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## **West African Journal of Industrial & Academic Research**

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**Editor-in-Chief: Professor O.E. Osuagwu, D.Sc, FNCS, FBCS**

# Performance Analysis of Distributed Generation at different Penetration Level

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## Abstract

*:To make the operation of a power system reliable and stable, Distributed Generation (DIG) must be incorporated in the system so that voltage profile can be improved and real and reactive loss can be reduced. Although incorporation of DIG can bring lots of benefit to the system, the location and size of the DIG must be optimally selected so that the benefit can be maximized. This work utilizes different indexes such as voltage profile improvement index (VPPI) and active and reactive power losses to analyze the impact of penetration level of DIG on these parameters. To achieve this, the penetration level of DIG was changed from 0% to 100% of the total load MVA and at each step, the active and reactive power losses and VPPI were computed.*

**Keywords:** Distributed Generation, Radial Distribution System, Penetration Level, Voltage Profile Improvement Index, Active power loss, Reactive power loss.

## 1. Introduction

Recently, electrical power system experiences a tremendous increase in energy demand from customers end. This is due to either increase in the number of the customers connected with the network or due to increase in the social welfare[1]-[2]. So, the system must be able to meet all the demand and to provide a sufficient and reliable power to the connected customers. [3]. This is done by few ways (a) installing more power generation units (b) implementing small generator at the customers end (c) increasing power transfer capability of power system equipments[4]-[5]. Those issues lead to special interest towards Distributed generation (DIG) technology [6].

Integration DIG in distribution networks may create technical and safety problems [8]. Depending on its location, DIG may increase fault currents, cause voltage oscillations, interfere with voltage-control processes, diminish or increase losses, etc. As distribution networks with DIG are no longer passive, all questions about planning, maintenance, and operation become more interesting and demand reassessment. The main issues include where to locate and how

to operate DIG to minimize the impact on distribution management. Additionally, it will be necessary to investigate whether DIG capability and placement of could be used to enhance distribution network planning and operation [8]-[9]. Consequently, it is critical to assess the technical impacts of DIG in power systems in order to apply generators in a manner that avoids causing degradation of power quality and reliability.

Benefits accrue by integrating DIG with utility networks. These benefits should be clearly understood, analyzed and quantified in order to increase the potential and value of penetration level of the device. The benefits have been evaluated and quantified in terms of voltage profile improvement, active line-loss reduction, and reactive line-loss reduction [8]-[11]. The purposes of this paper are to briefly discuss the benefits of employing compensating device at different locations of the system and for different power outputs i.e. penetration level [12] and quantify some of the technical benefits of the device in terms of voltage profile improvement and line-loss reduction.

## 2. Objective Functions

In this study, the installation cost, maintenance cost, grid energy reduction costs

are taken as economic objectives whereas the reductions of real and reactive power losses are considered as the technical aspects. This section represents a detailed description of these indexes as given below:

#### A. Voltage profile improvement index (VPPII)

A wider range of voltage stability can be achieved if the voltage magnitude of all the buses becomes equal to the nominal value of the system voltage. In the absence of DIG, the voltage magnitude of most of the buses is far lower than the nominal value. However, as DIG provide a significant enhancement in system voltage, the bus voltage magnitude is likely to increase. To measure the improvement of voltage magnitude, an index namely VPPII is proposed as shown below:

$$VPPII = \frac{(V_{overall})_{with\ DIG}}{(V_{overall})_{without\ DIG}} \quad (1)$$

#### B. Active and Reactive loss reduction index (ALRI & RLRI)

A significant amount of line loss reduction is possible with the incorporation of DIG and accordingly, a formula namely active and reactive loss reduction index (ALRI & RLRI) is formulated as follows:

$$ALRI = \frac{(P_L)_{with\ DIG}}{(P_L)_{without\ DIG}} \quad (4)$$

$$RLRI = \frac{(Q_L)_{with\ DIG}}{(Q_L)_{without\ DIG}} \quad (5)$$

where the active and reactive power loss of the system is defined as  $P_L$  and  $Q_L$ , respectively.

