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Analysis on power loss reduction and voltage profile enhancement of distribution system through optimal allocation of distributed generators

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Abstract

Distribution system are sensitive part of power system, complex to its consumers and faces more challenges when serving its consumers. Various issues related to power quality and reliability occurs in distribution network due to variable loading conditions and faults. Distributed generators (DG) can be integrated into the distribution network to solve voltage and power quality issues. In this paper, PSO (Particle Swarm Optimization) algorithm-based method is implemented for the optimal allocation of DG units in radial distribution system to minimize the power loss and improve the voltage profile. Four different types of DG are considered for the study. The proposed method is implemented on real case system of 114 bus Sitalnagar distribution system and the results are obtained using MATLAB. The analysis shows that optimal allocation of DG units reduces power losses and improves voltage profile of the 114 bus system.

Keywords - Distributed generation; Fitness function; Integration; Optimization; Power quality; Voltage profile

1. Introduction

Distribution system is the part of power system that is directly interfacing with the consumers. It needs to supply the required demand with good power quality. Many issues arise in the distribution system due to change in load and other abnormal conditions. The primary issues are reliability and power quality problems for the consumers and losses for utility. With the rise in population growth and industrialization, there is increase of energy demand that should be fulfilled with reliable, affordable, economic and environmental friendly energy supply. The limitation of fossil fuels and environmental issues have forced to use renewable energy resources. Distributed generation like solar, wind, biogas, micro-hydro can be integrated to the distribution system in order to meet the demand and solve the issues related to power quality and reliability[1].

Distributed generation units are being integrated into utility distribution network to reduce power losses, enhance voltage profile, booster the reliability and security of the system[2]. Appropriate size and position of the DG units should be determined to achieve these objectives. Different optimization algorithms such as GA, PSO, have been implemented to obtain the optimal size and position of DG in distribution networks[3]. PSO algorithm has been implemented for the optimal sizing and placement of DG in IEEE 34 bus radial distribution system to reduce line losses and improve voltage profile[4].

DG units can be classified into four major types according to their capacity to deliver active and reactive power [5].

• Type 1: DG with the capability to inject active power only (e.g., Photovoltaic, micro turbines, fuel cells).
• Type 2: DG with the capability to inject both active and reactive power (e.g., cogeneration, gas turbine, etc.)
• Type 3: DG with the capability to inject reactive power only (e.g., synchronous compensators)
• Type 4: DG with the capability to inject active power but consumes reactive power (e.g. induction generators in wind farms)

In[5], optimal allocation of DG units for power losses reduction and voltage profile improvement of distribution networks has been carried out. Analytical technique and PSO algorithm are used to find the optimal size and position of DG in IEEE 41 bus radial distribution system. In[6], optimal allocation of DG units has been presented at different penetration percentage for the performance improvement of distribution system.

This paper proposes a PSO based methodology for the optimal allocation of DG units in distribution network to reduce power losses and improve voltage profile. The algorithm uses backward / forward load flow method to analyze the power flow in the radial distribution network. The introduced algorithms are

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tested on the 114 bus radial distribution network of Sitalnagar distribution system. Four types of DG at different numbers are used for study.

2. Load flow approach

The backward-forward sweep method of load flow is used to analyze the radial networks. The forward/backward sweep algorithm is an iterative method in which two computational stages are performed in each iteration. The computation is based on two derived matrices, the bus injection to branch current matrix (BIBC) and the branch current to the bus voltage matrix (BCBV).

The power loss of the branch connecting buses 'i' and 'i+1' is given as [5]:

$$P_{loss(i,i+1)} = R_{i,i+1} \times \left(\frac{P_i^2+Q_i^2}{|V_i^2|}\right) \quad (1)$$

$$Q_{loss(i,i+1)} = X_{i,i+1} \times \left(\frac{P_i^2+Q_i^2}{|V_i^2|}\right) \quad (2)$$

Where Pi and Qi are the real and reactive powers flowing out of the bus 'i' respectively. The resistance and reactance of the line between buses 'i' and 'i+1' are denoted by $R_{i,\ i+1}$ and $X_{i,\ i+1}$ respectively.

