# Multi-objective Placement and Sizing of DGs in Distribution Network using Genetic Algorithm

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***Abstract*—The energy requirement has accelerated stupendously in the last few years, which recommends creation of newer transmission lines. Transmission lines are not only expensive but also requires land and maintenance. Distributed Generations (DGs) is a good alternative solution which postpones putting up of newer transmission lines and also helps to minimize the power loss in the lines. Along with the above benefits, DGs also enhance the voltage profile of the system and supports clean energy. In this work three different DGs namely, solar, wind and Combined Heat and Power(CHP) is connected to suitable nodes for a standard 10 node and 51 node system. Sensitivity analysis has been carried out to pinpoint the optimal location of the DG. Genetic Algorithm is utilized to optimize a multi-objective function to obtain the optimal size of the DGs.**

***Index Terms*—Distributed Generation, Distribution system, Genetic Algorithm**

## I. Introduction

THE use of electricity has increased a lot in the past few years. The power plants are located far away from the consumption center. Thus, the industry suffers from transmission and distribution line losses. The distribution scenario in India is even more complex. Apart from high distribution loss, the end nodes of the radial distribution system suffers from poor voltage magnitude. To reduce the loss and improve the voltage profile Distributed Generations (DGs) can be included in the system. DGs are defined as de-centralized power plants placed in the consumer side, capacity ranging from 1 kW to 300 MW. The DGs when connected to optimal nodes, decrease the current drawn from the substation and hence reduces the power loss.

The definition of DGs has been provided by Ackermann et al [1]. A thumb rule was presented by Willis [2] to install a DG of approximately 2/3rd capacity of the incoming generation and place them at approximately 2/3rd of the length of line. Gautam and Mithulanathan [3] conceived different objectives for optimal placement and size of DGs. The objectives are namely social welfare maximization and profit maximization and locating optimal nodes on the basis of locational marginal price (LMP). Singh and Goswami [4] has devised a nodal pricing method for optimally allocating DGs for profit, loss reduction and improvement in voltage regulation.Celli et al. [5] used Genetic Algorithm to optimize siting and sizing of DGs into existing distribution networks by optimizing multiobjective functions. It consisted of network upgrading, cost of power loss, cost of energy not supplied and cost of energy required for the served customers. An optimal approach to determine the optimal nodes is presented by El-Ela et al. Also sizes were optimized. [6] have used as well as optimal size of DGs with multi-system constraint.In another work Hung and Mithulananthan [7] introduced an improved analytical (IA) method for finding the optimal size of four DGs each one of distinct type and also finding the best location for DG connection. Dhass and Harikrishnan [8] have developed a methodology which determines per unit energy cost of Solar PV, wind and Biomass hybrid system. This paper showed that the life cycle cost or LCC and life cycle unit cost or LUC for solar biomass, wind biomass and PV-wind biomass hybrid system are always lower than a stand alone system for all the load demands. A probabilistic generation-load model introduced by Atwa et al. [9] includes all possible operating conditions of the renewable DG units for optimally allocating different types of DG (i.e., wind based DG, solar DG and biomass DG) into the distribution This results in decrease of power loss. Different DG allocation methods, with diferent sensitivity analysis have been compared by Murthy [10]. A PSO based algorithm presented by Karimyan et al. [11] for long term scheduling of optimal allocation and sizing of different types of DG units for loss minimization and improvement of voltage profile. A sensitivity analysis has been carried out for the selection of three nodes for maximum advantage. After finding out the optimal position, the optimum size of the DGs are found out with the help of Genetic Algorithm. The objective function formulation is novel and has been discussed first. The objective function contains three individual components which are important parameters for sizing of DGs. Additionally, the cost of the DGs have also been included in the objective function. In this paper results and discussions for a 10 node and 51 node radial distribution system is described.

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## II. Methodology

### A. Selection of best nodes for placement of DGs

Foremost a sensitivity index is defined as follows,

$$S_k = \frac{P^k_{lossdg}}{P_{loss}} \quad (1)$$

where,

$$\begin{aligned} P^k_{lossdg} &= \text{real power loss after the power injection at node k} \\ \text{k} &= 2, 3, \cdots, N \\ P_{loss} &= \text{real power loss without DG.} \end{aligned}$$

Then at each node, 10%, 20%, 30% of total real load is injected to compute the value of $S_k$, for k = 2, 3, .....,N. Then, the value of $S_k$ is arranged in ascending order and top 6 nodes are tabulated in Table-I for 10 node distribution system as shown in Fig.1.

