



# Application of Distributed Generation for Reduction of Power Losses and Voltage Deviation in Electric Distribution System by Using AI Techniques

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**Abstract.** Distribution Electric power system is the largest and the most complex system made by the mankind. The distribution network power system is being encountered by quickly rising load demand and it is detected that under certain critical loading circumstances, the distribution system poses maximum power losses and poor voltage profile and collapse in convinced areas. To overcome these problems integrating distributed generation (DGs) on the grid near to the load center is the better solution as compared to others. Though, for the DG to serve its purpose, its location and size have to be determined optimally. In this paper, Grid-Based Multi-Objective Harmony Search Algorithm (GrMHSA) has been utilized to determine the size and location of DG in the distribution system in Debre Markos town. By placing DG optimally, in addition to the reduction of the power loss in the distribution network, the proposed mechanism improves the node (bus) voltage profile of the system under consideration. A MATLAB program is developed to mitigate power losses and improve the voltage profile by optimally sizing and placing a DG in the distribution network. After sizing and placing the DG in the network, the total voltage deviation, active and reactive power losses are reduced by 93.42%, 81.63% and 82.45% for Debre Markos Feeder 3 and 85.20%, 84.94% and 85.73% for Debre Markos Feeder 4 respectively. The performance comparison of GrMHSA and MOPSO has been made and GrMHSA has been found better in terms of reducing voltage deviation and power losses in the system.

**Keywords:** Distribution systems · GrMHSA · Distributed generation · Power loss reduction · DG location and size · Voltage deviation

## 1 Introduction

Distributed Generation is the source of electrical energy which is connected directly to distribution network without requiring high voltage power transmission network. As most of the DG sources are renewable energy, it produces a clean power. Typical energy

sources of DG are solar and wind. Some of the desirable features of DG are better power system efficiency, better voltage profile, cost saving from additional power transmission line, improved power system reliability and usage of local energy resources. However, wrong DG location and capacity leads to more power loss and more cost than not having it [1, 2] and [3].

The penetration of DG into distribution systems has been increasing around the world. Moreover, developments in DGs have ready it a viable and smart choice for perfection [4, 5]. Distributed generations (DGs) are mostly used for active and reactive power injection in distribution networks. It is used also for power loss reduction and voltage profile improvement. The advantages of this kind of mechanism depends on how much and where to place the DGs in the radial distribution network system [6, 7] and [8].

Many optimization techniques have been utilized for optimal siting and sizing of the DG considering technical and economical performances [9–11] and [12]. Tools like heuristic, deterministic and hybrid techniques are capable and still sprouting in this field.

When connected to the distribution network, various DG technologies can lead to improved levels of power quality, reliability and security, if the DG units are in the best position and size [10, 11] and [12].

Various approaches and algorithms have been used for the siting and sizing of DGs; the majority of which are aimed to minimize active power losses and improve the voltage variations [13, 14]. The methods applied for solving the problems can be broadly divided as mathematical, heuristic, meta-heuristic, and hybrid types [15]. Mathematical methods include mixed integer linear programming [16, 17], mixed-integer second order cone programming [16] and multi-period optimal power flow [18]. In [19] and [20] power flow algorithm is used to determine the optimum DG size at all load buses assuming every load bus is connected to the DG source. Such a method is, however, inefficient due to a number of load flow computations. The genetic algorithm (GA) is used to determine the size and location of DG as presented in [21, 22] and [23]. GA is suitable for multi-objective problems like DG allocation and can give near-optimal results, but it is computationally demanding and slow in convergence. In [24], an analytical method to place DG in radial as well as meshed systems to minimize power loss of the system is presented. In this method, separate expressions for radial and meshed network systems are derived and a complex procedure based on phasor current is proposed to solve the location problem. However, this method only optimizes the location and considers the size of DG as fixed.

In this paper, the proposed optimization method for measuring and segregating DG components in an active distribution system is based on a Grid-based Multi-purpose agreement Harmony Search Algorithm (GrMHSA).

