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Abstract: This paper propose an analytical method to calculate the optimal size and an effective method to find the corresponding optimum location for DG placement for total power loss minimization in primary distribution systems. The analytical expression and the method is based on the exact loss formula. The proposed methodology is tested and validated for standard IEEE 33 bus system. Results obtained from the proposed methodology is compared with that of the load flow method using AMPL.

I. INTRODUCTION

The share of distributed generators (DGs) in power systems has been increasing slowly in the last few years. As the penetration of DG in distribution system increases, it is in the best interest to allocate DG in an optimal way such that it will reduce system losses and hence improve voltage profile. Studies have indicated that inappropriate selection of location and size of DG, may lead to greater system losses than the losses without DG [1,2]. Utilities already facing the problem of high power loss and poor voltage profile, especially, in the developing countries cannot tolerate any increase in losses. By optimum allocation, utilities take advantage of reduction in system losses; improve voltage regulation and improvement in reliability of supply [1–3]. It will also relieve capacity from transmission and distribution system and hence, defer new investments, which have a long lead-time.

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. It would be more beneficial to install DG in the present utility setup, which is moving towards a more decentralized environment, where there is a larger uncertainty in demand and supply. However, given the choices they need to be placed in appropriate locations with suitable sizes. Therefore, tools are needed to be developed to examine locations and sizing of such DG installation.

In Ref. [4,5], power flow algorithm is presented to find the optimum DG size at each load bus assuming every load bus can have DG source. Such methods are, however, inefficient due to a large number of loadflow computations. The genetic algorithm (GA) based method to determine size and location is used in [6–8]. GA is suitable for multi-objective problems like DG allocation and can give near optimal results, but they are being computationally demanding and slow in convergence. In Ref. [9], analytical method to place DG in radial as well as meshed systems to minimize power loss of the system is presented. In this paper, an analytical expression to calculate optimum size and an effective methodology to identify the optimum location for DG placement are proposed. The methodology is computationally less demanding. The objective of DG placement is to reduce the losses. The proposed methodology is suitable for allocation of single DG in a given distribution network.

II. DISTRIBUTED GENERATION

Distributed generation is known by various names like decentralized generation, dispersed generation, embedded generation, on-site generation, distributed energy or redistributed energy. Any distributed generation creates electricity from many small energy sources. Almost all the countries generate electricity in large centralized facilities, such as fossil fuel, nuclear, hydropower plants or large plants. According to their ratings, DG may be classified as micro(1W-5KW), small(5KW-5MW), medium(5MW – 50MW) or large(50MW – 300MW).

There are a number of DG technologies available in the market today and few are still in research and development stage. Some currently available technologies are reciprocating engines, micro turbines, combustion gas turbines, fuel cells, photovoltaic, and wind turbines. Each one of these technologies has its own benefits and characteristics. Among all the DG, diesel or gas reciprocating engines and gas turbines make up most of the capacity installed so far. Simultaneously, new DG technology like micro turbine is being introduced and an older technology like reciprocating engine is being improved [10].

Though the DG is considered as a viable solution to most of the problems that today's utility are facing, there are many problems (e.g. DG integration into grid, pricing, change in protection scheme, nuisance tripping etc.) that need to be addressed. Furthermore, the type of DG technology adopted will have significant bearing on the solution approach.

III. LOCATION AND SIZING

Issues:

For a particular bus, as the size of DG is increased, the losses are reduced to a minimum value and increased if the size is increased beyond optimum size at that location. If the size of DG is further increased, the losses starts to increase and it is likely that it may overshoot the losses of the base case. Also location of DG plays an important role in minimizing the losses. The important conclusion that can be drawn is that, given the characteristics of the distribution system, it is not advisable to construct sufficiently high DG. 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 through distribution substation), will lead to very high losses. So, the size of distribution system in term of load (MW) will play important role in selecting the size of DG. The reason for higher losses and high capacity of DG can be explained by the fact that the distribution system was initially designed such that power flows from the sending end (source substation) to the load and conductor sizes are gradually decreased from the substation to consumer point. Thus without reinforcement of the system, the use of high capacity DG will lead to excessive power flow through small-sized conductors and hence results in higher losses.

