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LOSS REDUCTION IN RDS USING DG BY ENHANCED LOSS INDEX FACTORS

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Abstract- Distributed generation (DG) units reduce electric power losses and hence improve reliability and voltage profile. Determination of appropriate size and location of DG is important to maximize overall system efficiency. In this paper, loss index factor method has been presented to determine the appropriate size and proper allocation of DG in a distribution network. Results obtained from this method have been compared with using the repeated load flow method.

Index Terms- *Distributed generation, Loss index factor, Loss index, Priority list, Load flow studies, Optimum location, Optimum size, enhanced voltage profile and minimise power loss.*

1. INTRODUCTION

DG is one of the better alternatives to fulfill the ever growing energy demand. Moreover, it reduces system energy loss, alleviates transmission congestion, improves voltage profile, enhances reliability and provides lower operating cost. Because of small size compared with conventional generation units, DG is more flexible to install in terms of investment and time. As a result, integration of Distributed Energy Resources (DER) with distribution network offers a promising solution; therefore, an intensive level of research is needed to understand the impacts of distributed resources on Distribution System.

Improper DG size and inappropriate allocation of DG may lead to higher power loss than when there is no dispersed generation in the system at all. Therefore, detail and exact analysis method is required to determine the proper location and size of DG more accurately and precisely. The problem of DG allocation and sizing is of great importance. The installation of DG units at non-optimal places can result in an increase in system losses, implying in an increase in costs and, therefore, having an effect opposite to the desired. For that reason, the use of an optimization method capable of indicating the best solution for a given distribution network can be very useful for the system planning engineer. The selection of the best places for installation and the preferable size of the DG units in large distribution systems is a complex combinatorial optimization problem.

2. ISSUES

In a distribution system, issues are from location and sizing of the DG in the radial distribution systems. Actually, the structure of distribution system is such that power should flow from the substation to the consumer end and conductor sizes are also decreased gradually [8]. When a DG is placed in the network, it is desirable that power should be consumed within the distribution network and thus improves power profile. Any size of DG more than the optimum size will create reverse flow of power towards distribution substation. Therefore, excessive power flow through small sized conductors towards the transmission area will increase the power loss in distribution network.

As the size of DG is increased, the losses are reduced to a minimum value and increased beyond a size of DG (i.e. the optimal DG 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 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 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.

3. PROBLEM FORMULATION

Loss index factor method is based on the principle of linearization of original nonlinear equation around the initial operating point, which helps to reduce the number of solution space. Loss index factor method has been widely used to solve the capacitor allocation problem. Its application in DG allocation is new in the field and has been reported in many papers.

3.1. Loss index

The real power loss in a system is given by (1). This is popularly referred to as ''exact loss'' formula.

$$PL = \sum_{i=1}^{N}\sum_{j=1}^{N}[\alpha ij(PiPj + QiQj) + \beta ij(QiPj - PiQj)] \quad (1)$$

Where,

$\alpha ij = \frac{rij}{VijVj}\mathrm{Cos}(\delta i - \delta j)$ and $\beta ij = \frac{rij}{VijVj}\mathrm{Sin}(\delta i - \delta j)$ and rij +jxij = Zij are the ijth element of [Zbus] matrix with $[Zbus] = [Ybus]^{-1}$.

The index factor of real power loss with respect to real power injection from DG is given by

$$\alpha i = \frac{\partial Pl}{\partial Pi} = 2\sum_{i=1}^{N}(\alpha ijPj - \beta ijQj) \quad (2)$$

Index factors are evaluated at each bus, firstly using the values obtained from the base case power flow. The buses are ranked in descending order of the values of their index factors to form a priority list. The top-ranked buses in the priority list are the first to be studied alternatives location. This is generally done to take into account of the effect of nonlinearities in the system. The first order index factor are based on linearization of the original nonlinear equation around the initial operating condition and is biased towards function which has higher slope at the initial condition, that might not identify the global optimum solution. Therefore, priority list of candidate location is prerequisite to get the optimum solution. The index factor may not give the optimum result if a number of alternative locations are not taken into account.