The remainder of this paper is organized as follows: in Sect. 2, test utility distribution network is discussed; In Sect. 3, the proposed optimization technique is discussed; Sect. 4 introduces the problem formulation and constraints; Sect. 5 presents the result and discussions; finally, the conclusions are drawn in Sect. 6.

## 2 Test Utility Distribution Network

In this paper, the case study is taken from Debre Markos distribution network and the data is collected and analyzed. The parameters of interest are node voltage and active and reactive power loss.

Debre Markos, is the capital town East Gojjam Zone in Amhara National regional state, Ethiopia. It's located at 10o21'N latitude and 37o43'E longitude.

The town is supplied from Debre Markos power Substation with two 15 kV feeders, namely Feeder 3 (Line 3) and Feeder 4 (Line 4) as shown from Fig. 1 in detail. The data including single line diagram of distribution network, current loading of the feeders and their branches, resistance and inductive reactance of the feeder lines were collected from local electric utility. These data were used to model the feeders for power flow study.

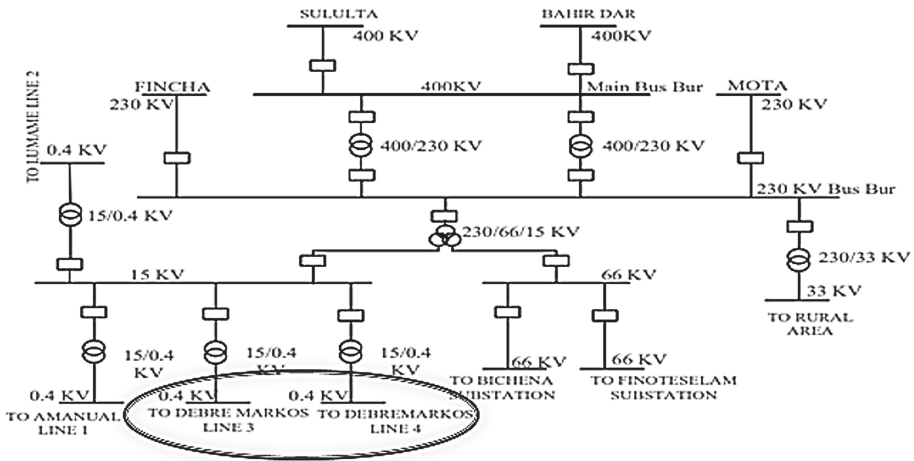


Fig. 1. Position of Feeder 3 (Line 3) and Feeder 4 (Line 4) in Debre Markos Power Substation

## 3 Implementation of Procedural Flow Charts for the Proposed GrMHTSA Techniques

Stimulated by the managing process of music in search of perfect harmony sound, harmony Search algorithm is one of the merging meta-heuristic optimization algorithms [25, 26] and [27]. In this paper, a grid strategy is implemented as a secondary criterion for optimal siting and sizing of DGs. Among other heuristic algorithms, GrMHTSA is preferred as it is simple for programming, faster in convergence and efficient in searching optimal solutions. The general flow chart of proposed algorithm of GrMHTSA is shown in Fig. 2.

