2017 IEEE 4th International Conference on Knowledge-Based Engineering and Innovation (KBEI)
Dec. 22nd, 2017
(Iran University of Science and Technology) – Tehran, Iran

A Grasshopper Optimization Algorithm to solve Optimal Distribution System Reconfiguration and Distributed Generation Placement Problem

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Abstract— **This paper presents a novel technique for solving simultaneous optimal distribution system reconfiguration and DG placement problem in order to minimize active power loss. A meta-heuristic Grasshopper Optimization Algorithm (GOA) inspired from the swarming behavior of grasshoppers in nature is implemented to determine optimal solution to this optimization problem. The proposed method is applied to 33 and 69- bus test systems. The obtained results have been compared with other existing evolutionary algorithms, so that the comparisons confirm the performance as well as the effectiveness of the proposed method to determine the global optimum solution.**

Keywords—distribution system reconfiguration (DSR); DG placement; active power loss; grasshopper optimization algorithm (GOA)

I. INTRODUCTION

Power loss reduction has always been a significant issue in power systems particularly in distribution systems. In distribution systems about 10-13% of the total power generated is lost as active power losses [1]. Therefore, some common methods such as capacitor placement, DG allocation, and distribution system reconfiguration (DSR) have been used for power loss reduction in distribution systems [2]. DSR is obtained by changing the status of the switches with different goals. In recent years, many researches have solved DSR problem with different methods. The DSR problem first was solved by authors in [3] in order to power loss reduction using a branch and bound-type optimization technique. Authors in [4] have presented a heuristic technique based on branch exchange to reduce power loss which this method has improved by authors in [5]. In [6] an efficient meshed heuristic method for optimal reconfiguration of distribution systems has been presented to minimize the network loss. In [7] a harmony search algorithm (HSA) has been proposed to solve the DSR to obtain optimal switching combination in the network which results in minimum power loss. In [8] a new method called Uniform Voltage Distribution based constructive Algorithm (UVDA) has been proposed for solving optimal reconfiguration of large-scale distribution systems. In [9] a Multi-Objective Invasive Weed Optimization Algorithm (MOIWO) has been proposed to solve the Optimal distribution system reconfiguration to simultaneously minimize active power loss, maximum node voltage deviation, number of switching operations and the load balancing index. In [10] a mixed-integer second-order conic programming (MISOCP) model has proposed for solving the robust distribution systems reconfiguration, in order to minimize active power losses and reliability constraints.

The role of distributed generators (DGs) for improving the efficiency of the distribution systems has been verified. One of the most important challenges for a better effectiveness of DGs in distribution systems is determination of optimal size and location of them. Optimal placement and sizing can reduce power losses and improve voltage profile [11]. In [12] an evolutionary programming (EP) has been presented for the optimal placement of distributed generation (DG) units based on wind and solar energy in a distribution system. A swarm intelligence technique which named Bacterial Foraging Optimization Algorithm (BFOA) has been used to find the optimal size and location of DG in order to minimize power losses, operation cost and improve voltage stability [13]. In [14] a novel application of multi-objective particle swarm optimization has been proposed to solve the optimal placement of DGs considering operational and economical aspects. In [15] an improved non-dominated Sorting Genetic Algorithm II (INSGA II) has been proposed for solving multi-objective optimization model of DG sitting and sizing in distributed systems.