3.2. Priority list

The index factor will reduce the solution space to few buses, which constitute the top ranked buses in the priority list. The effect of number of buses taken in priority will have effect the optimum solution obtained for some system. For each bus in the priority list, the DG is placed and the size is varied from minimum (0 MW) to a higher value until the minimum system losses is found with the DG size. In this study, 30% of the total number of buses is considered in preparing the priority list for each case. The process is computationally demanding as one needs a large number of load flow solution.

3.3. Optimal DG Sizing at various locations

According to Section 3, the total power loss against injected power is a parabolic function and at minimum losses the rate of change of losses with respect to injected power becomes zero.

$$\frac{\partial Pl}{\partial Pi} = 2\sum_{i=1}^{N}(\alpha ijPj - \beta ijQj) = 0 \quad (3)$$

it follows that,

$$\alpha iiPi - \beta iiQi + \sum_{j=1,j\neq 1}^{N}(\alpha ijPj - \beta ijQj)] = 0$$

$$Pi = \frac{1}{\alpha ii}[\beta iiQi - \sum_{j=1,j\neq 1}^{N}(\alpha ijPj - \beta ijQj)] \quad (4)$$

where, Pi is the real power injection at node i, which is the difference between real power generation and the real power demand at that node:

$$Pi = (PDGi - PDi) \quad (5)$$

where, PDGi is the real power injection from DG placed at node i, and PDi is the load demand at node i. By combining (4) and (5) one can get (6).

$$PDGi = PDi + \frac{1}{\alpha ii}[\beta iiQi - \sum_{j=1,j\neq 1}^{N}(\alpha ijPj - \beta ijQj)] \quad (6)$$

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 PDGi placed at bus i, will lead to higher loss. This loss, however, is a function of loss coefficient a and b. When DG is installed in the system, the values of loss coefficients will change, as it depends on the state variable voltage and angle. Updating values of a and b again requires another load flow calculation. But numerical result shows that the accuracy gained in the size of DG by updating a and b is small and is negligible. With this assumption, the optimum size of DG for each bus, given by relation (6) can be calculated from the base case load flow (i.e. without DG case).

3.4. Location to minimize losses

The next step is to find the optimum DG location, which will give the lowest possible total 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 a new methodology is proposed to quickly calculate approximate loss, which would be used for the purpose of identifying the best location. Numerical 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 minimum for a particular bus then, loss calculated by approximate loss method will also be minimum at that bus. This is verified by the simulation results. What differs is the amount of losses, which is not a concern for identifying location. With this methodology one can avoid exhaustive computation and save time.

3.5. Computational procedure

Step 1: Run the base case load flow.

Step 2: Find the index factor using Eq. (2) and rank the index in descending order to form priority list.
Step 3: Select the bus with the highest priority to place DG at that bus.
Step 4: Find the optimum size of DG for each bus using Eq. (6).
Step 5: Compute approximate loss using Eq. (1) for each bus by placing DG of optimum size obtained in step 4 for that bus. Add the injection from DG for that bus and use base case values for state variables.
Step 6: Locate the bus at which the loss is minimum after DG placement. This is the optimum location for DG.
Step 7: Run load flow with DG to get the reduced losses and enhanced voltage.
Step 8: Stop.

4. SOLUTION WITH SOME CASE STUDIES

The proposed methodology is tested on different test systems, of different sizes using MATLAB software to show that it can be implemented in distribution systems of various configuration and size. The loss index factor method has been implemented and after calculating particular DG size they have been placed at the maximum index value.

4.1. Load Flow Program
A power-flow study for a system operating under actual or projected normal operating conditions is called a base case. The results from the base case constitute a benchmark for comparison of changes in network flows and voltages under load flow study.