Based on this the DG allocation can be handled by resolving the sizing issue first followed by the location issue. However, existing technique such as loss sensitivity method finds the location issue before and sizing issue.

Sizing At Various Locations:

The real power loss in a system is given by (1). This is referred to as "exact loss" formula [11].

$$P_L = \sum_{i=1}^N \sum_{j=1}^N [\alpha_{ij} (P_i P_j + Q_i Q_j) + \beta_{ij} (Q_i P_j - P_i Q_j)] \quad (1)$$

$$\text{Where, } \alpha_{ij} = \frac{r_{ij}}{V_i V_j} \cos(\delta_i - \delta_j) \text{ and } \beta_{ij} = \frac{x_{ij}}{V_i V_j} \sin(\delta_i - \delta_j)$$

And r_{ij} and x_{ij} are the ij th elements of the Zbus matrix where, $Z_{bus} = [Y_{bus}]^{-1}$

For minimum losses the rate of change of losses with respect to injected power becomes zero which follows:

$$P_i = \frac{1}{\alpha_{ii}} [\beta_{ii} Q_i + \sum_{j=1, j \neq i}^N (\alpha_{ij} P_j - \beta_{ij} Q_j)] \quad (2)$$

$$\text{Where, } P_i = (P_{DGi} - P_{Di}) \quad (3)$$

And,

P_i = Real power injection at node i.

P_{DGi} = Real Power injection from DG placed at node i.

P_{Di} = Real power load Demand at bus i.

From (2) and (3) we get equation (4)

$$P_{DGi} = P_{Di} + \frac{1}{\alpha_{ii}} \left[\beta_{ii} Q_i - \sum_{j=1, j \neq i}^N (\alpha_{ij} P_j - \beta_{ij} Q_j) \right]$$

The above equation gives the optimum size of DG for each bus i, for the loss to be minimum. Any size of DG other than P_{DGi} placed at bus i, will lead to higher loss. This loss, however, is a function of loss coefficient α and β . When DG is installed in the system, the values of loss coefficients will change, as it depends on the state variable voltage and angle. So using relation (4) optimum size of DG can be calculated at each bus.

Location To Minimize Losses:

The next step is to find the optimum optimum DG location, which will give the lowest possible losses. Calculation of loss with DG one at a time at each bus again requires several load flow solutions, as many as number of buses in the

system. Therefore method used is such to quickly calculate approximate loss, which would be used for the purpose of best location identification. Result shows that approximate loss follows the same pattern as that calculated by accurate load flow. It means that, if accurate loss calculation from load flow gives lowest losses for a particular bus then, loss calculated by approximate loss method will also be lowest for that particular bus. What differs in this is only is the amount of losses being on either the highest or the lowest side, which is not a concern for identifying location. With this methodology one can avoid exhaustive computation and save time.

We will be using equation(1) for the calculation of losses to find the optimum location of DG.

IV. TEST SYSTEM AND RESULTS

The test system selected and shown in Fig. 1 contains 33 buses and 32 branches. It is a radial system with the total load of 3.72 MW and 2.3 MVAR