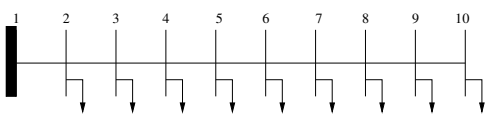


Fig. 1: 10 node distribution system

TABLE I: Ranking of the nodes

| Ranking | Node number |
|---|---|
| 1 | 10 |
| 2 | 9 |
| 3 | 8 |
| 4 | 7 |
| 5 | 6 |
| 6 | 5 |

Top three nodes are selected for the placement of DGs, i.e nodes 10, 9 and 8. It may be noted the active power loss of the 10 node network before placement of DGs is 783 kW.

## III. Formulation of Objective Function

Three objectives are considered for the placement of DGs. Thus the complete objective function $J$ now stands to be

$$\text{Minimize } J = \frac{P^k_{lossdg}}{P_{loss}} + \sum_{i=1}^{N}(1.0 - v_i)^2 + (\sum_{i=2}^{N} \text{kVA}_i v_i)^{-1} \quad (2)$$

The first term in equation 2 is for the purpose of active power loss reduction. Second term signifies that all the expected node voltage magnitudes must be near unity. Significance of the third term is that, if at any node, kVA load is high then generally at that node voltage goes to a low value. However, if it is desired that, if at any node kVA load is high and its voltage also, should be high then p $= \sum_{i=2}^{N} \text{kVA}_i v_i$ must be maximized. Hence its reciprocal should be minimized. Note that in equation 2 all the values are in p.u.

## IV. Results and Discussions

### A. Example-1: For this case a 10 node, 23 kV radial distribution network is considered

*1) Case 1:* Objective function as given in equation 2 is minimized using GA for determination of optimal values of upf DGs.

1) Optimal values of upf DG units is shown in Table-II.

TABLE II: DG values at the three different nodes

| DG sizing(kW) | |
|---|---|
| $P_{DG8}$ | 4171 |
| $P_{DG9}$ | 811 |
| $P_{DG10}$ | 2070 |

2) Active Power loss before and after placement of upf DG units is given in Table-III.

TABLE III: Active Power Loss

| Power loss | Before placement of upf DG | After placement of upf DG | % loss reduction |
|---|---|---|---|
| Active(kW) | 783 | 118.82 | 84.82 |

3) Minimum and Maximum Voltage Magnitude before and after placement of upf DG units is listed in Table-IV.The figure 2 shows the plot of voltage magnitude vs number of nodes, with DG and without DG. It can be seen that with the placement of upf DG, voltage profile has improved significantly.

TABLE IV: Minimum and Maximum node voltages

| Voltage | Before placement of upf DG | After placement of upf DG |
|---|---|---|
| Minimum voltage(p.u) | $V_{min}(10) = 0.8375$ | $V_{min}(6) = 0.9716$ |
| Maximum voltage(p.u) | $V_{max}(1) = 1$ | $V_{max}(1) = 1$ |

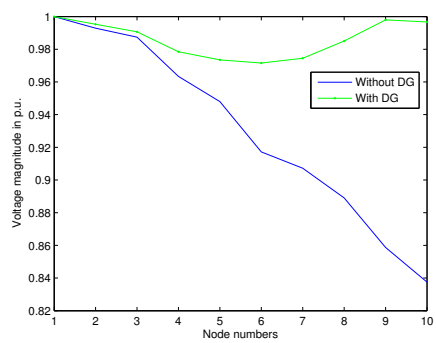


Fig. 2: Voltage profile before and after connecting DG (minimizing Eqn. 2)

*2) Case 2: Addition of weighted constants in the objective function of equation:* The objective function in equation 2, is commanded by three different parts, all in p.u. But it is seen that, the percentage participation of the third term is almost 99%, leaving the worth of other two parts almost nil. So, it

was decided to include two weighted constants for the first and the second terms, $\lambda_1$ and $\lambda_2$. These constants were also optimized using genetic algorithm. Thus the objective function becomes

$$\text{Minimize } J = \lambda_1 \, P_{lossDG} + \lambda_2 \sum_{i=1}^{N} (1.0 - v_i)^2 + \left(\sum_{i=2}^{N} \text{KVA}_i v_i\right)^{-1} \quad (3)$$

The results are given below,

1) The sizes of DG obtained is listed in Table-V.

