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# Optimal Placement and Sizing of DG in Distribution lines.

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**ABSTRACT**: With the ever increasing power demand from the consumers, there is a scope for the integration of renewable energy based distribution generation (DG) into the distribution lines. The non conventional distribution generation sources injecting power located near to the load centres provides an opportunity for loss reduction, system voltage support and reliability improvement. Therefore the placement and sizing of DG should be carefully done with the consideration of different types of DG. In this regard, this paper attempts to determine the optimal location based on fast voltage sensitivity index and optimum size using analytical expressions for four different types of DG. The proposed technique was implemented on IEEE 33 bus system.

**KEYWORDS:** Distributed generation (DG), Fast Voltage Stability Index (FVSI), analytical expressions, radial distribution system, optimal placement, optimum sizing

## I.INTRODUCTION

Distributed generation is the production of electricity by the small generators which can serve from few kilowatts to megawatts near the load centers at distribution level voltages. The share of DGs in power systems is increasing from the past few years due to the technical and economical benefits. The contribution of DGs in future smart grids is also expected to be more as they play a prominent role in system security, reliability, efficiency and power quality. The deregulation of electricity was introduced due to the various reasons. In deregulated environment the hunt for superior quality, reliability, controllability and cost has uplifted the development of DG by the manufacturers and customers. DG could be considered as one of the viable options to ease some of the problems e.g. high loss, low reliability, poor power quality, congestion in transmission system faced by the power systems, apart from meeting the energy demand of ever growing loads.

In a power system network that provides electric power to local customers, DGs can be an alternative for industrial, commercial and residential applications. With the usage of latest modern technology in DGs they try to compete with the traditional large generators in some areas. When DGs act parallel to the utility grid they operate in non-autonomous mode and if they are isolated from the grid, autonomous mode of operation is performed. In [1] the optimal siting and sizing of DG has been done for both autonomous and non autonomous mode of operation by using successive sizing method.

The global concern about the environment and the Kyoto protocol on the climate change had led the development of non conventional based DG technologies world widely [2] .In this aspect different types of DG based on renewable energy sources are introduced into the distribution systems. To have gain in the system voltage stability margin a synchronous type DG is installed or if to reduce stability margin an induction machine based DG is incorporated based on the availability conditions. When different types of DG sources are used in the distribution system the primary substation is no longer the sole source of power supply. Therefore, distribution systems with Distributed Generator (DG) units require new approaches in their planning and operation.

DG units can deliver both real and reactive power to loads so that the current carrying capacity of the feeder gets reduced from the source to the location of DG units. The installation of DG brings not only economical but also technical benefits like improvement of efficiency, reliability and security. However, studies have shown that if DG units are improperly allocated and sized, the reverse power flow from larger DG units that can lead to higher system losses. Hence, to minimize losses, it is important to find the optimal location and size of DG. A technique for DG placement using fast voltage sensitivity index and for sizing analytical approach has been presented.

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## II.PROPOSED METHODOLOGY

### A. Problem formulation

The objective function to minimize the total real power loss given by the exact loss formula is shown in (1) meeting the voltage constraints [3].

$$P_L = \sum_{i=1}^{n}\sum_{j=1}^{n} A_{ij}(P_iP_j + Q_iQ_j) + B_{ij}(Q_iP_j - Q_jP_i) \quad (1)$$

Where

$$A_{ij} = \frac{R_{ij}}{V_iV_j}\cos(\delta_i - \delta_j) \text{ and } B_{ij} = \frac{R_{ij}}{V_iV_j}\sin(\delta_i - \delta_j)$$

$P_i$ and $Q_i$ are the active and reactive powers at $i^{th}$ bus respectively.

$P_j$ and $Q_j$ are the active and reactive powers at $j^{th}$ bus respectively.

$V_i\angle\delta_i$ is the complex voltage at $i^{th}$ bus.

$R_{ij} + jX_{ij} = Z_{ij}$ is the $ij^{th}$ element of $[Z_{bus}]$ impedance matrix.

$n$ be the number of buses.

