Optimal Number of Distributed Generators in Power System Network

Sakshi Sharma, Jang Bahadur Singh

Abstract*— *The distribution generator (DG) may be defined as the small-scale power generation technology that provides electricity closer to customers. The positive impacts of DG are: voltage support, power loss reduction, support of ancillary services and improved reliability. The investigation is done to study the impact of multi-DGs on power losses using the line loss reduction index (LLRI). The study has been carried out on IEEE 14 bus system using Newton Raphson (NR) method for load flow analysis. The investigation is carried out with the insertion of DG at different locations and the minima point was found. The experiment was performed with different sizes of DGs in medium ranges. The analysis of the results show that simply by increasing the number of DGs in the system to reduce the losses is not beneficial all the time. Beside the optimal location and size of DG for the loss reduction in distribution system, number of DG is also a vital factor. In this work, it is concluded that the optimal number of DGs is very important parameter to reduce the losses. The study gives the optimal number of DGs that could be installed in the distribution system to have minimum line losses.

Index Terms*: *Line loss reduction index, line loss reduction index, Multi-DGs, Newton Raphson.

I. Introduction

Distributed power unit can be connected directly to the consumer or to a utility's transmission or distribution system [1]. Latest technologies allow the electricity to be generated in small sized plants located at the customers end. Also, in order to reduce the impact of power generation on environment the use of renewable sources leads to the development of new electrical energy supply schemes. In this latest concept of power generation, some of the energy-demand is supplied by the centralized generation and another part is produced by distributed generation [2]. Thus, a distribution generation may be defined as the small-scale power generation technology that provides electricity closer to customers [3]. Here the electricity is going to be produced closer to the customers [2]. The Electric Power Research Institute defines distributed generation as generation from 'a few kilowatts up to 50 MW [3]. The penetration of DG may impact the operation of a distribution network in both positive and negative ways. Some of the positive impacts of DG are: voltage support, power loss reduction, support of ancillary services and improved reliability, whereas negative ones are protection coordination, dynamic stability and islanding [4]. 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 is 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 [5].

Table 1. Size of DG [6]

Type	Size
Micro distributed generation	1 watt < 5 KW
Small distributed generation	5 KW < 5 MW
Medium distributed generation	5 MW < 50 MW
Large distributed generation	50 MW < 300 MW

To clarify about the DG concept, some categories that define the size of the generation unit are presented in Table 1.

A bus is a node at which one or many lines, one or many loads and generators are connected. In a power system each node or bus is associated with 4 quantities, such as:

1. Magnitude of voltage
2. Phage angle of voltage
3. Active or true power
4. Reactive power

In load flow calculation, we are given with two quantities out of four quantities and remaining two is required to be determined. Depending on the quantities that have been specified, the buses are classified into three categories that is shown in Table 2, where predefined and the unknown quantities of the buses are given [7].

a) Load bus (PQ bus): A bus at which the real and reactive power is specified is called load bus. The objective of the load flow is to find the bus voltage magnitude |Vi| and its angle δi. All busses having no generators are load busses. A voltage on a load bus may change with changing loads. Therefore, load busses have specified values of P and Q, while V varies with load conditions [9]. The PQ buses are the most common comprising almost 85% of all the buses in a given power system.

b) Voltage controlled bus (PV bus): This bus is connected to a generator where the voltage is controlled using the excitation and the power is controlled using the prime mover control. So, this bus is also known as the generator bus. Such buses are also referred to as P-V buses. It is therefore required to find out the reactive power QGi and the bus voltage angle δi for PV bus. [10] PV buses comprise about 15% of all the

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buses in a power system.

Table 2. Classification of buses [8]

Bus classification	Pre specified variables	Unknown variables
Slack or swing	|V|, δ, PD, QD	PG, QG
Voltage controlled	|V|, PG, PD, QD	δ, QG
Load	PG, QG, PD, QD	|V|, δ

c) Slack bus or swing bus: This bus is considered as the reference bus. Slack bus is numbered 1 for the load flow studies and the angle of this bus is usually chosen as 0°. It must be connected to a generator of high rating relative to the other generators. During the operation, the voltage of this bus is always specified and remains constant in magnitude and angle [11].

In this paper, investigation has been done to find the optimal number of distributed generators in power system network. The paper is organized as follows: Section II explains impact of DG installation in system. Methodology is explained in Section III. Section IV shows the experimental results obtained and finally, conclusions in Section V are drawn based on results.

