Distributed Generator Placement for Loss Reduction and Improvement in Reliability

Priyanka Paliwal, N.P. Patidar

Abstract—Distributed Power generation has gained a lot of attention in recent times due to constraints associated with conventional power generation and new advancements in DG technologies .The need to operate the power system economically and with optimum levels of reliability has further led to an increase in interest in Distributed Generation. However it is important to place Distributed Generator on an optimum location so that the purpose of loss minimization and voltage regulation is dully served on the feeder. This paper investigates the impact of DG units installation on electric losses, reliability and voltage profile of distribution networks. In this paper, our aim would be to find optimal distributed generation allocation for loss reduction subjected to constraint of voltage regulation in distribution network. The system is further analyzed for increased levels of Reliability. Distributed Generator offers the additional advantage of increase in reliability levels as suggested by the improvements in various reliability indices such as SAIDI, CAIDI and AENS. Comparative studies are performed and related results are addressed. An analytical technique is used in order to find the optimal location of Distributed Generator. The suggested technique is programmed under MATLAB software. The results clearly indicate that DG can reduce the electrical line loss while simultaneously improving the reliability of the system.

Keywords—AENS, CAIDI, Distributed Generation, loss reduction, Reliability, SAIDI

I. INTRODUCTION

DISTRIBUTION systems whether they are radial type found in rural or suburban areas, or network type systems found in urban areas are generally designed to operate without any generation on the distribution systems or at customer loads. The introduction of generation sources on the distribution system can significantly impact the flow of power and voltage conditions at customers and utility equipment [1]. It can also have a significant impact in on the system and equipment operation in terms of steady state operation, dynamic operation, reliability, power quality, stability and safety for both customers and electricity suppliers. This impact may manifest itself positively or negatively depending on the distribution system, distributed generator placement and load characteristics [2]. The planning of the electric system with the presence of DG requires the definition of several factors, such as: the best technology to be used,

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the number and the capacity of the units, the best location, the network connection way, etc. The impact of DG in system operating characteristics, such as electrical losses, voltage profile, reliability, among other, needs to be appropriately evaluated. The selection of the best places for installation and the size of the DG units in large distribution systems is a complex combinatorial optimization problem [3].This paper investigates the impact of DG units installation on electric losses, reliability and voltage profile of distribution networks.

II. IMPACT OF DISTRIBUTED GENERATION

A. Losses

DG causes a significant impact in electric losses due to its proximity to the load centers. DG units should be allocated in places where they provide a higher reduction of losses. This process of DG allocation is similar to capacitor allocation to minimize losses. The main difference is that the DG units cause impact on both the active and reactive power, while the capacitor banks only have impact in the reactive power flow. In feeders with high losses, a small amount of DG strategically allocated (10-20% of the feeder load) could cause a significant reduction of losses [4].

➢ With the connection of DG in a system power losses are reduced.
➢ For a particular DG capacity there is a location in the system such that if we connect DG at that location power losses are minimum   in comparison when same DG is connected at any other point.
➢ That particular location where power losses are minimum is known as Optimum location.

B. Voltage Profile

The distribution systems are usually regulated through tap changing at substation transformers and by the use of voltage regulators and capacitors on the feeders. This form of voltage regulation assumes power flows circulating from the substation to the loads. DG introduces meshed power flows that may interfere with the traditionally used regulation practices.

Since the control of voltage regulation is usually based on radial power flows, the inappropriate DG allocation can cause low or over-voltages in the network. On the other hand, the installation of DG can have positive impacts in the distribution system by enabling reactive compensation for voltage control, reducing the losses, contributing for frequency regulation and acting as spinning reserve in main system fault cases.Under voltage and over voltage conditions can arise given the

incompatibility of DG with the voltage regulation in radial power flows.

