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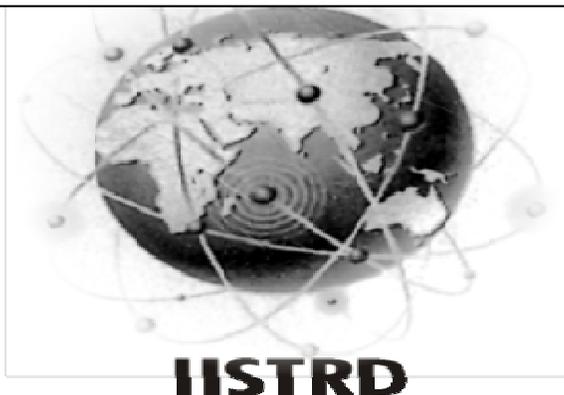
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### Reconfiguration of Distribution System in Presence of Distributed Generation

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#### Abstract

*Nowadays, to cope with the uncertain growth of load, capacity of substation and distribution feeders need to be increased, which is a costly solution for distribution system owner. In such context, reconfiguration of the network and incorporation of Distributed Generation (DIG) in the Radial Distribution System is one of the efficient and viable solutions to meet a significant amount of load growth. Accordingly, in this study, a logically developed particle swarm optimization (PSO) technique is used to reconfigure network and solve the optimal deployment problem of DIG in 33-bus radial distribution system. The main objective is to improve the voltage magnitude and reduce line losses of the network. To find the suitable location and size for device placement, indexes such as voltage magnitude improvement index (VMII) and active loss reduction index (ALRI), and reactive loss reduction index (RLRI) were formulated. Different cases are considered to analyse the importance of network reconfiguration and DIG deployment.*

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

## 1. Introduction

Recently, there has been enormous growth in loads for different types of customers. With the load growth, two major changes will happen in the radial distribution system [1]-[3]. Since distribution systems are radial in structure, the voltage magnitude of the buses situated at a far distance from the substation will face a significant voltage dip [4]. In such situation, if there is an enormous load growth, the situation will get worse and the need to make an arrangement of active power source in the network arises [5]. On the contrary, with the load growth, the total demand of distribution system will increase and there may be a possibility that the substation may not be able to deliver the total demand of the system [6]. As a result, distribution system owner need to take substation up gradation process. Equally, with the load growth, the power flow through the distribution feeders will increase and as time passes, these feeders can be overloaded above its maximum capacity [7]-[8]. In such context, the feeders' capacities need to be upgraded. The upgradation process of substation and feeders are very costly in nature. Therefore, distribution system owner have to invest in incorporation of distribution generation (DIG) in the system so that the load growth can be handled efficiently. DIG is the local source of electricity that is situated at a close distance of the customers and generates clean and green electricity. The

## 2. 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:

### A. 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:

incorporation of DIG can help to reduce the real and reactive power loss and improve the voltage magnitude of the system.

Reconfiguration of a distribution system can also be used to monitor the power flow through the feeders. Actually, reconfiguration is defined as process of changing the structure of the network by closing and opening of the tie switches. Similar to the DIG, reconfiguration can help to reduce line losses and improve voltage magnitude and the best part of utilizing reconfiguration is that it does not exhibits much investment cost [9]-[10].

There are different studies already available in the literature to reconfigure the distribution network in presence of reconfiguration [1]-[10]. Their main aim was to improve the technical benefits of the system by reducing losses and improve voltages.

To cope up with the ever increasing load demand of the customers, this paper proposes the optimal utilization of reconfiguration and DIG in 33-bus radial distribution system with an objective to reduce line losses and increase the voltage profile. Different logical indexes namely voltage magnitude improvement index (VMII), active line loss reduction index (ALRI) and reactive line loss reduction index (RLRI) were formulated in this study. Different cases were also arranged to make an in-depth analysis

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

### 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:

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

$$RLRI = \frac{(Q_L)_{with\ DIG}}{(Q_L)_{without\ DIG}} \quad (3)$$

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

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(4).

Minimize

$$F = w_1 \times VMII + w_2 \times ALRI + w_3 \times RLRI \quad (4)$$

### 3. 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:

$$v_{id}^{t+1} = w * v_{id}^t + c_1 * rand(pbest_{id}^t - s_{id}^t) + c_2 * rand(gbest_{gd}^t - s_{id}^t) \quad (5)$$

$$s_{id}^{t+1} = s_{id}^t + v_{id}^{t+1} \quad (6)$$

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.

