buses without and with distributed generation has been obtained for a DG capacity of 0.5 p.u. The voltage variations are plotted shown in Fig. 6. It can be observed from the figure that in the presence of DGs, the bus voltages improve at all buses. The increase in voltage beyond maximum value is also not suitable for the system. So, in order to avoid that the VPI has been proposed, where the value of VPI becomes zero as voltage at any bus crosses the limiting value.

The line flows without and with DG for few lines are observed with optimally integrating the DGs. It can be observed from the Table V that the line flows become uniformly distributed throughout the system.

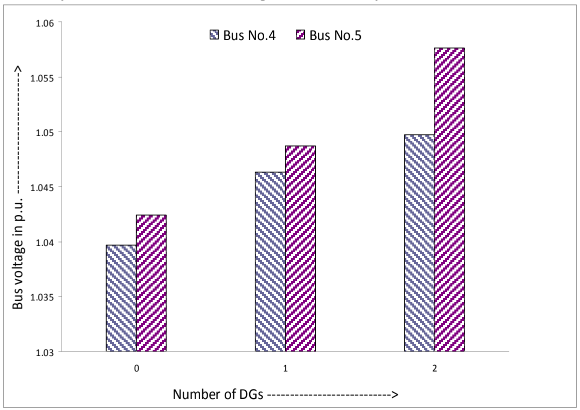

Fig. 6. Voltage profile without and with DGs.

TABLE I
LSF VALUES AND RANKING OF LOAD BUSES FOR DG PLACEMENT

Bus No.	LSF	Rank
4	-0.0241	2
5	-0.0287	1

TABLE II
TOTAL POWER LOSS IN THE SYSTEM WITH AND WITHOUT DG

No. of DGs	Total system loss
0	0.0319
1	0.0270
2	0.0252

TABLE III
LINE FLOWS FOR FEW LINES WITHOUT AND WITH DGS (IN CASE OF LOSS REDUCTION SENSITIVITY METHOD)

From	To	No DGs	One DG	Two DGs
1	4	1.400	1.077	0.737
2	3	-0.438	-0.536	-0.576
3	5	0.874	0.738	0.718

TABLE IV
VPI VALUES AND RANKING OF LOAD BUSES FOR DG PLACEMENT

Bus No.	VPI	Rank
4	0.0297	1
5	0.0159	2

TABLE V
LINE FLOWS FOR FEW LINES WITHOUT AND WITH DGS (IN CASE OF VOLTAGE IMPROVEMENT SENSITIVITY METHOD)

From	To	No DGs	One DG	Two DGs
1	2	-0.089	-0.250	-0.430
1	4	1.400	1.059	0.737

B. IEEE 24-bus Reliability Test system

Case I: LSF is calculated for each load buses. Figs. 7 and 8 show the plots of LSF with respect to DG capacity. The minimum value of LSF shows the suitable location for DG placement. The best locations can be determined directly from the Figs. 7 and 8. The values of LSF for different load buses with their ranking for a DG capacity of 0.1 p.u. are given in the Table VI. This shows the operational ranking of DGs when operating at a capacity of 0.1 p.u. and which may vary as the capacity of DGs is increased. This gives a signal to the system operator to increase or decrease the operating volume of DGs based on the ranking obtained for a particular load level.

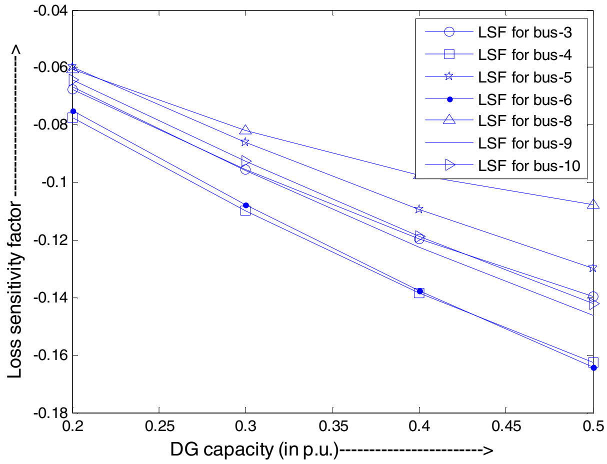

Fig. 7. Loss sensitivity factor with DG capacity.