All the above researches focused only on the optimization of either network reconfiguration or the DG placement. Some researchers have integrated both the DSR and DG placement problems to improve the efficiency of distribution network [16–21]. In [16] a meta heuristic Harmony Search Algorithm (HSA) has been used to solve the reconfiguration problem in the presence of DGs in order to minimizing real power losses and improving voltage profile in distribution system. In [17] a novel integration method based on fireworks optimization algorithm (FWA) has been proposed to solve DSR problem together with optimal placement of DGs to minimize real power losses and improve voltage stability. In [18] the DSR problem has been implemented concurrently with the optimal placement of DGs in order to minimizing the real power loss. A heuristic algorithm based on uniform voltage distribution based constructive reconfiguration algorithm" (UVDA) has been proposed for solving this complex problem. Distribution system reconfiguration in the presence of DGs has also been carried out using a meta-heuristic cuckoo search algorithm (CSA) inspired from the obligate brood parasitism of some cuckoo species [19]. In [20] authors have presented distribution system feeder reconfiguration considering different model of DGs using quantum particle swarm optimization (DQPSO) with an objective of minimizing real power loss. In [21] a discrete Teaching-learning based optimization (DTLBO) algorithm has been proposed for solving the DSR in presence of DGs to minimize active power loss and improve voltage profile.

In this study, the proposed method based on GOA simultaneously uses active power loss as an objective function to determine the optimal configuration of distribution system, and the optimal location and size of DGs. The proposed method is tested on 33-bus, 69-bus test systems, and the obtained results are compared with the results of other methods available in the literature to evaluate the performance and effectiveness of the proposed method.

II. PROBLEM FORMULATION

A. objective function

For the optimal distribution system reconfiguration and DG placement problem in this study, the considered objective function is formulated to minimize the total active power loss which is given by:

$$f_{ploss} = \sum_{i=1}^{N_B-1} k_i r_i \frac{P_i^2 + Q_i^2}{V_i^2} \tag{1}$$

Where, r_i is the resistance of line i, V_i is voltage magnitude at bus i, P_i and Q_i are real and reactive power injected to bus i respectively. k_i is a binary variable, $k_i = 0$ or 1 indicates if the switch i is open or close. N_B is the total number of buses.

Subject to:

Power flow equation:

$$\begin{cases} P_i + P_{DGi} - P_{Li} - V_i \sum\limits_{i=1}^{N_B-1} V_j[G_{ij}\cos(\theta_{ij}) + B_{ij}\sin(\theta_{ij})] = 0 \\ Q_i + Q_{DGi} - Q_{Li} - V_i \sum\limits_{i=1}^{N_B-1} V_j[G_{ij}\sin(\theta_{ij}) + B_{ij}\cos(\theta_{ij})] = 0 \end{cases} \tag{2}$$

Where, P_{DGi} and Q_{DGi} are power generation of DG at bus i, P_{Li} and Q_{Li} are the active and reactive power load at bus i. G_{ij} and B_{ij} are the conductance and susceptance of the line between bus i and bus j respectively. θ_{ij} is the angle between bus i and bus j.

Bus voltage and line capacity limits:

$$V_{i\,\min} \le V_i \le V_{i\,\max} \tag{3}$$

$$S_{ij} \le S_{ij\,\max} \tag{4}$$

DG capacity limit:

$$P_{DGi\,\min} \le P_{DGi} \le P_{DGi\,\max} \tag{5}$$

Where, P_{DGimin} and P_{DGimax} are the lower and upper limits of DG at bus i respectively.

Radial network limit

$$N_L = N_B - 1 \tag{6}$$

N_L is defined as the number of lines.

III. PROPOSED METHOD

A. Grasshopper Optimization Algorithm

Grasshoppers are a type of insect with long hind legs that can leap high into the air and fly. These creatures have a specific social interaction network which equip them with a particular predatory strategy. The network makes a connection between grasshoppers in a way that the location of each grasshopper can be harmonized to a proper one. Through this harmonization and the group awareness in the network, grasshoppers can choose the predatory direction.

To explain the social interaction in the network, a search agent is shown as an example in the Fig. 1. There are two opposite forces between grasshoppers called reputation and attraction forces. Attraction forces allow grasshoppers to exploit promising regions (local search), and the reputation forces encourage them to explore the search space (global search). Comfort zone refers to the area in which the mentioned forces are equal. Since the target location is undiscovered, the location of the grasshopper owns the best fitness in considered as the nearest one to the target. To reach the goal, Grasshoppers keep on their movement along with the direction of the target in the social interaction network. To make a balance between global search and the local search, the locations of grasshoppers are updated and thus, the comfort zone deceases adaptively. After following the exploitation and exploration process, grasshoppers finally reach a convergence and find the best solution [22].