### 4. Results and Discussions

The developed analytical technique is applied on 33-bus radial distribution system to solve the reconfiguration of the distribution system with DIG. The bus and line data for the test system can be acquired from [7] and Schematic diagram of the test network is shown in Figure 1. This system consist of 33 buses, 32 lines, 32 loads and 5 tie switches namely 33, 34, 35, 36 and 37. At the initial condition, these switches are in open condition. 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.

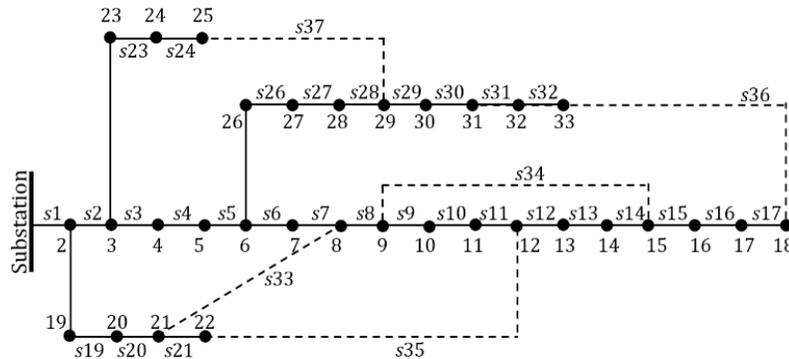


Figure 1: Schematic diagram of 33-bus radial distribution system.

Different cases are considered for the analysis purpose:

- Case 1: System performance at Base case
- Case 2: System performance with Reconfiguration only
- Case 3: System performance with DIG only
- Case 4: System performance with Reconfiguration and DIG

In this scenario, 33-bus distribution system is considered to integrate reconfiguration and DIG and the obtained values interns of optimal size, optimal

bus location and its corresponding objective function are presented at Table 1. The obtained results show that In case 2, the switches that arte opened for the reconfiguration purposes are 7, 9, 12, 16, and 28

whereas in case 4, the opened switches are 7, 9, 12, 16, and 28. The optimal location for DIG for both case 3 and 4 is Bus 6, but the optimal size of DIG is more in case 4 as compared to case 3. As compared to case 1 i.e. base case, there is increment in VMII and decrement in both ALRI and RLRI. Therefore, it can be concluded that reconfiguration and DIG can contribute to improve bus voltage magnitude and reduce active and reactive line losses. However, the highest value of VMII and the lowest value of ALRI

and RLRI are obtained in Case 4, which indicates that the reconfiguration of the system network in presence of DIG is more beneficial as compared to separate integration. On the other hand, comparing cases 2 and 3, it is evident that the value of VMII is more in Case 2 and the value of ALRI and RLRI is less in Case 3. Therefore, from the standpoint of voltage magnitude improvement and loss reduction, DIG is more effective than reconfiguration.

Table 1: Reconfiguration, location and sizes of DIG, and objective values in 33-bus system

Cases	Location of DIG	Size of DIG	Reconfiguration (Switches opened)	Value of VMII	Value of ALRI	Value of RLRI
Case 1	-	-	-	1.000	1.000	1.000
Case 2	-	-	7-9-12-16-28	1.045	0.703	0.769
Case 3	1945.2	Bus 6	-	1.125	0.541	0.574
Case 4	2072.5	Bus 6	7-9-12-16-28	1.145	0.469	0.518