DG unit is modeled as PQ bus. The net injected power at ith node is given as:

$$P_i = P_{DGi} - P_{Li} \quad (3)$$

$$Q_i = Q_{DGi} - Q_{Li} \quad (4)$$

Where, P_{DGi} and Q_{DGi} are active & reactive power output of DG unit located at bus i respectively; P_{Li} and Q_{Li} are active & reactive power demand at bus i respectively.

3. Objective Function Formulation

The objective function is used to minimize real power loss, reactive power loss and voltage deviation index in the distribution network while taking care of the voltage limits. The objective function is mathematically expressed in Eq. (5):

$$Minimize(f1) = \min(w_1 f_1 + w_2 f_2 + w_3 f_3) \quad (5)$$

Where f_1, f_2, f_3 represents total active power loss, reactive power loss and voltage deviation index respectively, while w_1, w_2, w_3 are the weighting factors, which are used to give preference to the specific objective function compared to other by the utility.

Active power loss (f_1): The total active power losses (peak loss) at all nodes caused by circulating current in the network by substation and DGs are obtained by objective function given by Eq. (6):

$$P_{T,loss} = \sum_{i=1}^{N} P_{loss(i,i+1)} \quad (6)$$

Reactive power loss (f_2): The total reactive power losses at all nodes caused by circulating current in the network by substation and DGs are obtained by objective function given by Eq. (7):

$$f_2 = \sum_{i=1}^{N} Q_{loss(i,i+1)} \quad (7)$$

Voltage deviation index (f_3): Voltage deviation index is calculated using Eq. (8):

$$f_3 = \sum_{i=1}^{nb}(1 - V_i)^2 \quad (8)$$

Where V_i is the voltage at bus i and n_b is the number of buses.

Constraints:

The constrained optimization problem is used to determine the optimal allocation of DG. The magnitude of bus voltage should be maintained within the standard limits. The voltage constraints is given as:

$$V_i^{min} \le V_i \le V_i^{max} \quad (9)$$

Where V_i^{min} is minimum and V_i^{max} is maximum values of the system voltage.

Power balance is one of the constraints to be satisfied in order to keep the system stable and given as:

$$\sum P_{DG} + P_{grid} = \sum P_{loss} + P_L \quad (10)$$

P_{DG} is the power delivered by DG P_L is the total load demand P_{grid} is the power delivered by the source P_{loss} is the real power loss in the system.

The active power of each DG units should be selected within a predetermined range and the sum of the capacity of all DG units should not be higher than the load demand.

The DGs capacity is assigned to support 0-75% of the load demand.

The DGs capacity are restricted by minimum and maximum real power, as:

$$P_{DG}^{min} \le P_{DG} \le P_{DG}^{max} \quad (11)$$

Where P_{DG}^{min} and P_{DG}^{max} are the minimum and maximum active power injected by DG.

4. Optimization Using PSO Algorithm

PSO technique is an evolutionary computation technique developed by Kennedy and Eberhart[7]. The performance of the algorithm is based upon the interaction and communication among various particles. PSO is initialized with the group of random particles and then it searches the optimal solution by updating the generations through iterations. Each particle moves randomly based on its own best knowledge and the swarm experience. The updated velocity and position of the particle is given by Eq. (7):

$$V_i^{k+1} = w.V_i^k + C_1 r_1[X_{pbest}^k - X_i^k] + C_2.r_2[X_{gbest}^k - X_i^k] \quad (12)$$

$$X_i^{K+1} = X_i^K + V_i^{K+1} \quad (13)$$

Where i is the index of the particle; V_i^k, X_i^k are the velocity and position of particle i at iteration k, respectively; w is the inertia constant and it is often in the range [0 1]; C_1 and C_2 are coefficients which are usually between [0 2]; r_1 and r_2 are random values which are generated for each velocity update.