TABLE V: DG sizing

| DG sizing(kW) | |
|---|---|
| $P_{DG8}$ | 3422 |
| $P_{DG9}$ | 1408 |
| $P_{DG10}$ | 1539 |

2) The active power loss before and after DG installation is given in Table-VI.

TABLE VI: Active power loss

| Power loss | Before placement of upf DG | After placement of upf DG | % loss reduction |
|---|---|---|---|
| Active(kW) | 783 | 103.73 | 86.75 |

3) Minimum and Maximum Voltage Magnitude before and after placement of upf DG units is displayed in Table-VII. The representation of voltage profile with and without DGs is shown in Fig. 3.

TABLE VII: minimum and maximum voltage magnitude with node numbers

| Voltage | Before placement of upf DG | After placement of upf DG |
|---|---|---|
| Minimum voltage(p.u) | $V_{min}(10) = 0.8375$ | $V_{min}(6) = 0.9648$ |
| Maximum voltage(p.u) | $V_{max}(1) = 1$ | $V_{max}(1) = 1$ |

4) The optimized $\lambda$ values are listed in Table-VIII.

TABLE VIII: The optimized $\lambda$ values

| values of $\lambda$ | |
|---|---|
| $\lambda_1$ | 133.55 |
| $\lambda_2$ | 100.07 |

5) Another table helps to get a better realization of the effect of adding weights to the objective function. The Table-IX shows the power loss for three different cases, i.e without DG, with upf DG ($\lambda$=1) and with upf DG as well as ($\lambda$).

After addition of weighted constants it can be seen that the power loss drops to 103.73 kW from 118.82 kW, when the weights were not considered. Improvement in voltage profile can be seen from the figure. Also, the voltage profile after connecting upf DGs with $\lambda = 1$ and upf DGs with optimized $\lambda$ values is shown in Fig. 4.

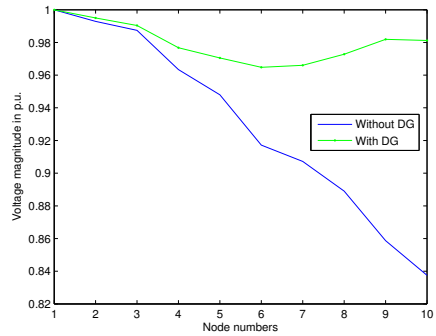


Fig. 3: Voltage profile before and after connecting DG (minimizing Eqn. 3)

TABLE IX: Active power loss

| Power loss | without upf DG | With upf DG($\lambda$=1) | With upf DG and $\lambda$ |
|---|---|---|---|
| Active(kW) | 783 | 118.82 | 103.73 |

*B. Example-2 :For this case a 51 node, 11 kV radial distribution network is considered.*

The 51 node system is shown in Fig. 5. For this system too, the nodes for placing DGs using sensitivity analysis as described in the previous example is carried out.

The ranking of the nodes to select the best nodes is given in Table-X. From the above table it can be concluded that the nodes to be selected for DG placement should be 13, 14 and 15.

TABLE X: Ranking of the nodes(51 node example)

| Ranking | Node number |
|---|---|
| 1 | 15 |
| 2 | 14 |
| 3 | 13 |
| 4 | 12 |
| 5 | 16 |
| 6 | 11 |

*1) Case 1:* The objective function minimized is equation 2. The results for 51 node example is presented below,