Constraints: $V_{min} < V < V_{max}$

### B. Types of DG

Distribution generators can be classified into four types based on the capability of delivering real and reactive power.
Type 1: DG capable of injecting real power only
Type 2: DG capable of injecting reactive power only
Type 3: DG capable of injecting real and reactive power only
Type 4: DG capable of injecting real power but consuming reactive power

### C. Optimal placement of DG

This method presents a new approach for optimal placement of DG. A fast voltage stability index is developed for the placement of DG to determine the most critical bus in the system [4]. Consider a simple two bus network for deriving the FVSI as shown in fig: 1

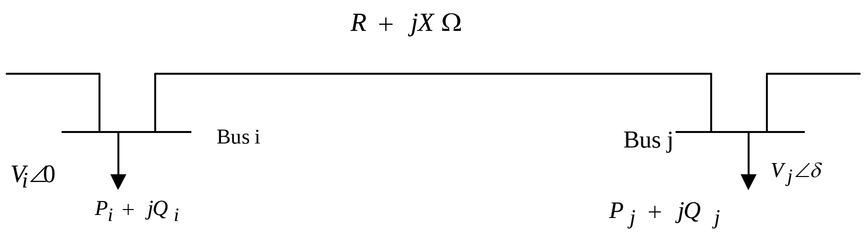


Fig.1Two bus network

By taking the $i^{th}$ bus as reference bus then the general current equation can be written as

$$I_{line} = \frac{V_i\angle 0 - V_j\angle\delta}{R + jX} \quad (2)$$

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The apparent power is given by the equation

$$S_j = I^*_{line} V_j \angle\delta \tag{3}$$

It can be rewritten as

$$I_{line} = \left[\frac{S_j}{V_j \angle\delta}\right]^* \tag{4}$$

Totally it can be represented as

$$I_{line} = \frac{P_j - jQ_j}{V_j \angle -\delta} \tag{5}$$

From (2) and (5) we have

$$(V_i \angle 0 V_j \angle -\delta) - V_j^2 = (R + jX)(P_j - jQ_j) \tag{6}$$

Separating the real and imaginary components of the above equation (6)

$$V_i V_j \cos\delta - V_j^2 = RP_j + XQ_j \tag{7}$$

$$-V_i V_j \sin\delta = XP_j - RQ_j \tag{8}$$

By substituting the $P_j$ of equation (8) in (7) yields

$$V_j^2 - \left(\frac{R}{X}\sin\delta + \cos\delta\right)V_i V_j + \left(X + \frac{R^2}{X}\right)Q_j = 0 \tag{9}$$

The roots for $V_j$ will be

$$V_j = \frac{\left(\frac{R}{X}\sin\delta + \cos\delta\right)V_i \pm \sqrt{\left[\left(\frac{R}{X}\sin\delta + \cos\delta\right)V_i\right]^2 - 4\left(X + \frac{R^2}{X}\right)Q_j}}{2} \tag{10}$$

The discriminant is set to greater than or equal to zero to obtain the real roots

$$\frac{4Z^2 Q_j X}{V_i^2 (R\sin\delta + X\cos\delta)^2} \leq 1 \tag{11}$$

The angular difference is small that it can be neglected and made equal to zero.

$$FVSI = \frac{4Z^2 Q_j}{V_i^2 X} \tag{12}$$

FVSI should be always less than 1.The line that exhibits the higher value is the most sensitive value to collapse. Hence a DG is placed at the $j^{th}$ bus for a line i-j to reduce the voltage instability and losses.

**D. Optimal sizing of DG**

The analytical equation for the four types of DG presented in the [5] has been used for optimal sizing of DG. The power factor plays a crucial role in determining the sizing of DG and it depends on the type of DG subject to operating

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conditions. The analytical expressions give the required real and reactive power in the form of DG size, at each bus i, for the loss to be minimum. Any size of DG other than placed at bus i, will lead to a higher loss.