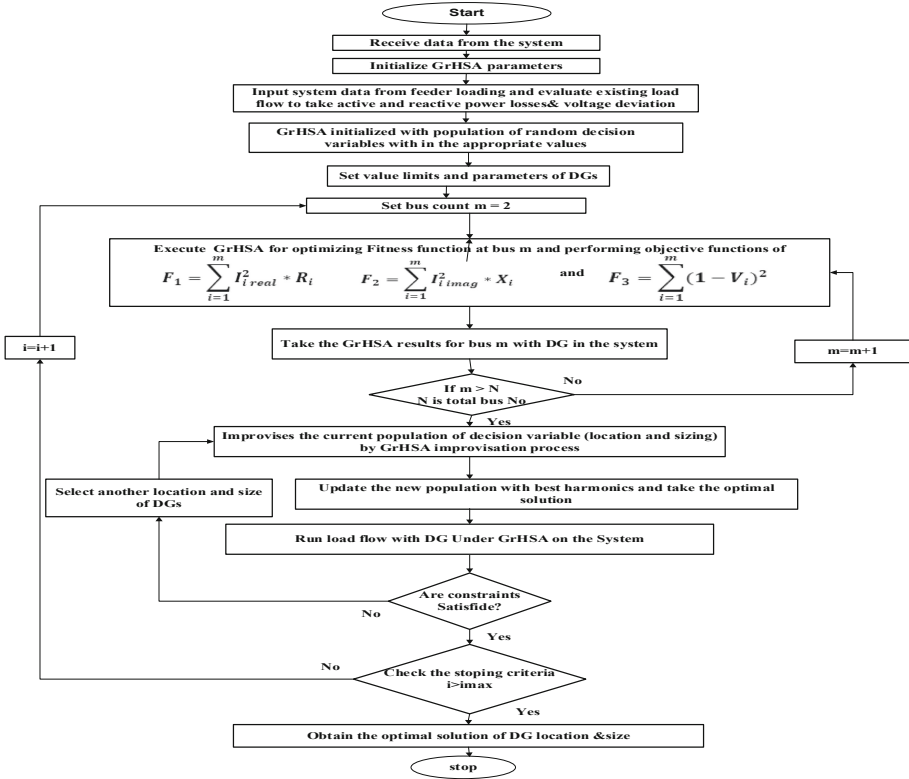


Fig. 2. Proposed GrMNSA algorithm for optimal DG sizing and placement

### 4 Formulation of Objective Functions and Constraints

The most important objective functions are total active power loss, total reactive power loss and total voltage deviation with constraints of voltage magnitude, branch thermal limits, and DG capacity limit. The objective functions are:

Total real power loss,  $P_1$ :

$$P_1 = \sum I_{i,real} R_i \tag{1}$$

Total reactive power loss,  $P_2$ :

$$P_2 = \sum I_{i,imag} X_i \tag{2}$$

Total voltage deviation,  $P_3$ :

$$P_3 = \sum |1 - V_j| \tag{3}$$

Where,

$R_i$ : the resistance of branch  $i$

$I_i$  : the current magnitude flows in-branch  $i$

$X_i$ : the reactance of branch  $i$

$V_i$  : voltage of node  $j$

A Backward-Forward Sweep Load Flow algorithm has been utilized to solve the distribution networks, and in the solution, the real and reactive power loss and voltage deviation need to be reduced.

The objective functions are to be minimized under the constraints presented from Eq. (4) to (7).

(i) **Node voltage constraint:**

$$0.95 \leq V_i \leq 1.05 \quad (4)$$

where,  $V_i$  is node voltage in p.u.

(ii) **Branch thermal limit constraint:**

$$I_{i,j} \leq I_{\text{rated}} \quad (5)$$

where,

$I_{(i,j)}$  : Current carrying capacity of existing line branch between node  $i$  and  $j$

$I_{\text{rated}}$ : Thermal current carrying capacity of the line

(iii) **DG Capacity Limit:**

The capacity of the DG to be connected to the existing distribution network should not be too high with respect to the feeder loading or too small to be economical. Therefore, selected DG must have the allowable size between the minimum and the maximum limits.

$$S_{\text{DGm},i}^{\min} \leq S_{\text{DG},i} \leq S_{\text{DG},i}^{\max} \quad (6)$$

where:

$S_{\text{DGm},i}^{\min}$ : Minimum power output limit of DG at node  $i$

$S_{\text{DG},i}^{\max}$ : Maximum power output limit of DG at node  $i$

$S_{\text{DG},i}$ : actual The power output of DG at bus  $i$

## 5 Results and Discussion

### 5.1 System Base Case and Comparison of Solution Algorithms

The GrMHS algorithm has been applied to find the optimal location and determine the optimal size of DGs in the distribution networks shown in Fig. 3 (Feeder 3) and Fig. 4 (Feeder 4).