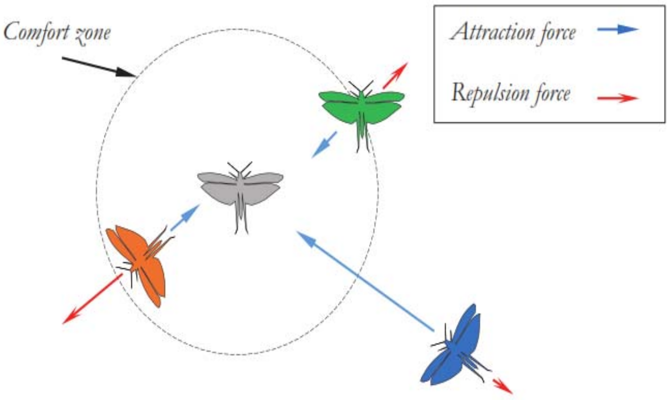

Fig. 1. Social interaction of grasshoppers [22]

Mathematical description of the process comes as follows. By considering *G* grasshoppers in the swarm, the *d*-dimensional location of the *i*th grasshopper can be defined as:

$$X_i^d \, (i = 1, \ldots, G) \tag{7}$$

To mimic the predatory process, the following equation is proposed:

$$X_i^d(t+1) = c\left(\sum_{\substack{j=1\\ j\neq i}}^{G} c\,\frac{ub_d - lb_d}{2}\, s\left(\left|X_j^d(t) - X_i^d(t)\right|\right)\frac{X_j(t) - X_i(t)}{d_{ij}}\right) + \hat{T}_d \tag{8}$$

$$s(r) = f\,\exp\left(\frac{-r}{l_s}\right) - \exp(-r) \tag{9}$$

Where; *t* is the current iteration; *s* is a function to determine the strength of reputation and attraction forces; *f* defines the intensity of attraction; *l* is the attractive length scale; ub_d and lb_d are the upper and the lower bound in the *d*-dimensional function*s* respectively; d_{ij} is the distance between the *i*th and the *j*th grasshoppers; $\hat{T}_d$ is the *d*-dimensional location of the target (the best solution); *c* is the deceasing factor to make a balance between exploration and exploitation. Large value of c leads to more exploration in GOA, and small value of c results in more exploitation. *c* is a set always between $c_{\max}$ and $c_{\min}$. t_{max} is also the maximum iteration of the process.

$$c(t) = c_{\max} - t\,\frac{c_{\max} - c_{\min}}{t_{\max}} \tag{10}$$

GOA's search process is the same as particle swarm optimization (PSO). But, in PSO, each particle updates its location by its current position, the global best and the personal best. However, in GOA, each grasshopper updates the position by its current position, the global best, and by the positions of all other grasshoppers. Thus, GOA encourage all search agents to participate in the optimization procedure which leads to higher efficiency of the search [22]. The flowchart of Grasshopper Optimization Algorithm is shown in Fig. 2.