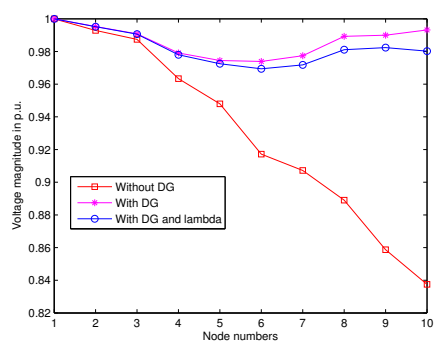


Fig. 4: Combined Voltage Profile

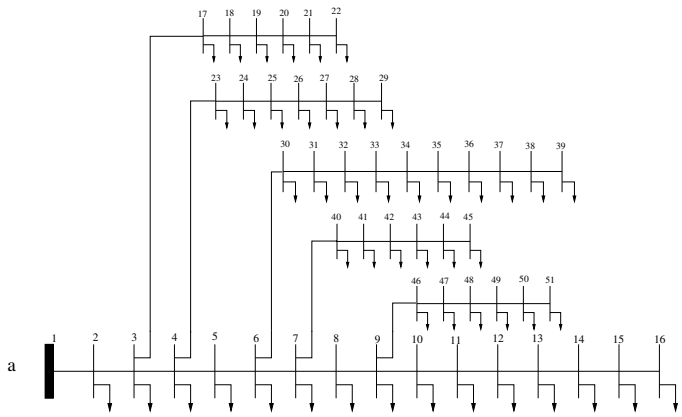


Fig. 5: 51 node Distribution System

1) Optimal values of upf DG units is tabulated in Table-XI.

TABLE XI: DG sizes

| DG sizing (kW) | |
|---|---|
| $P_{DG13}$ | 417.14 |
| $P_{DG14}$ | 341.1 |
| $P_{DG15}$ | 294.94 |

2) Active Power loss before and after placement of upf DG units is shown in Table-XII.

TABLE XII: Active Power Loss

| Power loss | Before placement of upf DG | After placement of upf DG | % loss reduction |
|---|---|---|---|
| Active(kW) | 147.05 | 112.69 | 23.36 |

3) Minimum and Maximum Voltage Magnitude before and after placement of upf DG units is available in Table-XIII. It can be seen clearly from the Fig. 6 that after connecting upf DG, the voltage profile improves significantly.

TABLE XIII: Min and maximum Voltage magnitudes with node numbers

| Voltage | Before placement of upf DG | After placement of upf DG |
|---|---|---|
| Minimum voltage(p.u) | $V_{min}(16) = 0.9023$ | $V_{min}(45) = 0.9338$ |
| Maximum voltage(p.u) | $V_{max}(1) = 1$ | $V_{max}(1) = 1$ |

*2) Case 2:* The second case repeats the minimization problem as described in equation 3 with the 51 node example. In this case weighted constants are included. The results follow.

1) The sizes of DG obtained is given in Table-XIV.
2) The loss before and after DG installation is shown in Table-XV.
3) Minimum and Maximum Voltage Magnitude before and after placement of upf DG units is listed in Table-XVI. The representation of voltage profile with and without DGs is shown in Fig. 7.Improvement in voltage profile can be clearly seen from the plot.

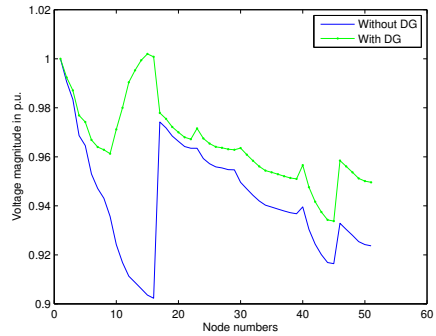


Fig. 6: Voltage profile before and after connecting DG (minimizing Eqn. 2)

TABLE XIV: DG sizes

| DG sizing(kW) | |
|---|---|
| $P_{DG13}$ | 296.99 |
| $P_{DG14}$ | 292.45 |
| $P_{DG15}$ | 80.8791 |

4) The optimized $\lambda$ values are shown in Table-XVII.
5) To get a better realization of the effect of adding weights to the objective function, Table-XVIII shows the power loss for three different cases, i.e without DG, with upf DG ($\lambda$=1) and with upf DG as well as ($\lambda$).

After addition of weighted constants, it can be seen, that the power loss drops to 99.16 kW from 112.69 kW when the weights were not considered. Also the voltage profile after connecting upf DGs with $\lambda = 1$ and upf DGs with optimized $\lambda$ values is shown in Fig. 8.