II. IMPACT OF DG INSTALLATION

DGs are installed in system to fulfill the demand of the power. Before installing distributed generation, its effects are assessed on voltage profile, line losses, short circuit current, harmonic and reliability. Certain parameters need to be studied for installing DG into the system, such as: the best technology to be used, the number and the capacity of the units, the best location, the type of network connection, etc. The impact of DG on the power system performance such as electric losses, voltage profile, stability and reliability needs to be appropriately evaluated. Reduction of power losses by Distributed Generation (DG) is becoming a popular technique worldwide. [12].

a) Reliability improvement

Reliability is a very important feature of power system that consists of security and capability evaluation. The penetration of distributed generation in electrical distribution system has adverse affect on these two characteristics [13].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 and it can also be operated during peak load conditions to compensate the load demands. The goal of a power system is to supply electricity to its customers in an economical and reliable manner. Reliability indices are used by system planners and operators as a tool to improve the level of service to customers [15]. The reliability indices such as SAIFI, SAIDI, CAIFI, CAIDI, ASAI, ASUI, ENS etc presented by the IEEE guide are used to evaluate reliability of the system [16]. The presence of DG into the distribution system helps to increase the level of system security. It could be understood by taking the following example:

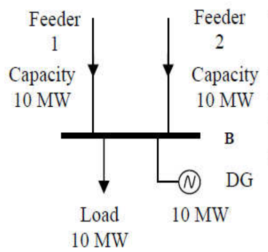
A distribution network is shown the Fig. 1. It consists of two radial feeders, each having a capacity of 10 MW. A constant load of 10 MW is connected to bus bar B. The FOR of the two feeders is given in the table in Fig. 1. Additionally, a 10 MW DG source with an availability factor of 80 percent is also connected to the bus bar B.

Case 1: Let us only consider the two feeders and assume there is no distributed resource connected to bus bar B. The loss of load probability (LOLP) also defined as the probability that load is not served, is simply the probability of both feeders being out of service at the same time which can be calculated by multiplying the two probabilities of failure. Consequently, LOLP= (0.04 x 0.04) = 0.0016. Now, if we have to find the number of days for which the load experiences the outage can also be calculated by multiplying the LOLP by 365, which results in 0.584 days/year. And in terms of hours/year, multiply it with 24 and we will get the answer of 14 hours/year.

Case 2: Now let us consider the case 2 with DG source connected to the system. It has an outage rate greater than the two feeders at 0.20, but it also adds a triple redundancy to the system. The LOLP in this case is the probability that both feeders and the DG source fail at the same time. Therefore, the LOLP = (0.04 x 0.04 x 0.20) = 0.00032. Here, the probability of being unable to serve load is five times less than before. Load being unserved in terms of hours/year is less than 3 hours per year in our example [14].

b) Power losses reduction

Electrical line loss occurs when current flows through distribution systems. Since we know that the electrical loss depends on amount of current flow and the line resistance. Therefore, line loss can be decreased by reducing either line current or resistance or both. When DG is provided nearer to the load centers, there is decrease in current flow in some part of the network and thus line loss can be reduced. However, DG may increase or reduce losses, depending on the location, capacity of DG and the relative size of load quantity, as well as the network topology and other factors [13].



Equipment	FOR (Forced Outage Rate)
Feeder 1	0.04
Feeder 2	0.04
DG	0.20

Fig. 1. Security of supply with DG [14]

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. [15]. Installing distributed generation nearer to the load point can help to reduce the transmission and distribution losses which are caused by the resistance of the power lines, cables and transformers. Most of the power demand is on the distribution network side and thus connecting generation to a point close to the load on the distribution network will be likely to reduce the losses [17].

c) Voltage profile improvement the voltage of the distribution system is regulated through the load changing

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transformers at the substation end and by the use of capacitors on the distribution feeders. 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 [15]. By changing the direction and magnitude of real and reactive power flows DG may result in changes in voltage profile along a feeder. Fig. 2 shows that the installation of DG units along the power distribution feeders may cause overvoltage due to too much injection of active and reactive power. Without DG, voltage received at the load terminals is lower than the voltage at the primary of the transformer. The connection of DG can cause a reverse power flow, and can raise the voltage on the secondary side of the distribution transformer which may result in high voltage on the customers end. This can happen if the location of the distribution transformer is at a point on the feeder where the primary voltage is near or above the fixed limits [2]. In Fig. 2, there is shown a DG installed downstream the LTC transformer which is equipped with a line drop compensator (LDC). In this case, the voltage becomes lower on the feeder side with DG than without the DG installed in the network. The DG reduces the load observed from the load compensation control side, which makes the regulator to set less voltage at the end of the feeder [2].