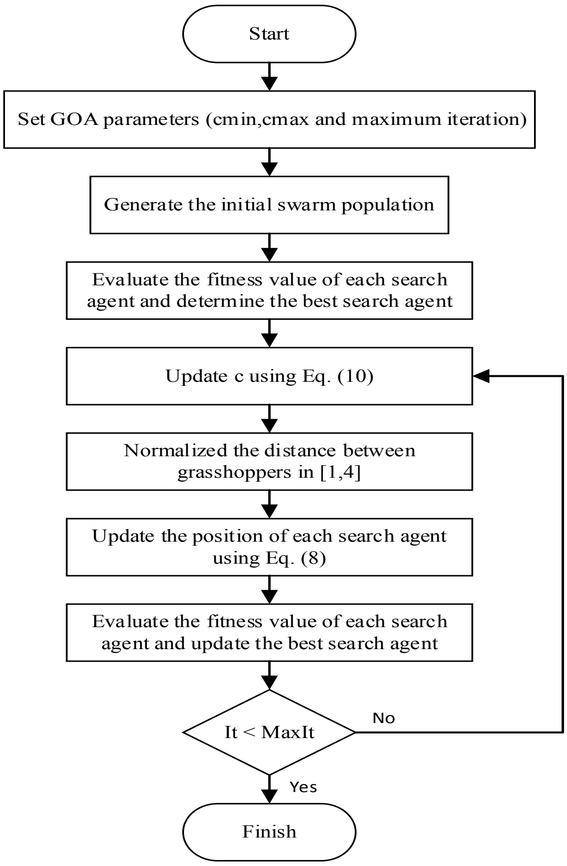

Fig. 2. Flowchart of Grasshopper Optimization Algorithm

B. Application of GOA to solve DSR considering DG placement problem

Distribution systems include two type switches; tie lines (normally opened) and sectionalize switches (normally closed). When tie lines are closed some loops are created in the system. Therefore, a loop in distribution system consists of a tie line and some sectionalize switches. The number of the loops equal to the number of tie lines. System reconfiguration in distribution systems is achieved by changing the status of the switches in the loops. For keeping the system radial, one switch must be opened in each loop.

The goal of this paper is to find optimal solution for the optimal distribution system reconfiguration and DG placement problem to reduce active power loss. Therefore, each search agent in GOA consists of 11 variables which are divided into two parts. One belongs to the location of tie lines and the other one indicates the location and size of DGs. The coding of each search agents which is set for 33-bus test system is shown in Fig. 3. The five first variables indicate tie lines location and the rest of variables determine DGs location and size.

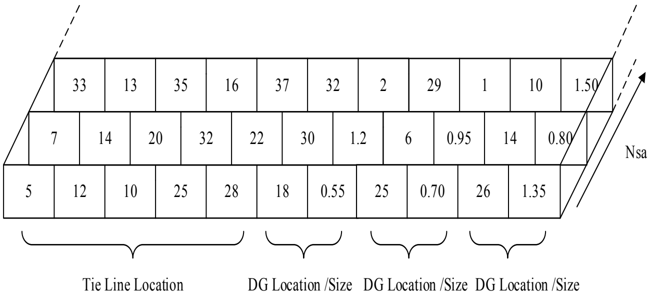

Fig. 3. Variable architecture of each search agent

IV. SIMULATION RESULTS

In order to demonstrate the effectiveness of the proposed method in solving the simultaneous optimal distribution system reconfiguration and DG placement problem using GOA, it is applied to two test systems consisting of 33 and 69 buses. The simulation results are compared with those of ref [16-18] which has considered the problem. For both the test systems, the maximum number of DGs is limited to three. In addition, the limits of DG sizes are considered 0 to 2 MW for both the test systems. In the simulation of system, five scenarios are considered to analyze the effectiveness of the proposed method.

Scenario 1: The system is analyzed without reconfiguration and DG units (base case).
Scenario 2: The system is only optimally reconfigured.
Scenario 3: Allocation and size of DG are optimized.
Scenario 4: Allocation and size of DG are optimized after scenario 2.
Scenario 5: The system is optimally reconfigured and simultaneously, DGs are allocated.

The proposed algorithm, GOA, has been implemented in MATLAB2016a and a system with INTEL Core 2 DUE CPU, 2.6 GHz and 4 GB RAM. For both the test systems the parameters of GOA algorithm used in the simulation are maximum number of iteration $Iter_{max}$ =200, number of search agents N_{sa} =30, C_{min} =0.0004, C_{max} =1.