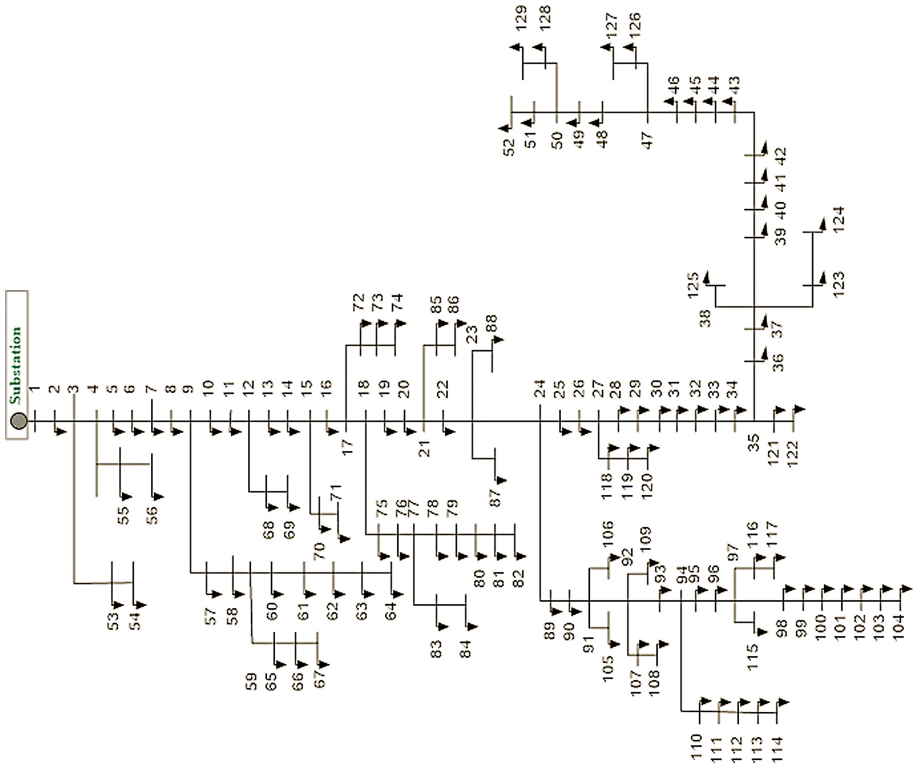


Fig. 3. Single line diagram of Feeder 3

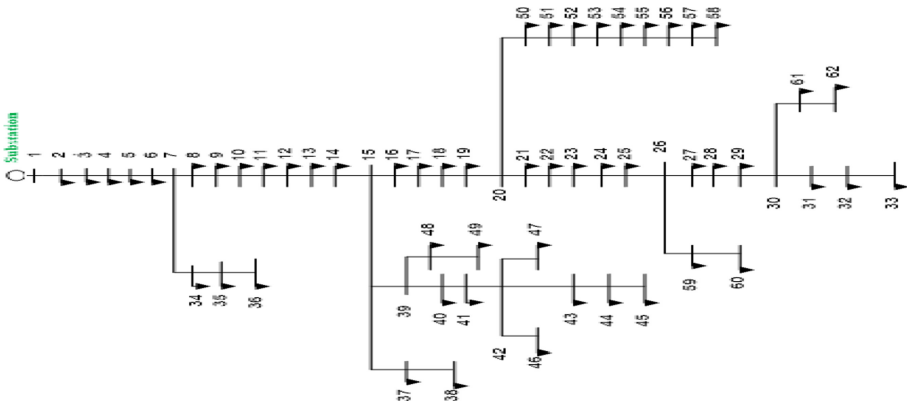
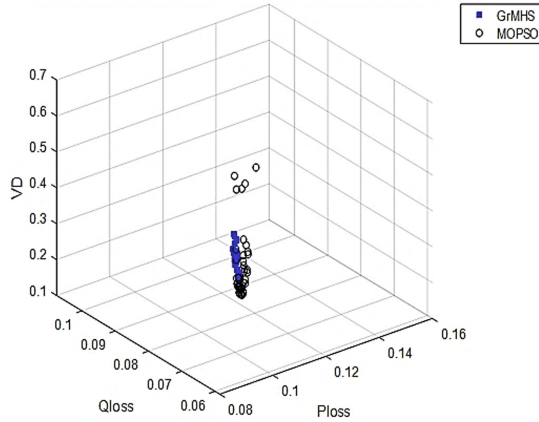


Fig. 4. Single line diagram of Feeder 4

On the distribution system shown in Fig. 3 and 4, the performance of the proposed algorithm, GrMNSA) is compared with multi-objective particle swarm optimization (MOPSO) by measuring its spread and time of convergence. MOPSO is chosen for

comparison because it is more known by its ability to fast convergence and easy for implementation as compared to other algorithms [28].