The flowchart of implemented PSO algorithm for solving objective function is shown in Fig.1. The objective of the implemented algorithm is to minimize the objective function involving active power loss, reactive power loss and voltage deviation index. The convergence criteria for the algorithm is the iteration number at which the desired result is obtained

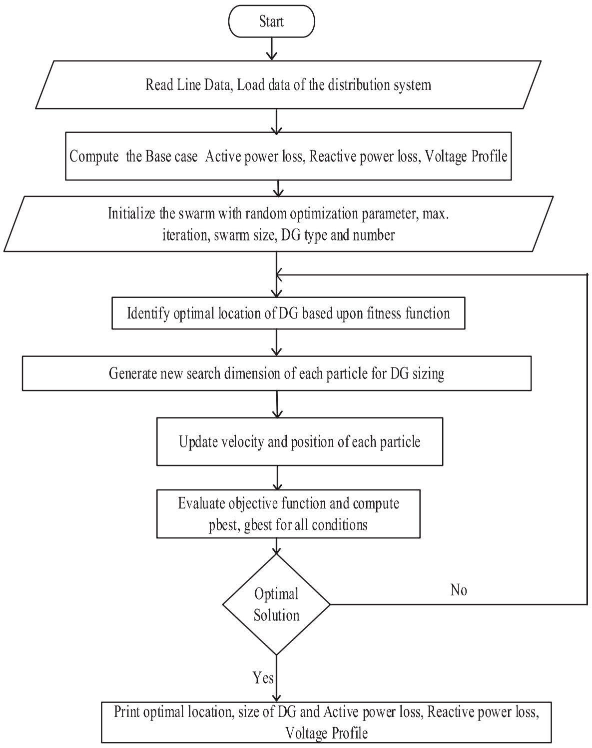

Figure 1: Flow chart of implemented PSO Algorithm

5. Case Study

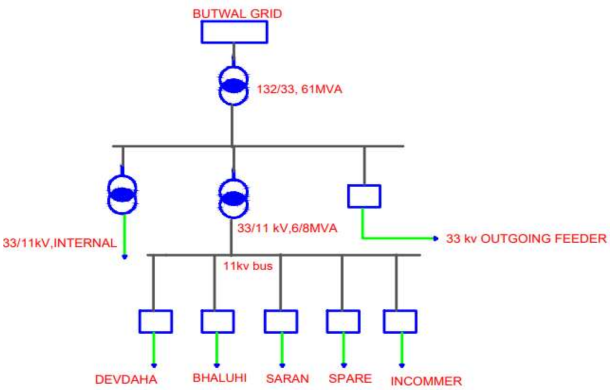

Figure 2: Single Line Diagram of Sitalnagar NEA Substation[6]

Sitalnagar substation shown in figure 2 consists of three outgoing feeders and one spare feeder. The nominal voltage of four feeders is 11kV. The data of substation is obtained from Nepal Electricity Authority (NEA) Butwal Distribution System. The substation supplies from one power transformers out of which two winding 6/8MVA with 33/11KV and other is 100 kVA internal three winding 33/0.4KV transformer. The three outgoing feeders are named as Devdaha, Bhaluhi feeder & Sarantadi feeder. Sitalnagar s/s distribution system faces power quality problems like under and overvoltage due to the high industrial load such as Laxmi steel, Palpa cement, Sarbottom cement. The main problem is under voltage during in peak load due to high power demand & high inductive load. The 114 bus system taken under study is shown in Figure 3.