### 3. Results and Discussions

The Figure 1 represents a schematic diagram of a 33-bus radial distribution system that consists of 1 slack bus generator (connected at bus no.1) and 32 load buses. Total real power and reactive power load of the system are 3.715 MW & 2.3 MVAR respectively

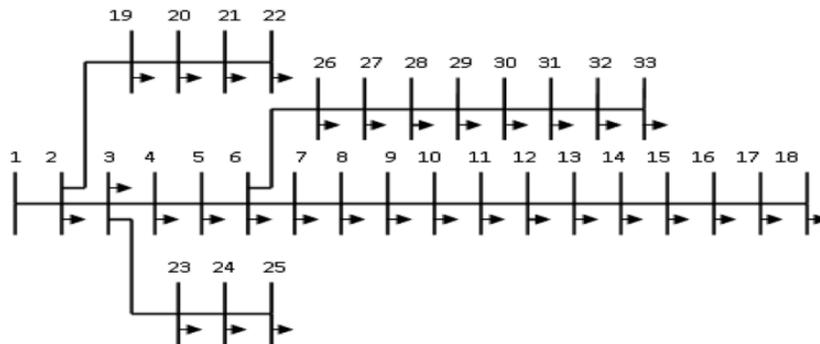


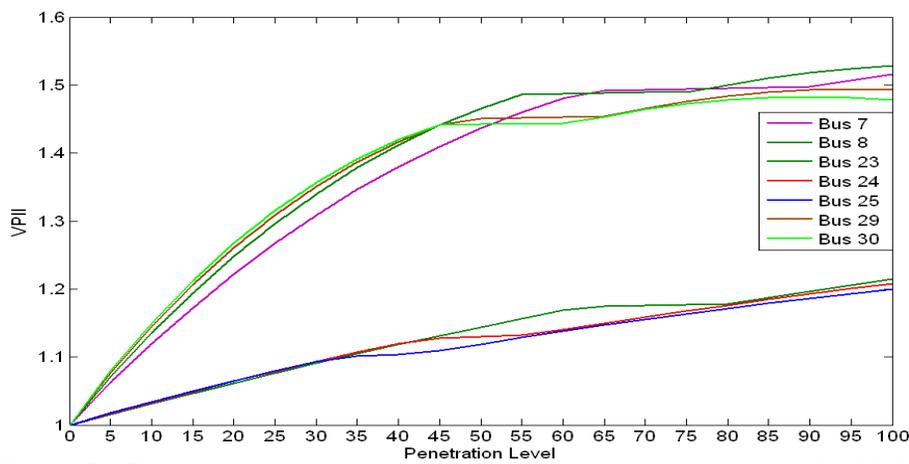
Figure 1: 33-bus radial distribution system

After checking the voltage profile of the distribution system, it is evident that buses 7, 8, 23, 24, 25, 29 and 30 are showing low voltage magnitude. Therefore, these buses are considered as weaker buses and they are taken into account for the analysis purpose.

#### 3.1 Impact of DIG penetration level on system voltage profile

Figure 2 presents the change of VPPII with the variation of DIG penetration level at each weak bus locations. In all the weak bus location, an inverse U-shape trajectory is found after plotting VPPII against penetration level of DIG. When the penetration level is

increased then accordingly the value of VPPII increases until it reaches its maximum values. By introducing DIG in the system, voltage profile can be improved because DIG can provide a portion of the real and reactive power to the load, thus helping to decrease current along a section of the distribution line, which, in turn, will result in a boost in the voltage magnitude at the customer site. A declination in the value of VPPII is observed when we further increased the penetration level. This will lead to a result that the penetration level of the DIG unit should be chosen carefully