**Type 1 DG**: It is capable of injecting real power only. The Solar cells, micro turbines which are integrated into the grid with the help of converters and inverters come under this category. The power factor is unity in this type of DG. The optimal size of DG at each bus i for the minimum loss is given by reduced equation.

$$P_{DGi} = P_{Di} - \frac{1}{A_{ii}}\{B_{ii}Q_{di} + \sum_{\substack{j=1 \\ j\neq i}}^{n}(A_{ij}P_j - B_{ij}Q_j)\} \tag{11}$$

**Type 2 DG**: It is capable of delivering reactive power only. Synchronous compensators are the best example for this type of DG. Here the power factor is zero and the optimal size for injecting reactive power type DG is given by the equation (12)

$$Q_{DGi} = Q_{Di} + \frac{1}{A_{ii}}\{B_{ii}Q_{di} - \sum_{\substack{j=1 \\ j\neq i}}^{n}(A_{ij}Q_j + B_{ij}P_j)\} \tag{12}$$

**Type 3 DG**: The DG capable of injecting both real and reactive power. These types of DGs like synchronous generators etc. work in cogeneration plants. In this type the power factor plays a crucial role in determining the size of DG. The optimal power factor required for optimum size of DG is considered as the optimal power factor of the combined load. The optimal size of DG for i$^{th}$ bus is given below.

$$P_{DGi} = \frac{A_{ii}(P_{Di} + aQ_{Di}) + B_{ii}(aP_{Di} - Q_{Di}) - X_i - aY_i}{a^2 A_{ii} + A_{ii}} \tag{13}$$

$$Q_{DGi} = aP_{DGi} \tag{14}$$

Where

$$a = (sign)\tan(\cos^{-1}(PF_{DG})) \tag{15}$$

$$X_i = \sum_{\substack{j=1 \\ j\neq i}}^{n}(A_{ij}P_j - B_{ij}Q_j)$$

$$Y_i = \sum_{\substack{j=1 \\ j\neq i}}^{n}(A_{ij}Q_j + B_{ij}P_j)$$

$$PF_D = PF_{DG} = \frac{P_D}{\sqrt{P_D^2 + Q_D^2}} \tag{16}$$

**Type 4 DG**: It is capable of injecting real power but consuming reactive power. In wind farms induction generators inject active and consume reactive power with the lagging power factor are included in this type of DG. Similar to Type 3 DG, the optimal size is given by equations (13) and (14) but the sign in (15) is considered to be negative as reactive power is consuming.

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### E. Algorithm for optimal placement and sizing of DG

To determine the optimal location the fast voltage stability index is considered and for optimal sizing analytical expressions are used.
1. Run load flow for the base case by using backward and forward sweep and find losses using equation.(1)
2. Find the optimal locations for DGs using the following steps.
   a) Fast Voltage Stability index given by the equation (12) is calculated for all the lines
   b) Rank buses in descending order of the obtained values of FVSI to form a priority list.
   c) Select the top most value as the optimal location for the DG placement.
3. Estimate the required size of the DG units.
   a) Select the type of DG to be placed.
   b) Calculate the power factor of DG using equation. (16).
   c) Calculate size of DG at every location using equations. (11)- (14) for four types of DGs.
4. Place the obtained DG size from step (3) for four types of DG at the optimal location obtained from the step (2).
5. Run load flow and calculate losses using equation (1).

## III.NUMERICAL RESULTS

The proposed methodology as described in the section-II is tested on the 33 bus radial distribution system [6].It has a total real and reactive power of 3.72 MW and 2.3 MVAr respectively. The base voltage is 12.66 KV and the base MVA is 100.

### A. Load flow results

The backward and forward method [6] that exploits the radial nature of distribution lines has been used for the load flow analysis of the system. With this method the convergence is fast and the computation time required is less compared to other methods especially for radial distribution systems. The real power losses for the IEEE 33 radial distribution network are found to be 202.7 KW. The below figure show the voltages of all the buses for the base case without DG. The minimum voltage is found to be 0.9131 P.U. at the bus 18.

### B. Fast voltage stability index

The fast voltage stability index is calculated for the standard 33 bus system and the values obtained are represented in the Fig.3. The bus 30 having the highest value is selected as the top most bus to place the DG. Hence a DG is placed at the 30th bus.