*3) Case 3: Including Cost of DGs:* The most used DGs now-a-days is Solar, Wind and Combined Heat and Power or CHP. All the previous functions didn't consider the cost of the DG. If the only focus is decreasing the loss, without taking into account the cost of DGs, then it may lead to unsatisfactory sizing. This is because, bigger DG sizes will incur higher cost. So a balanced approach (i.e. balancing power loss and cost) should contain another term in the objective function. The new term in the objective function will keep into account the cost of the DGs and minimize them accordingly. Steps to calculate the advanced objective function,

1) In nodes 13, 14 and 15 solar, wind and CHP DGs are

TABLE XV: Active Power Loss

| Power loss | Before placement of upf DG | After placement of upf DG | % loss reduction |
|---|---|---|---|
| Active(kW) | 147.05 | 99.16 | 32.56 |

TABLE XVI: Minimum and maximum voltage

| Voltage | Before placement of upf DG | After placement of upf DG |
|---|---|---|
| Minimum voltage(p.u) | $V_{min}(16) = 0.9023$ | $V_{min}(45) = 0.9292$ |
| Maximum voltage(p.u) | $V_{max}(1) = 1$ | $V_{max}(1) = 1$ |

TABLE XVII: The optimized $\lambda$ values

| values of $\lambda$ | |
|---|---|
| $\lambda_1$ | 102.27 |
| $\lambda_2$ | 100.21 |

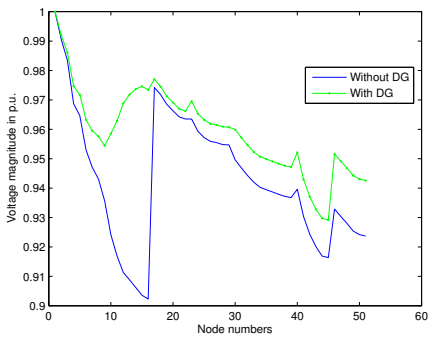


Fig. 7: Voltage profile before and after connecting DG (minimizing Eqn. 3)

connected respectively.

2) All the quantities are represented in per unit.The cost of the DGs are quite high. If the per unit values are not multiplied with some *weighted factor* then the cost values will alone govern the objective function.
3) So the objective function now becomes

$$\text{Min, } J = \sum_{i=1}^{N_{DG}} C_i P_{DGi} + \lambda_1 \sum_{i=1}^{N} (1.0 - v_i)^2 + \lambda_2 (\sum_{i=2}^{N} \text{KVA}_i v_i)^{-1} + \lambda_3 \frac{P_{lossDG}}{P_{loss}} \quad (4)$$

TABLE XVIII: Active power loss

| Power loss | without upf DG | With upf DG ($\lambda$=1) | With upf DG and $\lambda$ |
|---|---|---|---|
| Active(kW) | 147.05 | 112.69 | 99.16 |

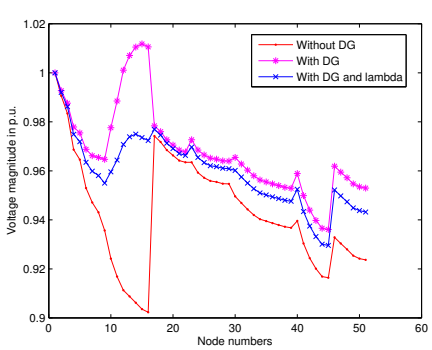


Fig. 8: Combined Voltage Profile

where,

$C_i$ = Cost of respective DGs in \$/kW.

$P_{loss}^{dg}$ = Real Power loss when DG in buses 13, 14 and 15 are connected.

$P_{loss}$ = Real power loss when no DG is connected

The results are given below,

1) The sizes of DG obtained is shown in Table-XIX.

TABLE XIX: DG size

| DG sizing(kW) | |
|---|---|
| $P_{DG13}$ | 299.63 |
| $P_{DG14}$ | 295.24 |
| $P_{DG15}$ | 158.83 |

2) The loss before and after DG installation is listed in Table-XX.

TABLE XX: Active Power Loss

| Power loss | Before placement of upf DG | After placement of upf DG | % loss reduction |
|---|---|---|---|
| Active(kW) | 147.05 | 103.50 | 29.61 |

3) Minimum and Maximum Voltage Magnitude before and after placement of upf DG units is given in Table-XXI. The representation of voltage profile with and without DGs is shown in Fig. 9.

TABLE XXI: Voltage profile vs nodes

| Voltage | Before placement of upf DG | After placement of upf DG |
|---|---|---|
| Minimum voltage(p.u) | $V_{min}(16) = 0.9023$ | $V_{min}(45) = 0.9322$ |
| Maximum voltage(p.u) | $V_{max}(1) = 1$ | $V_{max}(1) = 1$ |

4) The optimized $\lambda$ values are given in Table-XXII.