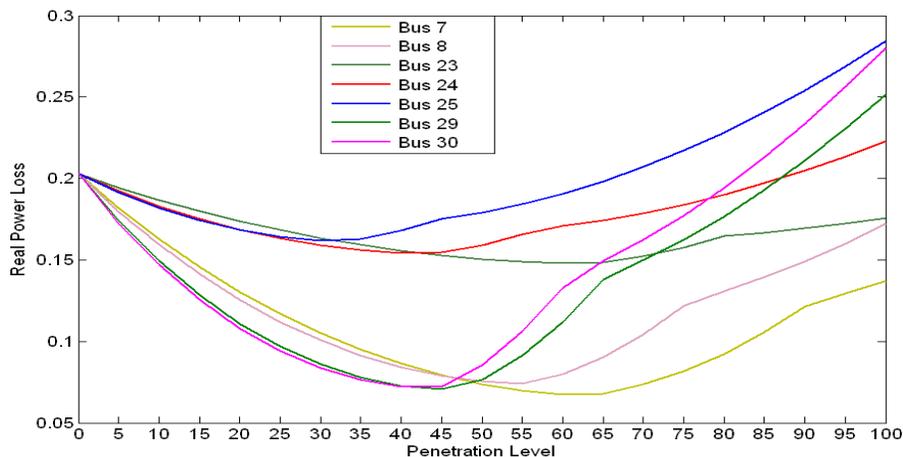
**Figure 2:** Change of system voltage profile with penetration level of DIG.

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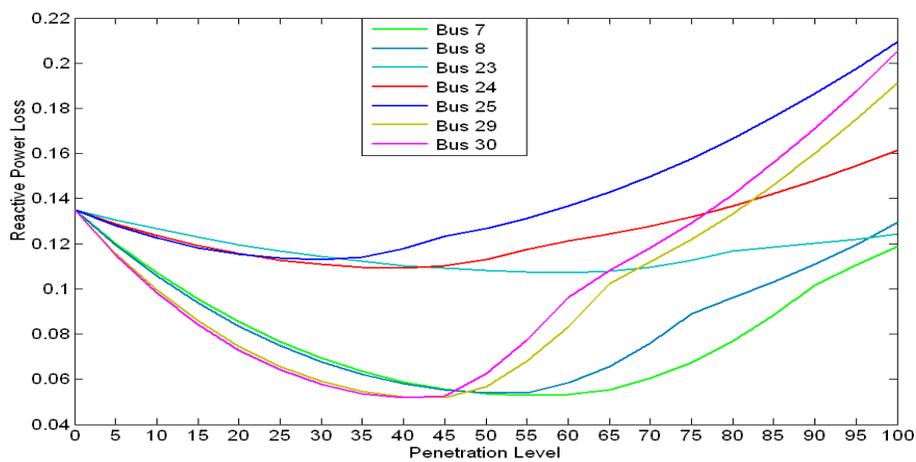
### 2.2 Impact of DIG penetration level on system power losses

Figure 3 and 4 represent the change of real and reactive power losses with the change of DIG penetration level. It is studied from both the figures that total real and reactive power losses of the system vary as a function of the penetration level of DIG. In all the weak bus location, the relation between power losses and penetration level of DIG shows a U-shape trajectory. Real and reactive power losses start to decrease when penetration level (i.e. size) of DIG is increased until losses reach its minimum level. Once this minimum level is reached, if DIG penetration level still increases, then losses begin to marginally increase too. This characteristic is noticed for most of the cases when penetration level is increased beyond 50% of the total load-MVA. If DIG penetration levels increase enough, then losses can be even higher than without DIG connected. The reason behind the behavior

that losses decreases with increment of penetration level is because DIG is injecting power (current) directly to the local load to satisfy their demand, which in turn reduces the power taken from the distribution substation. As a result of reducing the power taken from the distribution substation, the value of the total current flows from the distribution substation to the loads through the distribution lines is reduced. The substation current reduction means that the voltage drop across the lines is less and the power losses in the lines are greatly decreased by a square proportion. On the other hand, if DIG generated power is more than the local load then the remaining power will spread in the system, hence the overall system losses starts to increase. This will lead to a result that the penetration level of the DIG unit should be chosen carefully in order to prevent the increase of the overall system losses