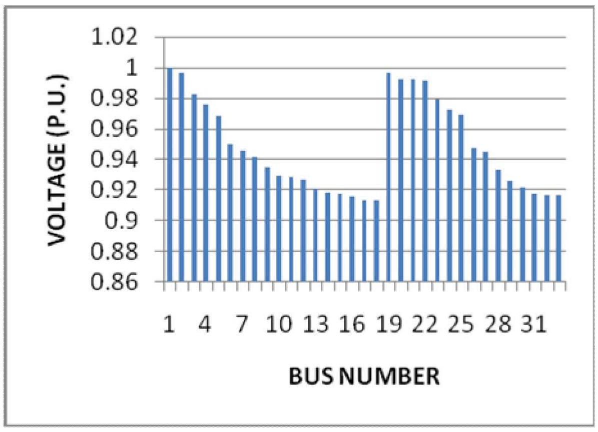


Fig. 2 Voltage profile of 33 bus RDS without DGs

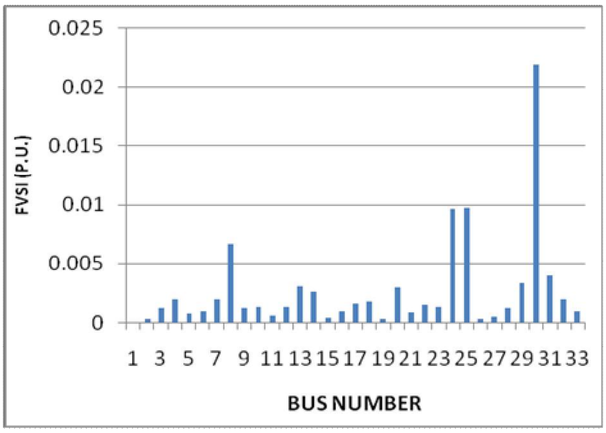


Fig. 3 Fast voltage stability indices for 33 bus RDS

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**C. Optimum Sizing of DG**

Type 1 DG

For 33 bus system without the installation of DG the real losses are 202.7 KW. The required size obtained from the analytical expressions is 1.468 MW is tabulated in Table 1. The optimal value is placed at the 30$^{th}$ bus and after installing the injection of real power type DG the losses are reduced to 117.8 KW. The voltage at all the buses is improved prior to the condition of without DG to with DG as shown in Fig. 4.

Type 2 DG

The injection of reactive power type of DG at the optimal location has reduced the losses to 143.6 KW. By placing the optimal size of 1.2267 MVAr DG the voltage at the 30$^{th}$ bus has improved from 0.922 P.U to 0.9517 P.U as represented in Fig. 5. There is a loss reduction of 29.15% in this case of DG.

Type 3 DG

With the injection of real and reactive power type of DG, the losses are reduced from 202.7 KW to 66.7 KW and the loss reduction is 67.09%. The placement of DG size 1.8939 MVA at the optimal location yields to an increase in the voltage from a minimum value of 0.9131 P.U to 0.947 P.U. at bus 18 as shown in Fig. 6