A matlab code has been developed for GrMHS and MOPSO algorithms and both algorithms are executed with 50 populations for 110 iterations. The simulation spread is shown in Fig. 5, and it can be shown that efficient penetrating has been complete by GrMHSA over MOPSO in obtaining the best optimal solutions with respect to objectives functions of power losses ( $P_{loss}$  and  $Q_{loss}$ ) and total voltage deviation (VD).



**Fig. 5.** Performance comparison of GrMHS with MOPSO algorithm

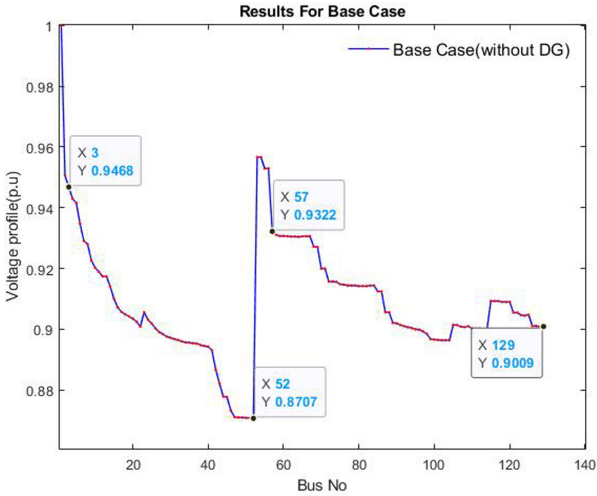
The load flow result for of the base case (the system with no DG) is shown in Table.

**Table 1.** Base case load flow result

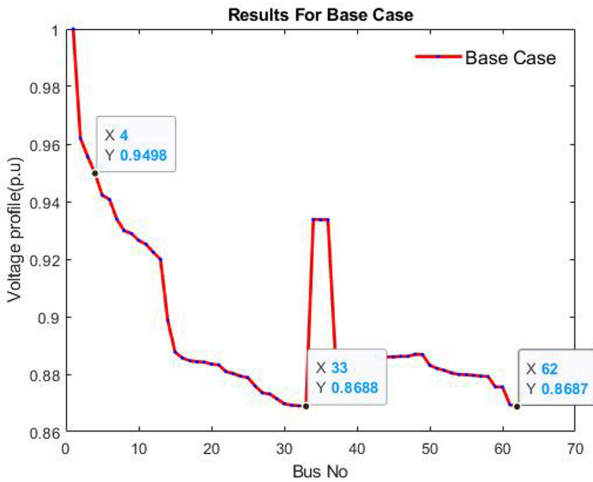
Feeder	Feeder Current (A)	Connected Load (MVA)	Total real Power loss (kW)	Total reactive Power loss (kVAR)	Total Power loss (kVA)	Total Voltage deviation (p.u.)
Feeder 3	192.6	5.00	523.28	516.49	735.24	17.26
Feeder 4	128.3	3.33	472.97	410.43	626.22	6.85

The total power loss as a fraction of connected load to Feeder 3 and Feeder 4 is 14.70% and 18.81%, respectively. The overall efficiency of the distribution network is 16.34% considering only the reactive and active power losses on the conductors, which certainly tells one the system requires enhancement to reduce the power losses.

The node voltage profile of the base case system under consideration is shown in Fig. 6 and 7.