**Figure 3:** Change of system real power loss with penetration level of DIG



**Figure 4:** Change of system reactive power loss with penetration level of DIG

#### 4. Conclusion

The introduction of DIG in a distribution system offers several benefits to utilities, customers, and society, such as reduced line and transformer losses, reduced central generating station reserve requirements, improved system voltage profile, increased system reliability and enhanced power quality, peak shaving, reduced environmental impacts, and relieved transmission and distribution congestion.

This study has proposed an approach to quantify the technical benefits of introducing DIG that are placed at weak bus locations and its penetration level was changed from 0% to 100% of total load-MVA at a step of 5%. A set of indices such as  $VPII$ , Total Real and Reactive Power Losses, were considered and Simulation results obtained using 33-Bus test

system. This clearly shows that DIG can improve system voltage profile, and reduce electrical active and reactive line losses. As expected, their rating as well as location plays a vital role in determining the amount of voltage profile improvement. Typically, as  $VPII$  goes up, rating increases and these were altered from location to location. However, this trend may not always be applicable to line-loss reduction because the amount of real and reactive power loss may go up or down depending on rating and location. This implies that the location and the penetration level of the DIG unit should be chosen carefully by the network operator in order to prevent the decrease of voltage profile, and increase of the overall system losses

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# Optimal Allocation of Distributed Generation in Radial Distribution System

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## Abstract

*In the current circumstances of energy market restructuring, deployment of Distributed Generation (DIG) in the Radial Distribution System is one of the efficient and viable strategies that can be adapted by the Distribution System owner for the improvement of bus voltage magnitude and reduction in line losses of the system. Accordingly, in this study, a logically developed particle swarm optimization (PSO) technique is used to identify the optimal location and size of DIG in 69-bus radial distribution system to improve technical benefits of the system. To find the suitable location and size for device placement, indexes such as voltage magnitude improvement index (VMII) and line loss reduction index (LLRI) were formulated. Different cases were considered to establish that in the presence of DIG, there is significant voltage profile improvement and line loss reduction in a radial distribution system.*

**Keywords:** Distributed Generation, Radial Distribution System, Particle swarm optimization, Voltage magnitude improvement index, Line loss reduction index.

## Introduction

There are various kinds of customers in radial distribution systems and recently, there has been a continuous rise in power demand of these customers. Moreover, due to the introduction of different private energy generation companies in power market, there are trades due to undesired power exchanges. These factors have forced the power system utilities to operate near the stability margin, which is pushing the system towards the voltage collapse point [1]. The expansion of existing network or installation of new centralized generation units is not practically feasible due to the shortage of conventional resources, financial problems, legal constraints, and a growing concern about the environment [2]. Therefore, maintaining an efficient and reliable power supply to the customers has become a challenging issue for the power industries. These kinds of problem are more acute in the distribution system (DS) which transfers the electrical energy directly from the substation to the consumer point [3]. Traditionally, DS is planned with a radial topological configuration and have a large resistance/reactance ratio that makes it suffer from poor voltage profile and higher system losses [4-5]. Also, a large portion of the total

power demand is provided by the fossil fuels based on conventional power plants. As a result, a huge amount of greenhouse gases are emitted into the environment which are creating the global warming [6]. Considering the above-mentioned issues, the incorporation of Distributed Generation (DIG) has become a smart choice for the Distribution System owner to earn significant technical benefits. DIG is defined as a small-scale power generating unit that is utilized at the consumer end in radial distribution system [8]. The presence of DIG can be beneficial for the system in many aspects. But an inappropriate size or improper location of the device may give the opposite impact of the desired one [7-8]. Therefore, proper attention should be paid before incorporating DIG in radial distribution system.