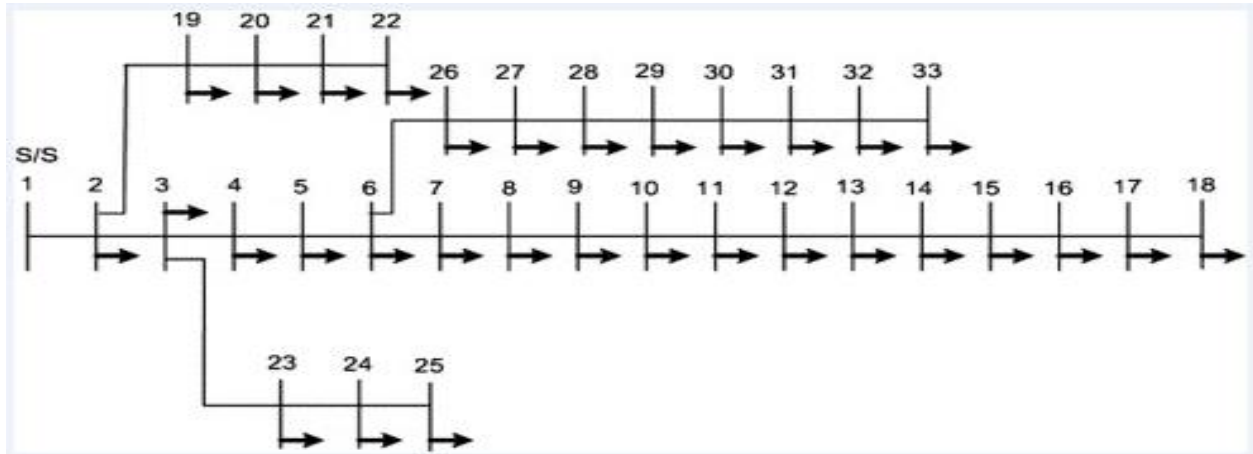


FIG. 1 IEEE 33Bus Distribution System

Sizing And Location Using Proposed Method:

The optimum size of the DG is calculated using equation(4) and is depicted by Fig 2. It can be seen that the range of the optimum size for the test system is between 0.38 – 4.0 MW. The optimum location for the placement of DG found using equation 1 is at bus 6. The power loss at all the buses is shown in Fig 3.