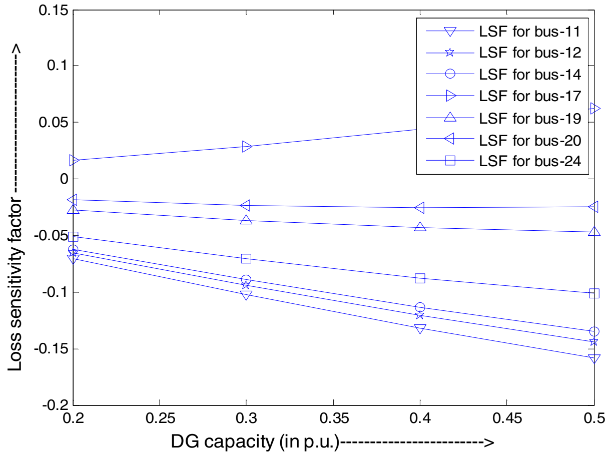

Fig. 8. Loss sensitivity factor with DG capacity.

TABLE VI
LSF VALUES AND RANKING OF LOAD BUSES FOR DG PLACEMENT

Bus No.	LSF	Rank
3	-0.0678	4
4	-0.0775	1
5	-0.0599	10
6	-0.0750	2
8	-0.0606	9
9	-0.0668	5
10	-0.0642	7
11	-0.0705	3
12	-0.0649	6
14	-0.0623	8
17	0.0162	14
19	-0.0273	12
20	-0.0185	13
24	-0.0506	11

The impact of integrating DGs on total system loss has been observed. Without any DG in the network, the total real power loss is found to be 0.5108 p.u. With the integration of DGs, it has been observed that the losses in the system decreases. For a DG capacity of 0.5 p.u., Fig. 9 shows total system loss with respect to the number of available DGs. Also, the system loss without and with DGs are given in the Table VII.

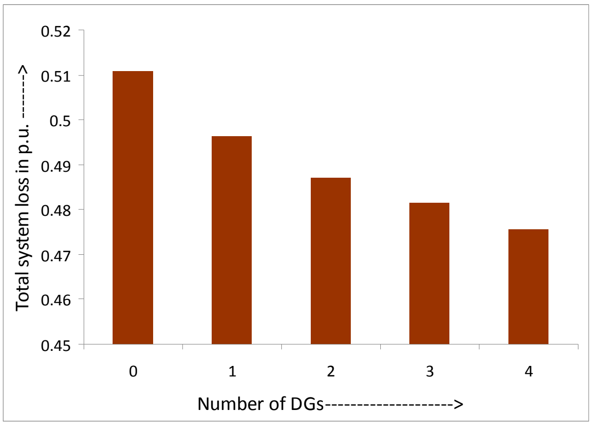

Fig. 9. System loss without and with DGs.

TABLE VII
TOTAL POWER LOSS IN SYSTEM WITH AND WITHOUT DG

No. of DGs	Total System loss
0	0.5108
1	0.4962
2	0.4870
3	0.4814
4	0.4755

The line flows without and with DGs for few lines are given in Table IX. It has been observed from the table that the line flows with DGs are uniformly distributed throughout the system.

Case II: VPI is calculated at each load bus and the variation with respect to change in DG capacity is shown in the Figs. 10 and 11. With load buses having higher value of VPI have been selected for optimal placement of distributed generator. Load buses 9,3,11 and 4 have been considered for optimal location of distributed generation. The values of VPI for different load buses with their ranking are given in the Table VIII. It can be observed from the table that VPI for load buses 5 and 6 are zero, because voltages at these buses cross the limiting values.

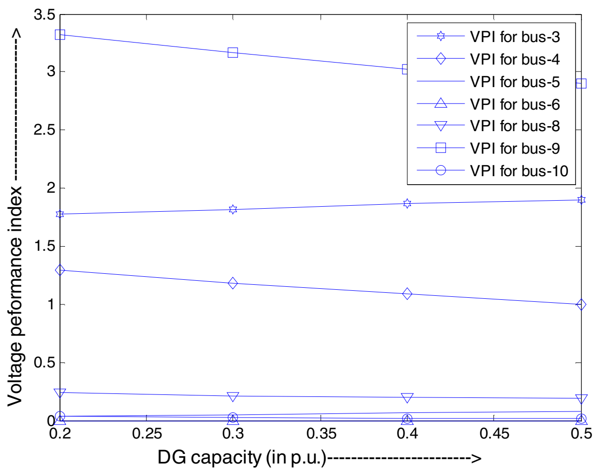

Fig. 10. Voltage performance index with DG capacity.