A. The 33-bus test system

This test system consists of 37 branches, 32 sectionalize switches and five tie lines. The line, load and tie line data are taken from [5]. In the system, sectionalize switches which are normally closed are numbered from 1 to 32, and tie lines which are normally opened are numbered from 33 to 37. The total active and reactive power loads of the system are 3.72 MW and 2.3 MVAr, respectively. The single line diagram of the system and its loops is shown in Fig. 4.

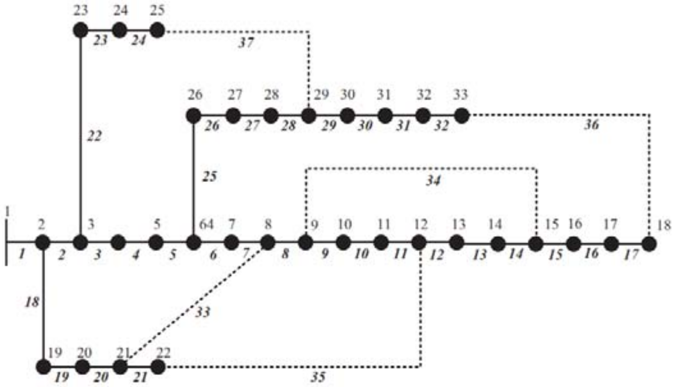

Fig. 4. 33-bus test system

The optimal answers obtained by proposed method for each of the scenarios are presented in Table 1. From Table 1, it is observed that power loss (kW) in the system is 202.685 (base case), which is reduced to 139.2, 71.305, 58.743, and 55.59 using scenarios 2, 3, 4, and 5 respectively. Also, the percentage of power loss reduction for the scenarios 2-5 are 31.32%, 64.82%, 71.02%, and 72.57%, respectively. In all scenarios, the highest power loss reduction is obtained using scenario 5. It can also be seen from Table 1 that the minimum voltage of the system is significantly improved in all the scenarios. The minimum voltage improved from 0.9131p.u. (base case) to 0.9380, 0.9687, 0.9742, and 0.9702 p.u. using scenarios 2, 3, 4, and 5 respectively. The voltage profiles are compared and shown in Fig. 5. for all the scenarios. It is markedly obvious that the voltage of all the buses have greatly improved after applying the proposed method.

In addition, to show the performance of the proposed method, a comparison has been considered among different evolutionary algorithms which are presented in Table 1. According to the table, the performance of the proposed method has outperformed other methods. In all scenarios, the optimal results obtained by proposed method are better than HAS, FWA, and UVDA in term of power loss. In scenario 4 and 5, the minimum voltage is slightly lower than UVDA.