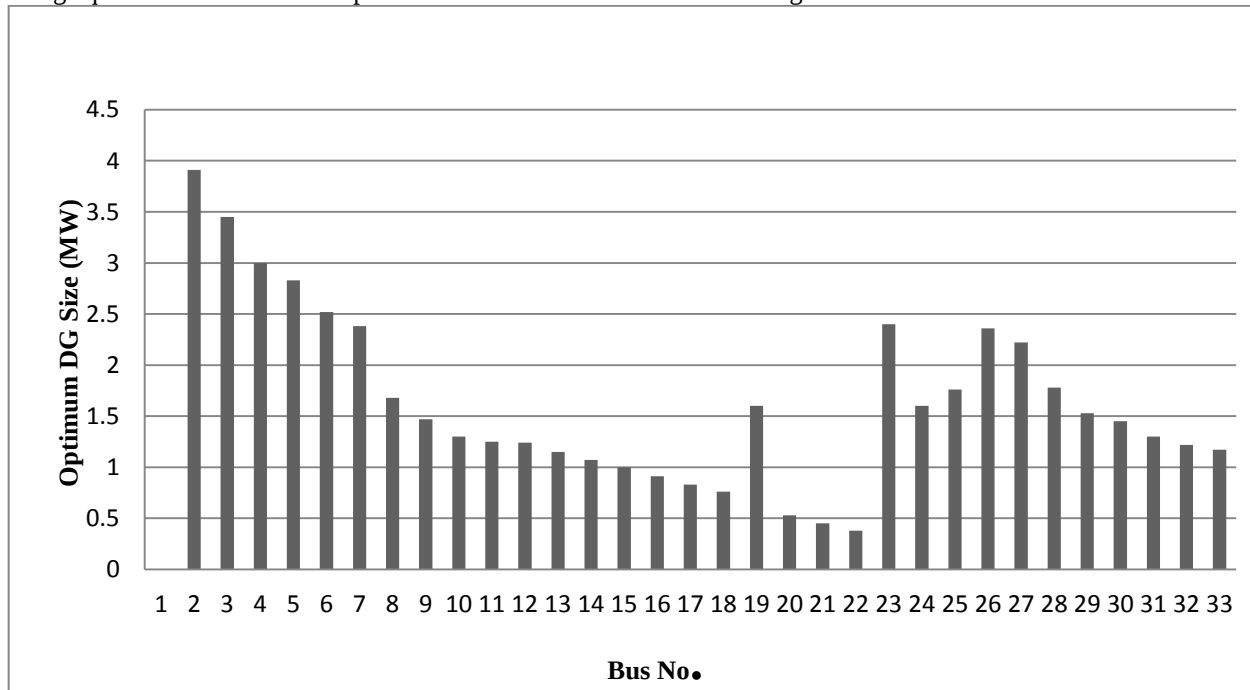


Fig 2. Optimal DG Size At Each Bus

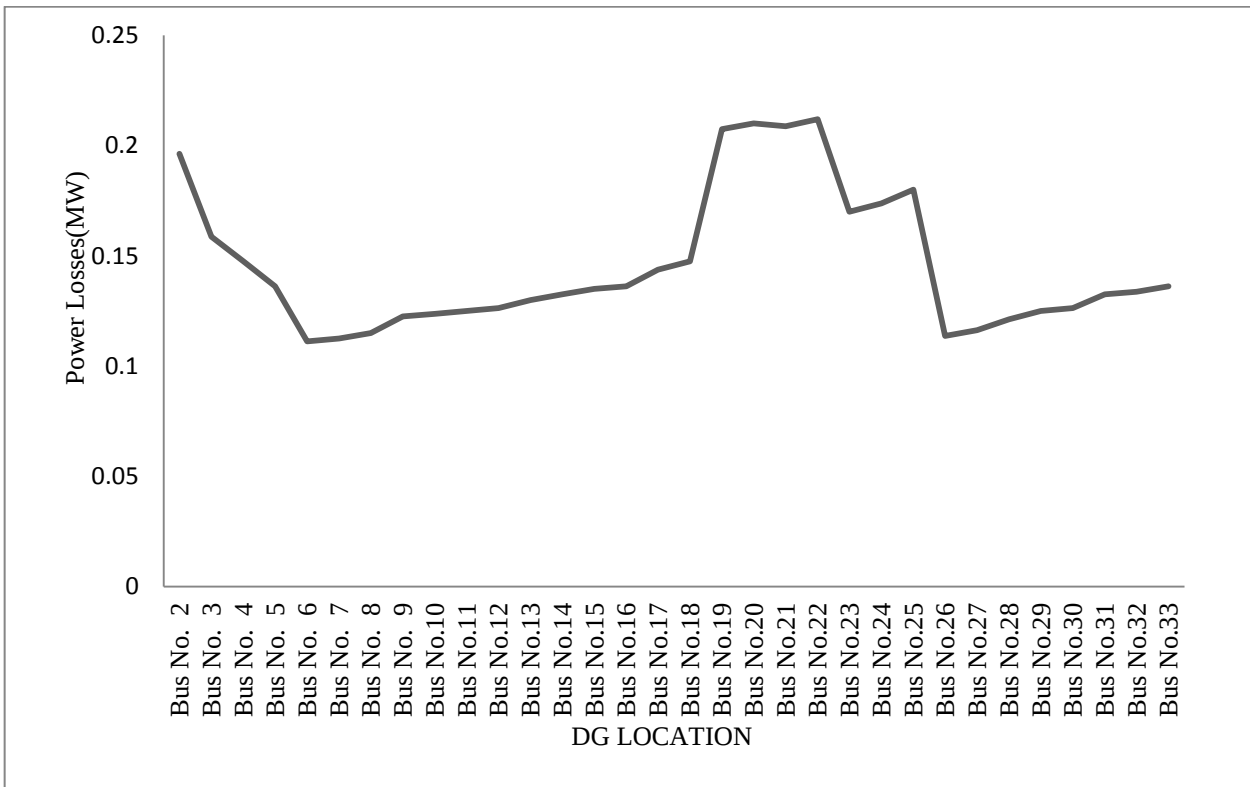


Fig 3. Location For Minimum Power Loss

DG LOCATION USING LOAD FLOW:

Optimal location of DG is found using load flow analysis using AMPL. The program is runned for optimal DG size at each bus and location is calculated for minimum power losses and optimal location is at bus 6 as shown in Fig4.