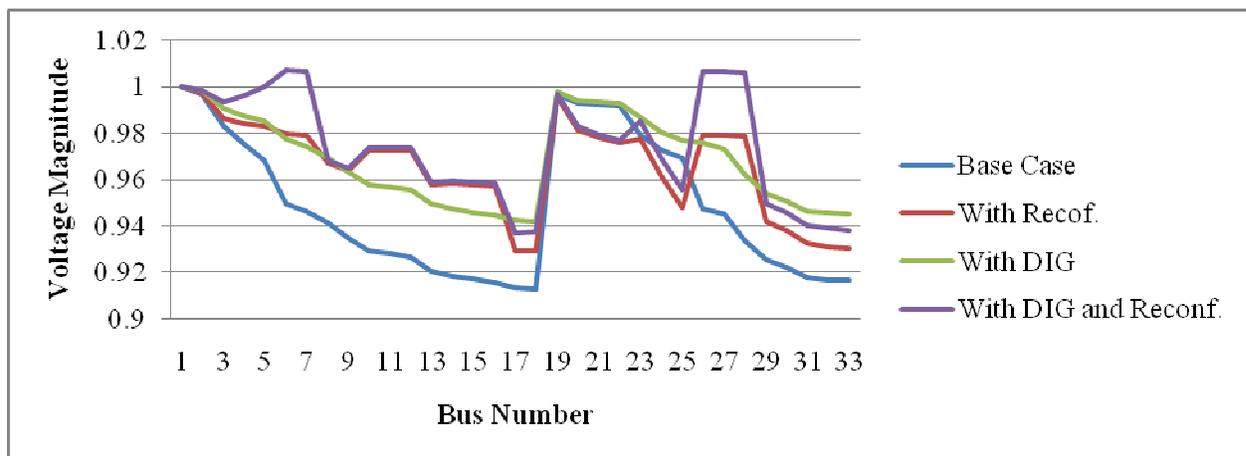


Figure 2: Bus voltage magnitude at different cases for 33-bus system.

The voltage magnitude of different buses of 33-bus radial distribution system at base case and after integration of DIG and reconfiguration 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, it can be noticed from the figure that in cases 2-4, there is significant enhancement of voltage profile of all the buses and most of the bus voltage magnitude is

obtained more than the minimum voltage limit i.e. 0.95 P.U. On the other hand, a comparison between different cases 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 and reconfiguration, there is significant reduction of real and reactive power in radial distribution system. But the highest reduction of losses occurs when both DIG and reconfiguration are used simultaneously as compared to their separate utilization

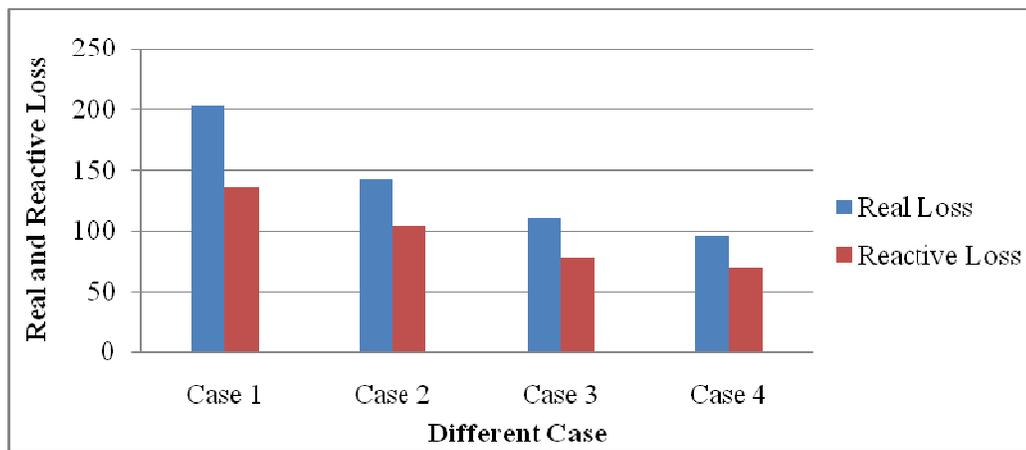


Figure 3: Real and Reactive power loss of different cases for 33-bus system.

## 5. Conclusion

This study presented a PSO based optimization technique to maximize voltage magnitude and minimize real and reactive power losses of 33-bus radial distribution system. In such context, reconfiguration was utilized in the presence of DIG. Different cases were considered to make an in-depth analysis. The obtained results revealed that significant amount potential benefit can be obtained with the incorporation of DIG and

utilizing reconfiguration. However, compared to reconfiguration, DIG is superior in the context of line loss reduction and voltage profile improvement. On the contrary, the highest reduction of system losses and the highest enhancement of voltage profile were obtained when both reconfiguration and DIG were utilized simultaneously.

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# Optimum deployment of Distributed Generation and Shunt Capacitor for maximizing Power System Economy

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## Abstract

*In this study, to maintain secure and stable operation of power system, distributed generation (DIG) and shunt capacitor are optimally placed in radial distribution system. In such regard, a particle swarm optimization (PSO) based technique was used to find the optimal location and optimal size of the DIG and shunt capacitor. The main aim of this study is to increase the economic benefit of the distribution system operator as well as to reduce the active and reactive power loss. Different indexes such as Cost Index (CI), Active loss reduction index (ALRI), and Reactive loss reduction index (RLRI) are proposed and formulated accordingly. Different cases are considered and the obtained results are deeply analyzed for finding out the best option of system operator.*

**Keywords:** Distributed Generation, Shunt Capacitor, Radial Distribution System, Particle swarm optimization, Cost Index, Active loss reduction index, Reactive loss reduction index.