TABLE I. SIMULATION RESULT FOR THE 33-BUS TEST SYSTEM

Scenarios	Item	Proposed method (GOA)	HAS [16]	FWA [17]	UVDA [18]
Scenario 1	Switches opened	33, 34, 35, 36, 37	33, 34, 35, 36, 37	33, 34, 35, 36, 37	33, 34, 35, 36, 37
	Power loss (kW)	202.685	202.685	202.685	202.685
	Minimum voltage (Bus number)	0.9131 (18)	0.9131 (18)	0.9131 (18)	0.9131 (18)
Scenario 2	Switches opened	7, 9, 14, 32, 37	7, 9, 14, 32, 37	7, 9, 14, 32, 28	7, 9, 14, 32, 37
	Power loss (kW)	139.2	138.06	139.98	139.55
	%Loss reduction	31.32%	31.88%	30.93%	31.15%
	Minimum voltage (Bus number)	0.9380 (32)	0.9342	0.9413 (32)	0.9378 (32)
Scenario 3	Switches opened	33, 34, 35, 36, 37	33, 34, 35, 36, 37	33, 34, 35, 36, 37	33, 34, 35, 36, 37
	Power loss (kW)	71.305	96.76	88.68	74.213
	%Loss reduction	64.82%	52.26%	56.24%	63.39%
	Minimum voltage (Bus number)	0.9687 (32)	0.9670	0.9680 (30)	0.9620 (33)
	Size of DG (kW) (Bus number)	1099.13 (24) 753.959 (14) 1071.36 (30)	107 (18) 572.4 (17) 1046.2 (33)	589.7 (14) 189.5 (18) 1014.6 (32)	875 (11) 925 (29) 931 (24)
Scenario 4	Switches opened	7, 9, 14, 32, 37	7, 9, 14, 32, 37	7, 9, 14, 32, 28	7, 9, 14, 32, 37
	Power loss (kW)	58.743	97.13	83.91	66.602
	%Loss reduction	71.02%	52.08%	58.60%	67.14%
	Minimum voltage (Bus number)	0.9742 (32)	0.9479	0.9612 (30)	0.9758 (32)
	Size of DG (MW) (Bus number)	1068.13 (24) 950.32 (30) 931.33 (8)	268.6 (32) 161.1 (31) 661.2 (30)	599.6 (32) 314.1 (33) 159.1 (18)	1125 (30) 592 (15) 526 (12)
Scenario 5	Switches opened	11, 30, 33, 34, 37	7, 14, 10, 32, 28	7, 14, 11, 32, 28	7, 10, 13, 27, 32
	Power loss (kW)	55.59	73.05	67.11	57.287
	%Loss reduction	72.57%	63.95%	66.89%	71.74%
	Minimum voltage (Bus number)	0.9702 (30)	0.9700	0.9713 (14)	0.9760 (32)
	Size of DG (MW) (Bus number)	966.55 (24) 1296.61 (6) 853.62 (33)	525.8 (32) 558.6 (31) 584 (33)	536.7 (32) 615.8 (29) 531.5 (18)	1554 (29) 649 (15) 486 (21)

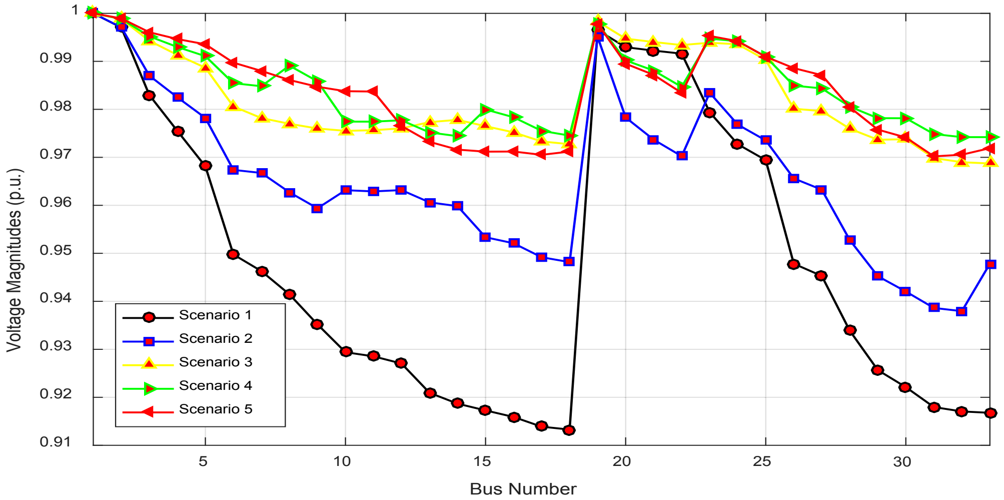

Fig. 5. Comparison of voltage profile of 33-bus test system

B. The 69-bus test system

The second test system is a 69-bus distribution system with 73 branches, 68 sectionalize switches and five tie lines. The sectionalize switches are numbered from 1 to 68, and tie lines are numbered from 69 to 73. The data of the system are given in [23]. The total active and reactive power loads of the system are 3.802 MW and 2.649 MVAr, respectively. The schematic diagram of the system with its loops is shown in Fig. 6. Similar to 33-bus test system, the five scenarios are considered for this case study.