In the past, researchers have proposed soft computing based approaches [7-10] and various analytical techniques [11-15] for the optimal placement of DIG in system. The soft computing techniques such as immune algorithm [7], grey wolf optimization [8], ant lion optimization [9], and particle swarm optimization [10] are broadly accepted for their ability of solving complex non linear problem and handling multiple security

constraints. In [11], an exact loss formula based analytical method is proposed to determine the optimal size and site of DG. Viral and Khatod proposed an analytical expression considering minimizing the loss after allocating the DG at various bus location of the network [12].

In addition, there are various kinds of consumers such as residential, industrial and commercial in power distribution system and their demand grows with the time horizon. Hence, a growth in load demand must be considered to model a system properly.

With an aim to deficit the above-mentioned issues, this paper proposes optimizing size and location problem of DG in 69 bus radial distribution system. The main aim of the study is to increase the voltage profile and reduce line losses. To find the suitable location and size for device placement, indexes such as voltage magnitude improvement index (VMII) and line loss reduction index (LLRI) are formulated. To make the study practical, analysis is carried out in different loading conditions.

### 5. Objective Functions

The technical aspects such as voltage magnitude enhancement and line loss reduction are taken as objective function in this study. This section represents a detailed description of these indexes as given below:

#### C. Voltage magnitude improvement index (VMII)

A wider range of voltage stability can be achieved if the voltage magnitude of all the buses becomes equal to the nominal value of the system voltage. In the absence of DIG, the voltage magnitude of most of the buses is far lower than the nominal value. However, as DIG provide a significant enhancement in system voltage, the bus voltage magnitude is likely to increase. To measure the improvement of voltage magnitude, an index namely VMII is proposed as shown below:

$$VMII = \frac{(V_{overall})_{with\ DIG}}{(V_{overall})_{without\ DIG}} \quad (1)$$

#### D. Line loss reduction index (LLRI)

A significant amount of line loss reduction is possible with the incorporation of DIG and accordingly, a formula namely line loss reduction index (LLRI) is formulated as follows:

$$LLRI = \frac{(P_L)_{with\ DIG}}{(P_L)_{without\ DIG}} \quad (2)$$

where the active power loss of the system is defined as  $P_L$ .

After bringing all the considered objectives in the same range, the multi-objective optimization problem is converted into a single objective optimization problem using proper weighting coefficient as shown in equation(3).

$$\text{Minimize } F = w_1 \times VMII + w_2 \times LLRI \quad (3)$$

## 6. Solution Algorithm

PSO is a stochastic optimization technique, which was developed by Dr. Eberhart and Dr. Kennedy in 1995. It is based on swarm intelligence, which is inspired by the social behavior of bird flocking or fish schooling. In this technique, a group of random particles are generated within the search space. The particle with the best fitness value guides the other particle towards the optimal solution. A randomized velocity is associated with each particle, which moves along the search space. Each particle updates its position and velocity according to the following equation:

$$v_{id}^{t+1} = w * v_{id}^t + c_1 * rand(pbest_{id}^t - s_{id}^t) + c_2 * rand(gbest_{gd}^t - s_{id}^t) \quad (4)$$