## Introduction

Distribution systems are the most important part of power system that are utilized to supply power to the different types of customers such as commercial, industrial and residential [1]. Distribution system are mostly radial in structure and there is only one power supply at the bus 1 of the system. Moreover, the type of system possess high resistance/reactance ratio [2]-[3]. As a result, there have been a more active and reactive power losses in distribution system and accordingly, the end customers will face voltage drop and there is a high possibility that the voltage magnitude of most of the buses may be below the minimum voltage limit i.e. 0.95 P.U. In such situation, there has been a constant load growth among different customers in recent years and this will worsen the voltage magnitude in the forthcoming years, which will reduce the power system stability margin [4]-[6]. Therefore, the active and reactive power sources must be integrated in the system to improve the voltage magnitude so that the power stability margin can be improved. For that reason, the system planning engineers are focusing nowadays on the incorporation of distributed generation (DIG) and shunt capacitor so that a secure and stable operation of power system can be achieved.

DIG is the local source of electricity that is situated at a close distance of the customers and generates clean and green electricity [5]-[8]. There are different types of DIG such as solar DIG, wind DIG etc. The incorporation of DIG can

help to reduce the real and reactive power loss and improve the voltage magnitude of the system [9]. Moreover, the active power generation of DIG helps to match the active power growth of the system [10].

On the other hand, shunt capacitor is a source of reactive power that can also be incorporated in radial distribution system [10]-[11]. Similar to the DIG, integration of shunt capacitor can help to reduce line losses and improve voltage magnitude. The yearly constant yearly reactive power growth can be handled easily with the proper utilization of shunt capacitor [11].

Although DIG and shunt capacitor are very useful for the distribution system, but to maximize the obtained benefit from the system, placement of these devices at optimal location with appropriate size is very much necessary to obtain the maximum benefit from the devices. In this regard, this paper proposes the optimal deployment of DIG and shunt capacitor in 33-bus radial distribution system with an objective to reduce line losses and increase financial benefit of the distribution system owner. Different indexes such as Cost Index (CI), Active loss reduction index (ALRI), and Reactive loss reduction index (RLRI) are proposed and formulated accordingly. Different cases are considered and the obtained results are deeply analyzed for finding out the best option of system operator.

## 6. 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:

### C. Cost Index (CI)

Due to the integration of DIG and shunt capacitor, there is reduction of active and reactive power from the electrical grid. As a result the distribution system owner will get benefitted. However, the cost of incorporation of these devices is very high. Therefore, a cost index (CI) is formulated in this study to check whether the investment of these devices is beneficial for the distribution system owner or not.

$$CI = \frac{\text{Obtained Benefit (OB)}}{\text{Investment Cost (IC)}} \quad (1)$$

$$IC = \{(P_{DIG} \times C_{DIG}) + [(Q)_{SC} \times C_{SC}]\} + \{(P_{DIG} \times M_{DIG} \times N_{Plan}) + [(Q)_{SC} \times M_{SC} \times N_{Plan}]\} \quad (2)$$

$$OB = \{(P_{wod} - P_{wd}) \times C_{ap} \times N_{Plan}\} + \{(Q_{wod} - Q_{wd}) \times C_{rp} \times N_{Plan}\} \quad (3)$$

Where  $P_{DIG}$  and  $Q_{SC}$  are the power output of DIG and shunt capacitor in KW and KVAR, respectively.  $C_{DIG}$  and  $C_{SC}$  are the cost of DIG and shunt capacitor per KW and KVAR, respectively.  $M_{DIG}$  and  $M_{SC}$  are the maintenance cost of DIG and shunt capacitor.  $N_{Plan}$  is the planning horizon that is taken as 10 years.  $P_{wod}$  and  $P_{wd}$  are the active power taken from the electrical grid without device and with devices, whereas  $Q_{wod}$  and  $Q_{wd}$  are the reactive power taken from the electrical grid without device and with devices.  $C_{ap}$  and  $C_{rp}$  are the unit price of active and reactive taken from the grid.