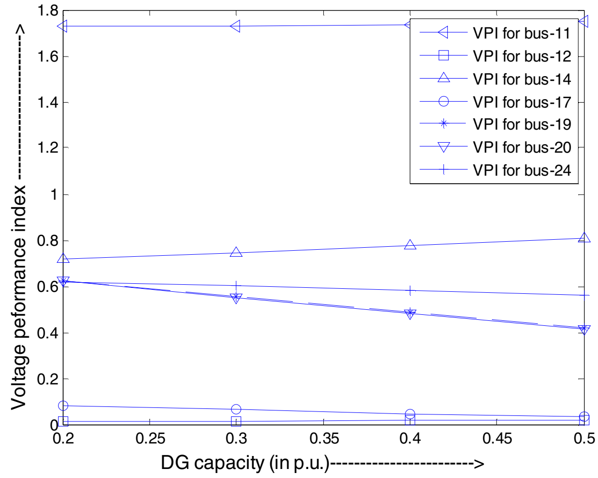

Fig. 11. Voltage performance index with DG capacity.

TABLE VIII
VPI VALUES AND RANKING OF LOAD BUSES FOR DG PLACEMENT

Bus No.	VPI	Rank
3	1.7748	2
4	1.2929	4
5	0.0000	13
6	0.0000	13
8	0.2425	10
9	3.3180	1
10	0.0317	11
11	1.7275	3
12	0.0133	12
14	0.7184	6
17	0.0840	5
19	0.6254	7
20	0.6216	8
24	0.6173	9

The voltage variations at some of the load buses without and with distributed generation has been obtained and is shown in Fig. 12. It can be observed from figure that in the presence of DGs, there is considerable improvement in voltage profile.

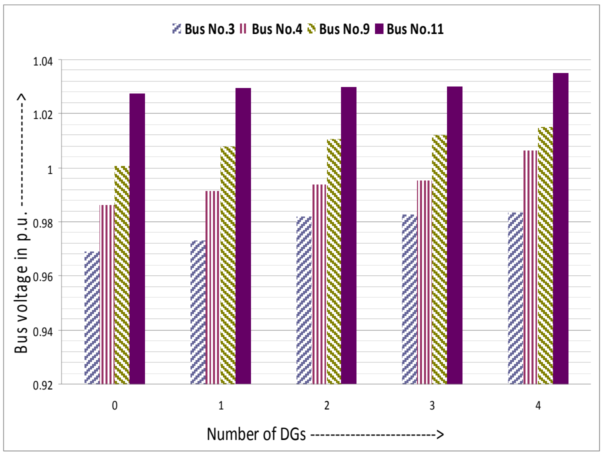

Fig. 12. Voltage profile without and with DG.

The line flows without and with DG for few lines are observed with optimally integrating the DGs. It can be observed from the Table X that the line flow throughout the system becomes uniformly distributed. In [13], the ranking was made for a particular loading and maximum DG capacity. This ranking may change with change in load level and DG capacity. The information of DG placement ranking variation is obtained in this work, which is shown in figures 7 and 8. This work can be useful for a well planned system, where there is a need of increasing the DG capacity due to load increase. Therefore, when adding the new DG capacity to the system the information obtained by this method will be useful.

TABLE IX
LINE FLOWS FOR FEW LINES WITHOUT AND WITH DGS (IN CASE OF LOSS REDUCTION SENSITIVITY METHOD)

From	To	No DGs	One DG	Two DGs	Three DGs	Four DGs
3	9	1.531	1.472	1.441	1.400	1.411
5	10	0.751	0.662	0.503	0.338	0.225
11	14	-2.105	-2.099	-2.080	-2.011	-2.080
19	20	0.076	0.074	0.062	0.068	0.112
20	23	2.020	-2.004	-1.990	-1.995	-2.038

TABLE X
LINE FLOWS FOR FEW LINES WITHOUT AND WITH DGS (IN CASE OF VOLTAGE IMPROVEMENT SENSITIVITY METHOD)

From	To	No DGs	One DG	Two DGs	Three DGs	Four DGs
5	10	0.751	0.608	0.495	0.330	0.241
13	23	-0.788	-0.788	-0.808	-0.794	-0.793
17	18	-0.727	-0.726	-0.739	-0.732	-0.731
19	20	0.076	0.070	0.115	0.121	0.118
21	22	-0.834	-0.835	-0.834	-0.837	-0.837

IV. CONCLUSION

In this paper, the impact of DG in an electric power system has been analyzed in terms of voltage profile improvement, line loss reduction and relieving of overloaded transmission lines. The proposed methodology identifies the best location for placement of DG with respect to loss reduction sensitivity and voltage improvement sensitivity. The LSFs and VPIs have been computed for each of the load buses by integrating DGs. The load bus with lower LSF and higher VPI value has been selected as the best location for DG placement. With the optimal placement of DGs, it has been observed that the line flows in the system become evenly distributed. DG can solve the distribution system renovation and planning problem along side improving the power quality.

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