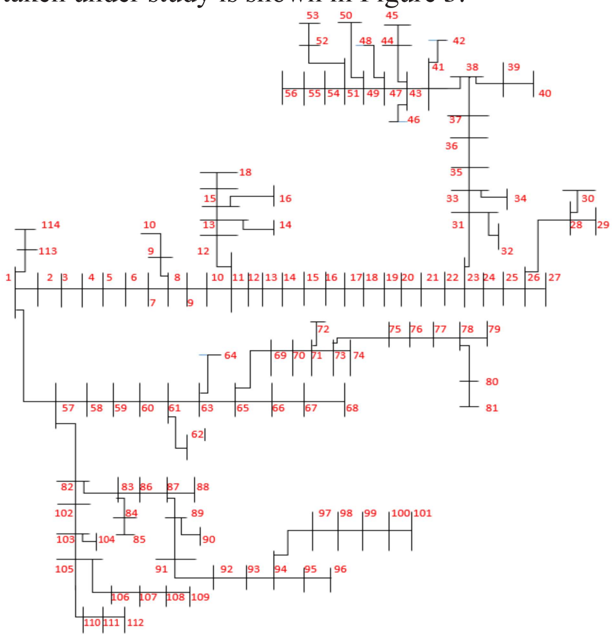

Figure 3: Single Line Diagram of 114 bus system of Sitalnagar Distribution System

6. Results And Discussions

The proposed PSO based method algorithm is tested on the 114 bus radial distribution system. The base case load flow study is obtained by using forward backward sweep algorithm. The base case active power loss is 181.399KW, and reactive power loss is 111.2838KVAR. The voltage is minimum at bus 56 with magnitude 0.92 p.u.

6.1 Power Loss Reduction

Table 1 below shows the optimal size and location of Type 1 DG units. The total active and reactive power losses decreases with increase in DG numbers.

Table 1. Total Power loss reduction for Type 1 DG

DG no.	Bus no.	DG Size (KW)	Total active Power loss(KW)	Total reactive Power loss(kVAr)
1	38	1749	96.3007	56.8239
2	38 71	1749 854	83.8107	45.8218
3	21 47 75	940 1717 839	53.6361	33.0178

For Type 2 DG, minimum power loss occurs when 3 DG unit of size 996.46 kVA, 1754.11 kVA and

881.17 kVA are placed at bus 23, 47 and 75 respectively. The results for type 2 DG is presented in Table 2.

Table 2. Total Power loss reduction for Type 2 DG

DG no.	Bus no.	DG Size (KVA)	Total active Power loss(KW)	Total reactive Power loss(kVAr)
1	38	1938.8	78.3179	45.3202
2	38 71	1276.23 1938.8	51.0992	32.0019
3	23 47 75	996.46 1754.11 881.17	27.8761	17.2821

The total power loss for optimal allocation of Type 3 DG at varying number is presented in Table 3. The results shows that reduction in power loss is less than those of Type 1 and Type 2 DGs.

Table 3. Total Power loss reduction for Type 3 DG

DG no.	Bus no.	DG Size (KVAr)	Total active Power loss(KW)	Total reactive Power loss(kVAr)
1	38	863	160.0391	97.6204
2	21 47	886 463	154.4532	94.071
3	20 47 75	469 897 412	149.0091	91.4098

The size and location of type 4 DG and power loss for varying number of DG units are presented in Table 4.

Table 4. Total Power loss reduction for Type 4 DG

DG no.	Bus no.	DG Size (KVA)	Total active Power loss(KW)	Total reactive Power loss(kVAr)
1	38	1018.34	150.614	91.58
2	22 47	559.99 1045.88	142.5979	86.49
3	21 47 71	562.34 1050.58 512.93	134.4106	82.4862

The active power loss for four DG types are compared at varying numbers as shown in Fig. 4. The result shows that Type 2 DG has best performance for active power loss reduction.

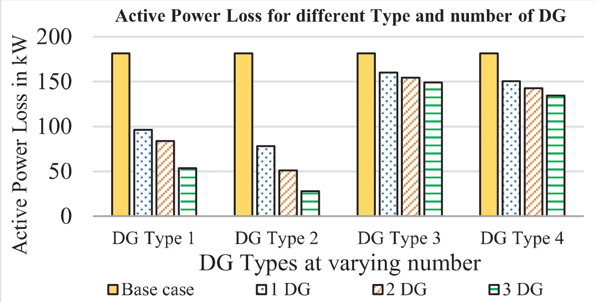

Figure 4: Active Power loss for different DG types

The reactive power loss for four DG types are compared at varying numbers as shown in figure 5. The result shows that Type 2 DG has best performance for reactive power loss reduction.