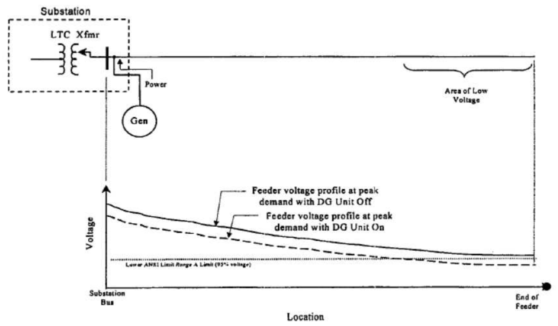

Fig. 2. Voltage profile with and without DG [2]

III. Methodology

For the investigation, the experiment was performed on 14 bus system. DGs were inserted at load buses locations such as 4, 5, 7, 9, 10, 11, 12, 13, and 14. The experiment was performed with different sizes of DGs in different ranges. Firstly, the DG1 was installed at different locations and the minima point was found. This minima location was kept fixed for the insertion of next DG and then again the study was carried on with the insertion of DG2 at different locations to find the minima location point. The location was again kept fixed for the next DGs and the process was repeated with total 6 DGs. Using these optima values, the line loss reduction index (LLRI) was found. Based on this line loss reduction index values, the optimum number of DGs that could be used in the distribution system to have minimum value of the power losses could be obtained. The whole investigation was repeated with DG size of 5 MW, 15 MW, 20 MW, 25 MW, 30 MW, 35 MW, 40 MW and 45 MW and accordingly their results were obtained and the final conclusion was derived. LLRI could be defined as:

$$LLRI = \frac{Line\,loss\,with\,DG}{Line\,loss\,without\,DG}$$

If LLRI < 1, then DG has reduced the electrical losses. Minimum value of LLRI corresponds to best location of DG in the distribution system.

IV. Result and Discussions

In this section, the line loss reduction index (LLRI) and the percent decrease in the losses are calculated based on which the minima points calculated for all 8 DGs corresponding to different sizes of DGs namely 5, 15, 20, 25, 30, 35, 40, 45 MW.

For DG size = 5 MW

Table 3. Analysis carried out on 14 bus data system with DG of size 5 MW

Number of DGs	Losses with DGs	LLRI	Percent decrease
1	17.54	0.96	4.31
2	17.24	0.94	5.90
3	17.13	0.94	6.51
4	17.02	0.93	7.11
5	16.98	0.93	7.34
6	16.95	0.93	7.48
7	16.93	0.92	7.62
8	16.90	0.92	7.78

It could be observed from the Table 3 that the line loss reduction ranges from 0.96 to 0.92 and corresponding percent decrease changes from 4.31 to 7.78. It can be easily examined that there is no significant decrease in LLRI ratio after 4 DGs.

For DG size = 15 MW

With DG size 15 MW, in Table 4, the line loss ranges from 0.90 to 0.55 and corresponding percent decrease changes from 9.82 to 44.46. The line losses decrease in significant way till DG 5 but after DG 5 the decrease was not noticed in that way. So, it's not advisable to install further more DGs in the system as it will only increase the total cost of the system.

Table 4. Analysis carried on 14 bus data system with DG of size 15 MW

Number of DGs	Losses with DGs	LLRI	Percent decrease
1	16.52	0.90	9.82
2	15.00	0.82	18.16
3	13.93	0.76	24.00
4	12.99	0.79	29.11
5	12.18	0.66	33.56
6	11.42	0.62	37.69
7	10.76	0.59	41.27
8	10.18	0.56	44.46

For DG size = 20 MW

Table 5. Analysis carried out on 14 bus data system with DG of size 20 MW

Number of DGs	Losses with DGs	LLRI	Percent decrease
1	16.06	0.88	12.37
2	14.01	0.76	23.55
3	12.71	0.69	30.65
4	11.57	0.63	36.84
5	10.58	0.58	42.28

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6	9.81	0.54	46.46
7	9.06	0.50	50.55
8	8.53	0.47	53.44

It could be observed from the Table 5 that the line loss ranges from 0.88 to 0.47 and corresponding percent decrease changes from 12.37 to 53.44. The line loss reduction was significant up to DG 5 and after that insertion of further more DGs didn't show any significant decrease in the line losses.

For DG size = 25 MW

Table 6 shows that with DG size 25 MW, the line loss ranges from 0.85 to 0.43 and corresponding percent decrease changes from 15.00 to 537.27. The line losses decrease in significant way till DG 5 but after DG 5 the decrease was not noticed in that way. So, it's not advisable to install further more DGs in the system.