**Fig. 6.** Node voltage for the base case at Feeder 3



**Fig. 7.** Node voltage for the base case at Feeder 4

As it can be seen in Fig. 6 and 7, nodes 3–52 and node 57–129 for Feeder 3 and node 4–62 for Feeder 4 have voltage profile below 0.95p.u., which is below the standard [29]. The voltage profile at node 3, 52, 57 and 129 are 0.9468 p.u, 0.8707 p.u, 0.9322 p.u and 0.9009 p.u for Feeder 3 and the voltage profile at node 4, 33 and 62 are 0.9498 p.u, 0.8688 p.u and 0.8687 p.u for Feeder 4, respectively.

With node voltage levels less than 0.95 p.u, the actual node voltage will be less than 14.25 kV since the distribution voltage of the feeders are 15 kV. Considering the voltage drops of low voltage lines and service transformers, the voltage at consumer premises will not be enough to run consumer electric and electronic appliances.

This implies that the system needs improvement to enhance at least the voltage profile at the nodes of the feeders and reduce active and reactive power losses in the system.

Hence, distributed Generation (DG) is proposed to mitigate the power loss and voltage deviation problems of the system.

## 5.2 Optimal Location and Size of DG with GrMHS and MOPSO Algorithms

The optimal sizes and location of DGs using GrMHS and MOPSO algorithms is presented in Table 2.

**Table 2.** Result of optimal sizing and placement of DG using GrMHSA and MOPSO

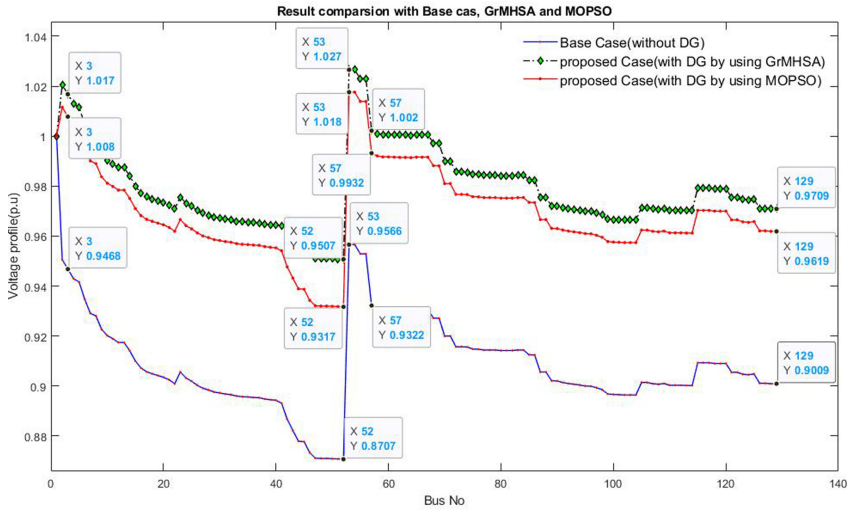
Feeder	Optimization techniques	DG location (@node)	Optimal DG size (MVA)	Real power loss (kW)	Reactive power loss (kVAR)	Total power loss (kVA)	Voltage deviation (p.u)
Feeder 3	GrMHSA	51	2.17	92.39	90.35	129.22	1.0642
	MOPSO	49	2.26	93.77	92.36	131.62	1.1852
Feeder 4	GrMHSA	30	1.88	65.27	60.68	89.12	0.8625
	MOPSO	27	1.96	67.33	63.86	92.80	0.9958

As shown in Table 2, with the GrMHS algorithm the required size of DG is optimally placed at node 51 for Feeder 3 and at node 30 for Feeder 4. However, MOPSO algorithm places the required DG size at node 49 (Feeder 3) and node 27 (Feeder 4). The optimal size of DG selected by MOPSO is 4.24% and 4.66% higher than that selected by GrMHSA for Feeder 3 and 4, respectively. Moreover, with GrMHSA algorithm, the total active and reactive power losses and total voltage deviation is lower than that obtained from MOPSO algorithm. This implies that GrMHSA chooses the most economical size of DGs and places them optimally resulting in the minimum power losses and voltage deviation.