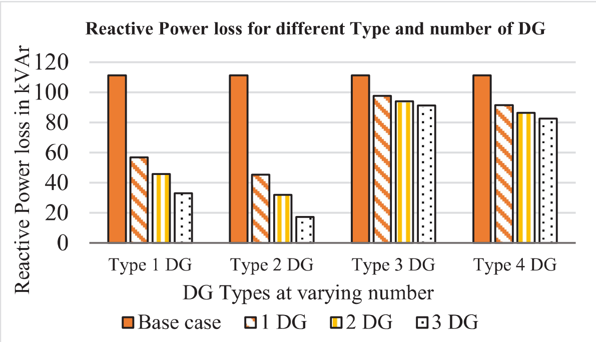

Figure 5: Reactive power loss for different DG types

The active power loss reduction for four types of DG units at varying numbers are compared shown in Fig.6. The results shows that Type 2 DG has the best performance for active power loss reduction. The reduction is power loss is increased from 56.82 % to 84.6% when Type 2 DG number is increased from 1 to 3. The reduction in active power loss is obtained 70.41% for three units of Type 1 DG. Type 3 DG has the least performance for loss reduction of 17.85% when three units are integrated. The active power loss reduction for Type 4 DG is obtained 25.9% with three DG units.

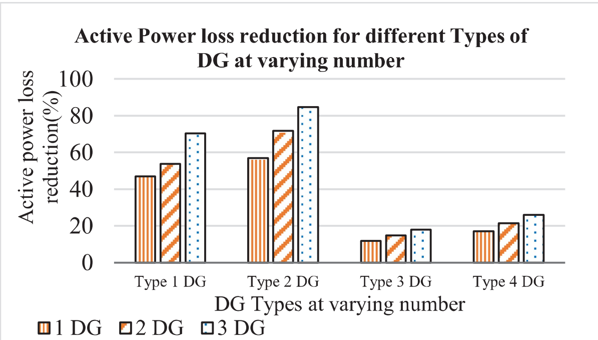

Figure 6: Active power loss reduction for different DG Types

The reactive power loss reduction for four types of DG units at varying numbers are compared shown in figure 7. For reactive power loss reduction, results shows that Type 2 DG has the best performance. The reductions in reactive power loss are 59.27%, 71.24% and 84.47 % respectively for one, two and three units of Type 2 DG number. For Type 1 DG, reduction in reactive power loss is obtained 48.93%, 58.82% and 70.33% for one, two and three DG units respectively. Type 3 DG has the least performance for reactive power loss reduction of 17.85% when three units are used. The active power loss reduction for Type 4 DG is obtained 25.87% with three DG units.

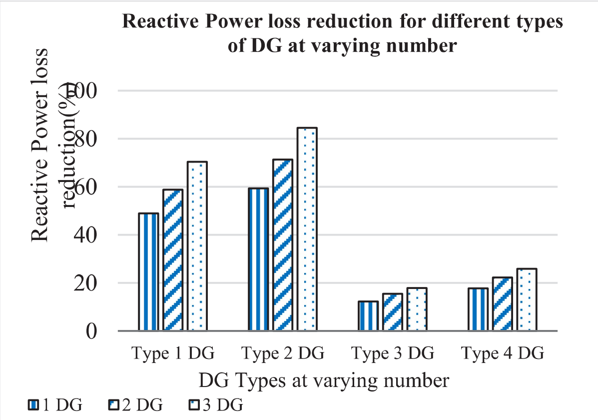

Figure 7: Reactive power loss reduction for different DG Types

6.2 Voltage Profile Improvement

The minimum voltage is found to be 0.92 pu at bus 56 after base case load flow without DG. The allocation of DG shows the improvement in voltage profile of the 114 bus system. The increment in number of DG units further increases the bus voltage. Voltage profile of the 114 bus system after optimal allocation of Type 1 DG is shown in Fig.8. One and two units of Type 2 DG has similar performance for voltage profile improvement up to bus 57. Above bus 57, 2 and 3 DG units have similar performance for voltage improvement. The voltage profile is enhanced above 0.96 pu.