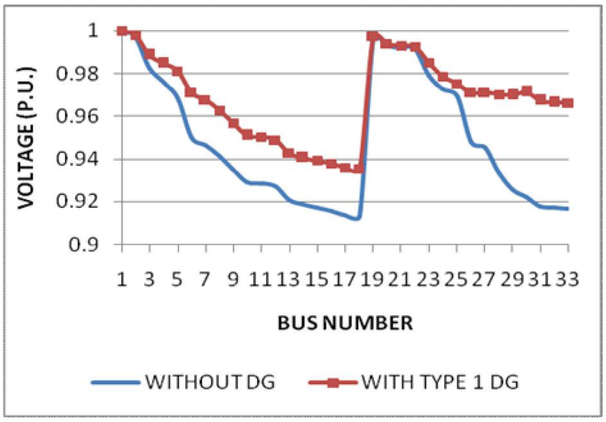


Fig. 4 Voltage profile without and with Type 1 DG

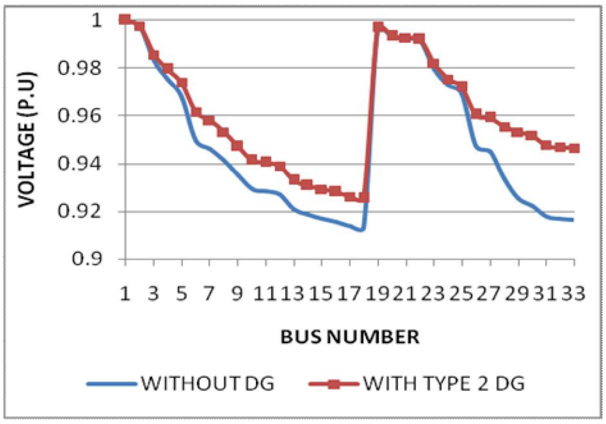


Fig. 5 Voltage profile without and with Type 2 DG

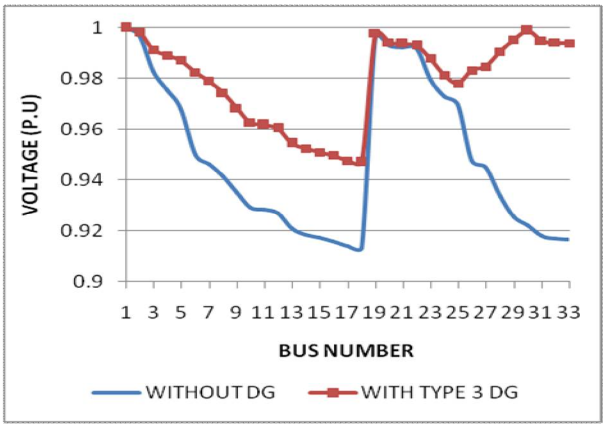


Fig. 6 Voltage profile without and with Type 3 DG

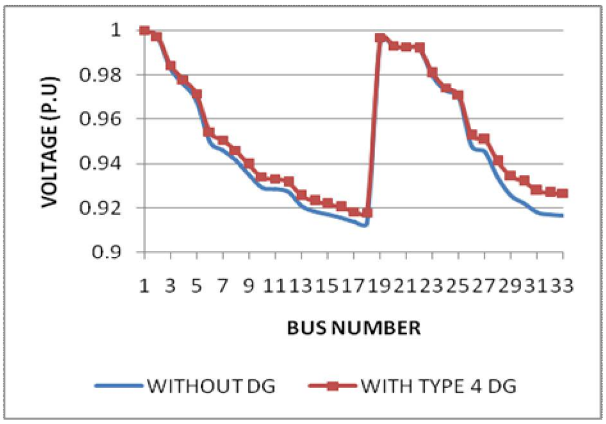


Fig. 7 Voltage profile without and with Type 4 DG

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Type 4 DG

By the placement of injecting real power and consuming reactive power type DG the losses are slightly reduced. The optimum size obtained was 0.5122-j0.3171 MVA with the decreased losses of 187.7 KW. Hence there is a loss reduction of 10.95%.In Fig. 7 voltages are also less improved in this type compared to other types of DG.

Table 1.Placement of different Types of DG

| Type of DG | Bus location | Installed DG size | Real power loss | Loss reduction |
|---|---|---|---|---|
| No DG | - | - | 202.7 KW | - |
| Type 1 DG | 30 | 1.4680 MW | 117.8 KW | 41.89% |
| Type 2 DG | 30 | 1.2267 MVAr | 143.6 KW | 29.15% |
| Type 3 DG | 30 | 1.8939 MVA | 66.7 KW | 67.09% |
| Type 4 DG | 30 | 0.5122-j0.3171 MVA | 187.7 KW | 10.95% |

## V.CONCLUSION

In this work DG are placed at the optimal location for four different cases for loss reduction and improvement of voltage profile. A fast voltage sensitivity index is developed to find out the most critical bus that is prone to voltage instability. Backward and forward sweep method is carried out for the load flow analysis. The DGs are placed at the optimal location with optimal sizes obtained from analytical expressions. With the optimal placement and sizing of DG there is increase in voltage at all the nodes compared to that of a case with no DG. The losses are greatly reduced with Type 3 DG than that of other DGs. The voltage profile and loadability of the system is improved.

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