### D. 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.

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(6).

$$\text{Minimize } F = w_1 \times CI + w_2 \times ALRI + w_3 \times RLRI \quad (6)$$

## 7. 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 particles 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:

$$v_{id}^{t+1} = w * v_{id}^t + c_1 * rand(pbest_{id}^t - s_{id}^t) + c_2 * rand(gbest_{gd}^t - s_{id}^t) \quad (5)$$

$$s_{id}^{t+1} = s_{id}^t + v_{id}^{t+1} \quad (6)$$

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.

## 8. Results and Discussions

The developed technique is applied on 33-bus radial distribution system to solve the optimum deployment problem of DIG and Shunt Capacitor. The bus and line data for the test system can be acquired from [10] and Schematic diagram of the test network is shown in

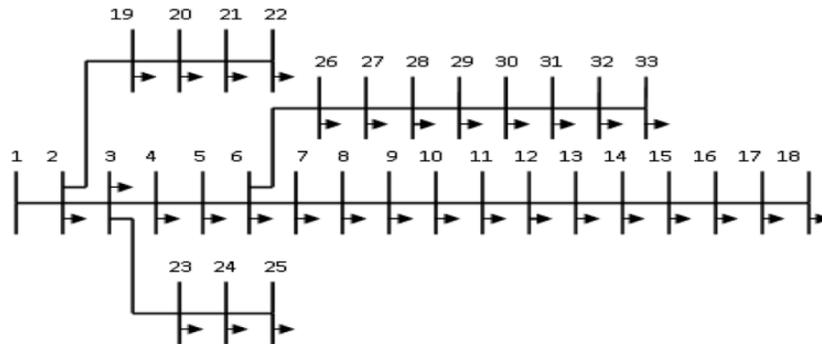


Figure 1: Schematic diagram of 33-bus radial distribution system.

Different scenarios are considered for the analysis purpose:

Scenario 1: System performance at Base case

Scenario 2: System performance with DIG only

Scenario 3: System performance with Shunt Capacitor only

Scenario 4: System performance with DIG and Shunt Capacitor

In 33-bus distribution system, all the above-mentioned scenarios are analyzed and the obtained results in terms of size and location of DIG and shunt capacitor and the obtained values of the objectives are shown in Table 1. The table indicates that the lowest values of ALRI and RLRI are

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.

obtained in the scenario 4, which indicates that the simultaneous incorporation of DIG and capacitor is important from loss reduction viewpoint. On the other hand, compared to shunt capacitor, more loss reduction is possible with DIG.

As shown in Table 1, the value of CI is the highest in case of scenario 3 and the lowest in scenario 2. In such context, a detailed economic analysis is done in Table 3. This table indicates that the highest IC is obtained for scenario 4 due to the incorporation of both the devices simultaneously. However, the net benefit after 10 years of time period is the highest for scenario 4. Moreover, scenario 3 presents the lowest benefits

Table 1: Optimal location and size of DIG and Capacitor and objective values for different scenarios.

Scenario	Shunt Capacitor		DIG		Value of CI	Value of ALRI	Value of RLRI
	Size	Location	Size	Location			
1	-	-	-	-	0	1.000	1.000
2	-	-	1875.8	Bus 6	2.145	0.538	0.562
3	1352.2	Bus 30	-	-	5.124	0.706	0.710
4	1375.5	Bus 31	1945.5	Bus 6	3.452	0.276	0.311

Table 2: Detail economic analysis of different scenarios.

Scenario	Investment Cost (IC)	Obtained Benefit (OB)	Net Benefit (NB)
1	-	-	-
2	1481882.1	3178637.7	1696755.6
3	94654.2	458008.1	363353.9
4	1576536.8	5442202.3	3865665.5

Figure 2 presents a comparative analysis between considered scenarios on the basis of real and reactive line losses. It is evident from the

figure that the real and reactive power is significantly reduced in radial distribution system in the presence of DIG and shunt capacitor. But

the highest reduction of losses occurs when both DIG and shunt capacitor are incorporated simultaneously as compared to their separate utilization. Moreover, DIG is superior to shunt capacitor regarding loss reduction.

The voltage magnitude of different buses of 33-bus radial distribution system at base scenario and after integration of DIG and shunt capacitor is determined to compare in Figure 3. 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, there is significant enhancement of voltage profile of all the buses and most of the bus voltage magnitude is obtained more than the minimum voltage limit i.e. 0.95 P.U. with the integration of DIG and shunt capacitor. However, in this case also, the simultaneous integration of DIG and shunt capacitor provides the highest voltage magnitude enhancement.