The distribution test systems are the 33 bus [10] and 69 bus [11] systems. The 33 bus system has 32 sections with the total load 3.72 Mw and 2.3 MVAr shown in Fig.4.1. The 69 bus system has 68 Sections with the total load of 3.80 Mw and 2.69 MVAr, shown in Fig.4.2.

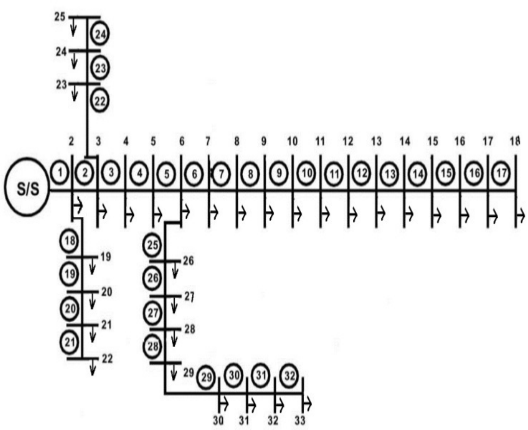

Fig 4.1: Single line diagram of 33 – bus radial distribution system

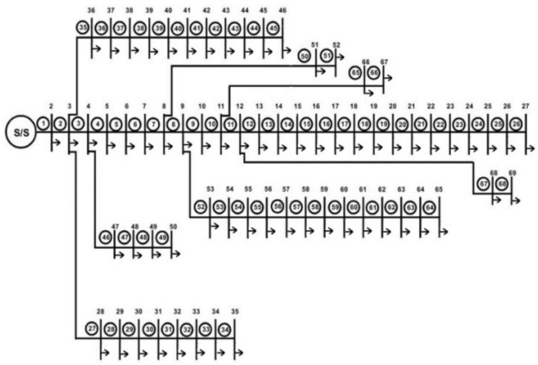

Fig.4.2: Single line diagram of 69 – bus radial distribution system

After evaluating the index factors, they are listed out in the descending order, which can be said as priority list made for placing the DG according to the list. After evaluating the size of DG they are placed at each bus location to find the losses which are compared with basic load flow studied losses and are found to be minimized. In a 33-bus system from the list 24, 25 and 30 are the locations selected for and at each location by placing the DG losses are evaluated.

After calculating at each location 30th location is found to be having minimum losses and hence can be said as the best location for placing DG. The values obtained are found to be improvement in voltage profile and also reduction in losses with inclusion of DG as can be seen in table 4.1.

Table: 4.1 Summary of results in 33-bus system

	Without DG	With DG
Real power losses (I^2R)	202.71 kW	155.97 kW
Reactive power losses (I^2X)	135.24 kVAr	113.33kVAr
Minimum Voltage (V_{min})	0.9130	0.9511
% of Voltage regulation (% ε)	8.7%	5%
Size of DG	2.46 MW	-

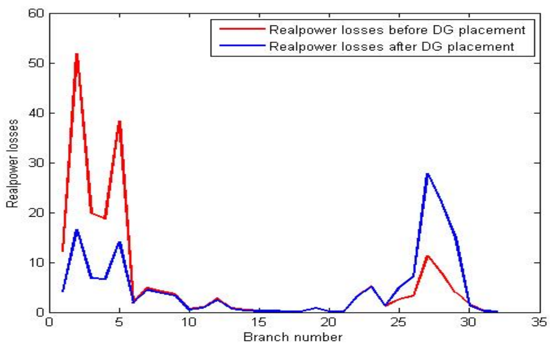

Fig: 4.3 Real power losses before and after DG placement in 33– bus system

The graphs drawn as shown in fig. 4.3 and fig. 4.4 are for the obtained results for before and after placing DG in case of real power and voltage magnitude. From these results it can be seen that the losses are reduced and voltage magnitudes are improved which satisfies the objective of the thesis.

Similarly, in a 69-bus system from the list 61 bus is the best location and is found to be having minimum losses and hence can be said as the best location for placing DG. The values obtained are found to be improvement in voltage profile and also reduction in losses with inclusion of DG as can be seen in table 4.2.