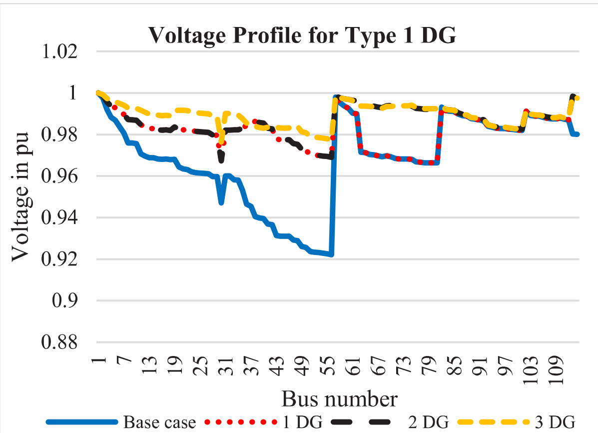

Figure 8: Voltage profile for Type 1 DG at varying number

The voltage profile for optimal allocation of Type 2 DG is shown in Fig.9. The voltage profile is improved above 0.96 p.u. The performance of voltage profile improvement is better for type 2 DG than other types. The voltage at weaker buses are enhanced better by the allocation of Type 2 DG units. At the bus no. below 57, one and two DG units have similar performance while three DG units gives better voltage profile. Two and three units of DG has similar performance from bus 57 to 82 for voltage enhancement. Above bus no. 82, voltage increment is nearly similar for varying DG number.

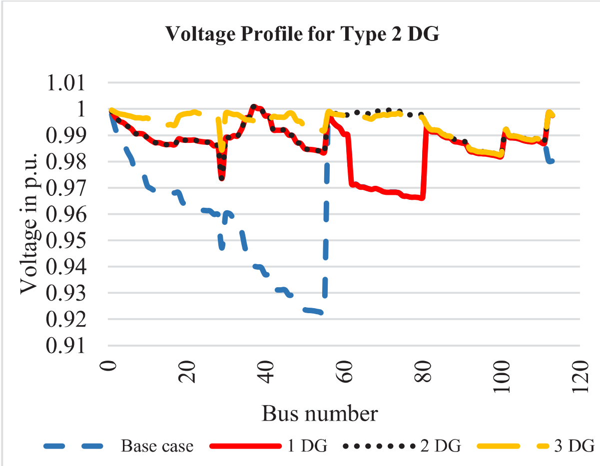

Figure 9: Voltage profile for Type 2 DG at varying number

Figure 10 shows the voltage profile after the allocation of Type 3 DG units. The voltage profile is improved above 0.94 p.u. The performance of three DG units is better for bus no. 57 to 82 and in the remaining buses two and three DG units have similar performance.

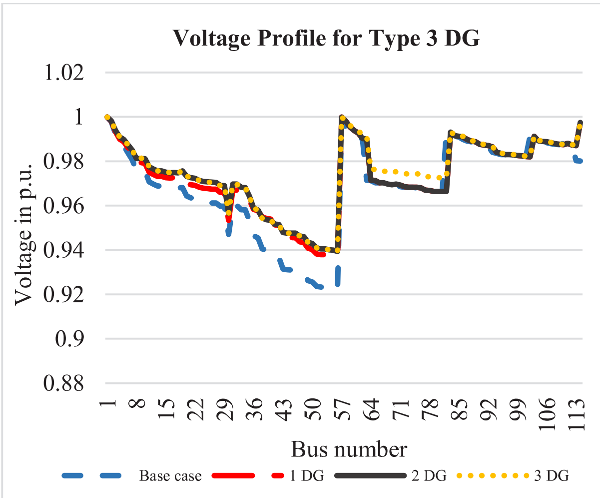

Figure 10: Voltage profile for Type 3 DG at varying number

The voltage profile improvement after the allocation of type 4 DG units is shown in Fig.11. The voltage profile is enhanced above 0.94 p.u. The three units of Type 4 DG give better voltage improvement at bus 65 to 82 and in remaining buses one, two and three units of DG units have similar voltage increment performance.