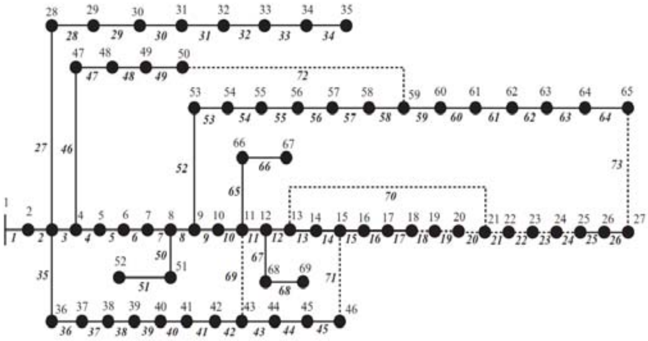

Fig. 6. 69-bus test system

The optimal results of applying the proposed method for all the scenarios are presented in Table 2. From Table 2, it is clear that the base case power loss (225 kW) is reduced to 98.57, 69.40, 36.48, and 35.19 using scenarios 2, 3, 4, and 5 respectively. Similarly, the percentage of power loss reduction for the scenarios 2-5 are 56.19%, 69.15%, 83.79%, and 84.36%, respectively. Similar to 33-bus test system, the highest power loss reduction is obtained using scenario 5 compared to other scenarios. It can also be seen from Table 2 that the minimum voltage of the system is significantly improved in all the scenarios. The minimum voltage improved from 0.9092 p.u. (base case) to 0.9495, 0.9792, 0.9810, and 0.9813 p.u. using scenarios 2, 3, 4, and 5 respectively. The voltage profiles are compared and shown in Fig. 7. for all the scenarios. It is easily observed that the voltage of all the buses have greatly improved after applying the proposed method.

The performance of the proposed method is also compared with the results of other methods similar to 33-bus test system. According to the table, the performance of the proposed method has outperformed other methods. In the all scenarios, the optimal results obtained by the proposed method are better than HAS, FWA, and UVDA in terms of power loss and minimum voltage.

TABLE II. SIMULATION RESULT FOR THE 69-BUS TEST SYSTEM

Scenarios	**Item**	**Proposed method (GOA)**	**HAS [16]**	**FWA [17]**	**UVDA [18]**
Scenario 1	Switches opened	69, 70, 71, 72, 73	69, 70, 71, 72, 73	69, 70, 71, 72, 73	69, 70, 71, 72, 73
	Power loss (kW)	225	225	225	225
	Minimum voltage (Bus number)	0.9092 (65)	0.9092 (65)	0.9092 (65)	0.9092 (65)
Scenario 2	Switches opened	69, 70, 14, 56, 61	69, 18, 13, 56, 61	69, 70, 14, 56, 61	69, 70, 14, 58, 61
	Power loss (kW)	98.57	99.35	98.59	98.58
	%Loss reduction	56.19%	55.85%	56.19%	56.19%
	Minimum voltage (Bus number)	0.9495 (61)	0.9428	0.9495 (61)	0.9495 (61)
Scenario 3	Switches opened	69, 70, 71, 72, 73	69, 70, 71, 72, 73	69, 70, 71, 72, 73	69, 70, 71, 72, 73
	Power loss (kW)	69.40	86.77	77.85	72.626
	%Loss reduction	69.15%	61.43%	65.40%	67.72%
	Minimum voltage (Bus number)	0.9792 (65)	0.9677	0.9740 (62)	0.9688 (65)
	Size of DG (kW) (Bus number)	517.1 (6) 382.13 (9) 1727.5 (29)	107 (18) 572.4 (17) 1046.2 (33)	408.5 (65) 1198.6 (61) 225.8 (27)	1410 (61) 604 (11) 417 (17)
Scenario 4	Switches opened	69, 70, 14, 56, 61	69, 18, 13, 56, 61	69, 70, 14, 56, 61	69, 70, 14, 58, 61
	Power loss (kW)	36.48	51.3	43.88	37.84
	%Loss reduction	83.79%	77.2%	80.50%	8318%
	Minimum voltage (Bus number)	0.9810 (61)	0.9619	0.9720 (61)	0.9801 (61)
	Size of DG (MW) (Bus number)	1419.69 (61) 673.1 (51) 552.14 (65)	1820.8 (61) 330.5 (60) 270.3 (58)	1001.4 (61) 214.5 (62) 142.5 (64)	1378 (61) 620 (11) 722 (64)
Scenario 5	Switches opened	69, 70, 14, 55, 61	69, 17, 13, 58, 61	13, 55, 63, 69, 70	14, 58, 63, 69, 70
	Power loss (kW)	35.19	40.30	39.25	37.111
	%Loss reduction	84.36%	82.08%	82.56%	83.51%
	Minimum voltage (Bus number)	0.9818 (61)	0.9736	0.9796 (61)	0.9816 (63)
	Size of DG (MW) (Bus number)	1433.88 (61) 537.547 (11) 527.457 (65)	352.5 (60) 1066.6 (61) 452.7 (62)	1127.2 (61) 275 (62) 415.9 (65)	1472 (61) 538 (11) 673 (17)