TABLE XXII: The optimized $\lambda$ values

| values of $\lambda$ | |
|---|---|
| $\lambda_1$ | $4.35 \times 10^6$ |
| $\lambda_2$ | $1.56 \times 10^5$ |
| $\lambda_3$ | $3.27 \times 10^5$ |

### C. With lagging power factor of the combined load

Till now unity power factor (upf) DGs was considered. For the 51 node problem the combined load power factor comes out to be 0.8409. Considering this power factor as power factor of the DGs the following results were obtained.

1) The sizes of DG obtained is displayed in Table-XXIII.
2) The loss before and after DG installation is described in Table-XXIV.

TABLE XXIV: Active and reactive power

| Power loss | Before placement of upf DG | After placement of upf DG | % loss reduction |
|---|---|---|---|
| Active(kW) | 147.05 | 90.91 | 38.17 |
| Reactive(kVAr) | 110.79 | 49.12 | 55.66 |

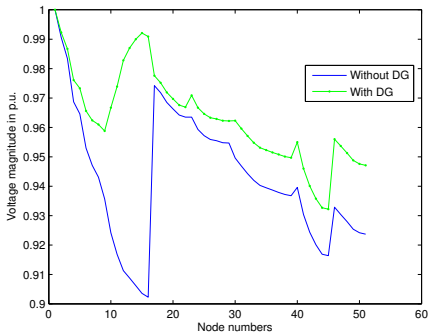


Fig. 9: Voltage profile before and after connecting DG (minimizing Eqn. 3)

TABLE XXIII: DG size

| DGs | $\frac{kW}{pf}$ |
|---|---|
| $P_{DG13}$ | 353.18 |
| $P_{DG14}$ | 347.78 |
| $P_{DG15}$ | 304.57 |

3) Minimum and Maximum Voltage Magnitude before and after placement of upf DG units is shown in Table-XXV. The representation of voltage profile with and without DGs is shown in Fig. 10.

TABLE XXV: Minimum and Maximum voltage

| Voltage | Before placement of upf DG | After placement of upf DG |
|---|---|---|
| Minimum voltage(p.u) | $V_{min}(16) = 0.9023$ | $V_{min}(45) = 0.9409$ |
| Maximum voltage(p.u) | $V_{max}(1) = 1$ | $V_{max}(16) = 1.0303$ |

4) The optimized values of $\lambda$ are tabulated in Table-XXVI.

TABLE XXVI: The optimized $\lambda$ values

| values of $\lambda$ | |
|---|---|
| $\lambda_1$ | $4.44 \times 10^7$ |
| $\lambda_2$ | $2.46 \times 10^6$ |
| $\lambda_3$ | $4.17 \times 10^6$ |

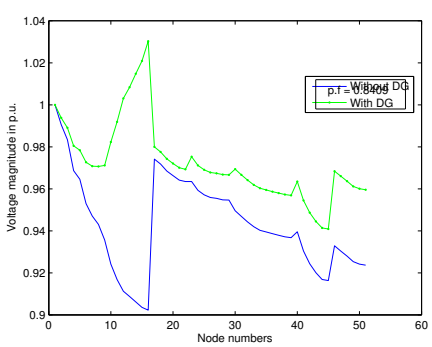


Fig. 10: Voltage profile before and after considering lagging power factor DG

## V. Conclusion

In this work, genetic algorithm (GA) has been employed for determination of DG sizes considering different objective functions. It has been seen after connection of DGs the power loss reduced considerably and the improvement of voltage profile is seen from the Fig.2 and Fig.6. The analysis rereads that if cost of DG is considered in the objective function then each constraint term must be multiplied by penalty terms. These penalty terms also need to be optimized along with the DG sizes. The result of inclusion of penalty or weighting terms in the objective functions have been showcased using Fig.4 and Fig.7. If penalty terms are set to unity, then the results are misleading. Unity power factor DGs have been considered in this work, except in the last case where the power factor of the DG has been made equal to the load power factor. The improvement of voltage and reduction in power loss have been reaffirmed from Fig.10. So in this paper the optimal location have been found out using sensitivity analysis and there after optimized DG values for peak load condition have been suggested.

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