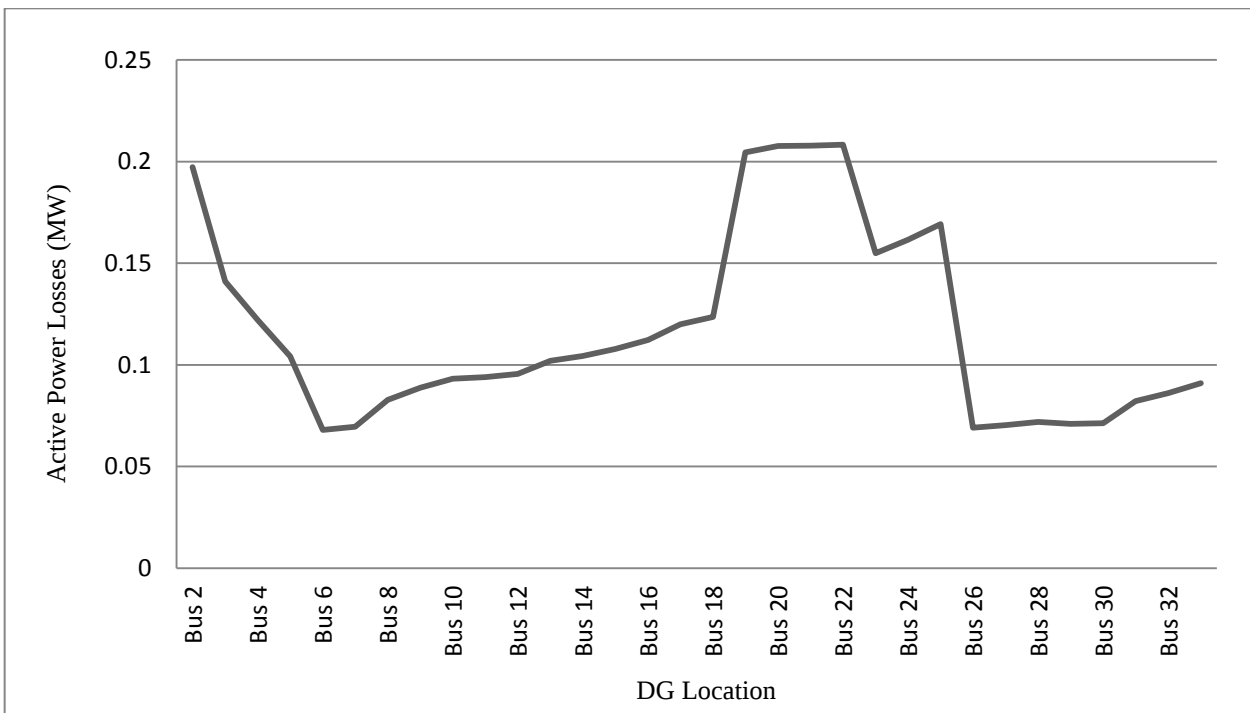


Fig 4. Location Using Load Flow

COMPARISON OF RESULTS:

The results for the sizing and location of DG for minimum power losses are compared for both the methods and are shown in table.

Proposed Approach		LOAD FLOW METHOD		
Optimum Location	Power Losses(KW)	Optimum Location	Power Losses(KW)	Losses Without DG(KW)
BUS 6	116.25	BUS 6	68.7	211.2
BUS 26	118.75	BUS 26	78.6	

V. CONCLUSION

Size and location of DG are crucial factors in the aspect of DG for power loss minimization. This paper presents an algorithm to find the optimum size of the DG in addition also proposes a fast method to find the optimum location of DG for minimum power losses. The benefit of the proposed algorithm for size calculation is that a table can be created with only one power flow calculation and the table can be used to restrict the size of DG at different buses, with the view of minimizing total loss. The proposed methodology for location selection correctly identifies the best location for single DG placement in order to minimize the total power losses. In practice, the choice of the best site may not be always possible due to many constraints. However, the analysis here suggests that the losses arising from different placement varies greatly and hence this factor must be taken into consideration while determining appropriate location.

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