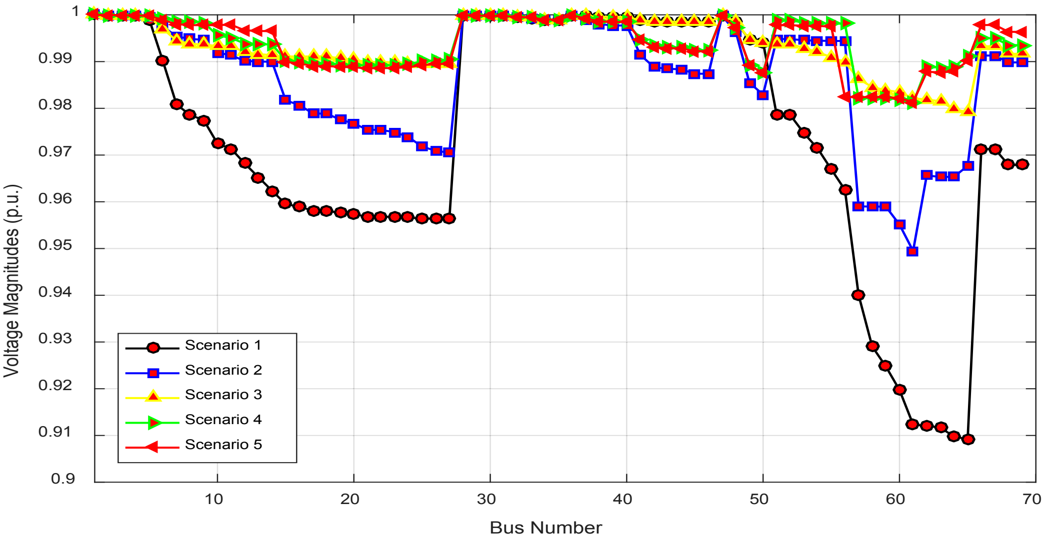

Fig. 7. Comparison of voltage profile of 69-bus test system

V. CONCLUSION

In this paper, Grasshopper Optimization Algorithm (GOA) was presented to solve simultaneous optimal distribution system reconfiguration and DG placement problem in order to minimize active power loss. The proposed method was tested on 33 and 69- bus test systems at different scenarios. The results verify that scenario 5 (simultaneous distribution system reconfiguration and DG placement) is more effective in terms of the active power loss and the voltage profile improvement in comparison with the other scenarios. Moreover, the results of the proposed method are compared with the results of other evolutionary algorithms named HAS, FWA, and UVDA. The comparison proves that the performance of GOA is better than HAS, FWA, and UVDA in the all scenarios.

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