C.Reliability

The goal of a power system is to supply electricity to its customers in an economical and reliable manner. It is important to plan and maintain reliable power systems because cost of interruptions and power outages can have severe economic impact on the utility and its customers. Traditionally, reliability analysis and evaluation techniques at the distribution level have been far less developed than at the generation level since distribution outages are more localized and less costly than generation or transmission level outages. However, analysis of customer outage data of utilities has shown that the largest individual contribution for unavailability of supply comes from distribution system failure.

One of the main purpose of integrating DG to distribution system is to increase the reliability of power supply. DG can be used as a back-up system or as a main supply. DG can also be operated during peak load periods in order to avoid additional charges.

A basic problem in distribution reliability assessment is measuring the efficacy of past service. A common solution consists of condensing the effects of service interruptions into indices of system performance. Reliability indices are used by system planners and operators as a tool to improve the level of service to customers [13]. Planners use them to determine the requirements for generation, transmission, and distribution capacity additions. Operators use them to ensure that the system is robust enough to withstand possible failures without catastrophic consequences. Reliability indices are considered to be reasonable and logic way to judge the performance of an electrical power system. Reliability indices used for the purpose of analysis in this paper are discussed below.

Considering the n lateral system the most commonly used reliability indices are defined as follows:

SAIDI: System Average Interruption Duration Index

It is commonly referred to as customer minutes of interruption or customer hours, and is designed to provide information as to the average time the customers are interrupted.

$$SAIDI = \frac{\sum U_i N_i}{\sum N_i} \qquad (1)$$

Here U_i is the annual outage time and N_i is the number of customers of lateral i.

CAIDI: Customer Average Interruption Duration Index
It is the average time needed to restore service to the average customer per sustained interruption.

$$CAIDI = \frac{\sum U_i N_i}{\sum \lambda_i N_i} \qquad (2)$$

AENS: Average Energy Not Supplied

It is defined as the ratio of the total energy not supplied to the total number of the customers.
AENS = (total energy not supplied) / (total number of customers serve

$$AENS = \frac{\sum La(i)U_i}{\sum N_i} \qquad (3)$$

where La(i) is the average load connected at load point i.

III. METHODOLOGY

The objective is to minimize the power loss subjected to the constraints of voltage regulation with added advantage of improvement in reliability of the system. Analytical technique [5] has been applied on the test system. First consider a radial feeder without DG. The loads are distributed along the line with the phasor current density as shown in Figure.
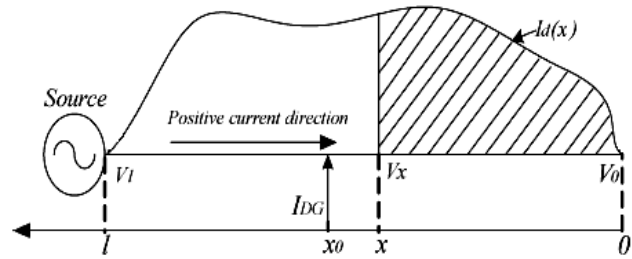

Fig. 1 Current distribution along the feeder

Consider a DG is added into the feeder at the location xo, shown in Fig. 1. For the purpose of analysis, the change in the load current density, resulted from the addition of DG is neglected. Thus the phasor current [5] is given by:

$$I(x) = \int_0^x Id(x)dx \qquad 0 \le x \le x_0 \qquad (4)$$

$$I(x) = \int_0^x Id(x)dx - I_{DG} \quad x_0 \le x \le l \qquad (5)$$

where Id(x) is the phasor current density

The corresponding power loss and voltage drop in the feeder are:-

$$Ploss(xo) = \int_0^{xo}\left(\int_0^x Id(x).dx\right)^2. Rdx +$$
$$\int_{xo}^l\left(\int_0^x |Id(x)dx - I_{DG}|\right)^2 .Rdx \qquad (6)$$

$$Vdrop(x) = \int_0^x \int_0^x Id(x)dx.Zdx , 0 \le x \le x_0 \qquad (7)$$

$$Vdrop(x) = \int_0^x \int_0^x Id(x)dx.Zdx$$

$$+ \int_{xo}^x \left(\int_0^x Id(x)dx - I_{DG} \right).Zdx \ , \ x_0 \le x \le l \quad (8)$$