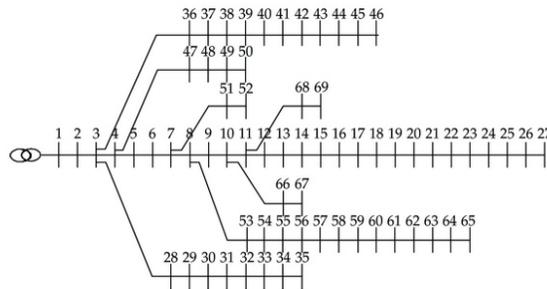
$$s_{id}^{t+1} = s_{id}^t + v_{id}^{t+1} \quad (5)$$

where  $s_{id}^t$  and  $v_{id}^t$  are the current position and current velocity of the  $i^{th}$  particle in the d-dimensional space, respectively.  $pbest_{id}^t$  is the  $pbest$  of  $i^{th}$  particle for the  $t^{th}$  generation,  $gbest_{gd}^t$  is the global best particle of the entire swarm considering the whole iteration that is up to  $t^{th}$  generation,  $v_{id}^{t+1}$  is the updated velocity of the  $i^{th}$  particle,  $w$  is the inertia weight of the  $i^{th}$  particle,  $rand =$  any random number in  $[0, 1]$ . The particle velocity is a very important factor in PSO algorithm because wrong direction and improper magnitude can lead to system divergence. Measurement of particle velocity is greatly dependent on PSO parameters such as inertia weight.

## 7. Results and Discussions

The developed analytical technique is applied on 69-bus DS to solve the optimum deployment problem for DG and DSTATCOM. The bus and line data for the test system is acquired from [7] and Schematic diagram of 69-bus radial distribution system is shown

in Figure 1. The backward-forward sweep method is utilized to conduct the power flow analysis after taking the base power = 100 MVA and the base voltage = 12.66 kV. Bus number 1 is considered as the substation that always maintains a voltage of 1 p.u.



**Figure 1: Schematic diagram of 69-bus radial distribution system.**

Different cases are considered for the analysis purpose:

Case 1: Base case i.e. without installing DIG

Case 2: After installing DIG.

### Scenario 1: At 100% of the Nominal Load

Table 1: Location and Size of DIG and the values of objective functions at 100% loading

Cases	Location of DIG	Size of DIG	Value of VMII	Value of LLRI
Case 1	-	-	1.000	1.000
Case 2	1745.2	Bus 61	1.125	0.373

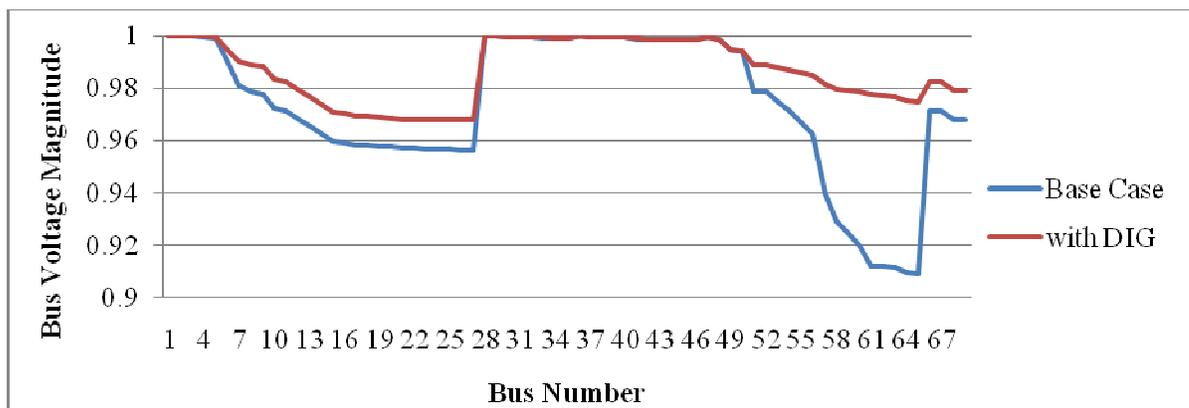


Figure 2: Bus voltage at different cases for 100% loading condition.