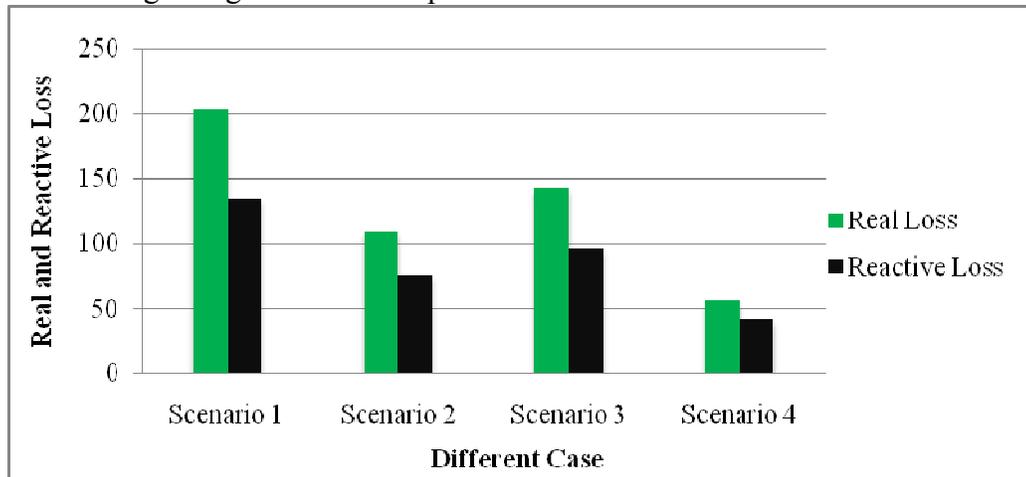


Figure 2: Real and Reactive power loss of different scenarios.

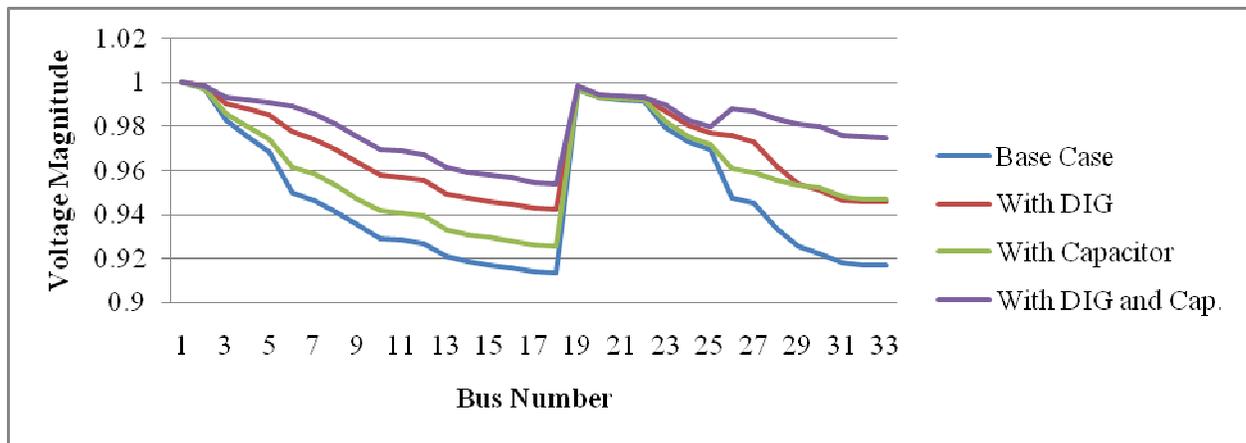


Figure 3: Bus voltage magnitude corresponding to different scenarios.

## 9. Conclusion

In this study, a PSO based optimization technique was presented to optimally deploy DIG and shunt capacitor in radial distribution system. The main objective is to minimize real and reactive power losses of the system and maximize the economic benefits. Different cases were considered to make an in depth analysis. The obtained results revealed that significant amount of potential benefits can be obtained with

the incorporation DIG and shunt capacitor. In comparison with the shunt capacitor, DIG presents more reduction of real and reactive power losses. Although the investment cost of DIG is more as compared to shunt capacitor, but DIG provides more economic benefits. However, the highest reduction of system losses and the highest economic benefit were obtained when both DIG and shunt capacitor were incorporated simultaneously

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