The goal is to add DG at a location to minimize the total average power loss and assure that the voltages Vx along the feeder are in the acceptable range, 1+/- 0.05 p.u., i.e

$$\frac{dPloss(x_0)}{dx} = 0 \quad (9)$$

The solution x_0 of the above equation will give the optimal site for minimizing the power loss, but it cannot guarantee that all the voltages along the feeder are in the acceptable range.If the voltage regulation cannot be satisfied at the same time, the DG can be placed around xo to satisfy the voltage regulation rule while decreasing the power loss as much as possible or the DG size can be increased.

IV. TEST SYSTEM

To support the proposed analysis on the impact of DG on the reliability and line losses of a radial feeder results were drawn based upon the application of theory on a 10 bus system shown in fig.2.
 ➢ The test system shown below comprises of a radial feeder with 10 laterals feeding certain loads in MW.
 ➢ The total load on the feeder is 47.5MW
 ➢ The capacity of DG is 50 MW
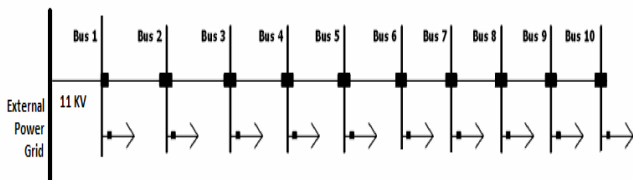 ➢ The power factor is assumed uniform throughout the feeder equal to 0.9.

Fig. 2 11 KV Radial Feeder

 ➢ The current carried by each section of the feeder is calculated first with the help of loads at the buses. DG capacity gives the value of the current fed by DG to the feeder.
The calculation proceeds by locating the DG at every bus and then calculating:
 ➢ Power loss on the entire feeder as well as the voltage profile of the buses.
 ➢ With the application of DG at any bus the voltage profile of that bus improves due to the injection of extra power at that bus. The current in the sections between the DG and the feeder end remains the same as it were in the absence of DG. The current in the sections between the source and DG gets reduced as

part of the total load on the source is compensated for by the DG.
 ➢ The sections with reduced current than before are the ones with lesser I²r losses.
 ➢ The application of DG results in the reduction of power losses in the sections following the bus with DG. With the movement of DG from start to the end of the feeder the power losses along the feeder varies in a parabolic fashion which tells that the location corresponding to minimum losses is around the middle of the feeder. But it depends much on the DG capacity also. This analysis is not the subject of this paper.
 ➢ Another important constraint governing the optimum location is the voltage profile along the feeder. As said above the application of DG improves the voltage profile but it can also boost up to levels beyond the safe mark. For safe operation the voltage profile along the feeder is restricted from 0.95pu to1.05pu. Thus along with power losses the voltage at each bus is also checked with the application of DG at every bus.
 ➢ Optimum location of DG from the consideration of power loss and voltage profile is determined.
 ➢ Improvement in Reliability indices is determined for this particular location of DG.
 ➢ The capacity of the DG is so chosen such that it is able to supply complete load of the system. Here DG capacity is assumed as 50 MW.
 ➢ Active failure rate of 11 KV lines is taken as 0.065 f/yr-km and switching and repair time for 11 KV lines are assumed to be 1 and 5 hours respectively.