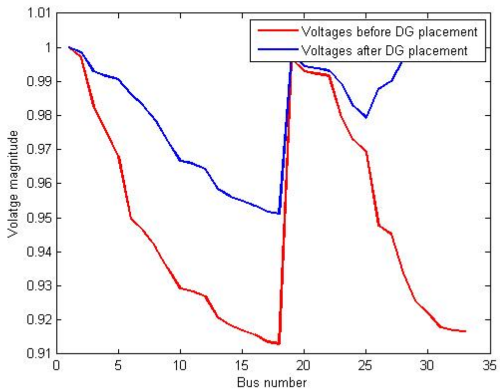

Fig: 4.4 Voltage before and after DG placement in 33– bus system

Table: 4.2 Summary of results in 69-bus system

	Without DG	With DG
Real power losses (I^2R)	224.98 kW	139.49 kW
Reactive power losses (I^2X)	102.16 kVAr	61.88 kVAr
Minimum Voltage (V_{min})	0.9092 p.u	0.9757 p.u
% of Voltage regulation (% ε)	9.08%	2.43%
Size of DG	1.9540 MW	-

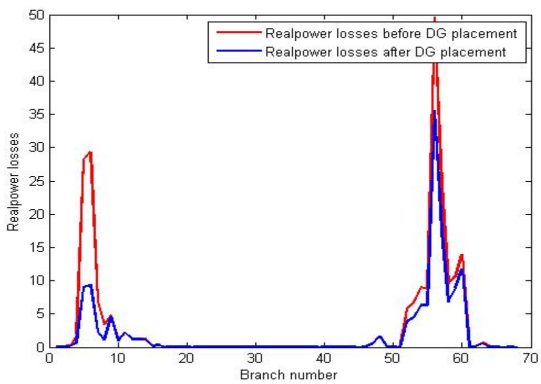

Fig: 4.5 Real power losses before and after DG placement in 69– bus system

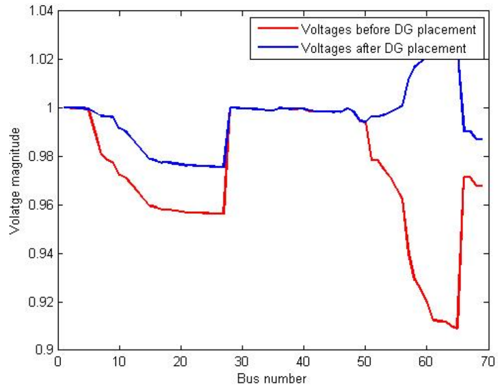

Fig: 4.6 Voltage before and after DG placement in 69– bus system

The graphs drawn as shown in fig. 4.5 and fig. 4.6 are for the obtained results for before and after placing DG in case of real power and voltage magnitude. From these results it can be seen that the losses are reduced and voltage magnitudes are improved which satisfies the objective of the thesis.

With analyzing of simulations we can conclude:

1. Suitable buses for DG placement are found to be 30^{th} bus in 33-bus system and 61^{st} bus in 69-bus system obtained from index factor.
2. By comparing the results it can be observed that losses have been decreased by making use of a DG.
3. Voltage profile is improved and has obtained within the tolerance limit.
4. Voltage regulation need to be reduced is achieved.
5. Installing proper size of DG at suitable bus improves network characteristics like power quality and even maintains reliability.

5. CONCLUSION

In this paper size and location of DG are crucial factors in the application of DG for loss minimization. This paper presents an algorithm to calculate the optimum size of DG at various buses and proposes a fast methodology to identify the best location corresponding to the optimum size for reducing total power losses in primary distribution network. If the DG is placed at different locations other than optimal locations then it leads to heavy losses and hence the system cannot maintain power quality. So, here loss index factor plays a prominent role in selecting the location for DG placing. Even the injecting power into the system i.e. size of DG is also calculated and said to be optimal size.

The proposed methodology for location selection correctly identifies the best location for DG placement in order to minimize the total power losses.

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