In this scenario, the system is analyzed at 100% loading condition and the obtained values in terms of optimal size, optimal bus location and its corresponding objective function are presented at Table 1. The optimal location for

installing DIG is Bus 61 with a capacity of 1745.2 kW. In the base case, both the values of VMII and LLRI are 1.000. However, with the integration DIG in the system, the value of VMII is increased to 1.125, which indicates that there

is an enhancement of overall bus voltage magnitude with DIG. On the other hand, the presence of DIG contributes to the reduction of LLRI to 0.373 as compared to 1.000 in base case. Therefore, it can be concluded that active line loss is reduced with the incorporation of DIG in the radial distribution system.

The voltage magnitude of different buses of 69-bus radial distribution system at base case and after integration of DIG is determined and they are compared using a graphical representation as shown in Figure 2. This figure clearly indicates that in base case, most of buses

exhibits a lower voltage magnitude as compared to the nominal voltage i.e. 1 P.U. However, in case 2 i.e. after incorporating DIG, it is clearly seen from Figure 2 that the voltage magnitude of almost all the buses increased and they almost reach to the nominal value. On the other hand, a comparison between cases 1 and 2 is carried out in Figure 3 on the basis of real and reactive line losses. It is evident from the figure that with the introduction of DIG, there is significant reduction of real and reactive power in radial distribution system.

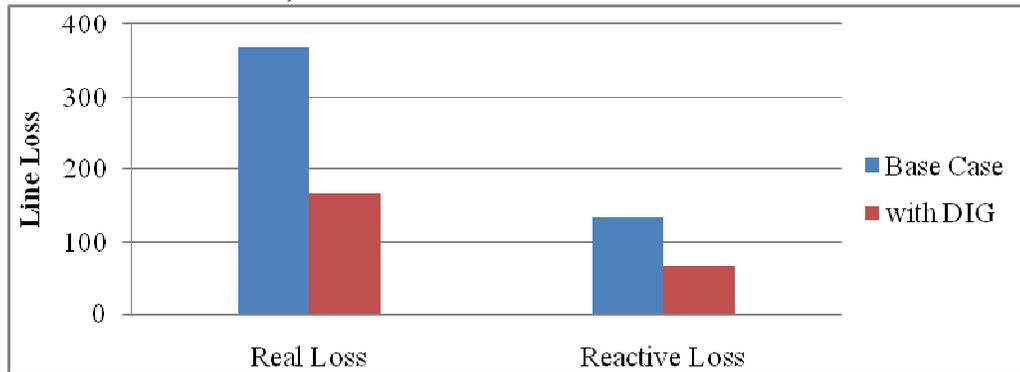


Figure 3: Real and Reactive power loss of different cases at 100% loading condition.

**Scenario 2: At 125% of the Nominal Load**

In this scenario, the system is analyzed at 125% loading condition and the obtained values interms of optimal size, optimal bus location and its corresponding objective function are presented at Table 2. The optimal location for installing DIG is Bus 61 with a capacity of 2076.8 KW. In the base case, both the values of VMII and LLRI are 1.000.

However, with the integration DIG in the system, the value of VMII is increased to 1.128, which indicates that there is an enhancement of overall bus voltage magnitude with DIG. On the other hand, the presence of DIG contributes to the reduction of LLRI to 0.365 as compared to 1.000 in base case. Therefore, it can be concluded that active line loss is reduced with the incorporation of DIG in the radial distribution system.

Table 2: Location and Size of DIG and the values of objective functions at 125% loading

Cases	Location of DIG	Size of DIG	Value of VMII	Value of LLRI
Case 1	-	-	1.000	1.000
Case 2	2076.8	Bus 61	1.128	0.365