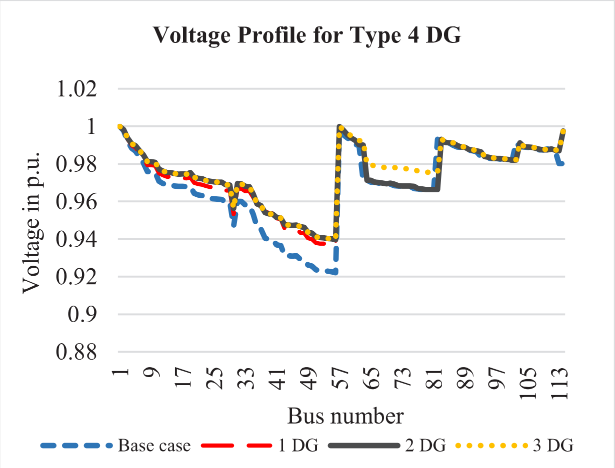

Figure 11: Voltage profile for Type 4 DG at varying number

The voltage at weakest bus 56 is observed and compared for the four DG types. The voltage at bus 56 is 0.92 pu at base case. For Type 1 DG, the voltage is increased to 0.969 p.u. and further to 0.977 pu when DGs are increased from one to three units.

The voltage is increased to 0.983 pu for 1 and 2 units of Type 2 DG. For three units of Type 2 DG, voltage profile is enhanced to 0.991 pu. For Type 3 and Type 4 DG voltage is increased to 0.93.6 pu and 0.94 pu when DG units are increased from one to three units. The result shows that Type 2 DG has better performance than other DG types for voltage enhancement. Type 3 and Type 4 DG has similar voltage increment performance. After Type 2 DG, Type 1 DG has better voltage boosting performance. The voltage profile at bus 56 for the four DG types at varying number is shown in Fig.12.

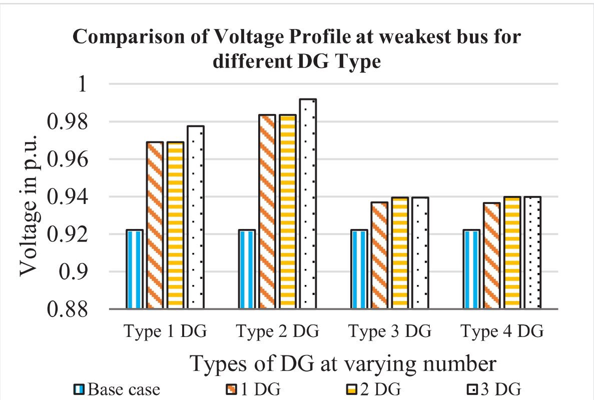

Figure 12: Comparison of voltage profile at weakest bus no. 56 for different DG Types

7. Conclusion

The performance of distribution system network can be enhanced by the appropriate integration of DG units to supply quality of power to the consumers. The PSO algorithm based methodology is proposed for the optimal allocation of DG units in distribution system network. The objective function for voltage profile improvement, active and reactive power loss reduction is developed to determine the optimal allocation of DG units. PSO algorithm is implemented to solve the optimization function. The proposed model is tested in real case data of 114 bus Sitalnagar Distribution System. The results show reduction in real and reactive power loss in the radial distribution system. The power loss is reduced further with the increase in number of DG units. The voltage profile is enhanced with the allocation of DG units. The performance of four types of DG are compared for power loss reduction and voltage profile improvement. The performance of Type 2 DG is found to be better than other DG types.

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