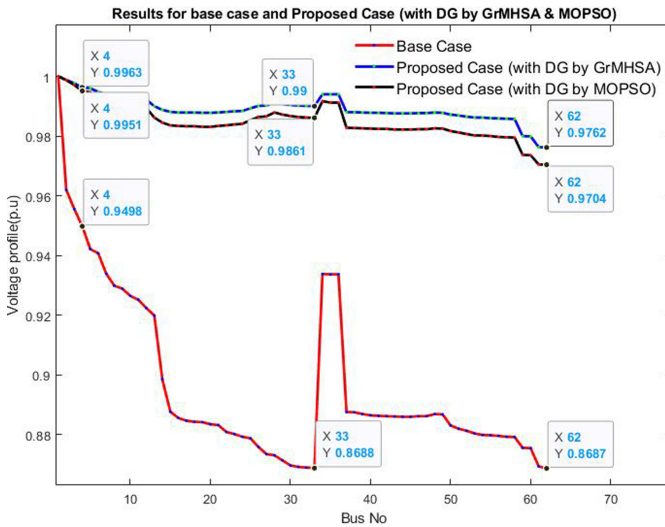
Comparing total power losses (in kVA) presented in Table 1 and Table 2, when DG is sized and placed using GrMHSA, the power loss of Feeder 3 is reduced from 735.24 kVA to 129.22 kVA by 82% while the power loss of Feeder 4 is reduced from 626.22 kVA to 89.2 kVA by 86%.

The total voltage deviation (p.u) is also reduced by 94% for Feeder 3 and 87% for Feeder 4, respectively.

The comparison of node voltage profile of the base case, of a system with DG optimally sized and place with GrMHSA and MOPSO algorithms is shown in Fig. 8 and Figalso compared as it is shown in Fig. 8 and Fig. 9.



**Fig. 8.** Feeder 3 node voltage profile for the three cases (base case, with DG by MOPSO & DG by GrMHSA)



**Fig. 9.** Feeder 4 node voltage profile for the three cases (base case, with DG by MOPSO and GrMHSA)

As it is shown above in Fig. 8 and Fig. 9, the voltage profile of the system with DG selected by GrMHSA is better than the result by MOPSO. As can be seen from Fig. 8 and 9, the voltage at nodes 3, 52, 57 and 129 are increased from 0.9468 p.u, 0.8707 p.u, 0.9322 p.u and 0.9009 p.u to 1.017 p.u, 0.9507 p.u, 1.002 p.u and 0.9709 p.u for Feeder3. The voltage profile at nodes 4, 33 and 62 are increased from 0.9498 p.u, 0.

8688 p.u and 0. 8687 p.u to 0. 9963 p.u, 0. 9900 p.u and 0. 9762 p.u for Feeder 4, respectively. The node voltages are now within the tolerable voltage limits (0.95 to 1.05 p.u) for both feeders after optimally sized DGs are placed in optimal locations.

## 6 Conclusion

The main challenges in distribution power networks are voltage deviation and power losses which lead to poor quality service and low efficiency of the system. There are different methods to tackle these problems, among thus are a reconfiguration of distribution network, incorporating capacitors into the network and adding DGs optimally into the distribution system. Integrating distributed generation (DG) into the system is one of the trending solutions which are done by many researchers. This paper has dealt with the sizing and location of DG in Debre Markos Feeder 3 and Debre Markos Feeder 4 of a distribution network system. Grid-based multi-objective harmony search algorithm (GrMHSA) has been used to size and find the optimal node for putting the DG. By placing of DG optimally, in addition to mitigating the power loss in the distribution network, the proposed mechanism enhances the voltage profile of the system under consideration. A MATLAB program is developed to mitigate power losses and improve the voltage profile by optimally sizing and placing a DG in the distribution network. After sizing and placing the DG in the network, the total voltage deviation, active and reactive power losses are reduced by 93.83%, 82.34% and 82.51% for Debre Markos Feeder 3 and 87.42%, 86.19% and 85.21% for Debre Markos Feeder 4 respectively. Moreover, the performance of the proposed algorithm, GrMHSA, is compared with Multi-Objective Particle Swarm Optimization (MOPSO), which has been made and GrMHSA has been found better in terms of reducing voltage deviation and power losses in the system.

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