Table 6. Analysis carried out on 14 bus data system with DG of size 25 MW

Number of DGs	Losses with DGs	LLRI	Percent decrease
1	15.57	0.85	15.00
2	13.17	0.72	28.11
3	11.65	0.64	36.42
4	10.44	0.57	43.01
5	9.31	0.51	49.17
6	8.58	0.47	53.17
7	8.07	0.44	55.98
8	7.83	0.43	57.27

For DG size = 30 MW

When 30 MW DG was installed, the line loss ranges from 0.82 to 0.44 and corresponding percent decrease changes from 17.62 to 55.78. The line losses were reduced to a great extent with the 5 DGs in the system. After DG 5, the losses are decreased till DG 7 but not in that expected way and with the installation of DG 8, the line losses are increased a bit. So, in this case 5 DGs were taken as the correct no.

Table 7. Analysis carried out on 14 bus data system with DG of size 30 MW

Number of DGs	Losses with DGs	LLRI	Percent decrease
1	15.09	0.82	17.62
2	12.48	0.68	31.90
3	10.82	0.59	40.96
4	9.64	0.53	47.40
5	8.63	0.47	52.90
6	8.08	0.44	55.87
7	7.96	0.43	56.55
8	8.10	0.44	55.78

For DG Size = 35 MW

Table 8 shows that with dg size 35 mw, the line loss ranges from 0.80 to 0.51 and corresponding percent decrease changes from 19.74 to 49.23. The line losses decrease in significant way till DG 4 but after DG 4 the decrease was not noticed in that way. When DG 7 and 8 were installed, the line losses seemed to be increased. So, it's not advisable to install more than 4 DGs in the system.

Table 8. Analysis carried out on 14 bus data system with DG of size 35 MW

Number of DGs	Losses with DGs	LLRI	Percent decrease
1	14.71	0.80	19.74
2	11.87	0.65	35.24
3	10.20	0.56	44.32
4	8.94	0.49	51.18
5	8.35	0.46	54.45
6	8.23	0.45	55.08
7	8.53	0.47	53.46
8	9.30	0.51	49.23

For DG size = 40 MW

It could be seen from the Table 9, the line loss ranges from 0.78 to 0.61 and corresponding percent decrease changes from 21.91 to 39.29 and the line loss reduction was significant up to DG 4 and with that insertion of further more DGs in the system, the losses started increasing. So, 4 DGs were taken as optimal no.

Table 9. Analysis carried on 14 bus data system with DG of size 40 MW

Number of DGs	Losses with DGs	LLRI	Percent decrease
1	14.31	0.78	21.91
2	11.38	0.62	37.90
3	9.75	0.53	46.76
4	8.69	0.47	52.57
5	8.49	0.46	53.70
6	8.81	0.48	51.93
7	9.78	0.53	46.63
8	11.12	0.61	39.29

For DG size = 45 MW

Table 10. Analysis carried on 14 bus data system with DG of size 45 MW

Number of DGs	Losses with DGs	LLRI	Percent decrease
1	14.04	0.77	23.34
2	11.00	0.60	39.94
3	9.30	0.51	49.26
4	8.68	0.47	52.63
5	8.87	0.48	51.56
6	9.82	0.54	46.38
7	11.40	0.62	37.75
8	13.69	0.75	25.30

In Table 10, the line loss ranges from 0.77 to 0.75 and corresponding percent decrease changes from 23.34 to 25.30. The line losses were reduced to DG 4 but with the installation of further more DGs in the system the line losses started increasing which is not at all desired. So, in this case 4 no. of DGs is taken as optimal no.

For significant decrease in the electrical line losses, the LLRI < 1. From the results derived in the above sections, it is clear that for all the DG sizes the value of LLRI is less than 1. But the optimal numbers of DGs to be used in the system are derived based on the fact that up to which point the loss reduction is significant. Otherwise simply increasing the

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number of DGs to reduce the electrical losses is not beneficial all the time.

V. Conclusion

The investigation is done to study the impact of multi-DGs on power losses using the line loss reduction index (LLRI). The study has been carried out on 14 bus system using NR method for load flow analysis. Based on this line loss reduction index values, the optimum number of DGs that could be used in the distribution system to have minimum value of the power losses are obtained. The results of the investigation show that with the installation of 8 DGs of different sizes, the line losses were decreased till 4 or 5 DGs in the distribution system but with the addition of further more DGs in the system, the losses were increased. So, it's concluded that 4 or 5 DGs could be used to have minimum losses in the system. The analysis of the results show that simply by increasing the number of DGs in the system to reduce the losses is not beneficial all the time. Beside the optimal location and size of DG for the loss reduction in distribution system, number of DG is also a vital factor. In this work, it is concluded that the optimal number of DGs is very important parameter to reduce the losses. The study gives the optimal number of DGs that could be installed in the distribution system to have minimum line losses.

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