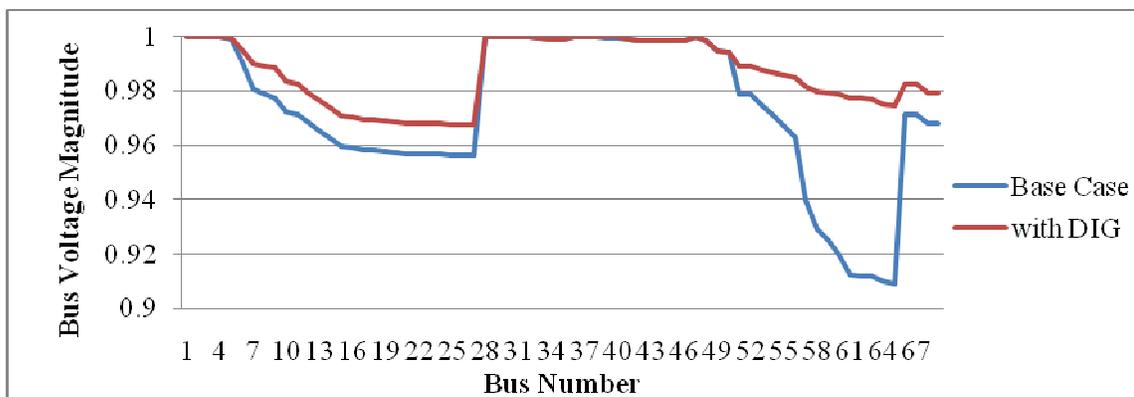


Figure 4: Bus voltage at different cases for 125% loading condition.

The voltage magnitude of different buses of 69-bus radial distribution system at base case and after integration of DIG is determined and they are compared using a graphical representation as shown in Figure 4. This figure clearly indicates that in base case, most of buses exhibits a lower voltage magnitude as compared to the nominal voltage i.e. 1 P.U. However, in case 2 i.e. after incorporating DIG, it is clearly seen from Figure 4 m.

that the voltage magnitude of almost all the buses increased and they almost reach to the nominal value. On the other hand, a comparison between cases 1 and 2 is carried out in Figure 5 on the basis of real and reactive line losses. It is evident from the figure that with the introduction of DIG, there is significant reduction of real and reactive power in radial distribution system.

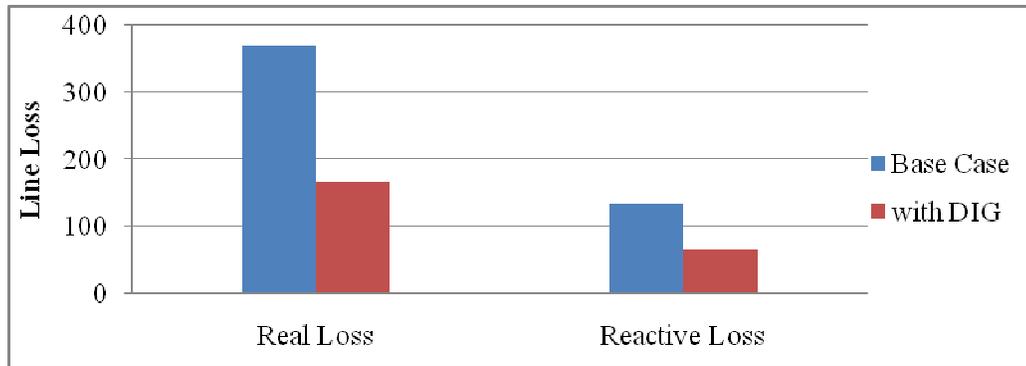


Figure 5: Real and Reactive power loss of different cases at 125% loading condition.

## 8. Conclusion

This study focused on the solving of the optimum deployment problem of DIG in 69-bus radial distribution system. The main objective is to improve system voltage and reduce line losses. PSO technique is as an optimization algorithm. Indexes such as voltage magnitude improvement index (VMII) and line loss reduction index (LLRI) are formulated and based on these indexes, the optimal size and location of DIG is

obtained. The simulation results revealed that significant amount of technical benefits in terms of line loss reduction and voltage profile improvement is obtained with the incorporation of DIG. This analysis is also done by increasing the load of the distribution network from 100% to 125% and the obtained results at 125% loading condition also exhibited the same results

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