The steps formulated in the analysis on reliability and line losses with and without DG are put together in the form of a generalized code written in MATLAB. Conclusions are drawn through comparison of resulting graphs from the code and showing the improvements with the connection of DG.The values of load, no. of customers at lateral and length of sections are given in the table as shown below:

TABLE I
LOAD AND CUSTOMERS AT RESPECTIVE LATERALS

Laterals	Load(MW)	No. of Customers
1	3	50
2	4.5	70
3	6	100
4	5	80
5	2	30
6	5.5	70
7	6	100
8	3	50
9	4.5	70
10	8	100

TABLE II
LENGTH OF RESPECTIVE SECTIONS

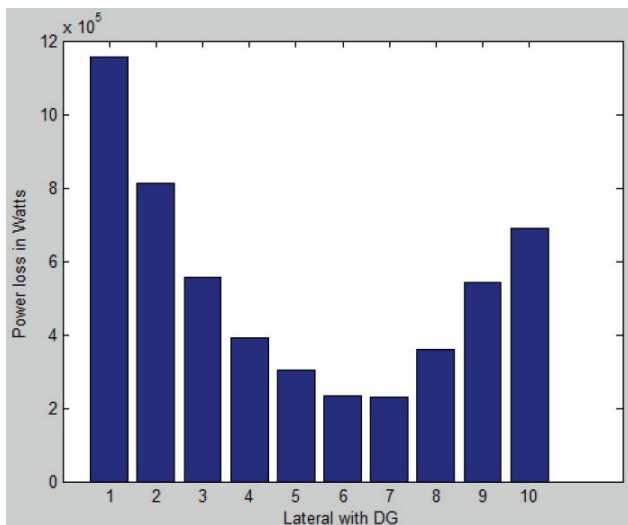| Section	Length(Kms)
1	1.0
2	0.85
3	0.8
4	0.75
5	0.65
6	0.65
7	0.80
8	1.0
9	1.0
10	0.75

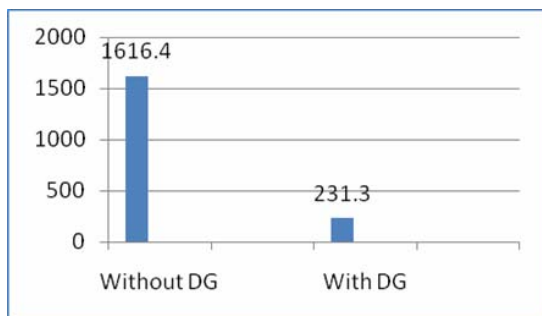Fig. 5 Improvement in SAIDI and CAIDI

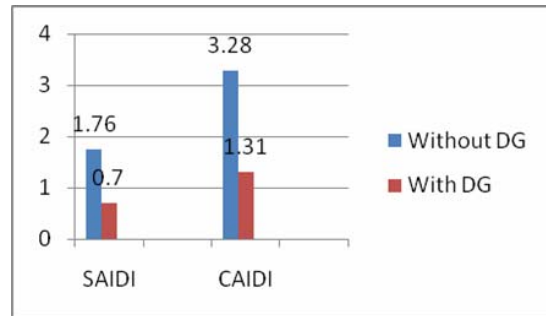## V. RESULTS

Fig. 3 Power loss with DG at various laterals

Fig. 4 Reduction in losses (KW)

VI. CONCLUSION

Use of distributed generation is one of the many strategies electric utilities are considering to operate their systems in the deregulated environment.

Inclusion of DG at the distribution level results in several benefits, among which are congestion relief, loss reduction, voltage support, peak shaving, and an overall improvement of energy efficiency, reliability, and power quality.

This paper has considered the benefit of DG on loss reduction and Reliability for a simple case of a radial distribution line.

The results clearly indicate that DG can reduce the electrical line loss while simultaneously improving the reliability of the system.

However, the inclusion of DG does not always guarantee the line loss. The DG rating and location are important factors for line loss reduction. Therefore, these factors have to be considered very carefully in order to determine the best location of DG.The improvement in reliability indices is maximum with DG at feeder end. Power losses decrease as location of DG from feeder end increases. We arrived at an optimal location by keeping into account these two mutually opposing factors

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